What, How and When to Harvest in Young Dense Stands

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Abstract:
What assortments should be harvested from young, dense stands, and how should it best be done? That is a more and more common question in today's first thinning, when we don't have the expected 2 000 stems per hectare, but more denser stands with weaker mean stem volumes. Rising prices on bio fuel has created a new assortment that can compete with pulp wood in weak early thinning. The price relations decided what assortment that will generate the best net value in the harvest. Should we harvest only for pulp wood, for energy wood or perhaps make an integrated harvest for the both? Often the answer is quite obvious – when we know the presumptions. But the marginal are small and it is important to be familiar with the determining factors. Most importantly the number of stem per hectare, mean stem volume and distribution of tree species, and of course the price relations between different assortments.

Keywords: biomass and pulp wood harvesting, small dimension stands, calculation, decision making, multi-tree handling

1 Introduction

The activities in pre-commercial thinning and early first thinning are presently too low, from a silvicultural point of view. The current trend, to postpone early density regulation leads to poor stem development, sensitivity to wind and snow damage and rising costs in later thinning. Thus, intensified treatment of young stands is desirable from a silvilcultural point of view and also offers a sustainable source of energy.

Athanassiadis et al (2011) makes the calculation that the potential removal in early thinning where the mean height in the stand is less than 14 meters and the potential harvested volume is more than 30 ODT per hectare, is about 9,4 TWh yearly.

2010 bioenergy contributed with 129 TWh or 21 percent of Sweden's total energy supply, that comes to a total of 616 TWh. Primary biofuel contributed with 17 TWh. 5,2 TWh was ordinary round wood and about 2,6 came from delimbed energy wood and whole trees, harvested in early thinning or along roadside and from pasture land. The harvest of these assortments increased by 76 percent from 2009 to 2010.

Forest fuel from small dimension stands can be harvested in different ways and as different assortments, whole, uncompacted trees, partly delimbed energy wood or as pulp wood. The fuel holds a good quality because of the high proportion of stem wood. It is also relatively unproblematic to handle in storage, chipping and transport. In terms of harvesting, it is advantageous to handle only one assortment, or possibly two. Harvesting for many assortments will arise to cost for logging, especially the forwarding.

Table 1: Additional volume in the form of partly delimbed energy wood increases with decreased mean stem volume in the removal

Mean stem volume, m3fub	0,02	0,03	0,04	0,05	0,06
Additional volume, %	120	75	40	20	10

A lot of the biomass in young stands can be found in the slender stems, branches and tops. Compared to removal of only pulp wood in dense thinning the harvested volume typically increases with 20-40 % when including also the small stems and tops of pulp wood stems in the harvest, for example as delimbed energy wood. You can then increase the productivity of the felling with 15-40 percent (Hakkila 2005). If harvesting for whole trees the harvested volumes will increase with 50-150 % depending of the diameter distribution and mean stem volume within the stand.

It increases revenues - but also the cutting cost per harvested volume increases due to the lower average stem volume.

In very weak stands the additional volumes in harvests that include wood fuel will be significant compared with a harvest of only pulpwood. The coarser the mean stem volume in the stand, the smaller is this additional volume. The figure 1 shows how the supplement volume can typically be increased with reduced mean stem volume in the removal when harvesting energy wood along with pulpwood.

2 Materials and methods

Studies were carried out during the autumn and winter 2010 in the central parts of Sweden in the county of Dalarna. Three different types of removals were carried out in two different types of stands, a mixed coniferous stand and a spruce dominated stand. Harvesting for delimbed energy wood, pulpwood and integrated harvest for both these assortments.

The weather was mild at the harvesting time. The forwarding were conducted about a month after the harvest, and at that time there were about 10 centimeters of snow in the spruce dominated stand, which made the forwarding more complicated.

2.1 Machine and equipment

The harvesting studies were conducted with an Eco Log 560C harvester equipped with a Log Max 4000B harvester head with accumulation arms. The work was carried out by a well trained and experienced driver.

In the mixed coniferous stand the forwarding were carried out by a Ponsse Elk that loads 13 m³, with a 9.5 meter crane and a 0.28 m² standard grip. The forwarding in the spruce dominated stand were carried out by a Valmet 840 that loads 13 m³, with a 8,5 meter crane and a 0,28 m² standard grip. Both forwarders were operated by experienced drivers, especially in the combined harvest plots.

2.2 Study plots

Table 2: Description of the mixed coniferous stand

Mixed coniferous stand	Pulp wood removal	Energy wood removal	Integrated harvest
Harvested areal, hectare	1,1	0,9	1,2
Tree per hectare after pre-cleaning	2720	2830	2750
Dry weight per ha, ODT	98	98	106
Volume per ha, m³	243	243	266
Volume per ha, m³ ub	146	146	165
Average dbh (arithmetic mean)	6	6,6	6,9
Basal area weighted diameter	14,1	13,4	13,9
Mean height, m	12,8	12,5	12,8
Average volume per tree, m³	0,055	0,059	0,063
Average volume per tree, m³ ub	0,033	0,036	0,039
Average volume per tree, kg dried	22	24	25

Strip roads were laid out in the study areas and each strip road were divided into two or three parts, sub-plots. The three different treatments (removals) were when divided between the sub-plots in order to conduct each treatment in as representative and similar conditions as possible concerning stand density, mixture of species and mean stem diameter.

