Advancing forest disturbance economics – assessing the impacts on timberland returns requires consistent economic approaches

Short: Forest disturbance economics

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Abstract. The discussion about economically optimal forest ecosystem management is almost as old as forest science. Continuous cover forestry renounces removing the tree canopy of forest ecosystems. In contrast, clear fell forestry suggests harvesting all trees at once to replace the crop trees with young trees. Assuming occurrence probabilities for stands of different ages, a study by Kärenlampi (10.1371/journal.pstr.0000146) introduced a forest portfolio perspective to analyse profitability (expected net revenues divided by forest value) and disturbance costs of continuous cover and clear fell forestry using data from another study (10.1007/s10640-022-00719-5). The reported results suggest that continuous cover forestry has a much lower economic performance and is economically more vulnerable to disturbance impacts than clear fell forestry, which differs from the results in the other study. In this work, we demonstrate that 1) the approach in Kärenlampi's research does not allow for deriving accurate economic performance indicators, 2) the hypothesised forest states are incomparable, and 3) the reported continuous cover disturbance costs are poorly conceptualised due to inconsistent assumptions. His study's proposition that a disturbance leads to a regime shift from continuous cover to clear fell forestry or that high maintenance costs are associated with it does not seem convincing. Managers can replant or adopt natural regeneration on forestland after disturbance to perpetuate continuous cover forestry long-term. Whilst Kärenlampi's study highlights valuable discussion points, our analysis reaffirms the necessity for more conceptually consistent and realistic approaches and avoiding oversimplification, which will more effectively support the economic assessment of forest disturbances.

Author summary: Here, we show how static economic assessments with inconsistent data may lead to misleading rankings of forest management regimes and how poorly conceptualised disturbance assessments reveal wrong disturbance costs. We suggest using dynamic economic approaches and disturbance concepts accounting for the possibly heterogeneous composition of forest ecosystems.

Keywords: Continuous cover forestry, forest value, economic resilience, disturbance costs, capital rate of return

Introduction

Forest science and practice have developed different silvicultural regimes to manage forests. Silviculture is the science of controlling forest stands' establishment, growth and maintenance to achieve private or public objectives [3]. A forest stand is a management unit of four to five hectares (for example, in Germany, but it can be much larger elsewhere) undergoing a unitary silvicultural treatment. Historically, simplifying forest stand structures by establishing a clear fell regime was proposed as a scientifically sound solution for managing forests economically, for example, in Germany [4] and Scandinavian countries [e.g. 5,6]. After establishing trees and some decades of waiting, all trees are harvested at once under such a regime when the planned production time is achieved, called the rotation period. New trees are planted on bare forestland, accumulate large timber volumes per hectare of land and are harvested periodically (Figure 1). However, such regimes are vulnerable to many disturbances, mainly when their standing timber volume is high [7]. An alternative regime known as continuous cover forestry establishes young trees in canopy gaps before achieving the rotation period. It reduces the standing timber volume in the vulnerable stand development phases. Simultaneously, the forest canopy is never purposefully clear felled. To continue the regeneration process (meaning the establishment of young trees), continuous cover forestry suggests harvesting moderate amounts of timber periodically, but never all the available timber at once. Continuous cover forestry may complicate the management [8] but leads to less volatile income at forest stand scales [9] and a faster recovery – should severe disturbances have destroyed the older crop trees but not the young regeneration trees [2]. Empirical evidence for a higher resistance of continuous cover forests compared with clear fell forests is consolidating [7,10].

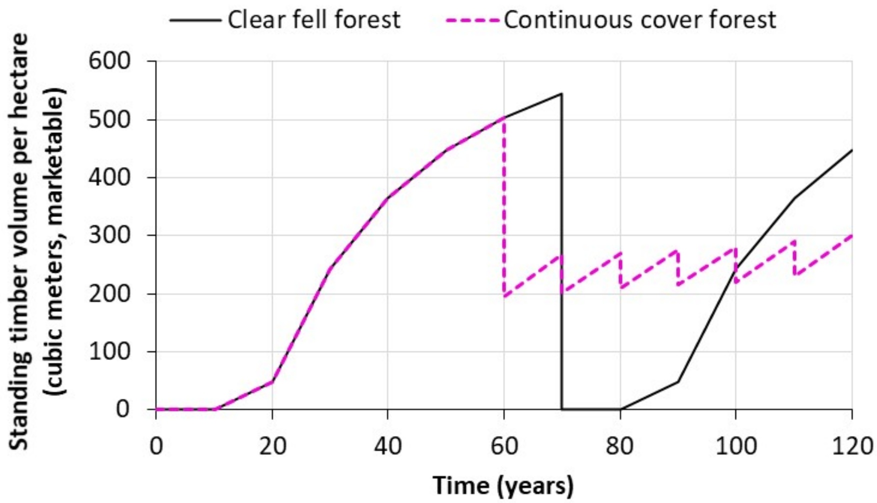

Figure 1 Schematic example of the development of the standing timber volume per hectare under a clear fell and a continuous cover forestry regime (German conditions)

The economics of both management regimes have been under research for a long time, with scientific studies showing substantial economic underperformance of continuous cover forestry [11,12] and others demonstrating the opposite [13–15]. However, when applying single-tree-based and single-species economic optimisation, continuous cover forestry is often economically superior in the long term [16]. One must be cautious when generalising such results, as economic assessment outcomes depend on the assumed context (initial state, disturbance regimes, other available assets, political stability, property rights) and decision-maker attitudes and preferences. For example, integrating less profitable tree species in a mixed forest may enhance the forest stand's resistance and income stability but reduce the expected economic profitability [17]. Depending on the decision-maker's attitude, a risk-neutral forest owner will likely prefer the clear fell regime. In contrast, a risk-avoiding forest owner would be more inclined to apply continuous cover forestry [18].

