Encouraging Greater Use of Continuous Cover Forestry

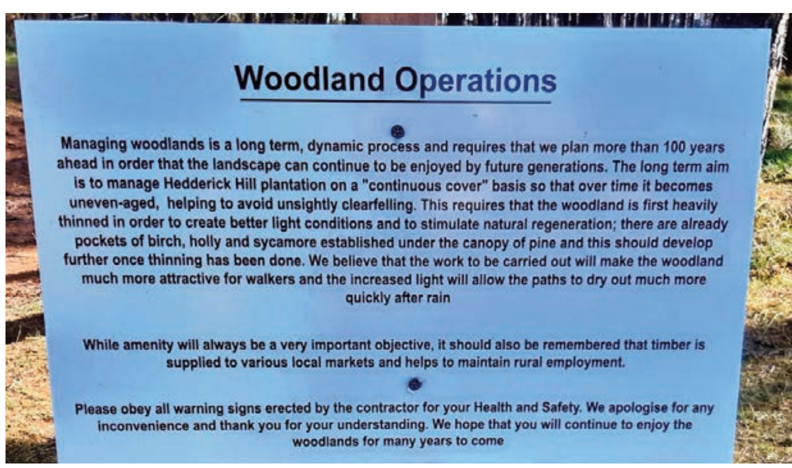
Part 1. Stand and site considerations

In the first of a two part series, **Bill Mason** discusses the role of stand and site characteristics in the adoption of CCF.

The term 'Continuous Cover Forestry' (CCF) started to be used in British forestry in the early 1990s following the formation of the Continuous Cover Forestry Group (CCFG) in March 1991. CCF is an 'approach to forest management' based on four principles: adapting the forest to the site; holistic management of the forest ecosystem rather than just the trees; the maintenance of forest conditions and avoidance of clear felling; and management focussed upon developing individual stems (CCFG, 2020). The term CCF has similarities to the German concept of 'Dauerwald' (continuous forest) that came to prominence in the early decades of the last century (Helliwell, 1997). The founders of the CCFG felt that 'Continuous Cover Forestry' provided a better description of the group's aspirations and a closer fit with the realities of British forestry than the term 'close-to-nature' forestry, which was used by similar organisations in continental Europe (Helliwell and Wilson, 2012). One additional benefit of CCF is that the term has a technical focus, avoiding philosophical debates about the naturalness or otherwise of silvicultural systems adopted in 'close-to-nature' forestry (O'Hara, 2016).

At the beginning of the 1990s the area of British forests managed by the uneven-aged silvicultural systems characteristic of CCF was 'extremely small', with perhaps 15 examples known (McIver, 1992). By 2010 there were over 150 examples of CCF management in Britain, representing perhaps 2-3% of British forests (Wilson, 2013). Now awareness of CCF is widespread within British forestry, exemplified by the programme for the now postponed RFS' 2020 Whole Society Meeting highlighting CCF as a topic for discussion on three days of the meeting. The UK Forestry Standard recognises the value of CCF in increasing structural diversity of forests and benefitting important forest functions such as enhancing biodiversity in mature woodland habitat, preserving carbon stocks, and reducing soil erosion (Forestry Commission, 2017).

Nevertheless, the actual area of British forests being managed through this approach appears to be small and only a fraction of the potential. The lack of good national figures on the proportion of forests managed through different approaches means that we have to rely on rough estimates. For example, Malcolm et al. (2001) thought that up to 50% of conifer forests could be suitable for transformation to CCF, while Wilson (2013) indicated considerable possibility for introducing uneven-aged silvicultural systems to broadleaved and mixed woodlands



An example of the increasing use of CCF in Britain. Sign at the Hedderwick Hill plantation in the John Muir Country Park near Dunbar explaining the reasons for using CCF in the management of these coastal woodlands.

in lowland Britain. This slow rate of uptake of CCF may reflect concerns about the time required for successful transformation to an irregular forest, a lack of skilled silviculturists, and the possible risks involved in transformation. However, it may also reflect difficulties involved in challenging the prevailing paradigm in British forestry where patch clear felling is often considered as the default silvicultural option (Helliwell and Wilson, 2012). Similar barriers have been identified in Finland where CCF has recently become accepted after several decades of being effectively banned (Valkonen, 2019).

