Factors affecting the economic assessment of continuous cover forestry compared with rotation based management

Paddy Purser[a*], Pádraig Ó'Tuama[b], Lucie Vítková[c] and Áine Ní Dhubháin[c]

Abstract

Economic comparisons between Continuous Cover Forestry and rotation-based forestry are complex and often inconclusive as there are fundamental difficulties in comparing even-aged and uneven-aged management systems from an economic point of view. These difficulties are multifactorial but they can be broadly grouped into methodological factors and management related factors. This paper explores some of the most influential issues affecting outcomes in economic valuations and in particular how they affect CCF compared with rotation based management. The discussion of these issues will help to inform the debate on CCF and its applicability to forest owners more familiar with rotation based forestry.

Keywords: *Valuation method, discount rate, timeframes, risk, management factors.*

Introduction

One of the most common questions that arises when discussing Continuous Cover Forestry (CCF) (often described as uneven-aged forestry) as a forest management option, particularly in countries where even-aged forestry is the norm, is how does CCF compare economically with rotation based management, such as conventional clear felling systems? Economic comparisons between these two approaches have previously been made. In a review of such studies, Hanewinkel (2002) attempted to interpret these comparisons using a model study but concluded that there are fundamental difficulties in comparing even-aged and uneven-aged management systems from an economic point of view and that it seems most unlikely that even technical improvements of model studies or new empirical studies with a broader data base could lead to improvements in such comparative economic studies. The reasons for this are multifactorial and depending on the valuation method used, not all factors are or can be included and "like" cannot be compared with "like". This paper aims to consider some of the issues that most heavily affect outcomes in economic valuations and in particular, how they affect CCF compared with rotation based management. These issues can be broadly grouped into methodological factors and management related factors and these are addressed below.

[a] Purser Tarleton Russell Ltd., Forest Sector Management, Consultancy & Research, Croghan Lodge, Woodenbridge, Avoca, Co. Wicklow.
[b] Coillte, Hartnett's Cross, Macroom, Co. Cork.
[c] School of Agriculture and Food Science, Agriculture and Food Science Centre, University College Dublin, Belfield, Dublin 4.
[*] Corresponding author: ptr@eircom.net

Methodological factors

Valuation method

A commonly used valuation method in even-aged forestry is *Net Present Value* (NPV) where future cash flows associated with the remainder of the rotation are discounted back to the present using a discount rate (Little et al. 2013). This type of valuation method is not suitable for uneven-aged forestry where there is no defined rotation and where the capital value of the forest is never liquidated and does not appear in the cash flow. Instead, the two main valuation methods associated with CCF (as cited in Süsse et al. 2011) include:

- Potential Value (PV). This was calculated by Süsse et al. (2011) by dividing the annual yield by a discount rate:

  PV = Annual Yield (€) / Discount Rate

  Such a valuation method is clearly unsuitable for rotation based forestry where the yield comes predominantly in a single year. However, this method is considered ideally suited to valuation in CCF stands as there is no requirement to predetermine the harvesting date of all or any trees. Instead it allows for the valuation to reflect the future optimal timing of harvesting of individual stems as determined by the manager. The Association Futaie Irréguliére (AFI), an association of forest owners and foresters originating in France, uses potential value as the basis of a performance management indicator for stands in its network (Vítková et al., 2013).

- Standing Value (SV). The current standing value of all timber, if realised (this is also known as the capital value) (Süsse et al. 2011). This clearly would not be useful in describing young or semi-mature even-aged forests as the future value, when mature, is not accounted for. Nor is it entirely suitable for valuing a forest in transition from even-aged to uneven-aged as in such a scenario, investment in forest management may not yet have resulted in the forest composition or structure ultimately sought.

Choosing a valuation method that suits both even-aged and uneven-aged forestry is therefore challenging and any comparison between forest management types must discuss the influence the valuation method has on the outcome.