The mixed coniferous stand was about 25 years old and relatively dense with a large spread in dimensions and in parts in need of pre-cleaning before the actual harvest.

The spruce dominated stand was about 27 years old with a lower dimension spread, and not in the same need for pre-cleaning.

Table 3: Description of the spruce dominated stand

Spruce dominated stand	Pulp wood removal	Energy wood removal	Integrated harvest
Harvested areal, hectare	1	0,8	1,4
Tree per hectare after pre-cleaning	2 400	2 680	2 720
Dry weight per ha, ODT	105	105	97
Volume per ha, m^3	251	243	231
Volume per ha, m^3 ub	125	123	115
Average dbh (arithmetic mean)	10,2	10	9,5
Basal area weighted diameter	14	13,5	13,4
Mean height, m	11,4	11,4	11
Average volume per tree, m^3	0,10	0,09	0,08
Average volume per tree, m^3 ub	0,047	0,045	0,04
Average volume per tree, kg dried	41	39	33

2.3 Economical presumptions

These calculations has assumed a pulp wood price of 36.5 €/m³ub for coniferous pulp wood, 38 €/ m³ub for spruce pulp wood, 36 €/ m³ub for birch pulp wood and 28 €/m³ob for energy wood. The costs for pre-cleaning varied from 111 to 278 €/ha depending on number on stems to clean per hectare. The costs for the harvester were set to 116.5 €/E-0 hour and 94.5 €/E-0 hour for forwarders.

When calculating the productivity and costs for the different assortments in integrated harvest the time consumption where distributed after the removed volumes.

2.4 Time study

The time consumption per work elements was recorded using an Allegro™ handheld computer with the SDI work-study software provided by Haglöv AB, Sweden. The resolution of the recorder was one centi-minute (0.6 seconds). Short delays were recorded but not included in further analysis, since the study was too small to obtain an estimate of general delay times for the different treatments. The effective work time excluding delays is denoted E-0, while work time including short delays (< 15 minutes) is denoted E-15.

3 Results

In the mixed coniferous stand the mean tree biomass in the removal was 37 kilograms DW/tree in the pulp removal, 22 kilograms DW/tree in the energy wood removal and 27 kilograms DW/tree in the integrated harvest. Table 3 describes the removals in the different study plots.

The remained volume in the stand was 150 m³ per hectare in after thinning for pulp wood, and 160 m³ in the other study plots. This indicates a thinning removal of 37-38 % in the different treatments.

Table 4: Description of the removal in the mixed coniferous stand

Mixed coniferous stand	Pulp wood removal	Energy wood removal	Integrated harvest
Removal (st / ha)	975	1 535	1 600
Removal (ODT / ha)	36	33	41
Removal, volume ($m3^3$ / ha)	90	82	102
Removal, volume (m^3fub / ha)	55	0	45
Average dbh (arithmetic mean)	11,2	8,2	9
Basal area weighted diameter	12,9	11,5	12,8
Mean height, m	11,7	9,5	10
Average volume per tree, m^3	0,09	0,05	0,07
Average volume per tree, m^3 ub	0,053	0,030	0,030
Average weight per tree, kg dried	37	22	27
Tree species (P, S, B), % (ODT)	59 / 34 / 7	50 / 37 / 13	56 / 35 / 9

After standardization, according to the table below, for differences regarding stand density and mean stem volume one can conclude that the productivity was the highest in the energy wood removal, mainly because of the larger volume harvested per hectare.

Table 5: Productivity in the mixed coniferous stand

Mixed coniferous stand	Pulp wood removal	Energy wood removal	Integrated harvest
Average weight per tree, kg dried	37	25	25
Average volume per tree, m^3 ub	0,053		0,055
Average volume per tree, m^3	0,07	0,048	0,02
Removal (st / ha)	1000	1500	1500
Removal, volume (m^3fub / ha)	53		45
Removal, volume (m^3f / ha)		72	14
HARVESTING			
m^3ub/E0-h	13,5		13
m^3/E0-h		15,5	7
FORWARDING			
m^3ub/E0-h	17,3		17,0
m^3/E0-h		23,5	5,5

In the integrated harvest only 25 % of the forwarded load was energy wood, which is a relatively small removal per hectare, 14 m^3. This leads to a low productivity in both harvesting and forwarding, and thereby also an expensive treatment.

