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RESEARCH PAPER

Variation in forest landowners' management preferences reduces timber supply from Finnish forests

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Abstract

• ***Key message*** **Forest owners who maximize profitability with a low discount rate or whose management goals are related to conservation and recreation, rarely sell timber. These owners make it difficult to achieve the high harvesting targets of the growing bioeconomy sector of Finland. To increase timber supply, these landowners should be informed about alternative silvicultural methods.**

• ***Context*** The round wood harvests from Finnish forests are increasing and approaching to the level of maximum sustainable cut. Cutting budget calculations assume that forests are harvested in an optimal way for national timber supply. The calculations ignore the variability of landowners' forest management preferences.

• ***Aims*** This study analyzed the effect of variation in the management objectives and silvicultural preferences of forest landowners on the forecasted timber supply from Finnish forests.

• ***Methods*** Forest owners were divided into savers (net present value maximized with a 1% discount rate), average owners (3% discount rate), and investors (5% discount rate). The owners of each group were further divided into three groups: those who allow only continuous cover management (12%), owners who use only rotation forest management (10%), and indifferent landowners who may use both silvicultural systems (78%). Scenarios were composed of management prescriptions that were optimized separately for the different groups of forest landowners.

• ***Results*** Compared to the even-flow timber drain scenario for rotation forest management (calculated without acknowledging the varying preferences of landowners), the scenario where the owners' preferences varied decreased harvested volume by 15–19% during a 100-year calculation period. The main reason for the difference was the saver type of landowners who rarely sell timber.

• ***Conclusion*** It was concluded that variation of the preferences of forest landowners may make it challenging to meet the increasing harvesting targets of the growing bioeconomy of Finland.

Keywords National forest inventory · Private forest owner · Timber trade · Boreal forest

1 Introduction

There are many investment plans in Finland that would increase the use of forest biomass. The official bioeconomy strategy of Finland promotes this development (The Finnish Bioeconomy Strategy 2014). Together with recently built pulp mills, the new investments would imply a great increase in the volume of harvested domestic round wood, which has been about 60 million m^3 $year^{-1}$ in the latest decade (Finnish Statistical Yearbook of Forestry 2014). In 2016, the round wood removal from Finnish forests was already 70 million m^3 $year^{-1}$ (Total roundwood removals…2017) and the demand may reach 90 million m^3 $year^{-1}$ in coming decades.

Forest industries in Finland and other countries would require an uninterrupted supply of wood. However, wood supply depends on many economic, technical, environmental, and social factors (Hetsch 2008), part of which may hamper the target of having a steady supply of timber. An important

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social factor are the attitudes of non-industrial private forest (NIPF) landowners towards the use of forest and the prevailing silvicultural systems, as well as temporal changes in NIPF owners' preferences (Pukkala et al. 2003; Sotirov et al. 2017; Trubins et al. 2017; Ficko et al. 2019). The NIPFs own 61% of the forestland of Finland. These forests account for 73% of volume increment and 83% of the volume of commercial harvests (Luke 2016).

NIPF owners constitute a heterogeneous group of people (Häyrinen et al. 2014; Ficko et al. 2019). For example, Trubins et al. (2017) classified the forest landowners into economists, traditionalists, multi-objective, conservationists and passive, and each category was further sub-divided into different groups based on the preferred forest management policy of the landowner. Assumptions concerning NIPF owners' forest management preferences significantly affect the predicted harvest level of forests (Pukkala et al. 2003; Sotirov et al. 2017).

The size of the forest holding, place of living (near forest holding or in a distant city or town), education, age, and the significance of timber sales in the owner's livelihood all affect the owners' timber sale behavior (Häyrinen et al. 2014). Also, the advisory organizations working in private forestry can have an effect on cutting decisions (Hujala et al. 2013). The forest management objectives of NIPF owners are also highly dependent on landowners' plans and expectations for the future and the significance of forest as a provider of economic security and liquidity (Häyrinen et al. 2014). According to Leppänen (2010), the share of multi-objective and indifferent (no clear management objectives) forest owners is increasing and the share of owners working fulltime in their own forest is decreasing. Many multi-objective NIPF owners have a clear intention to use their forests simultaneously as a source of income and for preserving nature (Nordlund and Westin 2011). In France, Brunette et al. (2017) found that the presence of paved forest roads and delegation of forest management to a professional increased the probability of harvest.