Discount rate

Future cash flows associated with future forest management can only be compared if adjusted to a common year and this is done using a discount rate. Little et al. (2013) stated that forest valuations are extremely sensitive to the discount rate used due to the length of time between planting and final harvest which can vary from 30 years for conifers to over 100 years for some broadleaf species such as oak. This obviously assumes a rotation based system of management. The choice of discount rate can significantly increase or decrease the valuation as well as determine the viability of a forest investment. To illustrate this point, Tahvonen (2011) attempted to compare uneven-aged and even-aged management systems in Norway spruce in Nordic countries and concluded that either system could be declared more economically favourable depending on growth rate and interest rates used. In general terms, a high discount rate favours short term projects, while a low discount rate favours longer term projects (Price, 2011; Little et al., 2013). Davies and Kerr (2011) use a declining discount rate in their analysis of costs and revenues of transformation to CCF. This is as recommended in the British Treasury *Green Book* (H.M. Treasury, 2003) which specifies that a declining rate is appropriate when considering long-term investments. The rates used range from 3.5% for the 0-30 year period reducing to 1% for the period beyond 300 years. Price (2011) examined the impact of declining discount rates and their applicability to forestry in some detail and discussed how they affected optimal rotation lengths depending on the nature, consistency and predictability of future forest management decisions. The question as to what is an appropriate discount rate is intimately connected with the time preference of the decision maker, the valuation timeframe and the treatment of risk. The influence of timeframe and treatment of risk are discussed separately below.

<u>Timeframes</u>

The timeframe or management period over which a forestry investment is valued has a significant bearing on the outcome. Typically, the economics of an even-aged forest management system are assessed for the duration of a single rotation and the residual land value following clearfelling is normally included in the analysis (Little et al., 2013). This rotation period is dependent primarily on species and site productivity and can range in Ireland from 30 years for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) to over 100 years for oak (*Quercus* spp.). The start point for such an analysis can be at any point in the rotation and the timeframe is simply the remaining management period up to and including clearfelling.

The timeframe for the economic assessment of CCF cannot be defined so simply or in the same way. The start and end points for such an analysis also have a significant bearing on the outcome. Davies and Kerr (2011) discussed how the choice of start point and the choice of length of a finite period for comparing cash flows are arbitrary and the effect of excluding cash flows beyond the time horizon must be considered when interpreting results. Considerations with regard to the start point and analysis period include:

- whether the forest is already in a "Steady State" and the management is focused primarily on the harvesting of increment (Hanewinkel 2002);
- whether the forest is currently even-aged but about to be transformed over an undefined period to an uneven-aged forest (Davies and Kerr 2011);

- whether the forest is undergoing transformation from an even-aged to uneven-aged status and at what stage in this process the forest is currently at.

The analysis period for all scenarios must obviously have start and end points. If the objective is to compare even-aged and uneven-aged forest management systems, it is difficult to define a common period which best reflects the particular characteristics of each system. A long period in which a "steady state" of CCF management is achieved would need to be matched by multiple even-aged rotations. A shorter period, for example, corresponding to one even-aged rotation, would need to include a capital value for the retained forest stand under CCF management. In their analysis of costs and revenues of transformation to CCF, Davies and Kerr (2011) examined three different timeframes, (20 years, 100 years and perpetuity) when comparing a rotation based management system with three different CCF scenarios. They found that each timeframe produced different results in terms of the relative economic ranking of each scenario. A similar study in Germany by Knoke and Plusczyk (2001) based the timeframe around the expected transformation period from even-aged to uneven-aged forestry (60 years) and added this to a 17-year lead-in period for which good baseline data were available. The theoretical analysis compared the 77-year period up until the stand was considered transformed with a similar period under even-aged management involving 57 years until clearfell and a further 20 years post clearfell of the restocked stand. The economic analysis showed a considerably lower amount of harvested timber and a considerably lower income earned for the transformation strategy compared with the even-aged management system. However, income from the transformation strategy occurred earlier and was more uniformly distributed over time. Due to this fact, the net present value (NPV) of transformation exceeded that of even-aged management during the 77-year period, given an interest rate of 2.6%.

<u>Market factors</u>

In general terms, forests managed under CCF will produce logs of larger dimension than those managed under a rotation based system (Hanewinkel 2002). This is because, particularly during a transformation period, individual trees are retained in the stand as seed producers and to provide shelter for a longer period. These retained stems are generally of higher than average quality as:

- they are selected as showing desirable traits as potential seed-producing trees;
- they are selected as trees which will result in greater value increment if retained, relative to other stems that may be selected for felling.

Common questions that arise for practitioners in CCF are whether or not it is possible to sell logs of larger dimension and, if so, whether or not a premium price is paid for large quality logs (Price and Price 2006, Süsse et al. 2011). This depends on both species and local industry conditions. While rotation based forest management generally references a single price/ size curve for the species and market in question, the mixed species and the increased focus on quality associated with CCF management means that a number of different price / size curves may come into play. For example, Douglas fir (*Pseudotsuga menziessi* (Mirb.) Franco) and Sitka spruce, often used in mixture in CCF management have two different price / size curves (Poore 2014). Similarly, high and low quality broadleaves have entirely different price / size curves.

