A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking

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Summary

Continuous cover forestry (CCF) is not a new idea in forest management but there has been renewed interest in it for the potential it has to meet the sustainability requirements which are part of the Rio/Helsinki process and certification. Broadly speaking CCF includes those silvicultural systems which involve continuous and uninterrupted maintenance of forest cover and which avoid clearcutting. However, there is considerable confusion with regard to terms and definitions and even the phrase continuous cover forestry is not universally known. CCF systems are being introduced throughout Europe, where there is emphasis on the direct transformation of existing even-aged plantations to some form of mixed, uneven-aged woodland. There is also the opportunity to establish such woodlands either at re-stocking or when afforesting former agricultural land but so far there has been little discussion of the methods that can be used to do this. One approach would be to use nurse crops to aid establishment of desired species, especially where there are difficult site conditions or the trees naturally require cover for optimal growth. The use of nurse crops is already a familiar part of forest practice and has found various applications in Britain, Scandinavia and other parts of Europe. This paper outlines the historical roots of continuous cover forestry, discusses definitions and features of the current debate and explores potential silvicultural methods with special attention to the direct establishment of mixed forest stands through afforestation and restocking.

Introduction

Continuous cover forestry (CCF) is not a new phenomenon but over the last decade there has been renewed worldwide debate regarding its position in forest management (Lähde *et al.*, 1999; Turckheim, 1999; Cairns, 2001; Gadow *et al.*, 2002; Guldin, 2002; O'Hara, 2002). However, the different terms and the wide variety of, sometimes contrary, definitions cause considerable confusion among politicians, practitioners and scientists, and need to be clarified.

The key to understanding and applying the concept of CCF is its history, as its past development still has impacts on present-day and future applications. This paper reviews the history and

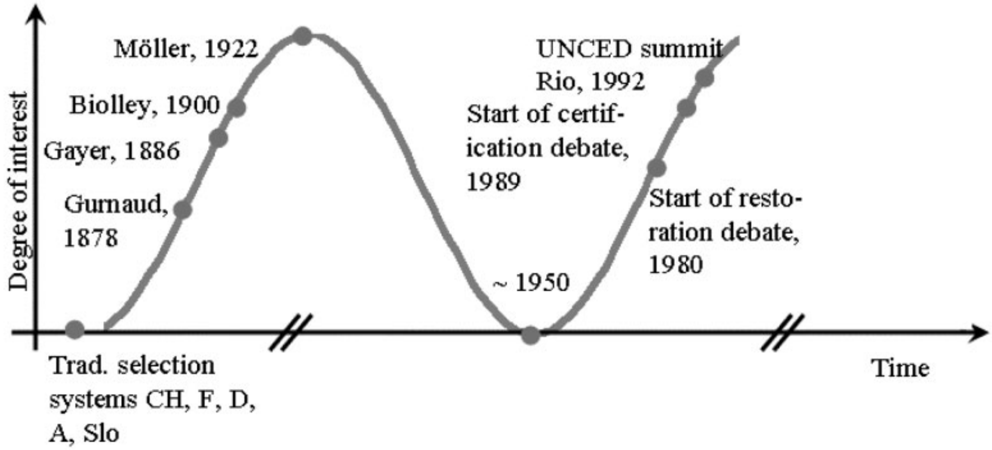

Figure 1. Schematic overview of the history of the continuous cover forestry idea in Europe (CH = Switzerland, F = France, D = Germany, A = Austria, Slo = Slovenia).

definitions of CCF to clarify the role of this management type as it is described in the international literature. It then explores potential methods for the establishment of mixed forest stands, because this particular aspect of CCF is often neglected.

History of continuous cover forestry

The history of CCF or uneven-aged silviculture reveals that the popularity of these practices has waxed and waned in successive cycles (O'Hara, 2002). Figure 1 gives a schematic overview of these cycles in Europe. Long before an accepted term and corresponding definition were agreed, selection systems, which are a form of continuous cover, were practised in parts of Switzerland, France, Germany, Austria and Slovenia. These traditional forest management methods became known as 'jardinage' in the French and 'Plenterwald' in the German literature.

Towards the end of the nineteenth century the French forester Adolphe Gurnaud and his Swiss colleague Henry Biolley began promoting the transformation of even-aged stands to selection forests and developed the so-called check method or *Méthode du Controle* for sustainable yield regulation. The French forester De Liocourt (1898) was the first to detect that the decrease in the number of trees per diameter class from the lower towards the upper end of the diameter distribution in a selection forest approximates a negative exponential curve. This approach, often referred to as the inversed J-shaped diameter distribution, and also known as the law of De Liocourt was further developed by Meyer (1933) with the aim of deriving an equilibrium diameter distribution and equilibrium growing stock as silvicultural guidelines.

In his seminal book *Der gemischte Wald* (*The Mixed Forest*) the German professor Karl Gayer (1886) emphasized the advantages of uneven-aged mixed forests and in 1913 his colleague Alfred Möller coined the term Dauerwald (continuous forest). In North America the earliest discussions of uneven-aged silviculture date back to Carl Schenck's early texts, e.g. his 'Biltmore Lectures on Sylviculture' (Schenck, 1907). He described several selection systems including systems involving group and individual tree removals (O'Hara, 2002). In 1922 Möller published his famous book *Der Dauerwaldgedanke: Sein Sinn und seine Bedeutung* (*The Dauerwald Idea: its Meaning and Significance*) which initiated a long running discussion. Möller discovered that most of his ideas and principles were being practised in the Scots pine forests of the Bärenthoren Estate near Dessau in the modern German state of Sachsen-Anhalt. He used these forests as management demonstration sites for his Dauerwald concept which gave rise to a considerable number of 'pilgrimages' by forest managers as well as members of the academia. With only a few exceptions, such as the trials at Glentress in Scotland (Anderson, 1960), the CCF initiatives of Lord Bradford and his forest manager Phil Hutt in Shropshire and Devon (Timmis, 1994), there was a decline in interest in CCF, following Möller's death. In Germany the critics of CCF – especially Eilhard Wiedemann – succeeded in discrediting the approaches of Möller and his colleagues. Also, during and after World War II there was considerable resistance from foresters in Germany to CCF as it had been imposed compulsorily by the national socialist government during the 1930s and 1940s (Huss, 1990).