In his paper "Disturbance effects on timberland returns," Kärenlampi [1] suggested a static economic assessment of continuous cover forestry while implicitly assuming a risk-neutral decision-maker to maximise her forest's expected profitability, i.e. the expected net revenues divided by the expected forest value in his approach. Net revenues are earnings minus expenditures (time profit rate in [1]). The aforementioned study used data from previous research [2] to rank the profitability of continuous cover forestry against that of clear fell forestry. In addition, Kärenlampi's study analysed the impact of severe disturbances on the economic net revenues of both forest management regimes. The incorporated considerations suggested that continuous cover forestry was economically inferior to clear fell forestry and had higher overall disturbance costs than the clear fell alternative. Both results differ from those in [2], which requires an explanation.

We know that the results of economic assessments always depend on the assumptions made. Consequently, proving the management regime's superiority or inferiority in a rigorous mathematical sense is impossible for all conditions and preferences. However, the quality of any economic assessment hinges on its consistency. In this context, analysing the conceptual consistency and integrity of Kärenlampi's research approaches, results, and conclusions, viewed as hypotheses, was considered a relevant basis for this study.

The scientific study Kärenlampi used as a data source and inspiration for analyses [2] had integrated growth and yield data from Pretzsch et al. [19], representing German conditions. It found a slightly superior economic performance of continuous cover over clear fell forestry (about 11% higher net present value when both regimes started with bare land). Notably, the recovery time after severe disturbance (the key topic in [2]) was excluded, which may have limited the perspective when assessing the economic consequences of both management regimes on the expected profitability in Kärenlampi's study. His approach used averaged financial data instead to assess the problem from a static forest enterprise-level perspective (implying static states of the forestry regimes) to circumvent discounting procedures. Discounting entails using the present values of future benefits and costs to consider the time preferences of decision-makers who commonly require a premium for waiting.

The following sections succinctly address different perspectives on Kärenlampi's considerations and approach. In the main sections of this article, we examine the perceived economic inconsistencies and, based on our analysis, the potential limitations in the data use within Kärenlampi's study. We will show that Kärenlampi's study arguably does not allow a consistent economic comparison of continuous cover and clear fell forestry and conclude with a discussion of the relevance of these findings.

From an economic method point of view, Kärenlampi's study is based on circular reasoning. He uses discounting-based forest values as approximations for actual market values to obtain the expected forest capital return rate. The underlying forest stand values depend on a chosen discount rate, an exogenous variable representing the decision maker's time preference and the capital-associated opportunity costs. Using these forest values implies that the used discount rate is the expected capital return rate for both silvicultural regimes.

Kärenlampi compared two forest states that may not be directly comparable, as inconsistent data were used. The transition period towards an equilibrium forest composition that, once achieved, promises constant average annual net revenues is commonly long and thus often more crucial for decision-makers than the equilibrium. Transitioning phases to desirable target compositions are rather common than an exception, as persistent equilibria hardly exist. Any realistic forest management is thus a continuous transition. We will show that considering the transition will strengthen the economic attractiveness of continuous cover forestry compared with clear fell forestry.

The concept Kärenlampi used for deriving disturbance costs for continuous cover forests appears to have limitations that may warrant further consideration. Based on forest values from [2], disturbance impacts on the net revenues of continuous cover forestry were estimated. However, his study's hypothetical disturbance rates were applied to a forest stand considered a homogenous entity, implying that disturbances will destroy all trees (young and old) with the same probability. This is not expected from forest disturbances typically observed in central Europe: some young trees likely survive even in severe disturbances. We will show that Kärenlampi's approach overestimates the disturbance costs of continuous cover forestry.

Based on our analysis, it can be concluded that while Kärenlampi's study raises valuable discussion points, certain aspects of his concepts and data preparation may limit the ability to conduct a conclusive and consistent economic assessment.

Subsequently, our conclusion will be supported by substantiating four propositions:

A) Adopting discounting-based forest stand values to estimate the expectation value of a forest's capital return rate builds on circular reasoning. It is unsuitable for an economic ranking of silvicultural management regimes.
B) The forest states and underlying data hypothesised by Kärenlampi are incomparable.
C) Considering a revised concept for disturbance costs results in lower costs for continuous cover forestry compared to Kärenlampi's approach, aligning more closely with empirical evidence.

Results

The usefulness of forest values to estimate capital return rates

The following section will demonstrate that Kärenlampi's estimated expected value of a forest's capital return rate builds on circular reasoning.

Economic method

Kärenlampi [1] (p. 3) defined the forest value C of a forest stand (of age b) referring to [2] with Eq. 1.

$$C(b,r) = \int_b^\infty c_t e^{-r \cdot t} dt \quad (1)$$

In Eq. 1, c_t is the time rate of profits (which we will call net revenues of a forest stand per hectare), r is the decimal discount rate, and t is the time elapsed from today onwards. Knoke et al. [2] used $r = 0.015$ to discount all future net revenues. To make clear that C depends on the choice of the discount rate, we use $C(b,r)$.