Because there are few published price / size curves for minor species or that account for the more sophisticated grading associated with species that produce higher value assortments depending on quality, most comparisons between even and uneven-aged forestry rely on standard price / size curves and commodity prices. In the eyes of CCF proponents, this results in an undervaluing of the economic returns available (Poore 2007) while in the eyes of proponents of rotation based forestry, the lack of concrete data for larger and supposedly higher grade timber achieved at local log auctions reflects the uncertainty associated with CCF (Price and Price 2006). Poore (2007) argued that CCF management allows for the felling of individual trees at their optimal size which he defines as the point where the expectation or potential value equals the standing value. This can be translated into what is commonly called a "Target Diameter" by CCF foresters and this varies with species, market conditions and quality. However, the only published analyses in which reliable timber prices for such categories can be used are retrospective and case studies of such management are currently the best way of exploring the economic performance of CCF relative to conventional management.

Davies and Kerr (2011) found, regardless of the fact that log sales are the only income source for their analysis, that in a sensitivity analysis, different product prices investigated did not alter the relative ranking of management scenarios by NPV. In a study of the economics of transforming Norway spruce (*Picea abies* (L.) H.Karst.) from a regular (even-aged) to irregular aged stand structure (considered synonymous with CCF by Helliwell and Wilson 2012) in Upper Bavaria (Germany), Knoke and Plusczyk (2001) also found similarly that log prices had a minimal effect on relative economic comparisons and that the most influential factor in such comparisons was the interest rate used.

While changes in timber prices may have little relative influence on the outcome of comparisons between silvicultural systems, they are significant when considering risk and strategies for mitigating these (Knoke et al. 2001). In general terms, more developed forest industries, where there is a long tradition of timber production and processing, will have more developed markets for niche products and in particular for quality timber grades. This is evidenced in central Europe by the existence of premium log auctions. At these events, premium logs across a range of conifer and broadleaved species are withheld from the general commodity markets and separately auctioned and sold into niche markets such as veneer, bespoke furniture etc.

Treatment of risk

The treatment of risk is an important consideration in any economic analysis of forestry and when different silvicultural management options are compared, unequal risks should be taken into account. In Ireland, Little et al. (2013) classified risks to forestry as either nature based (e.g. fire, wind, flooding etc.) or market based (e.g. changes in supply/ demand ratios for certain product assortments, fluctuating exchange rates in export markets etc.). While this classification is useful, the manner in which such risks are quantified economically is a subject of considerable debate in international literature. Forest management systems and practice can be used to mitigate against some risks and this is particularly pertinent in relation to CCF management. Proponents of certain silvicultural systems will often cite risk reduction as a reason for practising such a system. For example, the Northern Ireland Forest Service operates a "no-thin" policy for most forests to reduce the risk of windthrow (Phillips 1980). Conversely, Vítková and Ní Dhubháin (2013) point out that throughout Europe, forest authorities are choosing to transform stands in the belief that CCF will lead to greater stability and that a key driver for this policy was the high levels of windthrow experienced as a result of major storms in the 1980's and 1990's.

Knoke et al. (2005) developed a "hazard rate" per decade of age for spruce and beech (*Fagus* spp.) which demonstrated how risk of loss to natural hazards increases over time for both species. The increased risk of retaining older or larger trees has clearly to be balanced against their increasing value. Knoke et al. (2005) also analysed how varying the percentage of each species in mixture with each other affected the overall risk (nature and market based combined). They found that there were strong economic advantages for the ecological concept of mixed forests. Despite lower productivity in beech compared with spruce, a mixture of 30% beech would still result in 97% of the maximum economic utility of the site because of its role in reducing ecological and market based risk. In other words, they concluded, natural diversity can render economic advantages.

