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Economic assessment of transformation to continuous cover forest management in Estonia

PAAVO KAIMRE*, VIVIKA KÄNGSEPP AND RISTO SIRGMETS

Forest and Land Management Planning and Wood Processing Technologies, Institute of Forestry and Engineering, Estonian University of Life Sciences, Kreutzwaldi 5, 51006 Tartu, Estonia

* Correspondence:
Paavo Kaimre
paavo.kaimre@emu.ee

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Abstract

The discussion surrounding forest management principles, particularly those related to rotation and continuous cover forestry (CCF), has gained considerable momentum in Estonia in recent years. Advocacy for the adoption of selection cuttings over clear-cutting has been prominent. Despite the longstanding practice of continuous cover forest management in Estonia, there is a noticeable absence of economic analyses on this subject. This study aims to investigate pertinent criteria and methodologies for the economic assessment of alternative silvicultural systems. Additionally, we deliberate on the factors influencing the transition from even-aged to uneven-aged forest management.

The profitability of uneven-aged stand management was compared with even-aged forest management using an experimental stand that underwent recent selection cutting. To compute cash flows, stand inventory and removal data, categorised by timber assortments, were utilised to delineate changes in growing stock, timber prices and forest management costs. Net present value (NPV) was employed to assess rotation and continuous cover forest management scenarios.

The calculation results indicate that, in the long term, the NPV of CCF management is relatively similar to even-aged stand management at a 1% interest rate but lower when higher interest rates are applied. Prevailing requirements currently limit the economic attractiveness of transformation from even-aged to uneven-aged stand management. Revising forest management rules is imperative to enhance the profitability of uneven-aged forest management in Estonia. Adjustments to the stand age should be made, enabling selection felling and reducing the required minimum post-cutting basal area.

Keywords: continuous cover forestry; silvicultural systems; selection cutting; economics

Introduction

In recent years, Estonian public sentiment has markedly shifted towards a critical and disapproving stance on clear-cutting; many dislike this practice due to familiarity with the longstanding and cherished landscape. Consequently, the populace sees clear-cutting as a pronounced negative anthropogenic disturbance. Simultaneously, specific interest groups advocate for adopting alternative logging methods, particularly favouring selection cutting and implementing continuous cover forestry (CCF).

A poll released on 11 January 2023 (Turu-uuringute AS 2023) found that 77% of Estonians endorse the management of state-owned commercial forests as continuous cover forests. The draft of The National Forestry Programme until 2030, dated 13 December 2022 (Keskkonnaministeerium 2022), designates the proportion of shelterwood and selection cutting in regeneration cuttings as an indicator, with an initial value of 11%. The programme aims to augment this share.

Selection cutting has both proponents and detractors. Opponents underscore the drawbacks and consequences associated with this method. Notably, Estonia has historically employed selection cuttings. Selection cutting as an alternative to clear-cutting has been under consideration as early as in Oskar Daniel's 1926 silviculture textbook (Tullus 2002). In the early 1920s, a lively debate took place among Estonian silviculturists regarding the concept of 'Dauerwald'. The discussion concluded with an almost unanimous consensus that, due to natural and economic conditions, this management method was not applicable in Estonian state forests (Meikar 2000). In the latter half of the 1990s, private owners practiced intensive management of restituted forests, incorporating selection cuttings on a considerable scale. According to the Aastaraamat Mets 2010 (Keskkonnateabe Keskus 2012), the area subjected to selection cutting in 1999 was 4,571 hectares (ha), while the total area of all regeneration cuttings amounted to 22,601 ha. By 2019, these figures had dwindled to 80 ha and expanded to 52,812 ha, respectively, indicating a substantial abandonment of selection cutting. This decline is partly attributable to significant alterations in forest management regulations over the years.

The initial Forest Act of 1993, enacted post-independence restoration, delineated selection cutting as one method for wood procurement, emphasising its application in continuous cover forests. The subsequent Forest Act of 1998 defined rules permitting selection cutting in mixed stands, uneven-aged pine and spruce stands, multi-layered stands and grey alder stands managed as permanent forests. During the 1990s, numerous private forest owners in Estonia favoured this management approach due to the superior harvesting opportunities for larger trees compared to conventional thinning practices.