In his study, Kärenlampi introduced mathematical expectation values for net revenues and forest values (from here onwards $E[\cdot]$) by assuming an occurrence probability p for stands of age a (Eq. 2 and Eq. 3). For the expected net revenues that means:

$$E[c_t] = \int_0^T p(a) c_t da \quad (2)$$

With p being the probability of occurrence for single stands. T is the production period (called rotation) for a clear fell stand. Kärenlampi approximates Eq. 2 empirically with average net revenues for both silvicultural regimes.

For the expectation value of the forest value, Eq. 3 applies.

$$E[C(b,r)] = \int_0^T p(a) C(b,r) da \quad (3)$$

For the case of an equilibrium clear fell forest portfolio, we can alternatively compute the expected forest value according based on Eq. 4.

$$E[C(b,r)] = p(T)\frac{f(T) - L}{r} \quad (4)$$

With $f(T)$ being the harvesting value obtained by felling all trees at age T and L the annual re-establishment cost. For the equivalence of Eq. 3 and Eq. 4, consult [20].

Finally, Kärenlampi argued in his study that the expectation value of a forest's capital return rate can be estimated as:

$$E[r(b)] = \frac{E[c_t]}{E[C(b)]} \quad (5)$$

However, in Eq. 5, $E[C(b)]$ should be the actual market value of a forest. The market value is the price at which the forests under consideration can be purchased or sold. However, empirically solid forest market values are unavailable for the continuous cover or clear fell forests under consideration. However, land market data on forest assets is generally scarce [21].

As suitable market values were unavailable, Kärenlampi followed a pragmatic estimation approach based on calculated forest values from [2] to approximate them with $E[C(b,r)]$. The approximations build on Eqs. 1 and 3 and the expected capital return rates result from Eq. 6.

Critical assessment

$$E[r(b)] = \frac{E[c_t]}{E[C(b,r)]} \quad (6)$$

The expected forest value $E[C(b,r)]$ is a theoretical value anticipating all future net revenues of a forest discounted at $r = 0.015$ [2] and not a true market value. On top of that, a forest value solely based on land and standing timber tends to be a poor approximator for real-world market transactions in central Europe, as mother and often non-financial considerations influence market prices. The hypothetical market value calculation implies assessing all future net revenues against a benchmark investment opportunity (with an internal rate of return of 0.015), which may or may not be an investment into a market for forestland or any other market. Consequently, inferring expected capital return rates from Eq. 6 is circular reasoning, as we need r as input for Eq. 6.

Consistently applied, Eq. 6 will always result $E[r(b)] = 0.015$. As an illustrating example, consider a sustainable clear fell forest portfolio, where each stand is managed with a rotation of $T = 70$ years, the economically optimal rotation in [2]. Assume that the portfolio comprises 70 hectares and stands of different ages. Under the impact of disturbances, the youngest stands will cover 1.30, and the oldest stands 0.74 hectares of forestland, based on survival probabilities following from [22]. The oldest stands can be harvested each year. Given the data in [2] such portfolio provides average net revenues of $E[c_t] = 311$ € per hectare per year (including revenues from stands established after disturbance-caused salvage logging) and shows an average forest value of $E[C(b,r)] = 20271$ € per hectare. For the clear fell regime this results in an expected rate of capital return of:

$$E[r(b)] = \frac{311}{20271} \approx 0.015 \quad \text{p.a.} \qquad (7)$$

This clearly illustrates the circularity within the approach.

We cannot construct perfect equilibrium forest portfolios for the continuous cover forest based on the data given in [2]. However, a rough estimation of the empirical capital return rate comes with approximately 0.0145, close to the expected 0.015. For this, we can use net revenues shown in Figure 2 after 70 years to estimate expected net revenues of $E[c_t] = 322$ € per hectare per year. As an average forest value of stands from age 60 to 110 we can use here $E[C(b,r)] = 22199$ € per hectare.

Conclusion

It can be concluded that Kärenlampi's approach probably provides insufficient information for effectively ranking forest management alternatives. However, the solution to address the challenge of unavailable market values can be considered pragmatic. The discrepancies between the expected capital return rates published by Kärenlampi [1] and the theoretically derived value $E[r(b)] = 0.015$ suggest inconsistencies in the data used, an aspect that will be further explored in the following analysis. Consequently, when correctly applied, Kärenlampi's approach always reveals the applied discount rate as the expected capital return rate, which is no new information. Alternatively, the results will be incorrect because of biased input data.

Empirical consistency of the average net revenues

Economic data

In his publication, Kärenlampi's investigations summed the net revenues of five simulated management operations for the continuous cover regime (age 70 to 110) to obtain empirical input information (personal communication, not explained in [1]). The sum was divided by 50, but the first continuous cover net revenue was ignored at age 50. Kärenlampi's study used continuous cover net revenues, excluding revenues from previously salvage-logged and re-established forest parts. Considering the clear fell forest, his research assumed net revenues of $16000€ \div 60$ per hectare per year (Table 1), which included net revenues from salvage-logged and re-established stand parts. The resulting average net revenues were 154 and 267 € per hectare per year for the continuous cover and the clear fell regime, respectively. However, these average net revenues are incomparable and inconsistent with the average forest values of both silvicultural regimes assumed in Kärenlampi's study, which were 24000 (continuous cover forest) and 21000 € per hectare (clear fell forest).

Table 1. Economic input data.