The concept of mixed species and mixed aged forests being more resilient in terms of ecological or natural hazards is commonly discussed internationally. In Lower Saxony, Germany, the state government set up the LÖWE (Lanfristige Ökologische Waldentwicklung) Programme in 1991 whereby all state forests would be managed using 13 guiding principles associated with close to nature forest management/ CCF. This policy states that "silviculture in the state forests is to realise and maintain the (forest structure) types that are more varied and that pose fewer risks. These are vertically graduated stands with as much variation as possible in small areas". This policy has resulted in a reduction in the requirement to restock following clearfell, storms or fire from almost 80% to less than 5% over a 30-year period (Lower Saxony State Forest 2011). Similarly in Slovenia, where close to nature forestry has been formally used for over 50 years, the Slovenian Forest Service have identified this type of management as central to optimising resistance of forests against insect and disease outbreaks, storm damage and fires (Slovenian Forest Service 2008).

The risk mitigating features of CCF as experienced by Lower Saxony and Slovenia, for example, are not in question. Knoke (2012) cited a number of empirical and theoretical studies that all agree with the hypothesis that CCF results in more resilient stands and reduced risk from natural hazards. However, there is a question regarding the resilience of forests while undergoing the transformation process from even-aged monocultures to mixed age and species forests. This question is raised by Knoke and Plusczyk (2001) who point out how the resilience of stands in transformation to CCF is different on wet sites vulnerable to windblow (e.g. in Scotland) than on drier, stable sites (e.g. in Bavaria). The risk of windblow during and particularly in the early stages of, the transformation period is recognised by CCF practitioners in the United Kingdom and Ireland and early thinning interventions and irregular thinning patterns are recommended by both Otto (2002) and Morgan (2006) as mitigation. The question of site suitability for CCF is also addressed by Mason and Kerr (2004) who list stability as a selection criterion when identifying sites suitable for transformation from even-aged spruce plantations to CCF.

Knoke (2012) pointed out another risk-reducing feature of CCF management associated with the spread over time of timber sales, used to reduce the risk of exposure to cyclical or sudden fluctuations in timber prices. Rotation based forestry, in which most of the produced timber is sold over a very short timeframe, can be exposed to such fluctuations. However, on stable sites, the timing of all harvesting operations, whether CCF or rotation based, can be optimised to avail of peaks in timber price cycles.

Treatment of non-timber values

Most economic analyses of both even-aged and uneven-aged forestry do not take account of non-timber values such as income from recreational activity, carbon storage, ecosystem services etc. While there is little empirical evidence in the literature to suggest that either forest management system delivers such services more effectively than the other, most commentators accept that the value of such services are higher with CCF management than rotation based forestry (Price Undated, Vitkova and Ní Dhubháin 2013). In an analysis of the benefits and profits of single tree selection silviculture in the Ozark region of Missouri, USA, Hamatani and Goslee (2008) concluded that, without valuing ecosystem services, single tree selection is profitable for landowners and may even compete financially with even-aged management. While the focus of their analysis was on the economic aspects of uneven-aged management, they suggested that there were numerous ecological factors that should be considered for a complete comparison with even-aged management.

Taxation policy

The way in which taxation policy in different jurisdictions is applied to income from timber sales has implications with regard to the forest management system employed by forest owners. In situations where income from timber sales is not taxable then there is obviously no influence in this regard. However, in situations where progressive tax rates apply to timber income whereby the tax rate increases with increasing income, there is a strong incentive to maintain a smooth, regular income stream associated with CCF as opposed to once-off large income events associated with clearfelling. In Ireland, income from the occupation of woodland (which includes timber sales) of up to €80,000 per annum is exempt from income tax. This is equivalent to approximately 4 ha of a clearfell. Given that the average private forest is 9.1 ha (DAFM 2014), this taxation policy is likely to result in the staggering of clearfell operations on any single property and therefore a significant restructuring of existing private forests. Some forest owners are likely to go further and seek to regularise the income production from their forest through the transformation to CCF. In other jurisdictions such as France where a land tax is levied, this applies equally across all forest management types (Süsse et al. 2011) but regular income from CCF management may be more convenient to owners in discharging this tax.

Growth and yield models

The lack of stand based growth and yield models for CCF causes difficulties for researchers, practitioners and land owners in making comparisons with even-aged forestry for which such models are readily available. This is going to remain an ongoing issue as it is unlikely that reliable CCF models will be available to foresters for the foreseeable future. Such models would be considerably more complex to produce than even-aged forestry models and this is a further impediment to any short to medium term prospects of them becoming available. Single tree models have the potential to be used in forecasting future growth and yield of individual stems. However, most successful CCF management is very dependent on the qualitative selection of stems for both retention and felling made by the forest manager and single tree models are generally only quantitative and cannot reflect the important qualitative issues which arise when deciding which trees to retain and which to fell. The spatial and structural diversity and the stability of the stand are all affected by the qualitative marking decision of the manager (Vítková 2014). The mathematical models can aid foresters in making quantitative decisions only, thus reducing their reliability. In the absence of reliable growth and yield models, practitioners must interpret empirical and theoretical studies and apply them as best they can to their own forests. For most practitioners, referenced and observed case studies are probably the most useful resources to assist decision making with regard to future forest management choices. While there is a danger that "best practice" case studies may not be representative, they do act as useful indicators of the potential of different systems.