Wilson (2013) made several recommendations to facilitate wider uptake of CCF covering policy and support mechanisms, research and development, education and inventory, and demonstration and training. Members of the CCFG committee reviewed these recommendations and have combined them with some major concerns and uncertainties that foresters and forest owners have cited as reasons for their reluctance to adopt CCF (CCFG, unpublished data). The main items are listed in Table 1, classed according to five categories of challenge identified by Puettmann et al. (2015), namely: ecological, economic, logistical and administrative, educational and informational, and cultural and historical. This pair of articles reviews this list and provides guidance as to how these challenges may be overcome to increase the uptake of CCF. This first article examines general aspects relevant to CCF and then considers a number of site-specific ecological factors that can influence the decision to adopt this approach.

General observations

The increased interest in CCF reflects the need for British forests to be managed to deliver a wide range of objectives, where the provision of a variety of ecosystem services including recreational, aesthetic, and environmental aspects should be given at least equal prominence to timber production (Helliwell and Wilson, 2012). The delivery of such 'non-market' values is enhanced in forests of mixed species with a varied stand structure (e.g. Edwards et al., 2012). There is also increasing awareness that many existing forests, especially those of plantation origin, lack both the structural and species diversity desirable to increase forest resilience to the impacts of climate change, and various pests and diseases. Given that CCF explicitly seeks to develop irregular and complex forest structures, wider use of this approach seems ideally suited to help adapt British forests and forest management to the challenges of the present century.

CCF forms part of a worldwide movement to adopt alternative silvicultural practices as a reaction against the

Table 1. A list of the main concerns limiting uptake of CCF in British forestry as identified in Wilson (2013) and modified by the CCFG committee. Category of challenge refers to the groupings identified by Puettmann et al. (2015). Concerns are not listed in any order of priority.

Concerns considered in Part 1.

Concern	Category of challenge
Confusion over terminology	Informational and educational
Preferred sites for implementing CCF	Ecological
Species characteristics and choice of silvicultural system	Ecological
Defining desired future conditions (e.g. species composition) for a forest	Ecological
Wind stability in CCF stands and appropriate thinning regimes for use in CCF	Ecological
Developing successful mixtures in CCF stands	Ecological
Deer management in CCF forests and impacts on natural regeneration	Ecological

Concerns considered in Part 2.

Concern	Category of challenge
CCF and adaptation to climate change	Ecological
CCF stands and vulnerability to disease	Ecological
A lack of information about the economics of CCF	Economic
Uncertainty about the timber quality of trees produced from CCF stands	Economic
Training in CCF and related silviculture	Informational and educational
Access to documented and monitored demonstration sites with results readily available	Informational and educational
Financial support for CCF management	Logistical and administrative

Interest in CCF is international. Transformation to CCF in a private forest of Norway spruce and grand fir in Jutland, Denmark. The stand was originally planted in the 1930s and is being transformed using the profuse natural regeneration.

homogenous even-aged forests composed of few species and typically managed by clear felling and replanting which characterise conventional rotational forest management (RFM). These alternative approaches have different names such as 'ecological forestry' (USA), 'close-to-nature forestry' (central Europe), 'natural disturbance-based management' (Canada) or 'retention forestry' (Chile). However, all share certain silvicultural principles, namely: the avoidance of clear-felling with an emphasis on partial harvesting; a preference for natural regeneration where possible; the development of structural diversity within stands, generally at very intimate scales; the fostering of mixed species stands; and the avoidance of intensive site management practices (Puettmann et al., 2015).

Since CCF is an approach to forest management, it cannot be implemented without choosing an appropriate silvicultural system that meets the guiding principles of this approach. Given that the aim of CCF is to produce forests of varied (irregular) structure with a mix of species, it is natural that three silvicultural systems originally formalised in central Europe for managing mixed natural forests are generally considered most appropriate for CCF. These systems are single stem selection, group selection, and irregular shelterwood (Matthews, 1989). However, the choice of system also needs to consider the site and climatic conditions of stands to be managed under CCF, as well as the eco-physiological characteristics of the component species (e.g. their shade tolerance) (Mason et al., 1999). Identifying an appropriate system will also help define the scope of interventions (e.g. the proportion of basal area removed in thinning) and reduce the risk that stands are overcut.