Selection cutting could not be applied in even-aged stands. In the case of uneven-aged stands, the minimum density of 0.6 became the limiting factor for harvesting. Repeated selection cutting shall not decrease the growing stock to a smaller volume than it was after the first selective cutting. The sharp decline in the planning of selection cuttings began in 2005 (Figure 1), somewhat before the section on selection cutting in the Forest Act and Rules of Forest Management was amended. In 2007, the new Forest Act (Metsaseadus 2006) and the accompanying Rules of Forest Management (Riigi Teataja 2007) significantly changed the requirements for selection cuttings. Rules allowed selection cutting by harvesting single trees to improve protected species' growth and living conditions per the Nature Conservation Act. A few years later, in 2008, the area allowed for selection cuttings was restricted to mature commercial forests of specific forest site types. In 2017, all restrictions on site types were abolished.

Figure 1 delineates the intentions of forest owners to employ selection cutting. The volumes have remained relatively modest since 2005; however, measurements and evaluations conducted by specialists on the National Forest Inventory (NFI) plots reveal a notable discrepancy, indicating a higher prevalence of stands managed through selection cuttings or selection-type cuttings than the notifications. For example, in 2019, the area of selection cuttings was 2,400 hectares according to NFI data, and in 2020, it was 1,800 hectares (Keskkonnaagentuur 2023). Figure 2 illustrates the dynamics of various regeneration cutting areas, encompassing selection cutting.

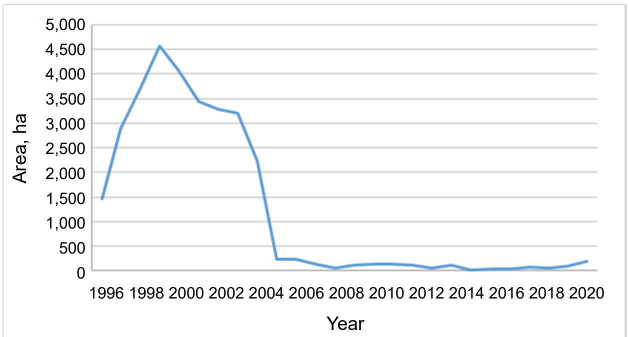

Figure 1. The area of selection cutting with reference to forest notifications (Source: Keskkonnaagentuur 2023)

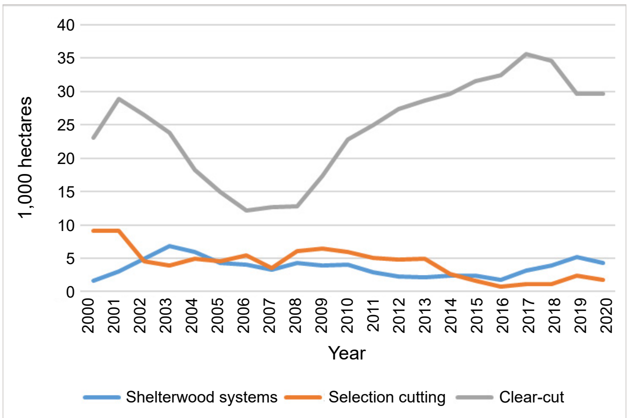

Figure 2. The area of clear-cut, shelterwood and selection cutting (in 1,000 ha) in Estonia (Source: Keskkonnaagentuur 2023)

The data presented in Table 1 delineate the area of the projected selection logging volume and anticipated removals from 2019 to 2022. The average planned harvesting volume stood at 54.5 m^3 ha^{-1}, providing insight into the potential removal volume for repetitive selection cuttings. Comparing this with the average removals in thinning, recorded as 72.8 m^3 ha^{-1} in 2019 (Keskkonnaagentuur 2023), shows that the expected harvesting volumes per hectare are lower for selection cutting than thinning.

