Stand-Level Optimization

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There is a vast backlog of conducted first commercial thinnings (FCTs) in Finland. The reasons are many, but probably the most crucial would be the lack of simultaneous economic incentives for participating agents, i.e., private forest owners and forest machine contractors. In this study an FCT was executed accruing to five predetermined management options: (1) Industrial wood thinning with only two timber assortments, pulpwood and saw logs, (2) Integrated procurement of industrial and energy wood, (3) Energy wood thinning solely consisting of delimbed stems, (4) Whole-tree energy wood thinning with an energy price of 3 € m−3 and (5) Whole-tree energy wood thinning with energy price of 8 € m−3. Then, a two-phase financial analysis consisting of stand-level optimization (private forest owners) and profitability assessment (contractor) was conducted in order to find out whether there would be simultaneous economic incentives for both participants of FCT. The stand-level optimization revealed the financially best management options for a private forest owner, and then, for a contractor, the profitability assessment exposed the profit (or loss) associated with the particular management option.

Keywords: stand-level optimization ; first thinning ; pine

1. Introduction

The growing stock volume of the Finnish forest resources has been accumulating steadily during the last decades, reaching a value of almost 2500 million cubic meters [1], and so too has the roundwood trade increased during recent years, ranging between ca. 60 and 71 million cubic meters *per annum* [1]. Despite these positive signals, first commercial thinnings (FCTs) tend to be a bottleneck of the Finnish silviculture—the area of managed/conducted FCTs falls distinctively short of the planned/scheduled area which is based on the silvicultural status and urgency [2]. For instance, in Lapland (the northernmost province of Finland), the need for FCTs within the next five years corresponds to a total of app. 470,000 hectares, while during the last five years there have been carried out app. 190,000 hectares of FCTs [3]. Such a gap between the need for FCTs and actually managed hectares of FCTs—the backlog of FCTs—would in time create problems at aggregate levels in the form of, e.g., a reduction in mean annual increment and decreased timber supply ("passive management", see [4]). In order to avoid the problems stemming from the backlog of FCTs, potential financial incentives need to be discovered and further revealed for various stakeholders involved in FCT operations. In addition, managing young forests could generate positive socio-economic impacts both at the regional as well as on the national level [5].

In general, stand density is controlled through thinnings to increase growth and to improve stem quality by removing low-quality stems (e.g., [6]). More precisely, FCT in conifer stands affects the diameter growth of dominant trees and, in general, the vigorousness of trees—so that neglecting FCT would delay the diameter growth and, in some cases, would increase the mortality at stand level [7][8]. On the other hand, one of the main reasons for the neglected FCTs is the generally low profitability due to the small stem size and high harvesting costs [9][10]. During the years, there have been several attempts to improve the profitability of FCT, for instance, by applying delimbed-tree [11][12][13][14], or whole-tree harvesting [14][15][16][17][18], integrated harvesting of energy wood and pulpwood [14][19][20][21] or rationalizing integrated harvesting of small-diameter wood by introducing a new technical prototype [22][23]. Regardless of various attempts and existing subsidies (for subsidies, see [24][25]) to improve the profitability of FCT, there still exists a challenge to carry out a financially viable FCT, at least so that each actor (forest owner, forest machine contractor and forest industry company) involved would have a solid financial incentive to venture into business. Further, we consider that the scope of this study (to discover financial incentives related to participating actors of FCT) is eminently country-specific due to, e.g., different legal and operational practices between countries (see [18][24]) facing seemingly similar FCT problems. Thus, the primary goal is to discover the financial incentives associated with FCT country-wise, and only after comparing the results between countries.

In order to assess the financial viability of forest management in a theoretically sound way, one needs to apply stand-level optimization [26], through which the bare land value is maximized (e.g., [27]). In brief, maximizing the bare land value (BLV) yields the discounted economic surplus over an infinite time horizon [28]. In the case of rotation forestry, RF (for terminology, see, e.g., [29]) stand-level optimization reveals the timing and intensity of thinnings as well as the length of the rotation. In this study, the RF approach was adopted, and five options to conduct a FCT were simulated and further optimized (to maximize the BLV) for discovering their financial performance from the viewpoint of a private forest owner. The five options present commonly-used practices applied for FCT, ranging from pure industrial roundwood procurement to a 'whole trees for energy wood' alternative. The real-life data for the analyses were derived from a silvicultural database consisting of non-industrial private forest owners' and NIPFs' forests in Finland [30]. When stand-level optimization is executed by applying stumpage prices (here), the results, i.e., optimal solutions, refer to the profitability from the private forest owner's point of view (e.g., [31]).