Confusion over terminology

The phrase 'Low Impact Silvicultural Systems' (LISS) is sometimes used as a synonym for CCF. However, LISS encompasses a wide range of management methods including small scale clear-felling (i.e. areas >0.25ha and <2.0ha), coppice and coppice-with-standards, and minimum intervention, as well as CCF (Anon., 2017). This broad grouping ignores that CCF is an approach to management rather than a silvicultural system, while some of the other categories (e.g. coppice) are separate silvicultural systems in their own right (Matthews, 1989). Therefore, LISS confounds approaches to management with the methods used to deliver an approach. Given this confusion arguably LISS should be abandoned as a term for describing alternatives to RFM. Another term sometimes heard is 'Alternatives to Clearfelling' (ATC), which was used to describe silvicultural options on the public forest estate; this covers a wide range of silvicultural systems including shelterwood and seed tree systems that result in regular stand structures.

A further area of uncertainty is if an upper limit of gap size of 0.25ha is used dogmatically to define what is or is not a CCF approach. This figure is based on the loss of the forest microclimate in a gap whose diameter is more than two times the heights of the surrounding trees (Malcolm et al., 2001). It further assumes that the gap is circular, that tree height is no more than 30m, and takes no account of effects of slope, gap orientation or shape. In other words, the 0.25ha limit should be used as a rule of thumb rather than a rigid boundary between CCF and another management approach. Studies of the effects of disturbances on forests have revealed a spatial pattern of many small gaps and a few larger openings (Puettmann et al., 2015). Therefore, within a forest being managed by CCF, the presence of a few gaps larger than 0.25ha should be acceptable and would provide for a wider range of species as forests are adapted for climate change (O'Hara, 2016)

Preferred sites for implementing CCF

Many sites in Britain where CCF was first introduced were those where the impacts of clear felling were not compatible with management objectives, for example in stands with high visual or recreational sensitivity. However, wider uptake of CCF will require use of irregular silvicultural systems on a much greater range of sites and for a wider range of reasons. These could include maintaining habitat continuity for wildlife or the need to reduce disturbance to soil carbon in forests.

Successful implementation of CCF requires evaluating a potential site and considering features that might influence the introduction of an irregular silvicultural system. An early attempt to rank site suitability for CCF combined wind risk, site fertility and potential vegetation competition, and species suitability into a framework that classed sites as having good, moderate or poor suitability (Mason and Kerr, 2004). This resulted in the view that "the older the stand, the less it has been thinned, the shallower the soil, and the more exposed the site, the lower the potential will be for transformation [to CCF]". (Mason and Kerr, 2004). However, accumulating evidence from various operational trials suggests this view may be pessimistic, particularly where soil characteristics and wind risk are considered. Thus, in Wales successful trials of transformation to CCF at Clocaenog (Mason, 2015) and in private forests such as Bryn Arau Duon are located on sites of comparatively high wind exposure (e.g. windthrow hazard class 5 or DAMS values of 18-19). A key feature is that these sites have freely draining mineral soils such as brown earths, podsols, or ironpan soils where the 'pan' is weak and/or easily broken by cultivation. Such soils allow deep rooting and improved tree stability. Therefore, any site having 'good' or 'moderate' potential could be considered as a suitable subject for CCF, and even a 'poor' site could be suitable if the soil type was favourable. In other words, the scoring system should be seen as a means of ranking sites in order of priority for introducing CCF rather than as a means of eliminating this approach. Elimination should be based on unsuitable site characteristics causing shallow rooting like gley or peat soils, and also if an existing tree species is not suited to the site.

It is important to understand the light requirements of regenerating species. This example from Blairadam forest in Fife shows a group of advance natural regeneration of Sitka spruce dying because of a lack of light and Elatobium defoliation.

The decision to implement a CCF approach also needs to consider the actual structure of any stand on the site (Mason and Kerr, 2004). Thus, when there is an unstable stand structure due to delayed thinning, the risk of windthrow can be too high to attempt transformation even on otherwise suitable site for irregular silviculture. It will make more sense to clearfell the existing stand and to transform its successor (Schütz, 2001). It is unlikely that any stand that has been managed on a non-thin regime will be suitable for CCF, unless it was originally a self-thinning mixture of two or more species and some structural differentiation has occurred.