The current forest management methods have faced a lot of criticism because the number of endangered forest-dwelling species has increased and intensive plantation forestry has made forest environments less suitable for outdoor recreation. The current forest management tends to favor methods that lead to one-species forests and clear cuttings (Äijälä et al. 2014). Diverse management methods, continuous cover forestry (CCF), and mixed stands among them have been found to be possible ways for simultaneous production of different ecosystem services (Knoke et al. 2008; Pukkala 2018). This would result in more diverse forests, providing more resilience and resistance against various risks (Thompson et al. 2009; Jactel et al. 2017; Pukkala 2018).

Due to these and other reasons, all landowners are no longer supporters of the prevailing practice of clear-felling and artificial regeneration. For example, the survey by Kumela and Hänninen (2011) showed that only 10% of Finnish forest landowners want to use only even-aged rotation forestry in all their forests, whereas 12% want to use only CCF. The remaining 78% are willing to try both methods. Partly because of the increased criticism towards rotation forest management (RFM), the forestry legislation of Finland was updated in 2014 so that uneven-aged management and other types of CCF can now be used on landowner's decision without any conditions (Äijälä et al. 2014).

The aim of this study was to analyze the effect of variation in the management objectives of NIPF owners on the timber supply from Finnish forests. The hypothesis was that variation of forest management preferences among landowners decreases the timber supply from private forests, compared to calculations were this variation is ignored.

The study differs from the previous analyses (e.g., Heinonen et al. 2017, 2018) in a few respects. First, two different management systems, RFM and CCF, were used, not only RFM as in most previous studies (e.g., Heinonen et al. 2017, 2018). Second, the effect of climate change on tree was predicted with a new meta mode (Seppälä et al. 2019), which most probably increases the realism of the predictions (see Pukkala 2017b), especially for northern Finland, for which previous studies (e.g., Heinonen et al. 2018) predict very high climate-induced improvements in tree growth. Third, the analyses assumed that forest landowners manage their forests according to their own preferences instead of following national preferences. As a result, our analyses may provide more realistic projections about the level of wood supply from Finnish forests during the coming decades.

The landowners were divided into owners who manage their forests according to RFM only, CCF only, or using both silvicultural systems. Each group was further divided into subgroups based on the required rate of return on investments. These groups were called as savers (net present value maximized with a 1% discount rate), average forest landowners (3%), and investors (5%). Combinations of management scenarios suitable for different NIPF owner groups were developed and compared with a forest management scenario that was based on the current silvicultural recommendations of Finland (Äijälä et al. 2014) and with a scenario that omitted landowners' preferences and maximized even-flow cuttings with the constraint that the growing stock volume must not decrease from its current level.

2 Material and methods

2.1 Forest data and simulation of treatment schedules used in analyses

The calculations of this study were based on the same sample plot data as used in Heinonen et al. (2017). The data were collected during the 11th National Forest

Inventory (NFI11) of Finland (Korhonen 2016). Sample plots measured in non-protected forests were included in the study. The number of NFI sample plots used in the analyses was 4685.

The data were imported to the Monsu forest planning software (Pukkala 2011). Monsu is a typical forest planning system consisting of a tool for simulating alternative treatment schedules for plots or stands and optimization tools for finding the optimal combination of simulated schedules. More information about the data and calculation methods can be found in Heinonen et al. (2017).

Different treatment schedules were simulated for every sample plot for ten 10-year periods. A treatment schedule means that a treatment was simulated whenever the stand fulfilled certain conditions such as mean tree diameter required for final felling or stand basal area required for thinning. Treatments were simulated in the middle of each 10-year period. RFM and CCF had their own simulation rules. Fertilization and ditch network maintenance were assumed to be done in both silvicultural systems and their effect on tree growth was simulated in the same way as in Heinonen et al. (2018). Fertilization was assumed in 25% of the cases where the criteria described in Heinonen et al. (2018) were met. The criteria of fertilization were as follows: temperature sum least 900 d.d., suitable site type (mesic for spruce and sub-xeric for pine), stand basal area at least 5 m^2 ha^{-1}, and mean tree diameter 15–30 cm (Pukkala 2017a). Fertilization was never done during the same 10-year period as thinning.

The crosscutting of harvested trees was simulated in the same way in RFM and CCF. The roadside prices of timber assortments were the same for both methods (Table 1). The incomes from timber sales were calculated by subtracting harvesting costs (Rummukainen et al. 1995) from the roadside value of harvested trees. Harvesting costs depended on the size of harvested trees (stem volume), harvested volume per hectare, and the type of cutting so that harvesting was cheaper in clear-felling than in thinning.