	Average (expected) forest values and net revenues			
	Continuous cover forest		**Clear fell forest**	
Age of continuous cover stands considered	Forest value [€ per hectare]	Net revenues [€ per hectare per year]	Forest value [€ per hectare]	Net revenues [€ per hectare per year]
70-110 years	24000 (Kärenlampi)	154 (Kärenlampi)	21000 (Kärenlampi)	267 (Kärenlampi)
60-110 years		308 (alternative)		

Critical assessment

Seeing the average forest values as an approximation of market values (as in [1], p. 3) raises the question of why a higher market value will develop for a continuous cover forest which delivers (according to Kärenlampi's study) only 58% of the average net revenues provided by the clear fell forest. Note that all economic values used in Kärenlampi are solely based on timber production and selling, and no other ecosystem service values or any particular forest owner preferences are reflected in the forest values in Table 1 (the carbon storage assessments in [1] are not part of our study). Consequently, an analysis of the data preparation in Kärenlampi's study (see Table 1) reveals several inconsistencies that merit further examination.

While the average net revenues for continuous cover forestry from Kärenlampi's study are actual net revenues (i.e., harvesting values of felled and sold timber), he used the forest value at age 60 to derive the average annual harvesting value provided by a clear fell forest portfolio. However, the forest value at age 60 is not an actual harvesting value, but the sum of all discounted future net revenues of a clear fell forest (to be harvested at $T = 70$). In addition to the discounted harvesting value of 70-year-old crop trees, this value includes the forest value of younger trees (see [2]), which had been established previously (at stand ages <60) after salvage loggings of crop trees affected by disturbances.

In contrast to the clear fell considerations, the forest value of replanted trees was omitted for the continuous cover regime in [1]. The young trees planted after the gap harvests at age 60 alone represented a forest value of about 4700 € per hectare [2]. In addition, if one considers the provided actual net revenues at age 60 (which have arbitrarily been excluded in Kärenlampi's research), the corrected average net revenues are 308 instead of 154 € per hectare for the continuous cover forest (Table 1).

Conclusion

It can be concluded that the selected empirical economic data used by Kärenlampi to compute the expected value of the forest's capital return is likely subject to significant bias. The results should not be used to economically compare continuous cover and clear fell forestry.

A lens on the transition from clear fell to continuous cover forestry

Economic approach

In Kärenlampi's study, the economic approach compared two equilibrium forest portfolio states consisting of several stands associated with specific occurrence probabilities instead of analysing both regimes dynamically. The equilibria represent sustainable forest stand compositions, allowing for constant average net revenues, meaning the timber harvested each year is perfectly regenerated to provide the next year's harvest. As mentioned, Kärenlampi's investigation assumed average forest values of 21000 and 24000 € per hectare for clear fell and continuous cover forestry, respectively. Given that equilibrium states are achieved, these average forest values anticipate all expected and appropriately discounted future net revenues for both management regimes. Since one can interpret such average forest values as the maximum willingness to pay for such a forest, one can infer that the continuous cover forest is more (and not less) economically valuable than the clear fell forest for potential forest investors when both forests are in equilibrium.

However, such perfectly equilibrated forests cannot be purchased, as they do not exist. Consequently, we will use a model consideration and assume that we convert a hypothetical clear fell forest portfolio into continuous cover forests. During such conversion, costs might occur, which may change the static economic picture substantially. It is thus of great interest to look at the transition period.

Only comparable regimes and data should be assessed for a fair comparison of maintaining the clear fell forest with transitioning to continuous cover forestry [23]. Thus, [2] used a clear fell forest with a rotation of 70 years (found to maximise the bare land value for $r = 0.015$) as a benchmark for the continuous cover regime. The timing and size of gap harvests were optimised for the continuous cover forest using the same discount rate. This optimised management suggested a large gap harvest already at age 60, ten years before the rotation age, but it never suggested clearing all crop trees at once. Consequently, some crop trees were kept longer than the rotation period, which had more space to grow than in a dense forest stand.

Critical assessment

In this light, the decision in Kärenlampi's study to choose a rotation of 60 years for the clear fell regime is inconsistent. A 60-year rotation corresponds to a higher discount rate than $r = 0.015$ and to a differently optimised continuous cover regime, which would establish the first gap harvest already at age 50 [2]. This means that a consistent comparison of clear fell net revenues with the continuous cover net revenues used by [1] requires a clear fell regime with rotation age 70. Such a

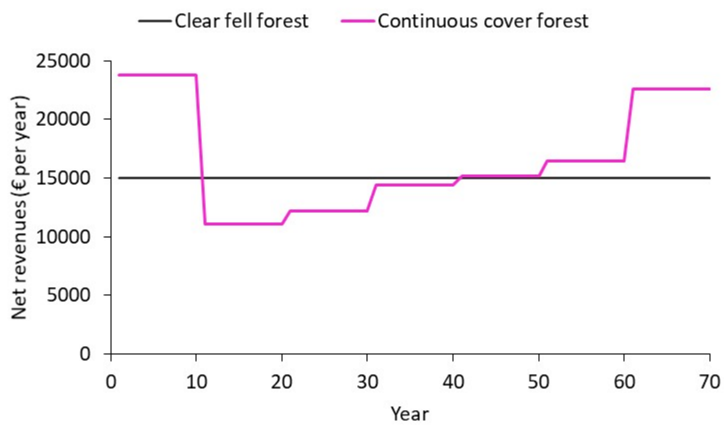

Figure 2 Net revenues when transitioning from clear fell to continuous cover forestry. For both regimes, 2000 € establishment costs have been considered

system provides annual net revenues of 15041 € if one hectare is cleared yearly, ignoring all revenues from forest parts previously re-established after salvage logging and accounting for 2000 € per hectare for establishment costs. Disturbance-associated net revenues were ignored for continuous cover forestry in [1], so they should also be ignored for the clear fell regime.