Table 1. The area and removals of planned selection cuttings in 2019–2021 (Keskkonnaagentuur 2023)

Year	Area, ha	Removal, m^3	Average removal, m^3 ha^{-1}
2019	80	3328	41.6
2020	113	5760	51.0
2021	202	10912	54.0
2022	135	8887	65.8
Average	132.5	7221.75	54.5

Deliberations upon the merits and drawbacks of selection cuttings have emphasised certain economic advantages, particularly the capacity to replace thinning and regeneration cutting, thereby amalgamating wood procurement with silviculture and regeneration practices (Örd 1977, 2000). Continuous cover forest management anticipates cost-effective natural regeneration, supplemented by planting or sowing if necessary. The individual-tree principle allows growing notably large-diameter and valuable assortments, with the flexibility to apply varied maturity ages. Using selection cuttings also empowers forest owners to respond promptly to market demands. When contrasted with clear-cutting-based forestry, the timber production benefits of CCF can be encapsulated in four key aspects, including the attainment of more valuable wood, reduced regeneration costs, risk mitigation and the option to forgo thinning (Puettmann et al. 2015).

Nonetheless, implementing selection cutting in Estonia has not been without its challenges. Etverk (2007) critically noted that 'theoretically, it is the most natural and forest-friendly method of harvesting, but in reality, it has become the biggest destroyer of Estonian forests'. In the pursuit of wood acquisition to offset high logging costs, the forest owner's focus on obtaining the best and most valuable wood can often lead to a compromised outcome – an extensively damaged stand that has forfeited much of its ecological and economic value. Echoing these concerns, Tullus (2002) warns of the risk of overcutting and deforestation, noting that in many countries (including Estonia), intensified selection cutting has necessitated subsequent forest restoration through clear-cutting. The effective management of a continuous cover forest demands a sustained and prudent approach over decades (or centuries), requiring owners with a long-term perspective and a sense of stewardship.

Economic assessment of CCF

In previous decades, the management of Estonian forests has predominantly adhered to rotation forestry; thus, economic studies have concentrated on even-aged stands, primarily focusing on the dominant tree species (Korjus et al. 2011, Pärt and Kaimre 2021). Conversely, in recent years, there has been a nascent effort to publish preliminary results from studies on the shelterwood system (Tishler et al. 2020, Kaimre and Kängsepp 2022). Research papers elucidating the economic analyses on CCF and selection logging are scarce. Currently, assessments of CCF are predominantly approached from a silvicultural perspective.

Nonetheless, many studies investigating the economic performance of CCF are accessible from other countries. Vítková and Ní Dhubháin (2013) offer a literature review detailing the nuances of the transition to CCF, encompassing economic aspects. Davies and Kerr (2015) analysed the transition to continuous cover forest management, discovering that the transformation to CCF may not necessarily incur higher costs than clear felling and replanting, especially when natural regeneration proves successful.

Beyond the transformation aspect, considerable research has delved into the profitability and economic optimisation of uneven-aged stand management. Various works have scrutinised the experience of forest management involving selection cutting in Central Europe (Hanewinkel and Pretzsch 2000, Hanewinkel 2002, Hanewinkel et al. 2013). The Nordic countries, notably Finland, have published comprehensive papers over the last decades (Tahvonen 2007, Pukkala et al. 2009, Tahvonen et al. 2010, Juutinen et al. 2021), exploring theoretical principles and presenting empirical results.

A profit-oriented landowner strategically manages their forest to optimise net income, aiming to maximise the net present value (NPV) of future cash flows from forest products and services. In the planning process, it is imperative to forecast the value of the uneven-aged stand at the end of the planning horizon. One approach involves assuming the attainment of a steady state at some juncture; however, more sophisticated stand models have been devised to scrutinise the management of uneven-aged stands, encompassing thinning and selective cutting, with stand density as an independent variable (Chang 1981, Trasobares and Pukkala 2004, Bollandsås et al. 2008, Parkatti and Tahvonen 2020).