Management related factors

Natural regeneration, subsequent re-spacing and tending

Regeneration of a forest can be achieved artificially through planting as is typically the case in the clearfell system, or through natural regeneration which is generally associated with shelterwood systems and CCF. The cost of re-establishing a forest post clearfell will vary depending on the site productivity, species selection, the owners' objectives and on the amount of money to be invested to achieve a desired economic return on the investment. Reforestation costs, including ground cultivation, planting costs and maintenance of the young trees to keep them free from vegetation and weevil attack until successfully established, are generally higher than afforestation costs. On low productivity sites these costs can often make the management of the forest uneconomic. On such sites, Yorke (1998) considered CCF to be desirable.

Natural regeneration is one of the key elements influencing the outcomes of financial comparisons of clearfell systems with shelterwood or uneven-aged forests. Davies and Kerr (2011) noted that the costs of natural regeneration (even including the costs of respacing) were lower than those of artificial regeneration. In their economic analysis of three CCF transformation scenarios and one clearfell and replant scenario, the transformation to a simple structure produced the highest NPV in perpetuity, a finding they attributed in part to the avoidance of replanting costs through the use of natural regeneration. However, it is wrong to assume that natural regeneration always has a positive effect on the economics of forest management. Depending on the density of the natural regeneration, the cost of tending operations and pre-commercial thinnings may have to be factored into any investment appraisal to reduce stem numbers to desired stocking levels prior to thinning. Dense natural regeneration, that can exceed 100,000 seedlings per hectare, has become increasingly common on recently clearfelled stands and stands managed as CCF in British uplands (Mason 2010). Even though there will be natural self-thinning through intense competition, respacing costs of up to £1,000 ha^{-1} (€1,400 ha^{-1} in August 2015) (Mason, 2010) may need to be incurred to ensure the future economic development of the stand. Such costs can arise in un-controlled situations and they serve to illustrate the importance of good management decisions in the transformation period to ensure that desired stocking levels are not dramatically exceeded. Even in situations where stocking levels achieved through natural regeneration are appropriate, it may still be necessary to incur the cost of enrichment planting whereby additional or compatible species for future CCF management which are currently absent from the site are purchased, planted and subsequently maintained.

Roads, racks and infrastructure
Road densities vary in stands managed under the clearfell system. In Ireland the standard road density for harvesting roads is considered to be 20 m ha^{-1} (Forest Service 2012) and this is the maximum level for which funding is available under the Forest Service's Road Grant Scheme (Forest Service 2012). With modern machine-based harvesting infrastructure, forwarding distances of up to 300 m allow for lower road densities to serve the forest. In general terms, the further the forwarding distance the higher the harvesting cost. In every forest property there is an optimal roading density that is a trade-off between the increased harvesting cost associated with less roading and the capital cost of developing road infrastructure (Ryan et al. 2004). This optimal roading density is also influenced by the timing, frequency and intensity of thinning operations and the capital cost of road development is more justified where there are regular thinnings planned than in a forest where no thinning is planned. For this reason, it could be claimed that CCF management requires more roading than conventional clearfell management. However, de Turckheim (1993) noted that the costs involved in the maintenance of roads and the infrastructure in CCF forests were similar to those of rotation based forest management. Knoke et al. (2001) also found that road costs were similar in transformation to CCF and in a clearfell system although it is unclear whether they are referring to capital or maintenance costs. Davies and Kerr (2011) also assumed no cost differential for roading maintenance between the four scenarios they compared. However, they qualified their assumption indicating that it applied to sites where conditions were considered to be highly suitable for machine access and where minimal remedial works were required for forest roads after harvesting.