2.2 Simulation of rotation forest management

Rotation forest management (RFM) refers to forestry that is based on rotations. Stands are regenerated after final felling, which is usually clear-cutting in Finnish conditions. The new rotation is started with artificial regeneration (seeding or planting), and the stands are even-aged or almost even-aged for the whole rotation. The timing of cutting treatments in RFM was varied by postponing cuttings to later 10-year periods from the earliest possible period. The earliest possible time for cuttings was obtained by multiplying the currently recommended lower thresholds for thinning (basal area) and final felling (diameter at breast height) (Äijälä et al. 2014) by 0.8. This was done to give more possibilities for the optimization to find the best treatments for all groups of landowners. Especially, the lower thresholds for cutting might be too restrictive when net present value is maximized with a high discount rate. The tending treatments of dense seedling and sapling stands were simulated according to recommendations (Äijälä et al. 2014). Thinnings were simulated by using the same thinning intensity in different diameter classes.

Artificial regeneration was simulated after clear cutting using either sowing or planting, following the current forestry practices and recommendations. The genetic growth gain of artificially regenerated trees was assumed to be 10% (Haapanen and Mikola 2008; Haapanen et al. 2016). Sub-xeric sites were seeded by Scots pine. Planting on mesic sites was randomized so that 60% were planted with Norway spruce, 30% with Scots pine, and 10% with silver birch seedlings. Mesotrophic herb-rich sites were planted using silver birch (20%) and Norway spruce (80%) seedlings. Other upland forest sites and all drained peatland sites were regenerated naturally. In addition, regardless of the regeneration method applied, natural regeneration was expected to appear on all sites according to the model of Pukkala et al. (2013).

2.3 Simulation of continuous cover forestry

In this study, CCF refers to management in which there are no clear fellings. The only cutting method was thinning from

Table 1 Specifications of timber assortments for the main tree species used in the scenario analyses. The roadside timber prices (€ m^{-3}) were different for southern Finland (SG), central Finland (CF), and northern Finland (NF)

	SF	CF	NF	Whole Finland	
	€ m^{-3}	€ m^{-3}	€ m^{-3}	Minimum top diameter (cm)	Minimum log length (m)
Pine saw log	58	55	54	16	4.3
Pine pulpwood	29	28	25	6	2.7
Spruce saw log	56	54	53	17	4.3
Spruce pulpwood	30	29	26	6	2.7
Birch saw log	49	45	42	18	3.7
Birch pulpwood	29	29	28	6	2.7
Energy wood	20	20	20	3	2.0

above. The lowest remaining stand basal area was higher than the legal limit specified in the forestry legislation (about 10 m^2 ha^{-1}). CCF schedules were simulated for all NFI plots. There was no requirement that the stand had to be multistoried or uneven-aged.

The treatment schedules that represented continuous cover forestry were based on thinning models developed specifically for CCF. These models are based on a high number of stand level optimizations. The optimization results were used to fit a model for the basal area at which the stand is thinned and another model for the percentage of trees removed from different diameter classes. The predictions of the models are mean tree diameter, site fertility, temperature sum, species composition of the stand, and discount rate. Higher discount rate leads to earlier thinning.

The ways of obtaining alternative cutting schedules were different in RFM and CCF. Whereas postponed cuttings were used in RFM as the means to have alternative schedules, alternative CCF schedules were obtained by applying the thinning instruction with different discount rates. This was not possible in RFM since the instructions for RFM (Äijälä et al. 2014) do not depend on discount rate. In the simulation of CCF schedules, the discount rates were 0%, 2%, and 4% for saver; 1%, 3%, and 5% for average owner; and 3%, 5%, and 7% for investor. As a result, the simulated alternatives already reflected the preferences of the landowner: alternatives simulated for savers represented higher growing stock levels and postponed cuttings, as compared to the average forest landowners and especially investors.

Climate change was taken into account by assuming the RCP2.6 scenario (Ruosteenoja et al. 2016). The metamodel developed in Seppälä et al. (2019) was used to simulate the effect of climate warming on tree growth. The model is based on the predictions of other models, part of which are ecosystem models (Kellomäki et al. 2018) and the other part is based on provenance trials (Beuker 1994; Persson and Beuker 1997; Kellomäki et al. 2008; Berlin et al. 2016). The meta model can be regarded as a compromise approach, which predicts the average prediction of previous models developed in Finland.

2.4 Cutting scenarios and optimization

The NFI plots were divided into three groups for the three groups of forest landowners based on their preferred forest management method: RFM (only rotation forestry), CCF (only continuous cover forestry), and indifferent (both RFM and CCF were allowed). Secondly, the plots of each owner group were divided into the plots of savers, average owners, and investors. When creating the management plans, net present value (NPV) was maximized with a 1% discount rate for savers, 3% for average owners, and 5% for investors. Maximizing NPV with a 3% discount rate leads to harvest and growing stock levels that correspond to typical and currently recommended forest management. A 1% rate leads to delayed cuttings and high growing stock, corresponding to savers' behavior. A 5% rate leads to early cutting and low average growing stock volume.

