Forest management systems for increased harvest of small trees for energy purposes.

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Abstract

The objectives of this study were to evaluate management systems in Scots pine stands, with high stem densities enabling biomass harvest in early thinning, and to compare these systems with common practice. On three site fertility classes we simulated stand development for four different management scenarios. In the common practice scenario the stand was precommercially thinned to standard spacing and three dense spacing scenarios were precommercially thinned to 4000 st ha^{-1}. Revenues from forest fuel, pulpwood and sawlogs were estimated through bucking simulations controlled by a price list used in present operations. Costs of operations were calculated using functions and data from operational forestry. Calculations of soil expectation values (SEV) and sensitivity analyses of these were made for all scenarios. In the dense stand scenarios the amounts harvested as forest fuel were 30-50% greater than those in the common practice scenario. The dense stands hampered diameter increment, reducing the amount and value of round-wood in later fellings. Also, the early biomass harvest reduced stand basal area, thereby reducing future volume increment. The highest SEV were found for the common practice scenario. Sensitivity analyses showed that a high density scenario when the biofuel thinning was delayed to 11-12 m dominant height has development potential. If costs for small tree harvest can be reduced by 30% a break-even between standard and dense spacing is reached on fertile sites. Higher prices for biomass and shorter transport distances to customers will contribute to improved economy in dense spacing systems.

Key words

Scots pine; thinning; soil expectation value; forest fuel; biomass, log properties

Introduction

Increased biomass production in forest management systems, with harvest of biofuels to substitute fossil fuels, have been identified as possible methods to mitigate climate change (Baral & Guha 2004, Poudel et al. 2011). Swedish forestry is based on clear cutting followed by regeneration by planting, direct seeding or natural regeneration. Precommercial thinning (PCT) is an important measure to regulate spacing and tree species composition and determines the management options and economy for the rest of the rotation. A denser spacing increase the biomass production but results in smaller trees and thus increased harvesting costs in the subsequent thinnings. Today the normal stand density after PCT ranges from 1500-2500 stems per ha depending on tree species and site conditions.

Thinning operations in dense young stands with extraction of small trees as biofuel has become a common practice in Sweden, mainly due to unintentionally reduced intensity in previous PCT resulting in unmanaged dense stands. These thinning operations may be economically feasible due to recent improvement in harvesting technology, e.g. multi-tree handling harvester heads, and improved harvesting methods, which have reduced logging costs for small trees. The amount of biofuel that can be harvested in dense first thinning stands is estimated to 2 million tonnes DM/year, equivalent to 10 TWh per year (Nordfjell & Iwarsson Wide 2010).

To evaluate the potential for biomass production and economy in forest management systems, the entire rotation has to be considered. Stem density in young age has the potential to impact diameter development and wood value in later stages of the rotation. Successful regeneration of *Pinus sylvestris* by direct seeding or natural regeneration normally results in high seedling density enabling the forest manager to choose spacing after PCT within a wide range. The objectives of this study were to evaluate management systems where *Pinus sylvestris* stands are intentionally managed to create high stem density up to the first thinning stage to enable biomass harvest in early thinning, and to compare these systems with traditional management on the same sites. Effects on biomass production, biofuel, round-wood products and economy were evaluated.

Materials and methods

The analyses were performed on the level of forest stands. To capture differences in site characteristics, geography and climate, the consequence analyses was performed for three different site index (SI) classes (Hägglund, 1974) for Scots pine (*Pinus Sylvestris* L.). The site index classes (T18, T22 and T26) were chosen to represent the areal distribution of SI in Sweden, based on data from the Swedish National Forest Inventory. For each SI-class a silvicultural tending program was specified, representing the base-line (standard spacing) and three alternative silvicultural scenarios with dense young stands. All calculations were made for one type stand in northern and one in southern Sweden to reflect the effects of differences in regeneration costs, stand area and distance to customers within the country.

After regeneration PCT was performed to space the stand to either a normal stand density for the SI or to 4000 stems per ha in the dense management scenarios. In the dense scenarios a biomass harvest is made either before or instead of the first roundwood thinning. After this harvest the stands in all scenarios are treated according to the normal management for pine given the SI. The first commercial harvest, either a biomass or a conventional first thinning, includes harvesting of strip road trees

The analysed scenarios can be described as:

S. <u>Standard spacing (base-line)</u> No. of stems after PCT: 1600, 1900 and 2200 stems per ha at site index T18, T22 and T26 respectively. First thinning at a dominant tree height of 12-13 m.