In a clearfell system, extraction racks are laid out at first thinning stage and these racks serve all future thinning operations. These racks are generally spaced approximately 12 to 14 m apart depending on the initial cultivation method. During the clearfell operation, no consideration is taken of where extraction previously took place as forwarding of timber to the forest roadside is on large brash mats formed from the brash residue from the clearfell. In a CCF system a permanent network of 4 m wide racks at 20 to 40 m spacing is required (Süsse et al. 2011), although closer rack spacing is being used in Britain and Ireland during the transformation stages. The permanency of these racks is extremely important as harvesting machinery is restricted to travelling on the racks only, leaving the forest soil between racks free from risk of damage or compaction. The concentration of machinery on these racks on wet or vulnerable soil types can potentially lead to rutting and, given the need for a permanent infrastructure in CCF, some rack development, strengthening and maintenance work will often be required at an additional cost that is not likely to be incurred in the clearfell system. On such site types, Graduated Density Thinning (GDT) as devised by Tallis Kalinars (cited by Vitkova and Ní Dhubháin 2013) has been used by some practitioners. In this system, both the first and second thinning will have sufficient brash matting for heavy forest machinery with subsequent selection of permanent machine racks and abandonment of other redundant racks from third thinning onwards.

Harvesting

If one assumes a mechanised approach to harvesting using modern harvesters and forwarders, the primary factors that dictate costs in timber harvesting are tree size (the smaller the tree size, the higher the cost) and forwarding distance to roadside (the longer the forwarding distance the higher the cost), regardless of silvicultural system. For even-aged plantations, the harvesting cost at 1st thinning therefore does not differ significantly between conventional management and the initial intervention in transforming to CCF (Davies and Kerr 2011). This is because a high percentage of the thinning volume is systematic in the form of lines of trees removed to create thinning racks rather than selective thinning. However, when the early stages of transformation to CCF are compared, i.e. 1st, 2nd and early subsequent thinnings with similar thinnings in conventional management it is reasonable to expect lower costs and greater revenues from CCF due to a higher average tree size and potentially a higher overall harvest volume. Davies and Kerr (2011) stated that transformation to CCF is less costly than current conventional management over a 20-year period because of high initial thinning returns. Vítková (2014) noted that thinning used in the transformation process to CCF will have to be heavier in intensity and commence earlier than in comparable even-aged clearfell / replant management. The resulting earlier and larger revenues skew the financial advantages in favour of the transformation process, especially when high discount rates are used (Knoke and Plusczyk 2001). Results from a thinning trial described by Vítková (2014) show greater volumes per hectare and greater average tree sizes removed for both crown thinning and GDT (both associated with transformation to CCF) at first and second thinning stages compared to conventional low thinning (Table 1).

Table 1: *Out-turn of volume, basal area, mean DBH and average tree size removed in first and second thinnings in trials in Ballycullen, Co. Wicklow and Fossy Hill, Co. Laois.*

Thin type	1st Thin				2nd Thin	
	Basal area removed (m^2 ha^{-1})	**Volume removed** (m^3 ha^{-1})	**Mean DBH removed** (cm)	**Average tree size removed** (m^3 $tree^{-1}$)	**Average tree size removed** (m^3 $tree^{-1}$)	**Mean DBH removed** (cm)
Low (Clearfell)	13	59	14	0.078	0.116	16
Crown (CCF)	14	66	16	0.105	0.164	18
GDT (CCF)	15	64	15	0.088	0.145	17

Source: Vítková (2014).

Similar trends were noted in an initial crown thinning operation carried out on AFI sites[1] with what would be forecast for those sites under conventional management (Vítková 2014).

In the latter half of the transformation period and in the "steady state" period, harvesting in CCF systems generally concentrates on the removal of larger trees (Hanewinkel 2002), leaving smaller trees to develop further. This results in a higher percentage of high value assortments and therefore a higher value per m^3 of timber harvested. Davies and Kerr (2011), referencing a number of other studies, show clearly that both harvester and forwarder productivity increases with average tree size. However, there is no consensus in the literature on this. Andreassen and Øyen (2002) compared harvesting costs in Norway spruce between a clearfell system (€14 m^{-3}), a group system (€16 m^{-3}) and a selection system (€15 m^{-3}). In this case, despite the average tree size being higher in the selection (CCF) system, the authors claim the increased harvesting cost is due to a greater distance between the harvested trees and restricted space for harvesting and forwarding between the retained trees. The potential for damage to naturally regenerating, pole stage and other retained trees during harvest operations in CCF systems is a common point of discussion amongst foresters. Davies and Kerr (2011) do refer to increased costs that will be incurred as a result of having to use skilled motor manual (directional) felling to avoid such damage and also because tree sizes become too large for harvesting machinery to control. De Turckheim (1993) stated that harvesting costs in CCF are slightly higher for trees of comparable size because of the need to protect young seedlings and poles.