Interest in CCF was revived in the 1980s when the discussions on acid rain, forest decline, restoration and certification stimulated debate on concepts of more environmental forestry (Hasenauer and Sterba, 2000). In 1989, 'PRO SILVA Europe' was founded as an association of foresters practising management which followed natural processes. In parts of central Europe the catastrophic storm events of 1984, 1990 and 1999 contributed much to a further promotion of the principles of CCF (Knoke and Plusczyk, 2001). In a similar way the large-scale flooding events (Otto, 1994) of recent years across Europe and the global climate change debate have stimulated the adoption of CCF (Hasenauer and Sterba, 2000).

The revival of the CCF debate also owes much to the United Nations Commission on Economic Development (UNCED) summit at Rio de Janeiro in 1992 when the terms and scope of sustainable forest management were re-defined and it was suggested that they become an integral part of modern forestry practice worldwide. Naturally the term sustainability is at the centre of the CCF idea. In the narrow sense of sustainable timber yield, sustainability is an old forestry maxim which goes back as far as the sixteenth century (Hasel, 1985). It has received a new emphasis since the summit at Rio 10 years ago. The new definition states that forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations (United Nations, 2001). Although initially raised as a separate issue the forest restoration debate is, in many regards, similar to the continuous cover idea, especially with issues like native species and stabilization. Transformation or conversion as a method of establishing CCF woodlands is also a technique used in forest restoration (Thompson *et al.*, 2003).

Definitions

There is an abundance of terms used to define and describe 'continuous cover forestry' not all of which are necessarily compatible. Table 1 identifies 24 semi-synonyms taken from the associated literature. Often these semi-synonyms highlight only a particular aspect of CCF rather than broadly defining it as a whole. It is possible to group the 24 semi-synonyms by using six general headings, i.e. continuity of woodland conditions, ecosystem management, structural diversity, retention, thinning/ harvesting methods and philosophy.

Of the many different definitions six examples may be quoted which reflect aspects already identified by the group headings.

1 According to the IUFRO Multilingual Forest Terminology Database the term describes a highly structured forest ecosystem managed to maintain continuous tree cover over the total forest area (IUFRO, 2002).
2 The British silviculturist Professor R.S. Troup was very interested in the Dauerwald idea of the 1920s, and visited Bärenthoren. He defined this form of silviculture in the following way: "The term Dauerwald may be translated briefly as 'continuous forest', that is, forest treated in such a manner that the soil is never exposed, the forest cover being continuously maintained over every part of the area." (Troup, 1928)
3 Möller applied the term Dauerwald in general not to any one particular method of treatment, but to any system not involving clearcut and the exposure of soil (Troup, 1928).
4 Mason *et al.* (1999) state 'continuous cover is defined as the use of silvicultural systems whereby the forest canopy is maintained at one or more levels without clear felling'.
5 Gadow (2001) came to the conclusion that 'CCF systems are characterized by selective

Table 1: The range of semi-synonyms used in connection with CCF

Synonym or semi-synonym	Source
Continuity of forest cover	
Dauerwald	Möller, 1922; Troup, 1928; Helliwell, 1997
Permanent forest	Anderson, 1953; Häusler and Scherer-Lorenzen, 2001
Alternatives to clearfelling, alternative silvicultural systems to clear cutting	Penistan, 1952; Hart, 1995
Low impact silviculture	UKWAS Steering Group, 2000; Mason *et al.*, 1999
Continuous forest	Troup, 1928; Hart, 1995
Continuous cover silviculture	Yorke, 1998
Ecosystem management	
Nature-orientated silviculture	Koch and Skovsgaard, 1999
Ecological silviculture	Lähde *et al.*, 1999
Close-to-nature silviculture	Schütz, 2001; Kenk and Guehne, 2001
Naturalistic silvicultural systems	Mitchell and Beese, 2002
Close-to-nature forestry/forest management	Mlinšek, 1996; Mason *et al.*, 1999
Ecological forestry	Mason *et al.*, 1999
Near-natural forestry/forest management	Benecke, 1996; Gadow *et al.*, 2002
Forest management based on natural processes	Pro Silva Europe, 1989
Structural diversity	
Uneven-aged/multi-aged/multi-cohort management/silviculture/forestry	Anderson, 1953; O'Hara, 1996; Oliver and Larson, 1996
Diversity-orientated silviculture	Benecke, 1996; Lähde *et al.*, 1999
Irregular structure forestry/silviculture	Johnston, 1978; Bradford, 1981; Pryor, 1990
Retention	
Variable retention	Mitchell and Beese, 2002
Managed retention	Forest Enterprise, 2000
Green-tree retention (GTR)	Franklin, 1989; North *et al.*, 1996; Vanha-Majamaa and Jalonen, 2001
Thinning/harvesting methods	
GTR harvest	North *et al.*, 1996
Selective cutting/selective timber management	Curtis, 1998
Philosophically driven semi-synonyms	
Holistic forestry	Mason *et al.*, 1999
New Forestry	Franklin, 1989

harvesting; the stand age is undefined and forest development does not follow a cyclic harvest-and-regeneration pattern'.

6 Hart (1995, p. 78) put forward a very detailed definition stating that continuous forest cover (*sic*) is '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 × 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. (The classical silvicultural system to create continuous forest cover is single tree selection.)'

These definitions mostly stress the idea of the continuity of woodland conditions over time hence the name 'continuous cover forestry'. They do not imply a lack of management but emphasize the need to avoid clearfelling over large areas. Within this broad concept a range of silvicultural systems are possible.