D1. <u>Biofuel harvest at 10 m height.</u> No. of stems after PCT: 4000 stems per ha at all site index classes. First thinning at the same time as Base-line scenario.

D2. <u>Biofuel harvest at 10 m height.</u> No. of stems after PCT: 4000 stems per ha at all site index classes. First thinning delayed five years compared to Base-line scenario.

D3. <u>Biofuel harvest performed at ordinary time of first thinning</u>. No. of stems after PCT: 4000 stems per ha at all site index classes.

The growth of the young stands, i.e. up to 10 m dominant height, was calculated according to functions by Pettersson (1993) (Fig.1). After 10 m height the development of all stands were calculated according to a stand growth simulator (SkogProd), based on single tree growth functions by Söderberg (1986).

Based on data of the harvested trees from the stand simulations productivity and costs for the operations has been estimated. Productivities and cost for works that are independent of stand factors (e.g. site index harvested volume ha^{-1}, tree size) are reported average productivity and costs in Swedish forestry (Brunberg 2010; 2012a; b) Productivities and costs dependent on stand factors has been calculated using functions from published productivity norms or with updated functions intended for internal use at Skogforsk.

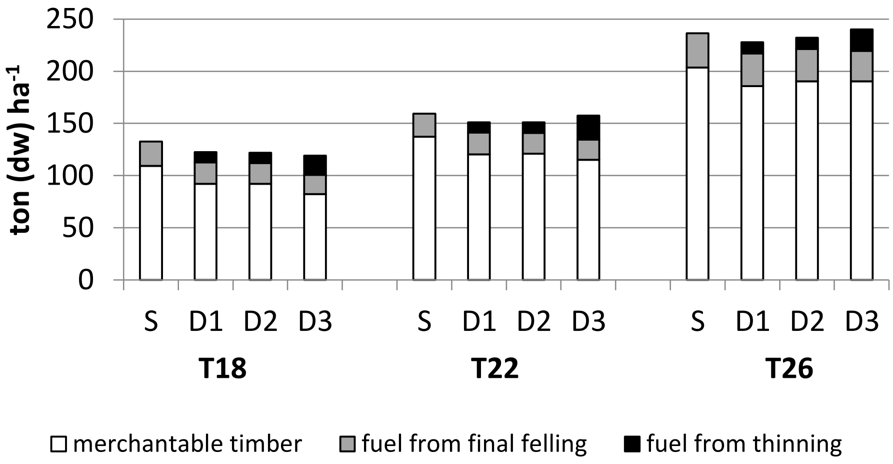
The total volumes of merchantable roundwood were predicted by two different calculation procedures a simpler for thinning operations and a detailed for final cut. Both procedures were based on output data from the growth simulator. Bucking in thinning operations was performed as stem sections of sample trees representing diameter classes according to functions developed by Ollas (1980). All merchantable logs from 1:st thinnings were bucked as pulpwood (≥5 cm u.b) exclusively. Merchantable stems from 2:nd and 3:rd thinning operations were divided into sawlogs (≥14 cm u.b.) and pulpwood (≥5 cm; <14 cm u.b). Predicted volumes and values from final cut were based on detailed bucking simulations of all individual stems from the growth simulator. Tree lists including individual tree height and breast height diameter over bark, were imported to the bucking simulation package Timber Analyses 3.0 (Arlinger et al. 2003) where an optimal bucking was done.

Soil expectation values (SEV) were used to evaluate the economic potential of the different forest management systems. They were calculated according to the generalized formula described by Faustmann (1849) using a standard interest rate of 2.5 per cent.