[1] An AFI (Association Futaie Irréguliére) site is a working research stand where the AFI Inventory Protocol (Susse et al. 2011) is in place and the forest is managed as Continuous Cover Forestry.

Price and Price (2006) addressed the question of thinning by removal of larger than average sized stems, referred to by them as "creaming". They concluded that this might be a financially attractive transformation route, yielding larger immediate revenues but it also results in greater openings in the canopy for natural regeneration than low thinning or conventional crown thinning.

Management costs

Süsse et al. (2011) commented that there is no particular distinction regarding overheads in CCF. However, they also accepted that the lack of clear management models, the need for a flexible approach to management and the potential for complex management decisions can lead to increased management costs. They reported that across the AFI network, CCF management costs range from €10 to €30 ha^{-1} yr^{-1}. This does not include the production of management plans, costed at €1.50 to €2.50 ha^{-1} yr^{-1} or the important cost of marking which averages €12 ha^{-1} yr^{-1} and ranges from €5 to €35 ha^{-1} yr^{-1}. This would give a total CCF management cost (across all AFI stands) of between €16.50 and €67.50 ha^{-1} yr^{-1}. Davies and Kerr (2011) failed to find a consistent pattern for the costs associated with CCF compared with conventional management systems, stating that published figures give little indication of what the range of management costs might be. They arrived at a cost of £30.27 ha^{-1} yr^{-1} (approx. €42.34 in August 2015) for conventional forest management operations and estimated that transformation to a simple structure will incur a 150% cost increase and a transformation to a complex structure will result in a 200% increase, due to increased demands for planning, supervision and training for staff who are unfamiliar with CCF. They also noted that even if these relative costs are realistic the differences will decline over time as experience of CCF systems increases.

Conclusion

Direct economic comparisons between rotation based management and CCF are difficult due to the irregular nature of CCF and its varying timeframes, development stages, age classes, mix of species, products and services. The very terms used by CCF practitioners such as "irregular" forest management and "close to nature" forest management give an indication of the difficulty in modelling such a process. Even where comparisons have been made, there are many assumptions and limitations which render the analyses as theoretical rather than conclusive. What this paper has attempted is to explore the issues which affect the valuation process and to discuss these in the context of CCF management. There is considerable experience to date with regard to many of these issues and where possible this has been reviewed. Further research is needed to develop stand based growth and yield models that can capture the complexity of interactions that occur in CCF stands. In the meantime, accurately assessed case studies of CCF practice, such as the AFI network, can be useful in demonstrating its economic strengths and weaknesses and more such studies over longer timeframes will become increasingly important in this regard.

References

Andreassen, K. and Øyen, B.H. 2002. Economic consequences of three silvicultural methods in uneven-aged mature coastal spruce forests of central Norway. *Forestry* 75: 483-488.

Davies, O. and Kerr, G. 2011. The costs and revenues of transformation to continuous cover forestry. *Report to the Forestry Commission by Forest Research*. Alice Holt Lodge, Farnham, Surrey, England.

DAFM, 2014. Ireland's Forests – Annual Statistics. Department of Agriculture, Food and the Marine (http://www.agriculture.gov.ie/media/migration/forestry/forestservicegeneralinformation/Annual%20Forest%20Sector%20Statistics.pdf) [Accessed August 2015].

De Turckheim, B. 1993. The Economic Basis of Close –To-Nature Silviculture. *Proceedings ProSilva First European Congress*, Besançon- France 21-24 June 1993.

Forest Service, 2012. *Forest Road Scheme*, January 2012. Forest Service Johnstown Castle Estate, Co. Wexford.

Hamatani, M. and Goslee, K.M. 2008. An analysis of the benefits and Profits of Single-Tree Selection Silviculture: *A Case Study of Pioneer Forest in Missouri's Ozarks. Pioneer Forest: A half century of sustainable uneven-aged forest management in Missouri Ozarks*. United States Department of Agriculture, Forest Service, Southern Research Station General Technical Report SRS 108.

Hanewinkel, M. 2002. Comparative economic investigations of even-aged and uneven-aged silvicultural systems: a critical analysis of different methods. *Forestry* 75: 473-481.