Concurrently, another research direction concentrates on delineating optimal management scenarios for CCF (Tahvonen 2007, Pukkala et al. 2010, Tahvonen et al. 2010, Tahvonen and Rämo 2016, Reventlow et al. 2021).

Matrix models have gained prominence and proven valuable in the economic analysis of uneven-aged stands. Adams and Ek (1974) authored one of the seminal works in optimal uneven-aged forestry. They introduced a transition matrix model and employed dynamic optimisation, albeit with several simplifications. The model's relatively straightforward structure is sufficiently detailed to incorporate the impacts of growth and logging (Pukkala and Gadow 2011). Furthermore, optimisation was conducted using an individual-tree model to ascertain whether the results are contingent on the model type. Pioneering individual-tree models tailored specifically for CCF were developed by Pukkala et al. (2009).

These models reveal that small trees exhibit slow growth in an uneven-aged stand, while large trees thrive. The slow early growth contributes to good wood quality and fast growth at older ages, sustaining high relative value gains. The robust and thick growth of large trees does not harm wood quality. The models show that the sustainable harvest of a fertile (*Oxalis-Myrtillus* site) uneven-sized Norway spruce forest in Central Finland ranges between 5.5 and 7 m^3 ha^{-1} $year^{-1}$, contingent on factors such as the length of the cutting cycle, stand density and the shape of the diameter distribution. Profitability considerations suggest harvesting larger diameter classes more heavily than smaller ones (Pukkala et al. 2009).

Tahvonen's (2007) comparison between even-aged and uneven-aged stand management revealed that clear-cutting and continuous cover forest management could yield an optimal solution for a specific stand, resulting in comparable economic outcomes. Variations in the discount rate, wood price or reforestation costs can shift the optimal solution from one management method to another. The findings demonstrated that managing an uneven-aged stand provides approximately 30% superior economic results compared to managing an even-aged stand of the same age. Notably, these results were obtained with certain simplifications, such as assuming that the stumpage price is independent of the management method. Additionally, the reforestation costs were not factored in, providing a particular advantage to CCF.

In Central Europe, the management of Norway spruce (*Picea abies* (L.) Karst.) has historically yielded a high net return since the early 20th century, whether based on models or empirical analysis. Hanewinkel (2002) initially postulated that uneven-aged forest management would result in a higher net income than even-aged forest management and subsequently undertook investigations to explore this hypothesis. The literature review revealed the absence of a reliable means to test the validity of the hypothesis empirically, necessitating modelling based on empirical data. Inputs with significant economic impact, such as wood price, risk and forest management costs, were incorporated alongside the latest stand and individual-tree growth models associated with both management methods.

The comparison of the two options demonstrated a very similar net income per unit area; thus, the established hypothesis of the superiority of one management method over the other was untrue. The author concluded that a difference of less than 5% in net income does not indicate the superiority of one method over the other, while considerations of wood quality and risk have a more significant impact on the results.

As noted before, no previous economic analyses regarding continuous cover forest management in Estonia have been published. The current study aims to identify a pertinent criterion and a method for the economic evaluation of selection cutting based on a literature review and then apply them to a sample stand. We aim to compare the profitability of stand management scenarios for the experimental stand, specifically contrasting clear-cutting and selection felling. We focus primarily on comparing the alternatives with each other rather than on the absolute values of the economic outcomes.

Material and methods

Study object

Test calculations were conducted with stand VA113-8, situated in Eastern Estonia and under the management of the State Forest Management Centre. Selection cutting was implemented in the stand in 2020. As per the harvester file, the total harvested volume amounted to 66.3 m^3 of various assortments (Table 2), equating to 43.6 m^3 ha^{-1}. For 2020,

Table 2. The volume of assortments from selection harvesting according to harvester's log data (Riigimetsa Majandamise Keskus 2022)

Assortment	Volume of harvested timber, m^3
Aspen pulpwood	0.2
Birch fuelwood	0.1
Birch pulpwood	8.3
Birch sawlogs	0.6
Birch plywood logs	0.6
Birch veneer logs	15.1
Spruce fuelwood	10.6
Spruce pulpwood	10.5
Spruce logs	15.5
Fuelwood	4.7
Ash logs	0.1
Sum	66.3

the average timber harvest with selection cutting in state forests was 70 m^3 ha^{-1} (Keskkonnaagentuur 2023).