However, the debate is wider than the mere

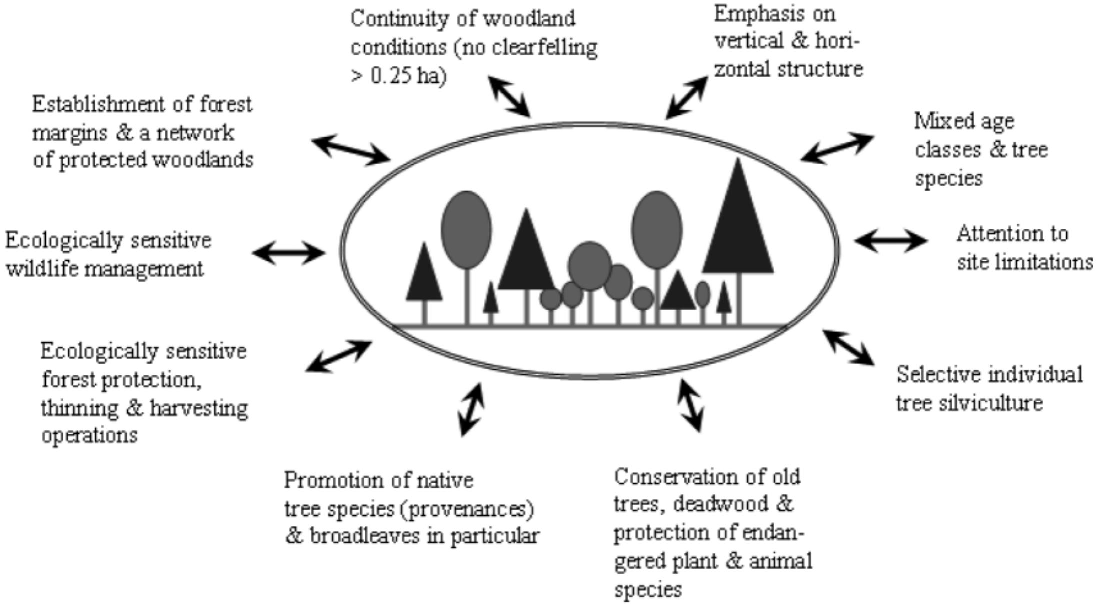

Figure 2. The main components of the contemporary international continuous cover forestry debate.

avoidance of clearcutting (Lähde *et al*., 1999; Kenk and Guehne, 2001; Nabuurs, 2001; Vanha-Majamaa and Jalonen, 2001). Some of the definitions above highlight other important components such as the selective removal of trees, allowable gap size, suitable silvicultural systems and vertical structure. In particular CCF is being seen as compatible with a holistic approach to forestry with multi-purpose management objectives (Niedersächsische Landesregierung, 1991; Landesanstalt für Wald- und Forstwirtschaft Thüringen, 2000; Forestry Commission, 2001; Häusler and Scherer-Lorenzen, 2001). Figure 2 illustrates the most important components of the current CCF debate and these are outlined in more detail below.

Continuity of woodland conditions

This is the oldest and most important part of the definition of CCF. The current understanding of continuous cover forestry may be said to include all those silvicultural systems which involve continuous and uninterrupted maintenance of the forest (Troup, 1928). From an ecological perspective some tree species require the continuity of woodland conditions with only moderate changes of their habitats, imposed by forest management, to ensure their survival. The same continuity is also an important feature of protection forests, securing and stabilizing watersheds, mountain slopes and coastlands, and for woodlands managed for amenity and recreation (Rittershofer, 1999). Historically continuity of woodland conditions has always been an important factor in timber production in traditional selection forests on the small-sized farm holdings of Slovenia, Switzerland, France, Germany and Austria (Burschl and Huss, 1997). There is, however, some debate on size of clearfell allowed especially because current regulations do not distinguish between tree species and site types involved. Since the late 1980s and the beginning of the 1990s, new forest legislation in Germany has required special permission from the forestry authority of the respective federal state if clearfell coupes exceed a certain size. In Germany the regulations governing the maximum clearfelling size vary from state to state. For example in the state Northrhine-Westfalia clear cutting is limited to a size of 3 ha, whereas in Baden-Württemberg permission is required for clearfelling areas larger than 1 ha (Häusler and Scherer-Lorenzen, 2001).

Emphasis on vertical and horizontal structure

In CCF, forest managers aim to create a varied horizontal and vertical structure of individual trees and groups of trees in a stand. By allowing a varied amount of horizontal and vertical structural elements it is possible to save establishment and tending costs. Experience has shown that forest structures can be managed in such a way that natural processes such as natural regeneration, natural pruning, the development of good stem form and self-thinning (natural stem number reduction) in the early growth stages are stimulated. In general, shelter results in thinner branches, higher wood density and reduced stem taper (Burschl and Huss, 1997; Rittershofer, 1999; Schütz, 2001). This form of steered self-regulation is often referred to as biological automation. The same effect can be reached by managing dense plantations with small initial spacing, but there is general consensus that the benefits cannot compensate for the additional cost incurred. Therefore managing vertical and horizontal structure in conjunction with natural regeneration is a clear alternative for controlling the level of competition (Klang and Ekö, 1999). The individual and collective stability of woodlands can be enhanced and another positive side effect of this strategy is a greater biodiversity. Well-structured forests like those managed as selection systems are appealing to visitors and therefore have an important recreation and amenity value (Jephcott, 2002; Nyland, 2003).

Mixed age classes and tree species

There is potentially a range of benefits to be gained by encouraging mixed coniferous/broadleaved woodlands. One of the aims of CCF is the diversification of monospecies coniferous plantations which are outside their natural range. These benefits include the reduction of biotic, abiotic and economic risk, e.g. diseases and insect calamities cannot spread as easily as in pure stands (Nyland, 2003). Recent research in pure and mixed stands of Norway spruce and beech showed that in such mixed woodlands total volume production does not decrease as stand density approaches the maximum but remains constant (Pretzsch, 2002). This contrasts with pure stands where total volume production decreases. The study also showed that the stability of predominantly pure spruce stands can be improved if unstable spruces are replaced by stable beeches. According to the study an important element of stability in these mixed stands is the presence of sub-dominant and co-dominant trees which, therefore, should be retained. These findings revealed that mixed stands are much better able than pure stands to compensate for impacts on the stand density, such as windthrow or heavy thinnings, through an accelerated increment of the residual stand (Pretzsch, 2002). The work of Pretzsch may even suggest extending the occurrence of mixed stands for stability reasons.

Mixed forests also provide a wider range of size classes and timber products allowing flexible and rapid response to market conditions. They contribute to greater biodiversity and therefore provide more habitats. Studies have shown that mixed woodlands are believed to be more appealing to visitors (Jephcott, 2002). Mixtures may also help to reduce risk from global or regional climate change (Lindner and Cramer, 2002). Swedish and Danish investigations on the nutrient status of Norway spruce in pure and in mixed-species stands revealed that spruce needles from mixed stands had higher concentrations and ratios to N of K, P and Zn than needles from pure spruce stands. Among the mixed stands, the K status appeared to be positively correlated with the percentage of deciduous tree basal area. Soil samples from mixed stands had a higher Mg concentration and base saturation than soil samples from pure stands. The authors came to the conclusion that the positive effects on spruce nutrient status in the mixtures may promote total stand productivity in the long run, increase the resistance to adverse effects of air pollution, and limit the need to counteract ecosystem nutrient imbalance with direct treatments like fertilization or liming (Thelin *et al.*, 2002).