Only treatment schedules representing RFM were used in optimizations for owners that accepted only RFM, and only CCF was used for the groups that did not approve RFM. When the forest owner accepted both management methods, the optimal combination of treatment schedules of sample plots was selected from all schedules simulated for the plots (both RFM and CCF).

After optimizing the management for different forest owner groups, two mixed scenarios were created from the results. These scenarios were named as ROTAT (only RFM was used but discount rate varied) and PREFER (10% RFM, 12% CCF, and 78% both RFM and CCF). PREFER is based on the study of Kumela and Hänninen (2011) where 10% of the respondents were willing to use only RFM, 12% wanted to use only CCF, and the remaining 78% may use both methods. In each scenario (ROTAT, PREFER), one-third of forest owners were assumed to be savers, one-third average owners, and one-third investors. The ROTAT scenario was included since it may correspond better to the current and past management of Finnish forests (compared to PREFER), although it may no longer correspond to the preferences of forest landowners.

In addition to the mixed scenarios, two reference scenarios were developed: RECOM and SUST. In RECOM, the treatments were simulated always according to the official Finnish forest management recommendations for RFM (Äijälä et al. 2014). In SUST, the highest non-decreasing annual cutting drain that did not lead to decreased growing stock volume was searched. Only treatment schedules representing RFM were used in RECOM and SUST.

In PREFER and ROTAT, the Hero heuristic (Pukkala and Kangas 1993) was used to find the optimal combination of treatment schedules simulated for the NFI plots. For the SUST scenario where the problem was more complicated, combinatorial optimization employed a hybrid method of simulated annealing and Hero (Heinonen et al. 2017).

3 Results

The average harvested volume during the 100-year planning horizon was the highest, 80.7 million m^3 $year^{-1}$, in the RECOM scenario where forests were managed according to the current recommendations for RFM (Fig. 1). When the objective was to maintain the current growing stock volume with the highest possible even-flow of timber (SUST), the mean annual harvested volume was 74.5 million m^3 $year^{-1}$. Harvested volumes decreased further by 15–19% when the varying preferences of NIPFs were taken into account in the calculations (ROTAT and PREFER). The harvested volume of

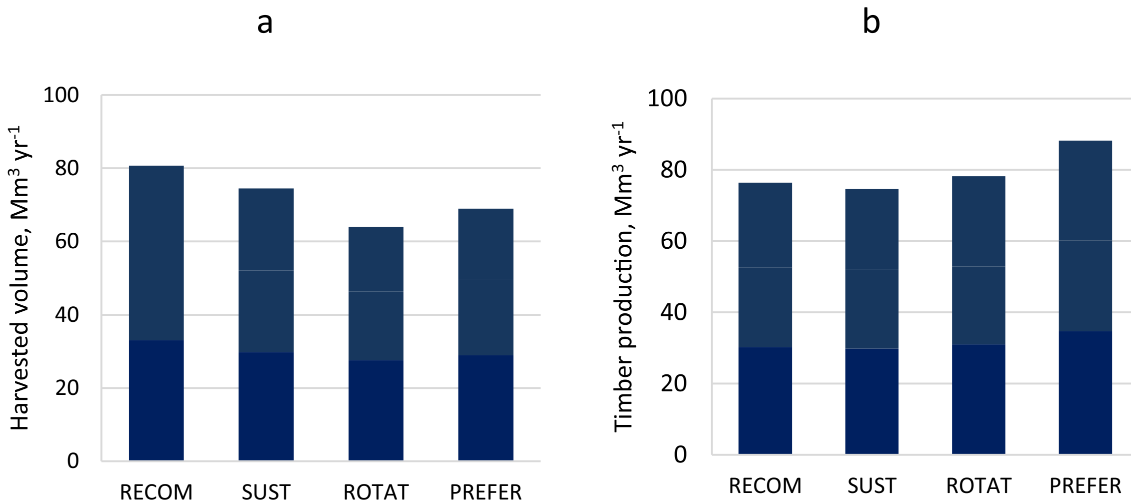

Fig. 1 Average annual harvested volume (**a**) and timber production (**b**) of Finnish forests in different cutting scenarios. Timber production is the sum of harvested volume and change in growing stock volume. RECOM = forests are managed according to the current recommendations for rotation forest management; SUST = rotation forest management with the maximum sustained harvest constraint; ROTAT = discount rate varies among forest landowners, all landowners use rotation forest management; PREFER = both discount rate and silvicultural system vary among forest landowners

mixed scenario PREFER was 69.9 million m^3 year^{-1}, which is higher than obtained for ROTAT, 65.2 million m^3 year^{-1}.