For our analysis of the dynamics of net revenues during the transition period from a clear fell to a continuous cover regime, we assume that 70 differently aged stands provide constant net revenues for the clear fell portfolio. The transition to continuous cover forestry starts with a large gap harvest at stand age 60, providing high additional net revenues during the first 10 years, where one hectare of a 70-year-old stand is also cleared in the transition regime. From year 11, we achieved net revenues from gap harvests in 60-year-old stands and smaller gap harvests in 70-year-old continuous cover stands (Figure 2).

The undiscounted sum of the continuous cover net revenues is about 10% greater than the net revenue sum of the clear fell regime. Independent of any discount rate applied, the continuous cover sum of all discounted net revenues is always greater than the clear fell forest's sum.

This result is plausible, as the timing and size of the gap harvests have been economically optimised in [2]. That means the retained trees have shown a profitability that justified keeping them longer than the trees already harvested, as the remaining trees showed higher growth rates in [2] because of the lower stand densities after the gap harvests.

The transition continues over 70 years, so the continuous cover regime applies in all previously clear fell stands when they reach age 60. Note that after 60 years of transition, net revenues from the timber grown on the gap harvest areas established 60 years before are contributed. The continuous cover transition also considered 2000 € per hectare for establishment costs, which is conservative, as cheap natural regeneration can commonly be used in such forests. The transition to continuous cover forestry results in discontinuous net revenues, compared to perfectly constant net revenues for the clear fell portfolio (Figure 2).

Conclusion

This means the specific continuous cover regime considered here is not economically inferior to the chosen clear fell reference system even during the transition. The clear fell portfolio's only advantage is its constant net revenue flow. However, for several reasons, such constancy will never be achieved in real-world forestry. We suggest that Kärenlampi's conclusion concerning the economic inferiority of continuous cover forestry cannot be inferred from consistent economic assessment.

Disturbance costs of continuous cover forestry

Economic approach

Kärenlampi's research tested the impact of different hazard rates (disturbance density rates in his paper) on the regime's associated disturbance costs [1]. The assumed hazard rates applied to all trees regardless of age. For example, a ten-year-old tree would have the same risk of being affected by wind, snow, fire or bark beetles as a 100-year-old tree. Kärenlampi derived disturbance costs for the clear fell system by modifying the equilibrium forest composition, accounting for the disturbances. This reduced the area that can be clear felled each year in the equilibrium forest portfolio and the corresponding annual net revenues.

However, Kärenlampi's research followed a different approach for the hypothetical continuous cover forest enterprise. He assumed that disturbances reduce the average forest value (minus bare land value in a proposed correction of his paper) at a rate corresponding to the hazard rate. For example, an annual hazard rate of $h = 0.003$ would mean an annual disturbance cost in the continuous cover system of $D = 0.003 \cdot 14000 = 42$ € per hectare per year. This approach assumes a stand of multiple differently old tree cohorts as a homogenous unit, where identical disturbance probabilities apply to all tree cohorts.

Critical assessment

It is very unlikely that a continuous cover forest will be destroyed entirely because the available regeneration, consisting of young tree cohorts, is much less vulnerable to disturbances, and at least part of it will likely survive. This regeneration will support a quicker recovery than under a clear fell regime, where disturbance regularly leaves only bare forestland. This highly interesting resilience effect is economically valuable (a core result in [2]) but was excluded in Kärenlampi's study.

For example, after severe disturbance of continuous cover stands at stand ages 60 and 70 with surviving young tree regeneration, the forest value was still between 15561 and 17032 € per hectare [2] and not just the bare land value as assumed by Kärenlampi (which is 10227 before the establishment of young trees). Thus, only in the worst case will the continuous cover regime start from bare forestland (for example, after all the trees have been burned), but this is not a standard case.

Even if all trees are lost, there is no reason to shift to clear fell forestry, as Kärenlampi suggested, because one can always start a continuous cover forest regime from bare land, as shown in [2].

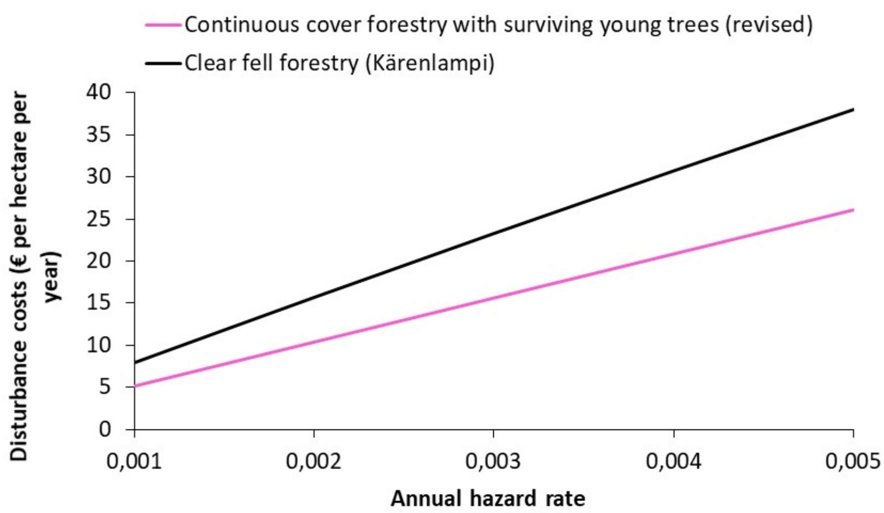

Figure 3 Disturbance costs for different assumed extreme disturbance hazard rates.