Attention to site limitations

As with all good forestry practice tree species/provenance choice should be dependent on site. This ensures that species/provenances are used that are well adapted to the particular site conditions and therefore can resist biotic and abiotic damage and have high growth rates (Burschl and Huss, 1997; Pro Silva Europe, 1999).

Selective individual tree silviculture

In managing stands for CCF, trees are individually marked, thinned and harvested in a compromise between silvicultural, economical and conservation needs (Rittershofer, 1999). Most CCF silvicultural systems aim at a combination of frame tree selection, crown thinnings and target diameter harvesting (Abetz and Klädtke, 2002). Selective fellings may increase timber quality and is a pre-requisite for many other points in this list. As the economic benefits of tourism become better understood it is important to realize that unsightly clearfelling areas put potential tourists off (Jephcott, 2002; Nyland, 2003).

Conservation of old trees, deadwood and protection of rare and endangered plant and animal species

Many CCF guidelines suggest retaining a certain amount of lying and standing deadwood in each forest stand for biodiversity reasons. It is also recommended that a certain percentage of old trees are kept for their amenity value. Forest management should also aim at promoting endangered plant and animal species along with other management objectives (Niedersächsische Landesregierung, 1991). This also includes the protection of special biotopes within forests such as wetlands, rocky outcrops and dunes (Otto, 1994). The biodiversity aspect gains some importance because continuous high forests with native species such as beech (*Fagus sylvatica* L.) can have a negative effect on tree species diversity because rare and less competitive species tend to be extinguished as opposed to in middle or low forests (Kausch-Blecken von Schmeling, 1992). [Low forests are forests entirely managed on a short rotation basis by coppicing (coppice system) while middle forests (coppice with standards) are a result of both coppice management and some individual trees allowed to develop full growth (Burschel and Huss, 1997).] Typical victims of this effect are the native European *Sorbus* species, i.e. whitebeam (*Sorbus aria* (L.) Crantz), true service tree (*Sorbus domestica* L.), wild service tree (*Sorbus torminalis* (L.) Crantz) and yew (*Taxus baccata* L.). In some countries policy makers are aware of this effect and therefore explicitly included the conservation of rare and endangered plant species and provenances in their CCF guidelines (Niedersächsische Landesregierung, 1991; Landesanstalt für Wald- und Forstwirtschaft Thüringen, 2000; Nyland, 2003).

Promotion of native tree species/provenances and broadleaves

For centuries fast-growing conifer species were promoted in large areas of Europe beyond their natural range on sites naturally dominated by broadleaves to increase commercial timber growth. These secondary coniferous stands mainly in areas below 1000 m a.s.l. turned out to be extremely sensitive to environmental stress factors and are highly susceptible to progressive loading by air pollution and potential climate change. Thus, the restoration of such forest ecosystems originally dominated by broadleaves is an important silvicultural task (Hasenauer and Sterba, 2000).

As there are many silvicultural problems with native tree species especially in upland forestry, this issue is traditionally very contentious in Britain, though it is a clear element of international definitions (Pro Silva Europe, 1999). The idea comes from the assumption that native tree species and provenances are better adapted to local site conditions and have co-evolved with other plant and animal species in a particular country or region. Numerous animal and plant species are directly connected to native trees in this co-evolutionary development. The introduction of exotic species disrupts this symbiosis and results in a fall in biodiversity (Pro Silva Europe, 1999). Species are considered native if they have not been introduced by humans, either recently or in the distant past (Peterken, 2001). However, this definition presents some difficulties and the natural range of species cannot always be delimited. There will always be considerable debate over the 'nativeness' of one species *vis à vis* another and it is questionable whether species which have just been excluded from a certain region by the last ice age, but before that had a long co-evolution with other plant and animal species of the same area, should be termed non-native (Pro Silva Europe, 1999). The boundaries of areas which can be described as the native range of a species change over time even without human influence. Also the 'site' to which a species is native can be defined at various scales, from a region through a discrete wood to each patch of contrasting soil within a wood. Provenance, too, must be considered (Peterken, 1996). Another consideration here is the consequent removal of invasive non-native tree species. According to Pro Silva Europe (1999) exotic tree species should only be planted in situations where this is an economic necessity, and then only if the exotics can be mixed with the indigenous vegetation pattern within certain quantitative and qualitative limits. However, the need to move towards a greater use of native tree species is a clear requirement of forest restoration. The removal of non-native and especially invasive species among natural regeneration might be necessary and underplanting with native species plays an important role (Niedersächsische Landesregierung, 1991; Thompson *et al.*, 2003).

Ecologically sensitive forest protection, thinning and harvesting operations, ecologically sensitive wildlife management

The idea behind this is to reduce the disturbance in the forest ecosystem to a minimum by carrying out only limited forest protection and promoting biological methods. In the same way thinning and harvesting should be conducted in a way which disturbs the remaining trees and the ecosystem (especially the soils and the ground vegetation) as little as possible. Artificial liming of forest soils is often conducted to compensate for soil degradation and branches, twigs, bark and tree tips should be left in the forest, as they contain most of a tree's stored nutrients (Otto, 1994).

The density of the deer population needs to be in balance with the carrying capacity of the site to make the use of natural regeneration feasible. This will also keep fencing costs low which could otherwise be quite high (Partl *et al.*, 2002). In Britain, apart from deer, this also applies to the grey squirrel, the control of which is absolutely crucial to the success of CCF.

The establishment of forest margins and a network of protected forests

Adopting a holistic approach to forest management by managing the ecosystem rather than just crops, is a very prominent feature of CCF. One way to contribute to this objective is the establishment of forest margins as transition zones between the open landscape and woodlands. Here a certain stage of natural succession is artificially and permanently preserved. Although there would be a strip of 25–30 m at the stand boundary with low or no timber production, this could significantly increase wind firmness (Otto, 1994; Burschl and Huss, 1997). Siebenbaum (1965) reported successful use of such forest margins for the purpose of forest stabilization in the windy climate of the German federal state Schleswig-Holstein.

In a similar way CCF guidelines often demand that riparian forests and streamsides are restored by appropriate and sensitive management (Forestry Commission, 2000; Nyland, 2003). This can contribute to decreasing catastrophic flooding events (Greger, 1998). Other authors additionally suggest the establishment of a network of protected woodlands, including some non-intervention areas, as 'stepping stones' in large areas of commercial forests which would provide areas of retreat and almost undisturbed development for flora and fauna (Niedersächsische Landesregierung, 1991; Otto, 1994).