RECOM had the lowest growing stock volume (1616 million m^3) at the end of the 100-year planning period (Fig. 2). The ending volume was 21% lower than the current volume, and only about a third of the growing stock volume reached in PREFER (4716 million m^3) and ROTAT (4291 million m^3).

The lower harvested volumes of mixed scenarios, as compared to RECOM and SUST, were mainly explained by the low cutting level of savers. Figure 3 shows that the harvested volumes of savers (1% discount rate) were about 25% lower than calculated for average forest landowners and investors. The harvested volume depended on the silvicultural system, especially at

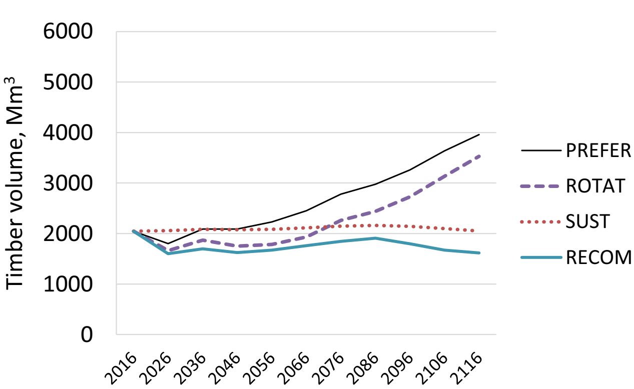

Fig. 2 Development of the growing stock volume of Finnish forests in different scenarios. RECOM = forests are managed according to the current recommendations for rotation forest management; SUST = rotation forest management with the maximum sustained harvest constraint; ROTAT = discount rate varies among forest landowners, all landowners use rotation forest management; PREFER = both discount rate and silvicultural system vary among forest landowners

a low discount rate (Fig. 3, top). However, the overall effect of discount rate was stronger than the effect of silvicultural system. The difference was large between 1 and 3% discount rates but maximizing NPV with a 3% or 5% rate resulted in almost the same average long-term harvest. When NPV was maximized with a 5% rate, harvest level was higher in the beginning of the 100-year period. However, high harvest level decreased growing stock volume, which in turn decreased volume increment, resulting in reduced harvests during later 10-year periods.

RFM had smaller timber production (harvested volume + change in growing stock volume) than CCF and the combination of CCF and RFM (Fig. 3, bottom). The result can be explained by the lower cutting level of CCF and combined use of CCF and RFM. This increases growing stock volume, which in turn increases volume increment as shown in previous studies (Heinonen et al. 2017). The total timber production of the 100-year period was the highest in PREFER, 82.2 million m^3 year^{-1} (Fig. 1) where optimization could choose either RFM or CCF in 78% of the sample plots. A higher number of treatment alternatives, representing both RFM and CCF, were the obvious reason for the good timber production of the PREFER scenario.

The temporal development of harvests (Fig. 4) shows that the harvested volume of PREFER was lower than in ROTAT during the first 10-year period, but higher during later periods. The harvested volume of the first period was very high in all scenarios except SUST. This is because of the current structure of Finnish forests: there are plenty of stands that have already passed the optimal time of cutting, and many of these stands were cut during the first 10-year period in all scenarios except SUST. Cuttings of the first period were the highest when management was optimized with a 5% discount rate.