Species characteristics and choice of silvicultural system

Experience has shown that all major and minor species present in British forests, plus several alternative ones proposed as part of 'diversification' programmes (Ennos et al., 2020) can regenerate naturally given a favourable stand microclimate. An issue identified at least 20 years ago (Malcolm et al., 2001) is that most major species grown in British forests, whether conifer or broadleaved, are either intermediate in shade tolerance (Sitka spruce, Douglas fir, oaks) or are light demanding (Scots pine, birch). This suggests that a very intimate silvicultural system like single stem selection is not well suited to many British forests, except for those limited areas dominated by shade tolerant species such as Norway spruce or western hemlock. The single stem selection system traditionally felt to epitomise uneven-aged forestry (Schütz et al., 2012), originated in central European forests composed primarily of shade tolerant species (e.g. beech, European silver fir) and is characterised by small regeneration gaps (0.05ha or less). Silvicultural systems characterised by larger gap sizes (e.g. 0.1 to 0.2ha or more) such as group selection or irregular shelterwood (Raymond et al., 2009) are more likely to be applicable in British forests.

A problem when attempting to regenerate light demanding species even when using larger gap sizes is that the gap can be dominated by advance regeneration of more shade tolerant species and/or that it becomes colonised by competitive ground vegetation before regeneration can occur (Harmer and Kerr, 2013; Kern et al., 2017). This occurred in larch dominated stands near Aberfoyle where, despite other regeneration factors being favourable, the lack of a bare mineral soil for larch seedling germination meant that the regeneration cohort was predominantly Sitka spruce (Mason et al., 2011). Sitka spruce also replaced light demanding Scots pine and larch over time in the Glentress trial area (Kerr et al., 2010), while in Belgium, the more shade tolerant beech outcompeted sessile oak in mixed broadleaved stands being managed through CCF (Ligot et al., 2013). Therefore, if seeking to perpetuate a light demanding species, it will often be necessary to control existing regeneration of other species or competitive vegetation to ensure a favourable environment for seedlings of the desired species. Underplanting (Kerr and Haufe, 2016) can also be used to establish light demanding species if natural regeneration appears insufficient.

Successful transformation of even-aged stands to CCF must maintain a proportion of the overstorey trees over extended periods while fostering the recruitment of natural regeneration. This will use thinning regimes similar to those practised in uniform and group shelterwood systems. The developing structure can seem relatively uniform, but this should be accepted as a natural stage of the transformation process (Nyland, 2003; O'Hara, 2014). In other words, use of a regular shelterwood system is a 'means to an end' where the eventual intention is to install a selection or irregular shelterwood system to produce a varied and resilient stand structure (Helliwell and Wilson, 2012).

> "Experience over the last two decades has shown that CCF can be introduced on both sheltered sites and those of moderate exposure."

Defining desired future forest conditions

Assuming that both site and species characteristics appear suitable for CCF, a practical difficulty that managers face is in defining the forest envisaged decades in the future when transformation has been achieved. The definition should encompass the preferred mix of species, their proportions, the distribution of stems in different size categories, and the amount of regeneration. Achieving the desired future condition should increase both resistance and resilience to anticipated biotic and abiotic disturbances (De Rose and Long, 2014). Once this future state has been defined, it becomes possible to work out how best to manipulate the current structure and composition of a forest to achieve a target condition that meets the objectives of management. Decision support systems such as the Ecological Site Classification can provide guidance on species suitability under current and future climates (Bathgate, 2011), and frameworks such as Forest Development Types (FDTs) can identify appropriate species combinations (Spencer and Field, 2019). A FDT describes the long-term forest composition and structure appropriate for a specific site and outlines the silvicultural actions required to guide actual forest stands in the desired direction (Larsen and Nielsen, 2007). (Colleagues at Forest Research are developing a framework of FDTs that could be applied to British forests and summary information on this project will appear in a forthcoming issue of the *QJF*.) Furthermore, establishing quantified targets for species composition and structure provides a means of evaluating information from regular monitoring and deciding whether the chosen silvicultural approach needs to be modified.