An alternative expectable disturbance-based loss of economic value after high-severity disturbances is shown by Figure 5 in Knoke et al. [2]. When comparing the forest value before and after a simulated high severity disturbance, the value differences were 4714 and 5733 € per hectare for stand ages 60 and 70, respectively. This is significantly less than Kärenlampi assumed. Accounting for such forest structural buffer effects caused by available young tree cohorts suggests a forest value exposed to disturbance effects of, on average, 5224 € per hectare. Weighted with the hazard rates assumed in [1], we receive revised disturbance costs for continuous cover forestry, shown in Figure 3.

Conclusion

The revised disturbance costs for the continuous cover regime are lower than those of the clear fell system—remarkably, surviving young tree regeneration may significantly reduce the disturbance costs in this example.

Discussion

Kärenlampi's research [1] provides a stimulus for discussing the economic assessment of forest disturbances under alternative forest management regimes. It shows the need to create and apply appropriate economic assessment approaches while we suggest a revised and more consistent economic methodology.

We second the adoption of simple models and assumptions in the sense of Ockham's razor hypothesis, but we suggest that the models and assumptions should not be too simple. For example, given the available empirical evidence in Hanewinkel et al. [10] or Mohr et al. [7], one may expect much lower disturbance costs under continuous cover forests than clear fell forests because of their high biological resistance. In contrast, our revised disturbance costs under continuous cover forestry were similar to those under the clear felling system. However, the low disturbance costs of clear felling from Kärenlampi's approach do not correspond with the experience German forest owners have with their clear felling forests [24]. This raises the question of whether or not assuming an identical vulnerability to disturbances of all trees, independent of their age, height, crown length, vitality, and their embedding into different tree neighbourhoods, would be the best approach. Our research demonstrated that high resilience is economically valuable [2] and should be considered in future studies, as economic resilience is a much-underrepresented research field, not only in forest science. However, continuous cover forests' presumably higher biological resistance has not yet been addressed in economic studies. The effects of tree species mixtures were also ignored [25,26] in Kärenlampi's research and in [2]. Within this framework, we suggest that establishing the economics of forest disturbances would greatly benefit from closer cooperation between forest economists and disturbance ecologists, who have provided tremendous knowledge over the last decades [27–37].

The economic argument presented by Kärenlampi in favour of clear fell regimes appears to rely on a concept that requires further refinement. The forest value used by Kärenlampi as a capitalisation value estimates the potential maximum willingness to pay for forestland, including the standing timber. These forest values heavily depend on the chosen discount rate. For example, we might assume the used discount rate to be the internal rate of return of an alternative benchmark investment against which all forest net revenues are assessed. Suppose such a forest value is considered a forest portfolio's purchase price or an approximation of the forest's market value. In that case, the investor implicitly accepts the discount rate used to calculate the forest value as his or her capital rate of return. Adopting such forest value to estimate a hypothetically expected forest enterprise's capital return rate remains inconclusive, as the capital return rate is already defined in advance and, per definition, identical for both regimes.

In addition, Kärenlampi's suggestion to eliminate time effects by defining equilibrium forest portfolios as theoretically perfectly sustainable static entities is well-known in forest economics [see 20 or 38]. However, due to the unrealistic assumption that no alternative investment opportunities exist, we suggest forest owners proceed cautiously with such approaches when the financial budgets are scarce. However, such opportunity costs do even exist if, as with many forest owners, reallocation of capital from forest assets is not an acceptable option: Money not earned during expensive transitions from one state to another may be spent on harvest infrastructure, pre-commercial thinnings forest conversion or pruning to enhance timber quality. As an alternative to discounting free approaches, we propose dynamic stand-level analyses or capital gain calculations to conduct enterprise-level investigations as decision support.

Our analysis of methodological concerns in assessing continuous cover forestry regimes has touched on only a few aspects of the broad field of forest economics. For example, considering silvicultural regimes as mutually exclusive is a limited perspective since multiple ecosystem services and desirable diversification effects to buffer against uncertainties require a landscape perspective. For example, given multiple objectives and landscape-level uncertainty considerations, an optimisation-based study has shown that continuous forest cover would cover certain proportions of desirable landscapes. Still, they would never dominate them [39]. This modelling-based outcome is supported by empirical studies, for example, concerning the influence of different silvicultural regimes on biodiversity [40]. Whether forest ecosystem services should be discounted to consider human time preferences [41], and if so, with which discount rates [42] constitutes an important subject for further research. The social value of avoided carbon emissions presents intriguing avenues for research [43], particularly regarding the impact of relative price changes on the future valuation of forest ecosystem services and how relative price changes will influence the future value of forest ecosystem services [44–46]. Regardless of the specific aspect of forest economics under consideration, it is essential that the methodology be appropriately selected and applied, as improper application may undermine the credibility of the assessment results [47].