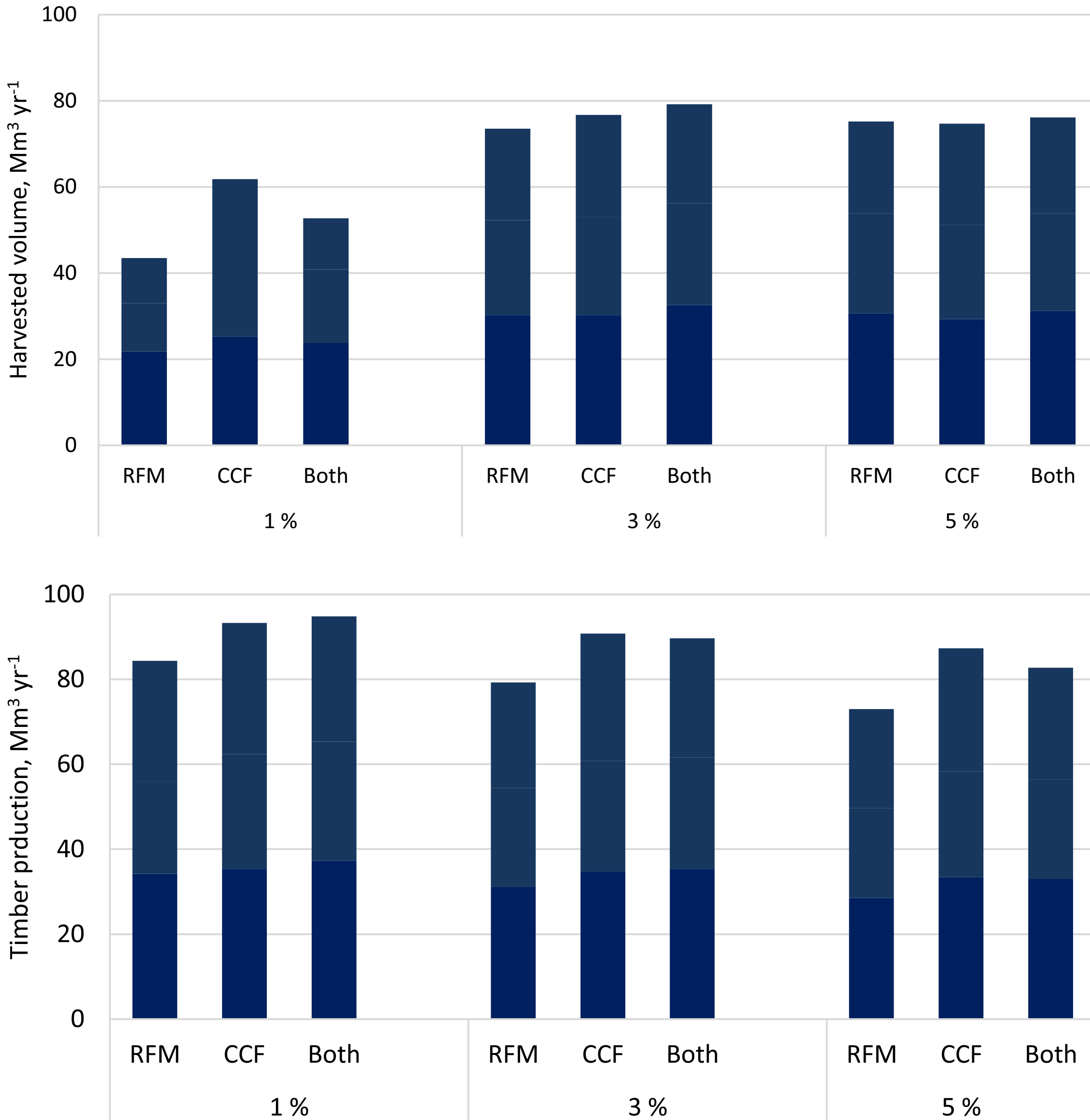

Fig. 3 Average annual harvested volume (top) and timber production (bottom) of Finnish forests in different silvicultural systems when net present value was maximized with a 1%, 3%, or 5% discount rate. Timber production = harvested volume + change in growing stock volume. RFM = rotation forest management; CCF = continuous cover forestry; Both = both RFM and CCF are allowed in every stand; the silvicultural system that yields higher net present value is used

4 Discussion

This study analyzed the timber supply from Finnish forest during a 100-year period. The analyses assumed that forest landowners manage their forests according to their own preferences with respect to discount rate and alternative silvicultural systems. The mixed scenarios of this study were combinations of management actions and timber sales of different forest owner categories. For simplicity, the proportions of savers, average owners, and investors were assumed to be equal, although studies describe more complicated partitions (e.g., Hujala et al. 2013; Takala et al. 2017; Ficko et al. 2019; Trubins et al. 2017; Sotirov et al. 2017). Preferred silvicultural system was another criterion for grouping forest landowners.

The three forest management groups used in PREFER were based on Kumela and Hänninen (2011), who found that there is a growing interest towards more diverse and CCF type of forest management, especially among forest owners who have non-monetary objectives. On the other hand, a part of forest landowners who have only monetary objectives also prefer CCF, at least in places where the productivity of the forest is low. The reason in these cases is the low profitability of intensive even-aged forest management (e.g., Tahvonen 2009).