Conducting a FCT requires that all agents involved find financial incentives to participate. Thus, a financially viable result for a private forest owner does not necessary guarantee that a FCT actually takes place—for example, if there is no economic incentive for a forest machine contractor to employ a thinning, i.e., cut the trees (cf. [32]).

2. Forest Data

The simulations and, further, the financial analyses were based on stand characteristics of six individual stands located in northern Finland (**Figure 1**). The six stands were derived from a database consisting of NIPF (non-industrial private forests) stands with an urgent need for the first commercial thinning, FCT [30]. The chosen stands belong to specific clusters of postponed FCTs. The clusters (consisting of individual stands) were derived from the project "Timber from postponed first thinnings in Northern Finland", implemented by the Natural Resources Institute Finland (Luke) and Finnish Forest Centre (Metsäkeskus), and funded by the Centre for Economic Development, Transport and the Environment (ELY) of Northern Ostrobothnia. The stands were selected according to: (*i*) the stand has passed the juvenile development phase but is not yet a mature stand (technically representing category 2 or 3 in the Finnish system) and (*ii*) a FCT had been suggested to be conducted in the stand within the past five years. The six chosen stands were quite similar with respect to stem number (trees per hectare) and soil type, but there was a distinctive difference in basal area and mean diameter (DBH) among the stands (**Table 1**).

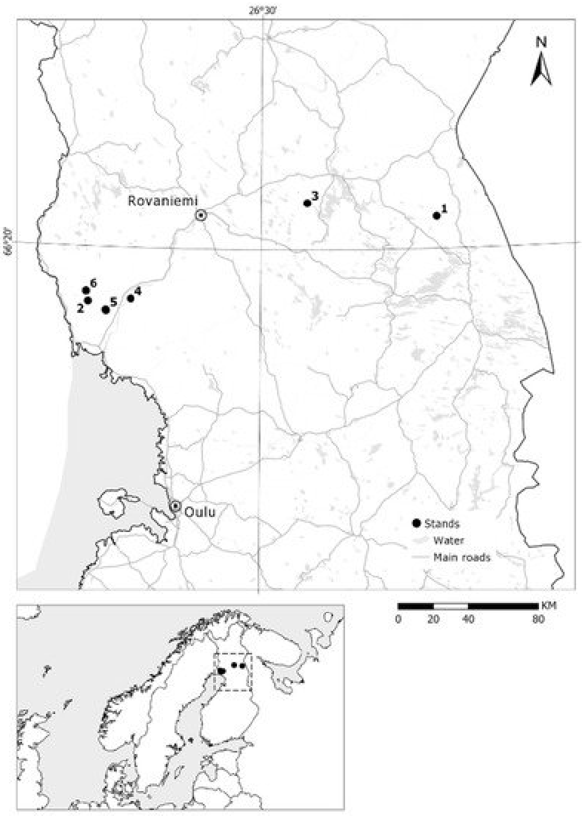

Figure 1. A map presenting the locations of Stands 1–6 under study.

Table 1. Stand characteristics of stands 1–6.

Stand Number	Main Tree Species	Site Type *	Stem Number/ha	Basal Area, m^2/ha	Mean Height, m	Mean DBH **, cm
1	Scots pine	MT	2044	24.63	9.58	15.13
2	Norway spruce	MT	1434	33.28	14.05	19.70
3	Scots pine	MT	1664	25.98	10.57	15.58
4	Norway spruce	MT	1689	35.68	13.67	18.33
5	Norway spruce	Mtkg	1320	32.95	14.29	20.21
6	Norway spruce	Mtkg	1481	26.72	12.47	17.71

* *Myrtillus* type (MT) on mineral soils and the corresponding site type on peatlands *Myrtillus* type (Mtkg) both indicate a fertile site type. For the Finnish forest site type classification, see [33]. ** Mean diameter at breast height.

3. Growth and Yield

As expected, the timing of the final cutting of the ongoing rotation fluctuated considerably, depending on the option (1–5) used to conduct the first commercial thinning (**Figure 2**, **Table 2**). For simplicity, optimal management associated with options 1–5 is presented only for stand 1 (**Figure 2**). In the integrated option (option number 2) the optimal rotation was 94 years, while in option 5 (energy wood, whole II) the corresponding rotation was as high as 107 years (**Figure 2**). Options 1 (traditional) and 3 (energy wood, stems) resulted in almost identical rotation periods of 101 and 102 years, respectively (**Figure 2**).