Stand inventory data after first selection cutting:

Area: 1.52 ha; Quality class: I; *Filipendula* site type;

Average diameter: 26 cm; Height index. H_{100}: 31.1 m; Annual increment: 4 m^3 ha^{-1};

Growing stock volume: I layer, 194 m^3 ha^{-1}; II layer, 13 m^3 ha^{-1}; Basal area: 18 m^2 ha^{-1}.

Stand composition after the first selection felling was the following: share of silver birch (*Betula pendula* Roth) amounted to 45%; Norway spruce (*Picea abies* (L.) Karst.) to 41%; aspen (*Populus tremula* L.) to 5%; grey alder (*Alnus incana* (L.) Moench) and ash (*Fraxinus excelsior* L.) accounted for 3% each; black alder (*Alnus glutinosa* (L.) Gaertn.) comrised 2% and goat willow (*Salix caprea* L.) 1%. In the second layer, Norway spruce amounted to 70%, grey alder – 20% and black alder – 10%. The average age of trees in the stand was 72 years.

In March 2022, a sample plot was established following the methodology of permanent sample plots (Kiviste and Hordo 2002), mapping the location of each tree (Figure 3) and documenting individual tree parameters. To monitor the stand's development, the trees on the sample plot will be subject to regular re-measurement in the future.

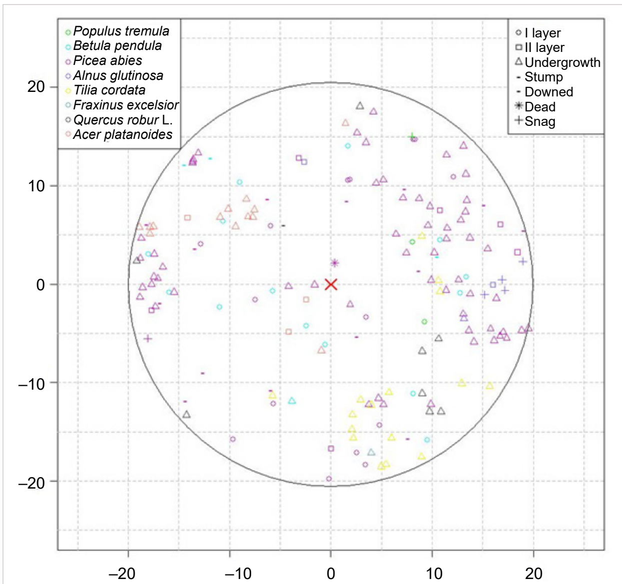

Figure 3. The graph of the sample plot in the studied stand – Coordinates of the centre: N 58.54462; E 26.93369

To ascertain the value of the remaining growing stock, we evaluated the distribution of trees into assortments using specialised software developed by A. Sims (2010) at the Estonian University of Life Sciences. The calculation of cash flows for forest management utilised average timber prices and costs at Järvselja Training and Experimental Forest Centre from 2019 to 2021. The data is suitable because the centre is located in the same region as the study object. Additionally, no public data on the costs of continuous cover forestry operations are available. The harvesting costs of uniform shelterwood harvesting 15.3 € per m^3 were applied for selection cutting, while clear-cutting incurred costs of 11.5 € per m^3 (Järvselja õppe- ja katsemetskond 2022).

Calculating the NPV of management scenarios involves a frequently used formula in forestry, which calculates the present value of future revenues and costs that forests accrue periodically at intervals of several years.

$$NPV_T = \frac{NR_T}{(1+i)^T - 1} - C_T \, , \quad (1)$$

where:
NPV_T – the net present value;
NR_T – the net revenue obtained at T-year intervals (€ ha^{-1});
i – the interest rate;
T – the length of the cutting cycle (years);
C_T – the value of the initial investment (€ ha^{-1}).