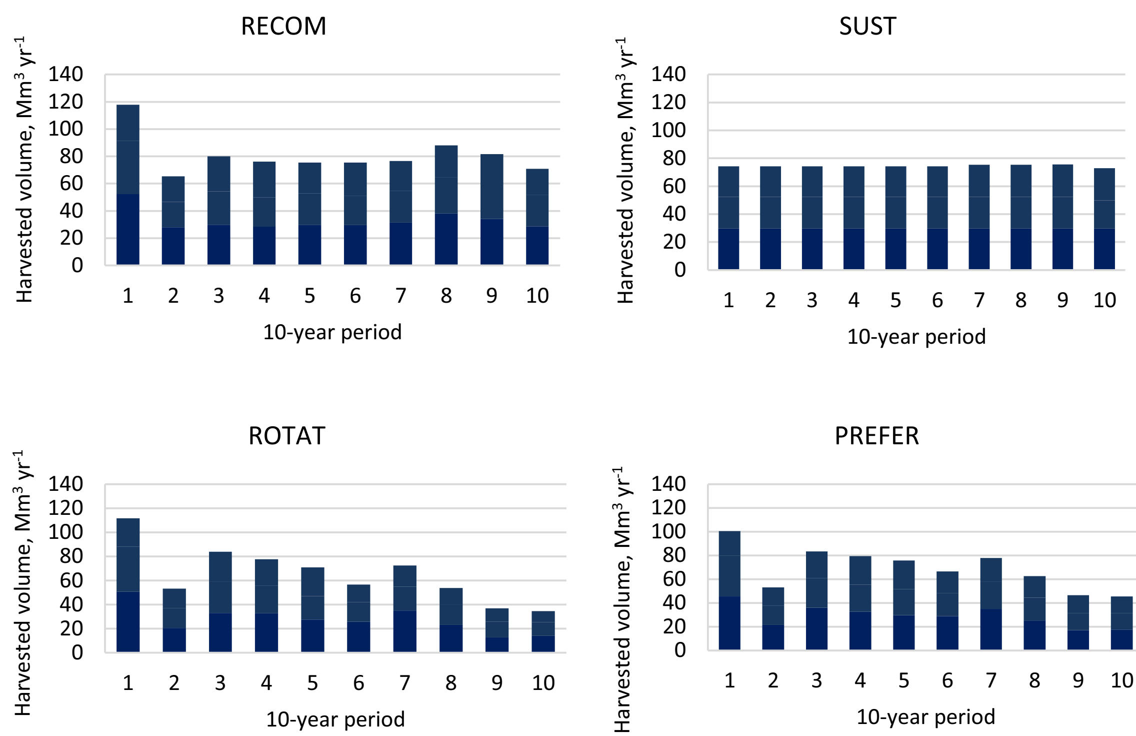

Fig. 4 Temporal development of harvested volume of Finnish forests in different scenarios. RECOM = forests are managed according to the current recommendations for rotation forest management; SUST = rotation forest management with the maximum sustained harvest constraint; ROTAT = discount rate varies among forest landowners, all landowners use rotation forest management; PREFER = both discount rate and silvicultural system vary among forest landowners

The main contribution of our study was not to provide exact forecasts of the timber supply from Finnish forests. The main contribution was to show that variation in the forest management objectives of landowners can have a significant reducing effect on the predicted timber supply, compared to calculations that ignore this variation (Sotirov et al. 2017). In our study, the sizes of landowner groups were partly based on studies (Kumela and Hänninen 2011) but the sub-division into savers, average owners, and investors was just an assumption. However, despite exact knowledge on the preferences and attitudes of NIPF owners is lacking, assuming the likely trends and generating plausible variation in preferences most probably leads to more realistic calculations on future timber supply than ignoring the variation on preferences completely as done in many calculations.

Knowing the current shares of NIPF owner groups does not remove the problem that the attitudes of NIPF owners change in time, likely trends being a gradual shift towards increased use of CCF and using forests to sequestrate carbon dioxide from the atmosphere. The effect of temporal changes on landowners' attitudes was analyzed in Pukkala et al. (2003). They generated a utility function separately for each landowner, using distributions of the weights of different forest management objectives. The distributions depended on the size of the forest holding, and they were allowed to change with time.

All cutting budget calculations include uncertainties related for instance to climate change, growth models, outbreaks of pests and pathogens, abiotic hazards such as wind throws and forest fires, as well as future markets and regulations. However, these uncertainties should not be used as a reason for not doing the calculations. Compared to most previous studies, our current calculations explicitly considered the management preferences of forest landowners, which may be interpreted as an additional element of uncertainty in our calculations, as compared to most previous scenario analyses (e.g., Heinonen et al. 2017, 2018). However, this is a wrong conclusion since ignoring uncertainties in calculations does not remove them.