References

1. Kärenlampi PP. Disturbance effects on timberland returns. PLOS Sustain Transform. 2024; 3:e0000146. doi: 10.1371/journal.pstr.0000146.
2. Knoke T, Paul C, Gosling E, Jarisch I, Mohr J, Seidl R. Assessing the Economic Resilience of Different Management Systems to Severe Forest Disturbance. Environ Resource Econ. 2023; 84:343–81. Epub 2022/09/06. doi: 10.1007/s10640-022-00719-5 PMID: 36712582.
3. Achim A, Moreau G, Coops NC, Axelson JN, Barrette J, Bédard S, et al. The changing culture of silviculture. Forestry. 2022; 95:143–52. doi: 10.1093/forestry/cpab047.
4. Hölzl R. Historicizing Sustainability: German Scientific Forestry in the Eighteenth and Nineteenth Centuries. Science as Culture. 2010; 19:431–60. doi: 10.1080/09505431.2010.519866.
5. Siiskonen H. The conflict between traditional and scientific forest management in 20th century Finland. Forest Ecology and Management. 2007; 249:125–33. doi: 10.1016/j.foreco.2007.03.018.
6. Siiskonen H. From economic to environmental sustainability: the forest management debate in 20th century Finland and Sweden. Environ Dev Sustain. 2013; 15:1323–36. doi: 10.1007/s10668-013-9442-4.
7. Mohr J, Thom D, Hasenauer H, Seidl R. Are uneven-aged forests in Central Europe less affected by natural disturbances than even-aged forests. Forest Ecology and Management. 2024; 559:121816. doi: 10.1016/j.foreco.2024.121816.
8. Price M, Price C. Creaming the best, or creatively transforming? Might felling the biggest trees first be a win–win strategy. Forest Ecology and Management. 2006; 224:297–303. doi: 10.1016/j.foreco.2005.12.050.
9. Knoke T, Gosling E, Paul C. Use and misuse of the net present value in environmental studies. Ecological Economics. 2020; 174:106664. doi: 10.1016/j.ecolecon.2020.106664.
10. Hanewinkel M, Kuhn T, Bugmann H, Lanz A, Brang P. Vulnerability of uneven-aged forests to storm damage. Forestry. 2014; 87:525–34. doi: 10.1093/forestry/cpu008.
11. Wikström P. A Solution Method for Uneven-Aged Management Applied to Norway Spruce. Forest Science. 2000; 46:452–63. doi: 10.1093/forestscience/46.3.452.

12. Davies O, Kerr G. Comparing the Costs and Revenues of Transformation to Continuous Cover Forestry for Sitka Spruce in Great Britain. Forests. 2015; 6:2424–49. doi: 10.3390/f6072424.

13. Assmuth A, Rämö J, Tahvonen O. Optimal Carbon Storage in Mixed-Species Size-Structured Forests. Environ Resource Econ. 2021. doi: 10.1007/s10640-021-00559-9.

14. Malo P, Tahvonen O, Suominen A, Back P, Viitasaari L. Reinforcement Learning in Optimizing Forest Management. Can J For Res. 2021. doi: 10.1139/cjfr-2020-0447.

15. Roessiger J, Ficko A, Clasen C, Griess VC, Knoke T. Variability in growth of trees in uneven-aged stands displays the need for optimizing diversified harvest diameters. Eur J Forest Res. 2016; 135:283–95. doi: 10.1007/s10342-015-0935-6.

16. Tahvonen O, Pukkala T, Laiho O, Lähde E, Niinimäki S. Optimal management of uneven-aged Norway spruce stands. Forest Ecology and Management. 2010; 260:106–15. doi: 10.1016/j.foreco.2010.04.006.

17. Knoke T, Kindu M, Jarisch I, Gosling E, Friedrich S, Bödeker K, et al. How considering multiple criteria, uncertainty scenarios and biological interactions may influence the optimal silvicultural strategy for a mixed forest. Forest Policy and Economics. 2020; 118:102239. doi: 10.1016/j.forpol.2020.102239.

18. Roessiger J, Griess VC, Knoke T. May risk aversion lead to near-natural forestry? A simulation study. Forestry. 2011; 84:527–37. doi: 10.1093/forestry/cpr017.

19. Pretzsch H, Biber P, Schütze G, Uhl E, Rötzer T. Forest stand growth dynamics in Central Europe have accelerated since 1870. Nat Commun. 2014; 5:4967. Epub 2014/09/12. doi: 10.1038/ncomms5967 PMID: 25216297.

20. Helmedag F. From 1849 back to 1788: reconciling the Faustmann formula with the principle of maximum sustainable yield. Eur J Forest Res. 2018; 137:301–6. doi: 10.1007/s10342-018-1101-8.

21. Hyytiäinen K, Penttinen M. Applying portfolio optimisation to the harvesting decisions of non-industrial private forest owners. Forest Policy and Economics. 2008; 10:151–60. doi: 10.1016/j.forpol.2007.07.002.

22. Brandl S, Paul C, Knoke T, Falk W. The influence of climate and management on survival probability for Germany’s most important tree species. Forest Ecology and Management. 2020; 458:117652. doi: 10.1016/j.foreco.2019.117652.

23. Hanewinkel M. Comparative economic investigations of even-aged and uneven-aged silvicultural systems: a critical analysis of different methods. Forestry. 2002; 75:473–81. doi: 10.1093/forestry/75.4.473.

24. Deutscher Forstwirtschaftsrat. 15 Milliarden Euro Waldschäden seit 2018 – „Unterstützung muss jetzt kommen“ – dfwr. 2022 [updated 5 Jan 2025; cited 5 Jan 2025]. Available from: https://www.dfwr.de/pressemitteilungen/15-milliarden-euro-waldschaeden-seit-2018-unterstuetzung-muss-jetzt-kommen/.

25. Parkatti V-P, Tahvonen O. Optimizing continuous cover and rotation forestry in mixed-species boreal forests. Can J For Res. 2020; 50:1138–51. doi: 10.1139/cjfr-2020-0056.

26. Knoke T, Seifert T. Integrating selected ecological effects of mixed European beech–Norway spruce stands in bioeconomic modelling. Ecological Modelling. 2008; 210:487–98. doi: 10.1016/j.ecolmodel.2007.08.011.