Having reviewed these elements of the current debate on CCF it is obvious that many different silvicultural systems can be included under the broad heading of CCF and Figure 3 gives an impression of how wide the spectrum of systems and their resulting diameter distributions is. It stretches from an even-aged coniferous woodland managed on a non-clearfelling basis to a selection forest. This stresses the need for clear definitions of interventions and envisaged management scenarios when transformation of even-aged stands or afforestation/restocking is proposed. Ultimately, no matter how we define our personal

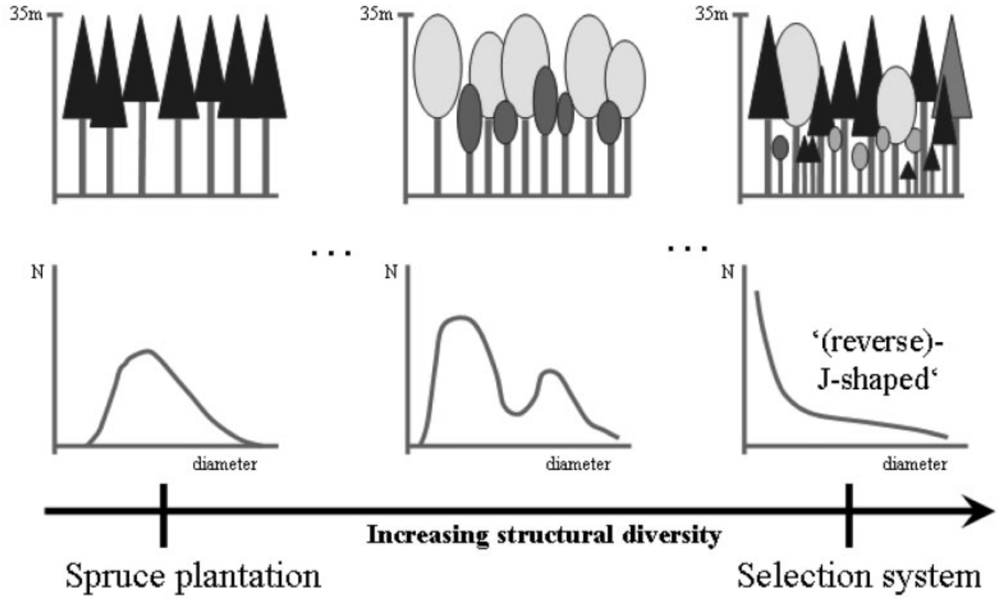

Figure 3. The continuum of continuous cover stretching from an even-aged coniferous woodland managed on a non-clearfelling basis to a selection forest.

understanding of CCF, the important feature of any CCF system is the maintenance of continuous woodland cover in space and time whereby natural disturbances such as windthrows, fires and insect calamities can be incorporated.

Continuous cover and afforestation/ restocking

According to Gadow (2001) there are three basic CCF situations: (1) establishment on bare land; (2) transformation of even-aged plantations; and (3) maintenance of existing CCF systems. At present most silvicultural interest focuses on the transformation or conversion of existing forests, such as monospecies even-aged coniferous plantations to diverse uneven-aged continuous woodlands (Schütz, 2001) or the restoration of native woodlands on ancient woodland sites (Williams, 1999; Thompson *et al*., 2003). For stands where direct transformation is considered too risky, it is generally proposed that a pure stand should be re-established after clearfelling. The new crop could then be managed in such a way to establish continuous forest conditions (Schütz, 2001). Having succeeded in transformation the uneven-aged forest needs to be maintained, i.e. managed in a way that sustainable and uninterrupted harvesting, regeneration and recruitment is possible. However, there is another silvicultural option, that of establishing mixed forests under CCF prescription directly from scratch on bare land, whether it has not been recently under forest or it is a restock site. Direct establishment of mixed forests has been very successful especially where severe climatic conditions, such as strong winds and high precipitation, along the North Sea coast of Germany and Denmark made other methods impossible (Siebenbaum, 1965; Kramer, 1970). Theoretically there are three main approaches to establishing diverse, mixed stands on bare land: direct planting, direct seeding and the indirect establishment of mixed stands under the shelter of a nurse crop. This paper chiefly concentrates on the last option, which is the one to be preferred where there are adverse climatic conditions.

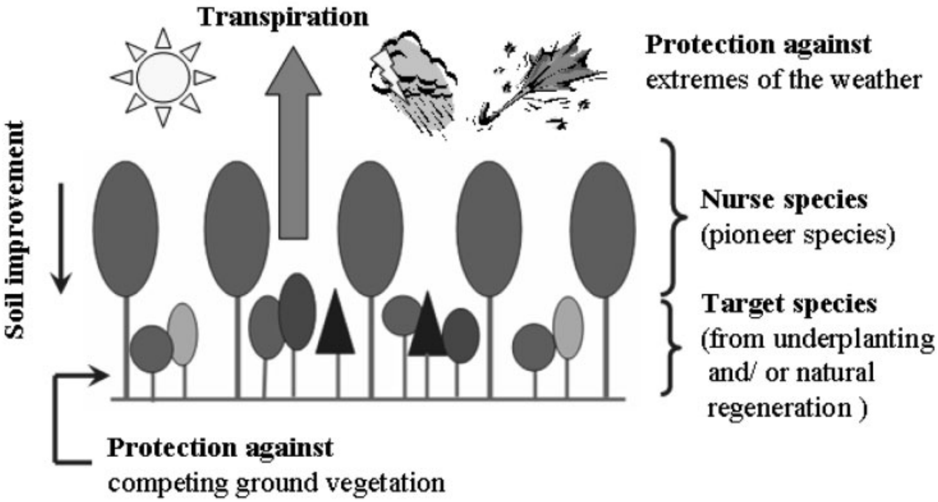

Figure 4. The nature and functions of a nurse crop used in afforestation.