The common feature of the mixed scenarios was a harvesting level lower than the current and future wood demand. The only exception was the first 10-year period, for which the cutting level was high. As a result of low harvesting level, the average growing stock volume increased substantially during the 100-year period when management was optimized without any constraints for harvested volume. There are a few possible reasons for this outcome. The first reason is that the current standing volume of Finnish forests (100 m^3 ha^{-1} on average) is below the optimal level, not only for timber production as shown in earlier studies (e.g., Lundmark 2017; Heinonen et al. 2017) but also for economic profitability. Another reason might be climate change, which improves tree growth and leads to a situation where a sufficient relative value increment can be maintained with higher stand densities.

A partial reason for the sharp decrease in annual harvests after the first 10-year period might be that the NFI plots were assigned randomly to different groups of landowners. As a result, many dense stands with high volume went to investors and average owners who cut these stands immediately. On the other hand, many plots with low volume were assigned to savers. These stands were harvested very late or not at all, contributing to increasing average growing stock volume and decreasing annual harvest after the first decades of the 100-year period.

The average harvested volumes of the mixed scenarios were at the level of the realized harvest volumes of recent years, which is less than the planned harvest level of coming years. This implies that it might be challenging to meet the increasing harvesting targets of the growing bioeconomy sector of Finland. In our study, the main reason for the low harvest volume was forest owners having a low discount rate. Although this group was called savers, it refers to all forest owners whose management objectives call for having a high growing stock volume. Previous studies have found a strong relationship between low willingness to sell timber and strong wish to use forests for recreation and nature conservation (Häyrinen et al. 2014).

Logically, predicted timber production was the higher, the more there were opportunities to select between RFM and CCF. In the PREFER scenario, 78% of sample plots could be managed with either method. Allowing more options in forest management was the best option from timber production point of view. The results showed that if the current management recommendations are followed and only RFM is used, the long-term timber production will be clearly lower than obtained in more flexible management.

The use of net present value as the only objective in optimization led to temporally varying timber drain. Especially, the harvests of the first period were quite high in scenarios other than SUST. These harvests might not be realistic due to the stable need of timber by forest industry. In addition, many forests with plenty of cutting possibilities most probably belong to saver type of landowners, which means that those forests may not be cut as much as assumed in our calculations. In our analyses, the NFI plots were randomly assigned to the different owner types due to lack of better information. This most probably led to exaggerated timber supply prediction for the first decade.

In our calculations, most of the timber was harvested from the forests of average owners and investors. As the wood demand of forest industry increases along with new investments, the forests of these owners might become overused as passive or saver type of landowners may not respond to the increased demand. This type of overuse in a part of forests would decrease timber production in the long term since the growing stock volume will be reduced to level lower than required for maximal timber production. For a steady and high wood supply, it is important to find management methods in which cuttings are not detrimental to non-economic management objectives. Increasing use of CCF would be a step towards this direction.

On the other hand, CCF may increase some biotic risks, for instance, e.g., *Heterobasidion* spp. and bark beetles such as *Ips typographus*. CCF favors the regeneration of shade tolerant species such as spruce. Damage to trees caused by logging machinery may have negative impact on long-term stand development. The combination of frequent mechanized harvests and the difficulty to change the species composition of the stand may be regarded as drawbacks of CCF (Piri and Valkonen 2013).

In the literature, there are contrasting results on the growth performance of CCF versus RFM (see, e.g., Lähde et al. 2001, Lundqvist et al. 2007, Laiho et al. 2011, Lundmark 2017). Our study used the models of Pukkala et al. (2013) to simulate stand dynamics in both CCF and RFM. However, although models exist, more studies are required to reliably simulate stand dynamics in all management systems and to learn the optimal ways to implement CCF, RFM, and their combinations.

5 Conclusions

The study showed that, due to the fact that forest landowners aim at their own and varying management objectives, it might be difficult to achieve the high harvesting targets of the growing bioeconomy sector of Finland. Especially, saver type of forest owners (management optimized with a low discount rate), or owners whose forestry ambitions are related to conservation and recreation, decreases the timber supply of the coming decades. To increase timber supply, these landowners should be informed about alternative silvicultural methods, and the advisory organizations should be trained in these methods.

A part of Finnish forest belongs to owner groups other than NIPF, the most important of which is the state, which owns 24% of forestland. However, also these forests are managed for different purposes, for instance, timber production, recreation, biodiversity conservation, and multiple uses. Therefore, it may be assumed that the mixed scenarios developed in this study sufficiently illustrate the effects of varying management objectives on the timber supply from all Finnish forests, although most of the discussion and reasoning was restricted to private non-industrial forest owners.

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Author contributions TH: design of the study, running simulations and optimizations, analyzing the results, writing the manuscript. TP: design of the study, providing simulation optimization model, writing the manuscript. AA: providing the data, writing the manuscript.

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Data availability The data that support the findings of this study were used under license for the current study and so are not publicly available.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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