Wind stability in CCF stands and appropriate thinning regimes

The risk of windthrow is a major constraint to silvicultural practice in Britain, particularly in more exposed oceanic and upland areas. Indeed, surveys in Ireland have identified concerns over windthrow as a major reason for managers' reluctance to adopt CCF (Vitkova et al., 2014). However, as noted above, recent experience has shown that CCF can be introduced on both sheltered sites and those of moderate exposure, provided an appropriate thinning regime is used and interventions start soon after canopy closure. Detailed studies of the wind environment experienced by individual trees in the Clocaenog study area showed that the dominant trees had adapted to a more exposed environment, evidenced by better stability characteristics (height/dbh ratio <80) (Cameron, 2015; Mason, 2015). The stability of the dominant trees in irregular stands and the presence of lower canopy layers that reduce wind penetration through a stand explain why irregular stands can be more windfirm than those subject to RFM, provided everything else is equal (Pukkala et al., 2016).

The thinning regime required for transformation to an irregular structure on a site of intermediate wind risk should be carefully designed and implemented. It will likely have the following characteristics: an initial line thinning to allow access, followed rapidly by one or two crown thinnings to identify and favour potential dominants; a longer period with little or no intervention to permit the stand to recover; and finally further thinnings to foster structural diversity. This allows the selected dominants to develop good stability characteristics from an early stage, and also keeps basal area at the lower stocking levels required to provide adequate light to promote natural regeneration without allowing excessive vegetation competition (Hale, 2004). All thinning regimes incur some risk of windthrow (Hanewinkel et al., 2013), and transformation to an irregular structure in a changing climate may result in increased disturbance from wind (or other agents), especially immediately after a thinning intervention when the retained trees experience greater wind loading. This explains why attempting to introduce CCF into older stands can be problematic if the dominant trees do not have good individual stability. However, once transformation is underway, the greater structural diversity of the developing stand should provide enhanced resistance to such disturbances (O'Hara and Ramage, 2013).

Successful mixtures in CCF stands

Just as increased structural diversity in CCF forests can enhance resistance to wind disturbance, so the greater compositional diversity in mixed stands developed through CCF can provide further improvements. For example, investigations of damage to Swiss forests following storm Lothar in December 1999 found that the resistance of

Mixed woodland of Scots pine, beech and Douglas fir developed through CCF management on the Eildon estate near Melrose in the Scottish Borders.

Norway spruce stands was improved by the presence of 10-20% of beech (Schütz et al., 2006). This was due to the spruce developing deeper crowns and a more stable form when grown in mixture, and a similar benefit occurred when a small percentage of Douglas fir (a deeper rooting conifer than spruce) was present. Similarly, Cameron (2015) recommended wider use of conifer-conifer mixtures to ease uncertainties over the future health and growth of pure Sitka stands, with western hemlock, Douglas fir, and grand fir being the most suitable species for planting in mixture.

One drawback of relying on natural regeneration in CCF is that the regeneration cohort is often dominated by seedlings of a single species. This is evident in British Sitka spruce stands being transformed to CCF where densities of tens of thousands of spruce seedlings per ha have been reported (Bianchi et al., 2019). Although Deal et al. (2014) observed that temperate rain forests in Alaska are characterised primarily by complex age and forest structures rather than by species diversity, they also noted biodiversity benefits that occur when Sitka spruce and broadleaves grow in mixture during stand development.

The introduction of CCF thinning regimes to even-aged forests will provide greater structural diversity with a more favourable stand microclimate and allow underplanting of additional species that are often difficult to establish in open-ground conditions characteristic of RFM. However, the pattern of underplanting will need to be adjusted to reflect the light requirements of individual species, for instance using larger gaps to introduce light demanding species (Kerr and Haufe, 2016). The use of CCF to create mixtures will be an important way of reducing risks associated with the prevalence of single species stands in Britain, recently estimated at 55% of all forests (MCPFE, 2011).

A FDT framework can provide guidance about the species that can be admixed on a particular site. Good understanding of the traits of the individual species (e.g. comparative shade tolerance, rooting habit, rate of height growth) will allow foresters to identify those species that can be grown together and the pattern of mixture (e.g. intimate, small groups, etc.) that will be most robust over time (Kerr et al., 2020). It will also enable them to identify species that should be introduced by underplanting because of the lack of a seed source.