Anderson (1960), who applied the method to establish his trials in Glentress, used the term 'advanced forest', while in the US this approach is sometimes called the 'one-cut' shelterwood method (Smith *et al.*, 1997). Other authors refer to this method simply as 'shelter' (Klang and Ekö, 1999). Fiedler (1962) describes the history of the nurse crop idea in a very detailed way. According to his findings the corresponding German term 'Vorwald' and its application has been in use for almost 200 years in Germany and Switzerland. The procedure is to establish a nurse crop of a pioneer species such as common alder (*Alnus glutinosa* (L.) Gaertn.), birch (*Betula* spp.) or aspen (*Populus tremula* L.) by planting or seeding at a comparatively wide spacing. A little later, or sometimes at the same time, the target species are introduced either by underplanting or from natural regeneration. Figure 4 illustrates the nature and the benefits of the nurse crop method. In a sense the nurse crop method mimics the classic shelterwood system. Such stratified stand mixtures, composed of late successional species in the lower strata and light-demanding early successional species in the upper strata have been recommended as a means of gaining a higher wood volume yield compared with a monoculture (Assmann, 1970). The method provides an open canopy which protects the target species against extremes of the weather such as too much sunlight and increased evapotranspiration, high precipitation, frost and wind (Örlander and Karlsson, 2000; Langvall and Ottosson Löfvenius, 2002). On damp sites the nurse crop helps dry the soil through transpiration (Klang and Ekö, 1999). It provides better soil conditions through litter recycling and suppresses competing ground vegetation. The temporary sheltering of the target species also results in an improvement of stem quality, e.g. stem straightness and branchiness (Fiedler, 1962; Burschl and Huss, 1997). Another important benefit of the nurse crops is the retardation of growth of the target species. From afforestation trials with silver fir (*Abies alba* Mill.) it is known that the lack of shelter, especially, led to failure (Schmidt, 1951; Kramer, 1970). Silver fir grown under canopy shows a slow but long-lasting growth with a late and slow culmination. In contrast to this, silver fir planted on bare land without shelter has a rapid growth when young which is followed by an early culmination at a lower level than under canopy, with quickly decreasing volume production thereafter. It is believed that in many cases the growth pattern of silver fir grown without canopy shelter is actually the reason for the increasing instability of silver fir stands around the age of 100 years (Kramer, 1970). Although not many studies have been done on this phenomenon with other tree species it is possible that there is similar growth behaviour, with resulting greater instability in crops grown without canopy.

All these benefits match what has been discussed in the section ‘Emphasis on vertical and horizontal structure’ of the introduction. The use of nurse crops can also be understood as a closer adherence to natural processes. In the sequence of natural succession from the initial herb and shrub stage to the climax stage the nurse-crop approach resembles a stage where pioneer tree species are gradually replaced by climax species. The only difference is that other stages are omitted in order to accelerate the process of producing timber.

Brief review of regional European experiences with nurse crops

The reviewed papers in this section are a selection of very different examples and give an impression of the wide range of applications.

Schmidt (1951) reviewed the growth of silver fir on poor sands in East Friesia (Lower Saxony) near the North Sea coast of Germany, where afforestation with this species commenced in 1758, and presented a regional yield model. He stated that, after the first systematic trials, it became clear that afforestation with silver fir would only be successful if a nurse crop of birch were used. A method was developed in which birch was planted first with an initial spacing of 2 × 2 m. When the birch reached a top height of 2 m they were underplanted with silver firs. Schmidt suggested that, if available, plants should be taken from natural regeneration or other sheltered positions nearby. They should be about 30 cm of height or 5–8 years old. Trials have shown that long-term mixtures of silver fir, Sitka spruce (*Picea sitchensis* (Bong.) Carr.), grand fir (*Abies grandis* (Dougl.) Lindl.) and beech (*Fagus sylvatica*), especially, led to stable and productive forests along the North Sea coast and silver fir proved to be very resistant to windthrow. Apart from birch the author suggested common alder as a nurse crop and mentioned that mountain pine (*Pinus mugo* Turra) is used in Denmark. When Anderson (1960) started his trials at Glentress in Scotland he used a similar method to introduce silver fir.

Siebenbaum (1965) discussed afforestation methods along the North Sea coast of the German state Schleswig-Holstein. The most successful method there was the establishment of mixed fir/spruce/broadleaved woodlands. Silver/grand/Caucasian fir (*Abies nordmanniana* (Stev.) Spach), sessile oak (*Quercus petraea* (Matt.) Liebl.), Japanese larch (*Larix kaempferi* (Lamb.) Carr.), beech, mountain pine and Sitka spruce were planted at the same time in intimate mixtures. These diverse plantations differentiated into two strata comprising the pioneer conifers in the upper storey and the firs and the broadleaves in the lower storey. Afterwards the mixed forest stands were then directly transformed to selection stands through subsequent thinnings. According to Siebenbaum (1965) this resulted in stable stands which were far less prone to biotic and abiotic damage than any other plantation types.

A very different understanding of nurse crops is evident in British and Irish forestry practice. Taylor (1985) stated that during the British afforestation campaigns in the 1920s and the 1950s/1960s Sitka spruce plantations suffered chronic nitrogen (N), phosphorus (P) and potassium (K) deficiency on many upland sites particularly where *Calluna* predominated. It was then found that, by using nursing mixtures of Sitka spruce with Scots pine (*Pinus silvestris* L.), Japanese larch and lodgepole pine (*Pinus contorta* Dougl. ex Loud.), this effect could be eased. The nursing effect is not simply through the suppression of heather, but involves a mycorrhizal relationship between the nurse and the Sitka which increases nitrogen availability (O’Carrol, 1978). All three species proved to be suitable nurses, although Sitka spruce in mixture with lodgepole pine achieved slightly better results in Scotland (Taylor, 1985). Thelin *et al.* (2002) reported similar effects in mixed Norway spruce/broadleaved woodlands where the admixtures compensate for poor and acidified soil on sites with low fertility. The long-term objective of all these trials, however, was primarily to produce a final pure crop of a desired target species such as Sitka spruce (Taylor, 1985).