Results & Discussion

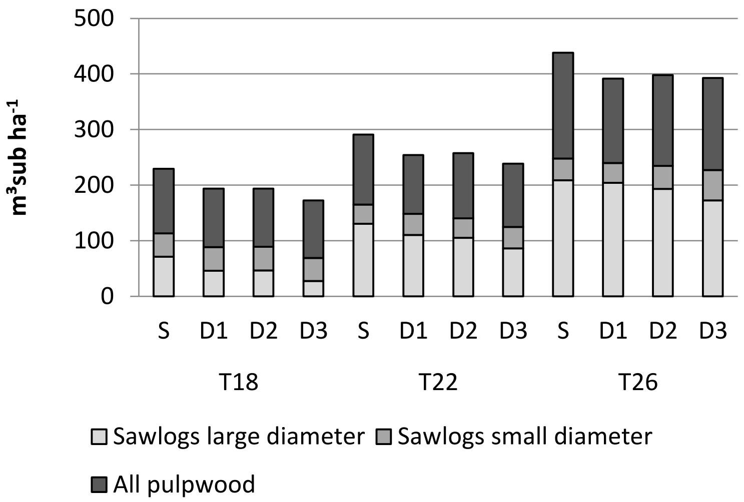
At the more fertile site type (T26) the total amounts of harvested biomass (Figure 1) in scenario D3 was on the same level, or slightly higher, than that of the base-line. However, the base-line scenario provided a larger harvested volume of saw logs and pulp wood (Figure 2). At the less fertile site types (T18 and T22) the base-line scenario gave the best total harvested yields, both in terms of saw logs and pulp wood volume and total amounts of extracted biomass (Figure 2-3). Not surprisingly, the scenarios with forest fuel thinning showed the highest total amounts of forest fuel extracted. The greatest amounts were found in Scenario D3 regardless of site type. However, the amounts of harvested forest residues from final felling were consistently highest in the base-line scenarios.

Figure 1. Total harvested amounts of biomass (d.w.) from thinnings and final cutting in the analysed scenarios.



The base line scenario (S) produced larger volumes of both sawlogs and pulpwood over rotation in comparison with the denser scenarios D1, D2 and D3 (fig 3). The D3 scenario resulted in the lowest amount of larger sawlogs as a consequence of reduced diameter growth of individual trees. Differences in log volumes and assortments between site indices (T18-T26) were large and this effect of larger trees on higher site indices was pronounced when comparing the harvested volume of larger sawlogs. The latter considerably affected the average prices per m³ub. When summing up the different effects the T22 (S) scenario appeared to result in the highest value per m³ub (57 €) while T18 (D3) resulted in 41 €/m³ub

Figure 2. Total volumes (m³sub) of merchantable logs per assortment, site index and scenario.



With the selected energy price, logging costs and interest rates, the base line scenario always has the highest SEV:s independent on Location and site index (table 1). The best performing dense spacing systems was D3 that always showed higher SEV:s than D1 and D2. Also the early biomass thinnings in scenario D1 and D2 were affected by low extraction levels of approximately 10 ton dry matter per ha. This low extraction levels cannot carry the costs for the harvesting operations and are thus not profitable. This creates a large incentive to postpone the biomass harvest to the same stand age as the normal first thinning when the harvest is profitable, i.e. scenario D3. However, these dense stands cause an increased risk for damage of snow and wind after thinning that has to be considered. Furthermore, the dense stands in scenarios 2A, 2B and 3 has a reduced diameter- and basal area growth under the rest of the rotation. This resulted in lower volumes of sawlogs and pulpwood in later thinnings and final felling unless the rotational age is increased.

Table 1. Soil expectation values (EUR/ha) for the different management systems.

	Northern Sweden			Southern Sweden		
	T18	T22	T26	T18	T22	T26
Standard spacing	-175	388	1735	-325	149	1548
Dense spacing						
D1	-499	-120	1125	-627	-276	980
D2	-487	-80	1166	-615	-230	1033
D3	-414	3	1444	-509	-75	1391

Sensitivity analyses show that despite the higher SEV:s for the base line scenario there is a potential for the dense stem scenarios, mainly scenario D3, under certain circumstances and especially if logging costs for harvest of small trees can be reduced with at least 15 % and/or with slightly increased energy prices. The logging costs we have used represent average costs with present equipment and operators. Studies show that the best machine / operators combinations can reduce logging cost up to 30 % compared to the average (Bergström et al. 2007, Iwarsson Wide 2010). We think the potential to reduce logging costs for small trees are great, both with improved machines and with proper training and selection of operators. Higher prices for biomass, which is less plausible in the near future given the current market situation, and shorter transport distances to customers than those used in the analyses will also contribute to improved economy in dense spacing systems.

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