C_T represents the disparity in net revenue between clear-cutting and selection-cutting options, specifically the monetary value of the growing stock after selection cutting. This difference signifies the investment that a forest owner must undertake if opting for uneven-aged stand management (Trasobares and Pukkala 2004, Pukkala et al. 2010, Rämo and Tahvonen 2014). This initial investment is determined by comparing two alternatives. First, the owner can opt for clear-cutting, generating immediate income. Second, the remaining portion and its value are considered investments in selecting-cutting.

Pearse (1990) and Hazard-Daniel et al. (2017) provide a convenient general formulation for calculating the present value of a perpetual forest, where the crop already exists, accounting for various harvesting revenues and costs expected at different times during the rotation.

$$NPV = \frac{R_0(1+i)^T + \sum_1^T R(1+i)^{T-X} - \sum_1^T C(1+i)^{T-X}}{(1+i)^T - 1} - \frac{A}{i} \, , \quad (2)$$

where:
NPV – the net present value of cash flows;
R_0 – is harvesting net revenue at the beginning of the management cycle;
i – the interest rate;
T – the length of the management cycle;
R – harvesting (thinning) net revenue;
X – the time from the present until the revenue or cost;
C – intermediate forest management costs;
A – annual management costs.

In this context, X represents the years from the present to the time when the periodic cost or revenue is anticipated. The numerator aggregates the value of all revenues and costs at the end of the current rotation, while the denominator accounts for the perpetual periodicity of this value.

Management scenarios

Five stand management scenarios were delineated and compared, utilising NPV as the criteria.

1. Continuous cover forest management with perpetual selection cuttings at 11-year intervals, assuming similar income as the first selection cutting;
2. Perpetual clear-cuts with a rotation period of 72 years;
3. Continuous cover forest management with perpetual selection cuttings at 11-year intervals, assuming similar income as the first selection cutting, without considering the growing stock value as an initial investment;
4. Clear-cutting of the current stand followed by reforestation;
5. Clear-cutting of the current stand followed by natural regeneration.

In the first scenario, the stand is managed as a continuous cover forest, with regular selection cuttings every 11 years. Since the annual growth of the post-harvest stand is 4 m^3 per hectare, it takes 11 years to restore the pre-harvest stock of the stand. The net income for each cutting is assumed to be 1,409 € ha^{-1}, similar to the cutting conducted in 2020. The value of the initial investment C_T is 7,536 € ha^{-1}. This represents the value of the stand that remains growing after the first selection cutting. To determine the value of C_T, the assortment quantities by tree species were calculated using the program developed by Sims (2010). These quantities were subsequently multiplied by roadside prices (Appendice 1), and the logging costs (Appendice 2) were deducted from the resulting total. Formula 1 is used in the calculation. The second alternative involves repetitive clear-cutting in a 72-year cycle. The net income for each clear-cut is 8,828 € ha^{-1}. The initial investment value C_T resulting from the mandatory retention of seed and retention trees is 465 € per hectare. Formula 1 is used in the calculation. The third scenario is analogous to the first one, but the remaining stand's value is not considered an initial investment; in other words, this value is not factored into the NPV calculation. In the fourth scenario, the stand is clear-cut, followed by the reforestation of the clearing. The cutting cycle length is 72 years, and the calculation follows Formula 2. The fifth scenario mirrors the fourth, but the clearing is left for natural regeneration instead of reforestation.

Results

Table 3 presents the NPVs of different management scenarios at an interest rate of 1% to 5%. If the NPV of a CCF managed with perpetual selection cuttings is positive at 1%, the NPV of future cash flows already becomes negative at 2%. The results presented in Table 3 show that all scenarios, including clear-cutting, provide a positive NPV even at an interest rate of 5%.