Evans (1984) mentioned that using conifer nurses to aid the establishment of broadleaves was by then almost universal in Britain, but suggested that the nurse species should not be allowed to overtop the target species. An ecological study presented by Pigott (1990)

Table 2: Tree species and initial spacings suitable for the nurse crop method according the Seitschek (1991)

Nurse crop species	Target tree species
Species	
Common alder *Alnus glutinosa* (L.) Gaertn.	Most species but particularly
Birch *Betula* spp.	(1) shade tolerant and
Aspen *Populus tremula* L.	(2) intermediate species
Scots pine *Pinus silvestris* L.	
Larches *Larix spp.*	
Willows *Salix* spp.	
Rowan *Sorbus aucuparia* L.	
(Grey alder *Alnus incana* (L.) Moench.)	
Initial spacing	
2 × 2 – 3 × 3 m = 2500–1111 plants ha^{-1}	Norway spruce: 2 × 2 – 1.8 × 1.8 m = 2500–3086 plants ha^{-1}
	Scots pine, oak, beech: 1.3 × 1.3 – 1.1 × 1.1 m = 5917–8265 plants ha^{-1}
	Ash, sycamore: 1.8 × 1.8 – 1.4 × 1.4 m = 3086–5102 plants ha^{-1}

The suitability of the nurse crop species decreases from top to bottom of the first column.

highlights potential problems with the technique. He looked at the influence of evergreen coniferous nurse crops on the field layer in two woodland communities at Leith Hill Place Wood in Surrey (England) where a clearfell site was restocked with a mixture of sessile oak and Norway spruce or Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco). The nurse crop failed to stabilize the final oak crop, led to the accumulation of coniferous litter and reduced the diversity of ground vegetation significantly.

Klang and Ekö (1999) reported on the use of nurse crops in Sweden. The driving factor for this practice is the frequent occurrence of early summer frosts which cause considerable damage to Norway spruce plantations. In these areas seedlings are either planted under a shelter of trees from the previous stand or a shelter is formed by naturally regenerated birch, established after clearcutting. Tham (1988, 1994) and Mård (1996) studied the influence of a birch (*Betula pendula* Roth and *Betula pubescens* Eh.) shelter on the growth of Norway spruce. Although the nurse crop reduced the yield of Norway spruce, the total yield, including birch, was greater than that of pure Norway spruce stands. Bergqvist (1999) came to similar results in his investigation of birch/Norway spruce nurse crop systems. Norway spruce growing under a birch shelter is a common type of two-storied stand in the Scandinavian boreal forest. In young conifer stands, there is often an abundance of naturally regenerated birch overtopping the conifers and the number of birch is usually reduced in pre-commercial thinnings.

Seitschek (1991) and Rittershofer (1999) summarized Bavarian examples on sites where frost suggests the use of nurse crops would be beneficial. The initial spacing they quoted as a result of their experience is similar to the one stated by Schmidt (1951): 2 × 2 to 3 × 3 m. They came up with the interesting observation that the target species should be introduced when the stand height exceeds the spacing of the plants. But in any case the authors emphasized the need for an early underplanting in order to keep the amount of competing ground vegetation low. In some situations it is even advisable to plant nurse crop and target species at the same time (Seitschek, 1991). The same author also stated that the establishment of forest margins can also contribute to the stability of the stand.

Table 2 provides an overview of recommended tree species for both nurse crop and target trees according to Seitschek's (1991) experience. Grey alder is recommended only for dry sites and should be used in rare instances because of its tendency to develop root suckers. Aspen and birch usually provide less shelter than alder. Perala and Alm (1990) reviewed the role of birch as a nurse crop worldwide.

Seitschek (1991) obviously prefers alder as the nurse crop species. Its success may be due to the fact that it forms a symbiotic relationship with the bacterium *Frankia alni* which belongs to the genus of the Actinomycetes and assimilates atmospheric nitrogen and therefore contributes to soil fertility (Savill, 1991). Moreover common alder shows a monopodial branching system and has a monocormicly growing continuous crown which is very similar to that of coniferous trees (Bartels, 1993). These desirable properties make the author suggest that individual alders should be allowed to develop in the target stand.

Greger (1998) described the afforestation of riparian zones along the river Elbe in the Stendal forest district. There the local forest authorities established a nurse crop to rapidly cover degraded soils and improve soil properties. Shrub species such as dog rose (*Rosa canina* L.), hawthorn (*Crataegus* spp.), blackthorn (*Prunus spinosa* L.) and pioneer tree species (elms, field maple and wild fruit trees) were used. The initial spacing for most nurse crop species was 2 × 2 m, though black poplar (*Populus nigra* L.), crack willow (*Salix fragilis* L.) and white willow (*Salix alba* L.) were planted at 4 × 5 m. In contrast to Seitschek the author suggested a very late introduction of the two target species common or pedunculate oak (*Quercus robur* L.) and hornbeam (*Carpinus betulus* L.), after 15–20 years. Elsewhere Heuer (1996) reported his experience concerning the establishment of mixed broadleaved and coniferous species under a Scots pine canopy in the borough of Berlin. One result of his study was that oak tolerates lower light levels than commonly believed.

Underplanting techniques

The underplanting of nurse crops is not fundamentally different from the underplanting of mature forest cover. Also some of the methods originally employed for afforestation with mixed species on bare ground have later been transformed to underplanting techniques by allowing wider spacings. Worldwide there is a lot of experience with underplanting involving a wide range of species, sites and climatic zones (e.g. Dannroth, 1972; Emmingham *et al.*, 1989; Smidt and Puettmann, 1998; Kenk and Guehne, 2001). However, it is clear that most authors prefer the establishment of mono-species groups of the target species or groups with only two different species rather than an intimate mixture of species over the whole afforestation area (Burschel and Huss, 1997; Rittershofer, 1999). This facilitates the organization of plant cover according to small-scale differences in site conditions and also makes tending of the young growth considerably easier. In any case, a more intimate mixture of species will be achieved later through the reduction of stem numbers in each group as a consequence of thinnings and natural mortality.

A quite sophisticated but efficient design, 'oak-nest-planting', was originally devised in Russia where it is known as the 'Ogijewski-method' or 'regeneration in small places' (Podkopaev, 1961; Tarasenko, 1962). The method has been successfully applied to the establishment of mixed oak in Poland on fertile sites with competing ground vegetation (Szymański, 1986, 1994). The technique has repeatedly been used for underplanting. Szymański (1994), for example, described the successful establishment of oak-nests under a Scots pine canopy. This author also applied the method as an enrichment planting technique and for beating up of natural regeneration. The invention of the silvicultural technique was inspired by the observation of natural seed dispersal and germination of oaks in native woodlands. The design presented in Figure 5 suggests 200 nests per hectare with 21 oaks and 16 hornbeams, respectively, in each nest. This results in 4200 oaks and 3200 hornbeams per hectare. Small-leaved lime (*Tilia cordata* Mill.) has frequently been used as an alternative to hornbeam. By using this design, costs of establishment as well as of the tending of the young growth and subsequent thinnings have proved to be lower than those of conventional plantations. Competing ground vegetation is largely naturally controlled by the close initial spacing. In each nest, a group with a positive bioclimate was established preventing frost and sun damage. Browsing by deer is, in most cases, concentrated only on the