Deer management in CCF and impacts on natural regeneration

The successful establishment of natural regeneration will make a major contribution to the long-term financial and ecological success of a CCF approach. However, a major constraint upon natural regeneration (as well as upon the survival and growth of any underplanted trees) is the browsing pressure exerted by deer. Thus, a survey of 15 different woodlands in lowland England with deer densities ranging from 0 (Isle of Wight) to nearly 50 animals km^{-2} found that regeneration success declined sharply with increasing numbers of deer. This trend was evident from relatively low densities (<5-10 deer km^{-2}) with a negative impact of browsing on both seedlings and saplings (Gill and Morgan, 2010). Similar detrimental effects of browsing pressure upon natural regeneration have been widely reported across northern temperate forests (e.g. Ramirez et al., 2018). Target deer densities ranging 4 and 14 deer km^{-2} have been recommended (Gill and Morgan, 2010), with the lower figure applicable for larger species (e.g. red deer) and/or in less fertile conditions (e.g. Scottish Highlands). Current deer population levels in Britain appear to be at a record high, for example between 593 and 783 thousand deer are estimated to occur in Scotland (Deer Management Working Group, 2019, Figure 6). This equates to between 7.4 and 9.8 deer km^{-2} across Scotland, assuming a uniform distribution. Since this assumption is far from true (e.g. effect of urban areas and other zones with few deer), actual populations present in Scottish forests must substantially exceed the target densities noted above. Given some of the densities reported by Gill and Morgan (2010), excessive deer numbers must be a problem limiting regeneration in many British woodlands and forests.

There will not be a simple relationship between a particular deer density and the presence or absence of natural regeneration of desired tree species, since browsing effects will depend upon the deer species present, the vegetation complex and the availability of alternate browse. However, if regeneration failure occurs despite all other factors being favourable, then deer and other browsing animals (e.g. rabbits) are likely to be the main cause. This can be checked by establishing small fenced enclosures to monitor vegetation and regeneration development in the absence of browsing. If the results demonstrate that browsing pressure is causing poor regeneration success, then the deer population must be brought down to an acceptable level. This will require a sustained control effort since naturally regenerated seedlings can take over a decade or more to grow to a height at which they are free from browsing pressure (e.g. Scott et al. (2000) for Scots pine regeneration in northern Scotland). The success of the effort should be supported by regular monitoring of the level of browsing occurring across the site, for example using methods like those proposed by Armstrong et al. (2014). Any culling programme intended to support CCF needs to be exercised across the whole area being managed in this way and not just concentrated on restock areas as often occurs in RFM. This may require the reconfiguration of internal rides and glades to provide attractive browsing habitat and lines of sight for stalkers.

> “On many sites in Britain, a CCF approach is both a feasible option and a pragmatic ecological choice for the management of a forest or woodland.”

Conclusion

Implementing CCF requires a forester to define the target species composition and structure for a forest, to decide on the silvicultural system(s) most suited to transform it from its current state, to implement appropriate silvicultural interventions, and to carefully monitor progress over time and adapt interventions accordingly. This article suggests that, on many sites in Britain, a CCF approach is both a feasible option and a pragmatic ecological choice for the management of a forest or woodland. The main exception is where the combination of exposure and restricted rooting on wet or shallow soils means that wind risk is too great to allow regular thinning. On all other sites, an appropriate and timely thinning regime should be used for developing a stable stand structure, and for recruiting a regenerating cohort into the stand. Most species can regenerate naturally in adequate numbers provided vegetation competition and browsing pressure are controlled while gap sizes can be adjusted to produce a variable light climate so allowing a mix of species to establish in the shelter of the mature trees. Because of the comparative scarcity of shade tolerant species, group selection or irregular shelterwood systems are probably better suited to British conditions than the more intimate single stem selection system traditionally favoured in 'close-to-nature' silviculture. During the early part of the transformation process, different shelterwood systems (e.g. uniform, strip, group) can develop a more varied stand structure and species composition. A mixture of silvicultural approaches, using a range of gap sizes, can be helpful in providing greater flexibility in forest management (Puettmann et al., 2015). Indeed, because of changes in stand structure over relatively small distances within a forest, it may be more useful to adopt a 'freestyle silviculture' that deploys elements of different silvicultural systems applied according to microsite and stand variations (Boncina, 2011).

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