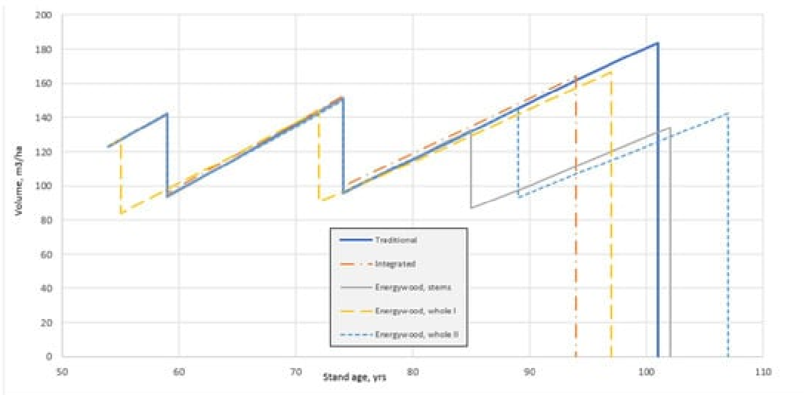

Figure 2. Volume of a growing stock associated with option 1 (traditional), 2 (integrated), 3 (energy wood, stems), 4 (energy wood, whole I) and 5 (energy wood, whole II) according to stand-level optimization in stand 1, m^3 ha^{-1}.FCT conducted at the stand age between 54 and 59 years, depending on the option.

Table 2. Thinning removal of the first thinning. Total cutting removal and rotation period associated with optimal solutions according to management options. Total cutting removal and rotation period associated with future generations also shown. Stand-level optimizations simulated with 3% interest rate.

Stand	Management option	Cutting Removal of the 1st Thinning, m^3 ha^{-1}	Total Cutting Removal m^3 ha^{-1} Ongoing [b]	Future [c]	Rotation Period, yrs Ongoing	Future
Stand 1	Traditional	45.0 (0.0)	279.1	324.0	101	98
	Integrated	54.0 (10.7) [a]	266.2	356.3	94	104
	Energywood stems	46.0 (46.0)	275.2	304.7	102	95
	Energywood whole I	52.0 (52.0)	268.9	346.3	101	102
	Energywood whole II	52.0 (52.0)	299.2	314.4	107	96

Stand	Management option	Cutting Removal of the 1st Thinning, $m^3\ ha^{-1}$	Total Cutting Removal $m^3\ ha^{-1}$ Ongoing [b]	Future [c]	Rotation Period, yrs Ongoing	Future
Stand 2	Traditional	76.0 (0.0)	303.7	404.3	110	78
	Integrated	88.0 (12.5)	312.8	381.0	110	78
	Energywood stems	52.0 (52.0)	311.9	426.0	111	81
	Energywood whole I	59.0 (59.0)	319.2	442.6	111	83
	Energywood whole II	60.0 (60.0)	315.8	420.3	110	80
Stand 3	Traditional	58.0 (0.0)	352.0	355.9	91	87
	Integrated	69.0 (11.6)	361.6	369.9	91	89
	Energywood stems	47.0 (46.6)	352.3	363.0	91	87
	Energywood whole I	57.0 (56.8)	362.8	388.1	91	91
	Energywood whole II	68.0 (67.9)	364.0	391.6	91	92
Stand 4	Traditional	82.0 (0.0)	325.3	390.8	112	79
	Integrated	95.0 (13.5)	330.3	414.6	111	82
	Energywood stems	64.5 (64.5)	320.9	413.1	110	82
	Energywood whole I	76.0 (75.7)	335.9	437.8	112	85
	Energywood whole II	75.5 (75.5)	332.4	423.3	111	83
Stand 5	Traditional	79.0 (0.0)	304.7	402.6	110	78
	Integrated	91.0 (13.3)	317.0	413.8	111	79
	Energywood Stems	51.0 (50.9)	317.6	425.7	112	81
	Energywood whole I	63.0 (62.5)	323.3	442.8	112	83
	Energywood whole II	75.0 (74.5)	332.4	423.3	111	83
Stand 6	Traditional	48.0 (0.0)	295.7	381.2	111	77
	Integrated	58.0 (9.5)	325.5	428.7	111	81
	Energywood Stems	45.2 (45.0)	298.2	372.4	111	76
	Energywood whole I	53.3 (53.0)	303.8	385.8	111	78
	Energywood whole II	54.0 (53.6)	312.6	399.2	114	80
	Traditional	64.4 (0.0) [d]	310.1	376.5	105.8	82.8
	Integrated	75.8 (11.8)	318.9	395.4	104.7	85.5
Average	Energywood stems	50.8 (50.8)	312.7	384.2	106.3	83.7
	Energywood whole I	59.9 (59.9)	319.0	407.2	106.3	87.0
	Energywood whole II	64.9 (64.9)	326.1	395.3	107.3	85.7