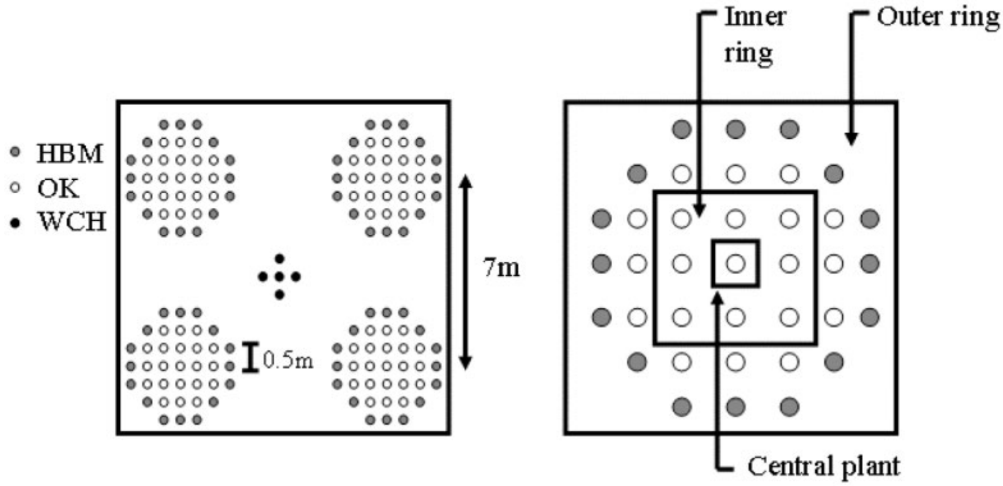

Figure 5. Design of a so-called 'oak-nest-planting'. On the left-hand side the arrangement of oak-nests on the afforestation area. On the right-hand side a detailed aspect of the arrangement of plants in one nest. Key to species codes: HBM = hornbeam, OK = oak, WCH = wild cherry (gean).

boundary trees of the nests, so that the valuable oaks in the centre are scarcely affected. Self-differentiation within the oak-nests as a consequence of the close spacing is supposed to enhance timber quality. Most silvicultural attention is therefore paid to the central oak of each nest which is supposed to be a final crop tree. The space between the nests can be planted with trees with short rotation period such as wild cherry or gean (*Prunus avium*), willows and birch, but it is also possible to leave it to natural seeding from adjacent forest stands (Szymański, 1994; Burschel and Huss, 1997). However, it is not recommended that this space be left without tree cover for too long (Guericke, 1996; Strobel, 2000). It has been suggested that the first pre-commercial thinning be carried out at a stand age of 20 years. The number of trees per nest is then reduced to the best five. The next intervention is then due at a stand age of 30 years (Szymański, 1994). In 1986 the Lower Saxony Forest Research Station at Göttingen (Germany) initiated a series of experiments to look into this afforestation method but used a closer initial spacing of 0.25 × 0.25 m (Mangold, 1988; Guericke, 1996). This method may have potential for use with other species.

Conclusions

Continuous cover forestry is currently being reconsidered as a suitable forest management tool to meet the various needs of the world's society. It is not a new concept and has a comparatively long history with various applications in different parts of the world. This has given rise to a large and steadily growing list of semi-synonyms used as labels for this management type (Table 1). The elements illustrated in Figure 2 are not always compatible and different stakeholders attach different levels of importance to them. This makes it difficult to give a concise and precise definition of CCF. Because of this it is always necessary to be clear about which of the elements discussed above are part of the local concept, what are the management objectives and what are the particular sequences of interventions to be applied. However, the lowest common denominator of all these definitions is the move away from clear-felling and towards the continuity of woodland conditions. In the past this was the main concern of the protagonists of CCF based on a sharp antagonism between themselves and the supporters of traditional forestry who used the concept of the normal forest which had strict rotation ages and clearcutting. Inevitably continuity of woodland conditions requires selective tree removals and permanence of residual trees. To what extent other elements of CCF, as discussed above, are part of regional or corporate ideas depends on management objectives, legislation and societal preferences.

Many authors come to the conclusion that CCF is a management type in its own right and Gadow (2001) suggests a simple distinction between rotation forest management (RFM) and CCF, based on the development of timber volume over age. CCF requires new skills and new silvicultural and biometric techniques, as well as personnel with intimate knowledge of forest dynamics to enable the management of stands, consisting of mixed species and age classes, on a non-clearfell basis (Helliwell, 1997; Gadow, 2001). These skills and techniques are only partly available in many of the countries of Western Europe where this management type has only recently been introduced. The consequences of such large-scale changes as proposed with CCF management are largely unknown. In Britain, for example, it is accepted that there is a lack of knowledge and training in the techniques and methods of CCF (Hart, 1995). In many countries CCF management has been politically driven and there is a lack of research looking into the many consequences of this new management type. Further research is therefore necessary to develop new techniques but also to adapt already existing ones which are successfully practiced in other countries.

There are three distinctive continuous cover situations: (1) establishment on bare land, (2) transformation, and (3) maintenance (Gadow, 2001). This paper has reviewed techniques which could be employed in the establishment of continuous cover directly in the form of mixed stands on former agricultural land or restocking sites particularly under severe climatic conditions. These techniques largely involve the use of nurse crops, and several very different approaches have been described. British and Irish experience differs from that of continental Europe in that the use of nurse crops can be characterized as

- having their main focus on the establishment of monospecies plantations
- using only coniferous trees as nurse species
- comprising nurse and target trees which were planted at the same time.

This contrasts with most of the continental approaches reviewed in this paper which by and large prefer broadleaves as nurse species and aim at establishing mixed stands either by underplanting nurse crops with more than one tree species or by taking parts of the nurse crop over in the target stand.

Mixed forest stands have many advantages which far outweigh their disadvantages and may contribute to more stable and sustainable woodlands especially in windy maritime conditions. The introduction of new and, modification of, existing techniques for afforestation and restocking seems to be desirable, e.g. the establishment of oak- and ash-dominated woodlands, could benefit from this approach. However, this review highlights the fact that there is a lack of information on appropriate methodology and the success of these techniques. The authors strongly recommend setting up more experiments to obtain this information.

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