Helliwell, R. and Wilson, E. 2012. Continuous Cover Forestry in Britain: challenges and opportunities. *Quarterly Journal of Forestry* 106: 214-224.

H.M. Treasury 2003. *The Green Book – Appraisal and Evaluation in Central Government*. Treasury Stationery Office, London.

Knoke, T. 2012. The economics of continuous cover forestry. In *Continuous Cover Forestry* (Chapter 5). Ed. Pukkala, T. and Klaus von Gadow, K., Springer Science, Netherlands.

Knoke, T. and Plusczyk, N. 2001. On Economic consequences of transformation of a spruce (*Picea abies* (L.) Karst) dominated stand from regular to irregular stand structure. *Forest Ecology and Management* 151: 163-179.

Knoke, T., Moog, M. and Plusczyk, N. 2001. On the effect of volatile stumpage prices on the economic attractiveness of a silvicultural transformation strategy. *Forest Policy and Economics* 2: 229-240.

Knoke, T., Stimm, B., Ammer, C. and Moog, M. 2005. Mixed forests reconsidered: A forest economics contribution on an ecological concept. *Forestry Ecology and Management* 213: 102-116.

Little, D., Phelan, J., McDonald, T. and Phillips, H. 2013. *A Guide to the Valuation of Commercial Forest Plantations*. COFORD, Dublin.

Lower Saxony State Forest, 2011. *The Löwe Programme – 20 years of long term ecological forest development*. Lower Saxony State Forest, Husarenstraße 75, 38102 Braunschweig, Germany.

Mason, B. 2010. Respacing naturally regenerating Sitka spruce and other conifers. *Forestry Commission Practice Note* FCPNO16.

Mason, B. and Kerr, G. 2004. Transforming even-aged conifer stands to continuous cover management. *Forestry Commission Information Note 40*. Forestry Commission, Edinburgh.

Morgan, P. 2006. What makes close to nature forest management an attractive choice for Irish farmers? *Pro Silva Ireland Booklet*.

Otto, H. 2002. *Approaches of Close to Nature Silviculture in Sitka spruce pioneer plantations in Ireland*. Pro Silva Ireland, 36 Fitzwiliam Square, Dublin 2.

Phillips, J.C.L. 1980. Some effects of a no-thinning regime on forest management. *Irish Forestry* 37: 33-44.

Poore, A. 2007. *Continuous Cover Silviculture and Mensuration in Mixed Conifers at the Stourhead (Western) Estate*. Wiltshire, UK. SelectFor Ltd.

Poore, A. 2014. Optimising stand development and economic performance in irregular stands. *Paper presented at CCFG National Conference*, 2014.

Price, C. 2011. Optimal rotation with declining interest rate. *Journal of Forest Economics* 17: 307-318.

Price, C. Undated. Cost Benefit Analysis of Continuous Cover Forestry. Robinwood Project, *a 45-month European Interreg 111c Regional Framework Operation Project*

Price, M. and Price, C. 2006. Creaming the best, or creatively transforming? Might felling the biggest trees first be a win–win strategy? *Forest Ecology and Management* 224: 297-303.

Ryan, T., Phillips, H., Ramsay, J. and Dempsey, J. 2004. *Forest Road Manual*. Guidelines for the design, construction and management of forest roads. COFORD, Dublin.

Slovenian Forest Service, 2008. Forest Management by Mimicking Nature – How to conserve forests by using them.

Süsse, R., Allegrini, C., Bruciamacchie, M. and Burrus, R. 2011. *Management of Irregular Forests – Developing the Full Potential of the Forest*. Association Futaie Irrégulière. Besançon, France.

Tahvonen, O. 2011. Optimal structure and development of uneven-aged Norway spruce forests. *Canadian Journal of Forest Research* 41: 2389-2402.

Vitková, L. 2014. *Continuous Cover Forestry in Ireland*. PhD thesis submitted to National University of Ireland in September 2014.

Vítková, L. and Ní Dhubháin, Á. 2013. Transformation to continuous cover forestry: a review. *Irish Forestry* 70: 119-140.

Vítková, L. Ní Dhubháin, Á., Ó'Tuama, P. and Purser, P. 2013. The practice of continuous cover forestry in Ireland. *Irish Forestry* 70: 141-156.

Yorke, M. 1998. *Continuous Cover Silviculture. An alternative to clear felling*. A practical guide to transformation of even-aged plantations to uneven-aged continuous cover. Continuous Cover Forestry Group, Bedford.