[a] (of which energy wood). [b] ongoing rotation. [c] future rotations. [d] arithmetic average of stands 1–6.

On average, the integrated option (2) resulted in the highest cutting removal at the first thinning: 75.8 $m^3\ ha^{-1}$ (**Table 2**). The lowest cutting removal at the first thinning was associated with option 3 (energy wood, stems), 50.8 $m^3\ ha^{-1}$ (**Table 2**). However, with respect to total cutting removal of the ongoing rotation, the options 1–5 were quite close to each other, the range being from app. 310 to 326 $m^3\ ha^{-1}$ (**Table 2**). For the future generations, the rotation period varied only mildly: from app. 83 to 87 years depending on the option (**Table 2**). The cutting removals of future generations, however, fluctuated a bit more, relatively: from ca. 376 to 407 $m^3\ ha^{-1}$ (**Table 2**).

4. Financial Performance

From the private forest owner's point of view, the best performer (expressed as *MaxNPV*, Equation (2)) was option 1, traditional, where only saw logs and pulpwood are procured (**Figure 3**a). For instance, the highest *MaxNPV* was reached with option 1, the value of 6999 € ha^{-1}, while the lowest *MaxNPV* value was associated with option 4 (Energy wood, whole I), 2665 € ha^{-1} (**Figure 3**a). For pure energy wood alternatives (option 3, 4 and 5), the best performer was option 5 (energy wood, whole II) with a median of 4879 € ha^{-1} (**Figure 3**a). Two options (traditional and integrated, options 1 and 2, respectively) distinctively outperformed the other three options (3, 4 and 5) from the contractor's point of view (**Figure 3**b). The highest profit among the six stands for a contractor at the first thinning was as much as ca. 2000 € ha^{-1} in option 1 (traditional), while in option 3 (energy wood, stems) a contractor might even operate at a loss (**Figure 3**b). Further, in option 4 (energy wood, whole I) and 5 (energy wood, II) the contractor barely makes a profit at the first commercial thinning (**Figure 3**b).

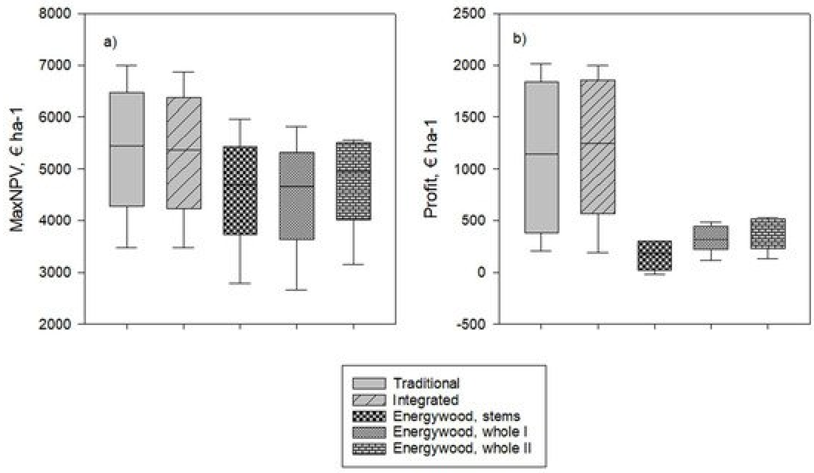

Figure 3. (**a**) Boxplots presenting the maximum NPV of options 1–5, € ha^{-1} (private forest owner's viewpoint), and (**b**) profit associated with options 1–5 at the first commercial thinning (contractor's point of view). (Note that bottom edge of each box illustrates the 25th percentile, upper edge the 75th percentile, a line within a box marks the median and whiskers of the boxplots indicate 5th and 95th percentiles.)

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