Table 3. The NPV of different management scenarios, € ha^{-1}

Scenario	Interest rate, %				
	1	2	3	4	5
	NPV, € ha^{-1}				
1	4,645	−1,747	−3,869	−4,924	−5,552
2	3,847	1,657	586	59	−202
3	12,181	5,789	3,667	2,612	1,984
4	12,138	8,605	7,683	7,375	7,284
5	15,258	10,649	9,398	7,857	7,684

In assessing cyclically recurring harvesting revenue and the growing residual stand value as an investment at a 1% interest rate, the NPV of selection cutting is approximately one-fifth higher than that of clear-cutting. Conversely, with a 2% interest rate, the ranking decisively shifts in favour of clear-cut management, and the NPV of selection cutting turns negative. If the value of the growing residual stand is not considered an investment, selection cutting at a 1% interest rate yields results similar to the immediate clear-cutting of the existing mature stand, followed by reforestation and subsequent rotation management; however, the highest NPV was obtained in the fifth scenario, i.e. managing the stand with clear-cutting and natural regeneration.

The calculations made with the data from the experimental stands reflect the impact of inputs (harvesting cycle length, value of the remaining stand considered as an investment and the interest rate effect) on the results.

The NPV of selection felling management is notably influenced by the value of the remaining stand, as exemplified in the results of scenario 1. To augment the NPV of cash flows, increasing the volume of wood harvested in selection felling is imperative. In the test stand, 43.6 m^3 ha^{-1}, equivalent to 17.4% of the growing stock, was removed, reflecting a moderate or modest harvesting degree. The basal area of the remaining stand is 17.9 m^2 ha^{-1}, aligning with the minimum requirement of 15.0 m^2 ha^{-1} stipulated in the Rules of Forest Management (Riigi Teataja 2021).

Discussion and conclusions

Pommerening and Murphy (2004) asserted that CCF is not a new concept and has a comparatively long history with various applications in different parts of the world. This concept is currently being reconsidered as a suitable forest management tool to meet the diverse needs of society.

The transformation to a continuous cover forest should ideally occur in a structurally diverse stand, where various tree species thrive in multiple layers. For instance, transforming an even-aged mature pine stand into an uneven-aged structure with selection felling raises questions due to the extended time required. The success of stand regeneration with economically valuable tree species is essential in the transition. While proponents of CCF argue for regeneration cost savings, forest management practitioners exhibit a degree of scepticism regarding the success of regeneration.

Our calculations align with Tahvonen et al. (2010), emphasising that the economic attractiveness of alternative silvicultural measures is contingent on the initial state in the short run; however, the impact of the initial state diminishes when economic calculations and comparisons are extended to a long or very long-time horizon. According to Tahvonen and Rämo (2016), flexible harvest timing becomes crucial in optimising the transition from clear-cut regimes towards CCF. If the initial state of the stand is unfavourable for CCF, it may be optimal to clear-cut it and then transform the stand towards an uneven-aged structure.

Following selection cutting, it is essential to ensure that the basal area of the stand (m^2 ha^{-1}) complies with the regulations set forth by the Rules of Forest Management (Riigi Teataja 2021). Our study categorises the quality class of the test as I, with the prescribed minimum basal area being 15.0 m^2 ha^{-1}. The basal area of the remaining stand in our investigation was measured at 17.9 m^2 ha^{-1}. The volume of wood harvested in selection felling must be increased to enhance the NPV. In the experimental stand, a relatively modest volume of 46.3 m^3 ha^{-1}, or 18% of the stock, was removed, leaving a residual volume of 207 m^3 ha^{-1}.

Juutinen et al. (2021) highlighted in a study on Finnish spruce stands that the optimal result was achieved with a felling interval of 15 years, a basal area of the stand at 10 m^2 ha^{-1} and a growing stock of the remaining stand ranging from 90–100 m^3 ha^{-1}. According to Pukkala et al. (2010) and Finnish datasets, the optimal basal area for the remaining stand was 11–12 m^2 ha^{-1} for fertile spruce stands and 4–9 m^2 ha^{-1} for pine stands. Compared to higher stand densities, harvesting the stand to a remaining growing stock volume of approximately 100 m^3 ha^{-1}, the economically optimal residual volume in uneven-aged management, does not significantly impact volume increment (Laiho et al. 2011).