27. Seidl R. The Shape of Ecosystem Management to Come: Anticipating Risks and Fostering Resilience. BioScience. 2014; 64:1159–69. doi: 10.1093/biosci/biu172 PMID: 25729079.

28. Seidl R, Schelhaas M-J, Rammer W, Verkerk PJ. Increasing forest disturbances in Europe and their impact on carbon storage. Nat Clim Chang. 2014; 4:806–10. doi: 10.1038/nclimate2318 PMID: 25737744.

29. Seidl R, Thom D, Kautz M, Martin-Benito D, Peltoniemi M, Vacchiano G, et al. Forest disturbances under climate change. Nat Clim Chang. 2017; 7:395–402. Epub 2017/05/31. doi: 10.1038/nclimate3303 PMID: 28861124.

30. Senf C, Buras A, Zang CS, Rammig A, Seidl R. Excess forest mortality is consistently linked to drought across Europe. Nat Commun. 2020; 11:6200. Epub 2020/12/03. doi: 10.1038/s41467-020-19924-1 PMID: 33273460.

31. Senf C, Seidl R. Mapping the forest disturbance regimes of Europe. Nat Sustain. 2021; 4:63–70. doi: 10.1038/s41893-020-00609-y.

32. Senf C, Seidl R. Persistent impacts of the 2018 drought on forest disturbance regimes in Europe. Biogeosciences. 2021; 18:5223–30. doi: 10.5194/bg-18-5223-2021.

33. Thom D, Seidl R. Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests. Biol Rev Camb Philos Soc. 2016; 91:760–81. Epub 2015/05/22. doi: 10.1111/brv.12193 PMID: 26010526.

34. Thom D, Seidl R, Steyrer G, Krehan H, Formayer H. Slow and fast drivers of the natural disturbance regime in Central European forest ecosystems. Forest Ecology and Management. 2013; 307:293–302. doi: 10.1016/j.foreco.2013.07.017.

35. Wohlgemuth T, Jentsch-Beierkuhnlein A, Seidl R, editors. Störungsökologie. 1st ed. Bern: Haupt Verlag; 2019.

36. Zimová S, Dobor L, Hlásny T, Rammer W, Seidl R. Reducing rotation age to address increasing disturbances in Central Europe: Potential and limitations. Forest Ecology and Management. 2020; 475:118408. doi: 10.1016/j.foreco.2020.118408 PMID: 35686290.

37. Janda P, Trotsiuk V, Mikoláš M, Bače R, Nagel TA, Seidl R, et al. The historical disturbance regime of mountain Norway spruce forests in the Western Carpathians and its influence on current forest structure and composition. Forest Ecology and Management. 2017; 388:67–78. doi: 10.1016/j.foreco.2016.08.014 PMID: 28860676.

38. Loehle C. Forest Land Expectation Value or Maximum Sustained Yield? Resolving A Long-Standing Paradox. Forests. 2023; 14:1052. doi: 10.3390/f14051052.

39. Knoke T, Biber P, Schula T, Fibich J, Gang B. Minimising the relative regret of future forest landscape compositions: The role of close-to-nature stand types. Forest Policy and Economics. 2025; 171:103410. doi: 10.1016/j.forpol.2024.103410.

40. Schall P, Gossner MM, Heinrichs S, Fischer M, Boch S, Prati D, et al. The impact of even-aged and uneven-aged forest management on regional biodiversity of multiple taxa in European beech forests. Journal of Applied Ecology. 2018; 55:267–78. doi: 10.1111/1365-2664.12950.

41. Jarisch I, Bödeker K, Bingham LR, Friedrich S, Kindu M, Knoke T. The influence of discounting ecosystem services in robust multi-objective optimization – An application to a forestry-avocado land-use portfolio. Forest Policy and Economics. 2022; 141:102761. doi: 10.1016/j.forpol.2022.102761.

42. Baumgärtner, S., A. Klein, Denise Thiel, K. Winkler. Ramsey Discounting of Ecosystem Services. undefined. 2015. Available from: https://www.semanticscholar.org/paper/Ramsey-Discounting-of-Ecosystem-Services-Baumg%C3%A4rtner-Klein/ab23b4e4cb4a332b06524600445f7fe3505d87e6.

43. Knoke T, Hanley N, Roman-Cuesta RM, Groom B, Venmans F, Paul C. Trends in tropical forest loss and the social value of emission reductions. Nat Sustain. 2023; 6:1373–84. doi: 10.1038/s41893-023-01175-9.

44. Drupp MA, Hänsel MC. Relative Prices and Climate Policy: How the Scarcity of Nonmarket Goods Drives Policy Evaluation. American Economic Journal: Economic Policy. 2021; 13:168–201. doi: 10.1257/pol.20180760.

45. Drupp MA, Hänsel MC, Fenichel EP, Freeman M, Gollier C, Groom B, et al. Accounting for the increasing benefits from scarce ecosystems. Science. 2024; 383:1062–4. Epub 2024/03/07. doi: 10.1126/science.adk2086 PMID: 38452091.

46. Knoke T, Elsasser P, Kindu M. Considering the land-cover elasticity of ecosystem service value coefficients improves assessments of large land-use changes. Ecosystem Services. 2024; 68:101645. doi: 10.1016/j.ecoser.2024.101645.

47. Bingham LR, Jarisch I, Quaas MF, Knoke T. How to Discount Monetized Ecosystem Services - Comment on 'High Economic Costs of Reduced Carbon Sinks and Declining Biome Stability in Central American Forests'. SSRN Journal. 2023. doi: 10.2139/ssrn.4473258.