Implementing CCF principles poses challenges for forest owners who must balance societal expectations with ecological and economic goals. Profitability depends mainly on selecting trees for harvesting and the wood obtained from them. Thinning practices that yield positive cash flow without additional management actions will maintain a positive NPV. Conversely, clear-cutting underscores the significant impact subsequent forest management actions can have on the NPV.

From an economic standpoint, the management system's design should be endogenously determined through optimisation based on underlying economic and biological factors. Developing a model that keeps the forest management system flexible and capable of determining the optimal rotational framework would be a prudent approach. Without such a comprehensive model, the theoretical foundation for comparing different management systems, such as even and uneven management, remains contentious (Tahvonen 2007). Purser et al. (2015) noted that a 'direct economic comparison between rotation-based management and CCF is difficult due to the irregular nature of CCF and its varying timeframes, development stages, age classes, mix of species, products and services'. Numerous assumptions and limitations in the analyses render them theoretical rather than conclusive.

However, Estonia's current forest management rules do not support the economically viable transformation from even-aged stands to CCF. According to the Estonian Forest Act, selection cutting can be applied at the same age as clear-cutting, specifically when the stand matures. Our study reveals that starting with selection cutting in a mature stand yields a NPV roughly comparable to that of clear-cutting at a 1% discount rate. However, starting from a 2% discount rate, the net present value of cash flows from selection cutting is significantly smaller. The primary reason for this disparity is the substantial initial investment represented by the financial value of remaining stand after the first stage of selection cutting. Therefore, it would be prudent to commence selection cutting much earlier than the maturity age to facilitate the transformation to a continuous cover forest. Stability is paramount in the transition to continuous cover forest, and conducting selection logging in a middle-aged stand, for instance, mitigates the wind throw risk. From an economic perspective, it would be judicious to implement a clear-cut in a mature stand and initiate the transformation to CCF in the subsequent forest generation.

The importance of the transition to CCF stems not only from direct financial considerations but also from environmental concerns and public demand for sustainable forest management. The study evaluates the profitability of stand management based on cash flows related to wood production, without considering the value of other ecosystem services. A future challenge in assessing the profitability of alternative silvicultural systems lies in integrating the values of other forest ecosystem services into profitability assessment models alongside wood production. One of the first steps could involve accounting for the stand's carbon sequestration and carbon stock, as this is crucial for mitigating climate change and has also gained monetary value through carbon trading.

Given the likely substantial differences in tree growth between an uneven and even-aged stand, it is crucial to incorporate empirical data from continuous cover forests into the model. Regrettably, such data is unavailable in Estonia, and research in this domain is nascent. It is imperative to persist with the monitoring and detailed documentation of continuous cover forest development within existing experimental areas to advance our understanding. This ongoing effort aims to accumulate a dataset for empirical economic analyses of long-term management. Initial steps in this direction are presently underway. Concurrently, conducting simulations to explore the impacts of various scenarios on production, economy and biodiversity would be beneficial.

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Appendices

Appendice 1. Average roadside prices of roundwood during the period 2019–2021 (Järvselja õppe- ja katsemetskond 2022)

Assortment	Average price, € per m^3
Spruce logs	73.3
Spruce logs d < 18 cm	59.7
Spruce pulpwood	33.0
Pine logs	86.0
Pine logs d < 18 cm	65.3
Pine pulpwood	41.0
Birch veneer logs	56.7
Birch pulpwood	36.7
Black alder logs	49.0
Aspen logs	44.8
Aspen pulpwood	31.7
Coniferous fuelwood	29.2
Deciduous fuelwood	26.0
Residues	20.5

Appendice 2. Average costs of logging during the period 2019–2021 (Järvselja õppe- ja katsemetskond 2022)

Harvesting method	Average cost, € per m^3
Thinning	15.3
Clear cut	11.3
Uniform shelterwood harvesting	33.0