The number of trees per crane cycle varied from 1.4 stem in the pulp wood removal up til 2.2 trees per crane cycle when harvesting for energy wood only. The lower degree of accumulation in pulp wood is explained by the lower removal per hectare, 975 stems compared to 1 500. The possibility to reach a high degree of accumulation is depended of the size of the removal. This also affects the productivity. On the other side a growing number of stems in the removal leads to a lower mean stem volume, which lowers the productivity, even though this is somewhat offset by the higher degree of accumulation.

Table 6: Description of the removal in the spruced dominated stand

Spruce dominated stand	Pulp wood removal	Energy wood removal	Integrated harvest
Removal (st / ha)	840	1 370	1 280
Removal (ODT / ha)	24	31	31
Removal, volume (m3³ / ha)	56	72	72
Removal, volume (m³fub / ha)	25,9	0	23,6
Average dbh (arithmetic mean)	9,5	8,3	9,4
Basal area weighted diameter	11,5	10,9	10,9
Mean height, m	9,8	8,9	8,9
Average volume per tree, m³	0,066	0,055	0,057
Average volume per tree, m³ ub	0,031	0,017	0,019
Average weight per tree, kg dried	29	23	25
Tree species (P, S, B), % (ODT)	0 / 49 / 51	0 / 50 / 50	0 / 55 / 45

In the spruce dominated stand the mean tree biomass in the removal was 29 kilograms DW/tree in the pulp removal, 23 kilograms DW/tree in the energy wood removal and 25 kilograms DW/tree in the integrated harvest. Table 5 describes the removals in the different study plots.

The remained volume in the stand was 195 m³ per hectare in after thinning for pulp wood, 170 m³ after removal of energy wood and 160 m³ in the study plot where integrated harvest had been conducted. This indicates a thinning removal of 21 % in the pulp removal and 31 % in the other treatments.

After standardization one can conclude that the productivity was the highest in the energy wood removal. In weak stands like this a large volume can be harvested from trees smaller than today's pulp wood dimensions. In the integrated harvest only 30-35 % was pulp wood, which shows a very small harvested volume per hectare, approximately 14 m³.

Table 7: Productivity for the harvest in the spruce dominated stand

Spruce dominated stand	Pulp wood removal	Energy wood removal	Integrated harvest
Average weight per tree, kg dried	29	23	23
Average volume per tree, m³ ub	0,03	0,023	0,035
Average volume per tree, m³	0,05	0,04	0,03
Removal (st / ha)	850	1300	1300
Removal, volume (m^3fub / ha)	26		14
Removal, volume (m^3f / ha)		52	27
HARVESTING			
m³ub/E0-h	7		5,2
m³/E0-h		10,7	10,5
FORWARDING			
m³ub/E0-h	8,6		6,2
m³/E0-h		14,2	10,0

The number of trees per crane cycle varied from 1.4 stem in the pulp wood removal up til 2.1 trees per crane cycle when harvesting for energy wood only. This is logical since the driver than is able to optimize the crane cycles and do not have to do any sorting into different assortments.

4 Discussion

When harvesting for energy wood also the small trees and tops are included in the harvest. This means a larger harvested volume per hectare, typically 20-40 percent extra, and since accumulating harvester heads are being used a larger volume is thereby produced per time unit. In the mixed coniferous stand the productivity in the harvest, m^3/E_0-h, was 15 % higher in the energy wood harvest than in the pulp wood harvest. In the spruce dominated stand the productivity was 52 % higher in the energy wood harvest, since the mean stem volume in pulp wood lead to a very small removal per hectare.

Forwarding after integrated harvest is less productive since two assortments needs to be handled separately and the harvest per meter strip road will be lower (Laitila 2007). In general a removal of at least 10 $m^3$is needed to reach an acceptable level of cost in forwarding (Kärhä 2010).

In the mixed coniferous stand the productivity in forwarding was 36 % higher in the energy wood harvest compared to pulp wood harvest. The corresponding increase was 65% in the spruce-dominated stand.

In the stand conditions, price and cost relations that existed during this study, it turned out, not to be economical interesting to make an integrated harvest. Previous studies in Finland have shown that it can be an interesting option and a way of allocating harvesting costs over a higher volume, (Heikkilä 2009, Kärhä 2010, Laitila 2010). The factors that have the greatest impact is the average diameter in the removal, the number of harvested stems per hectare, diameter distribution and tree species mix in the stand, additional volume in the branches and tops and the price relationship between different potential assortments.

To analyses how the price relation between pulp and energy wood, energy wood expressed as a percentage of softwood pulpwood prices, affect the income per hectare is shown in figure 2. The mean stem volume in the pulp wood harvest is 0.05 m^3 and the removal is set to 1 000 stems per hectare. The corresponding removal in the energy wood harvest would then have a mean stem volume of 0.04 m^3 and 1 500 harvested stems per hectare. The additional volume in the removal of energy wood is 20 percent. With today prices is the breakpoint at an energy price that is higher than 76 percent of the pulp wood price.

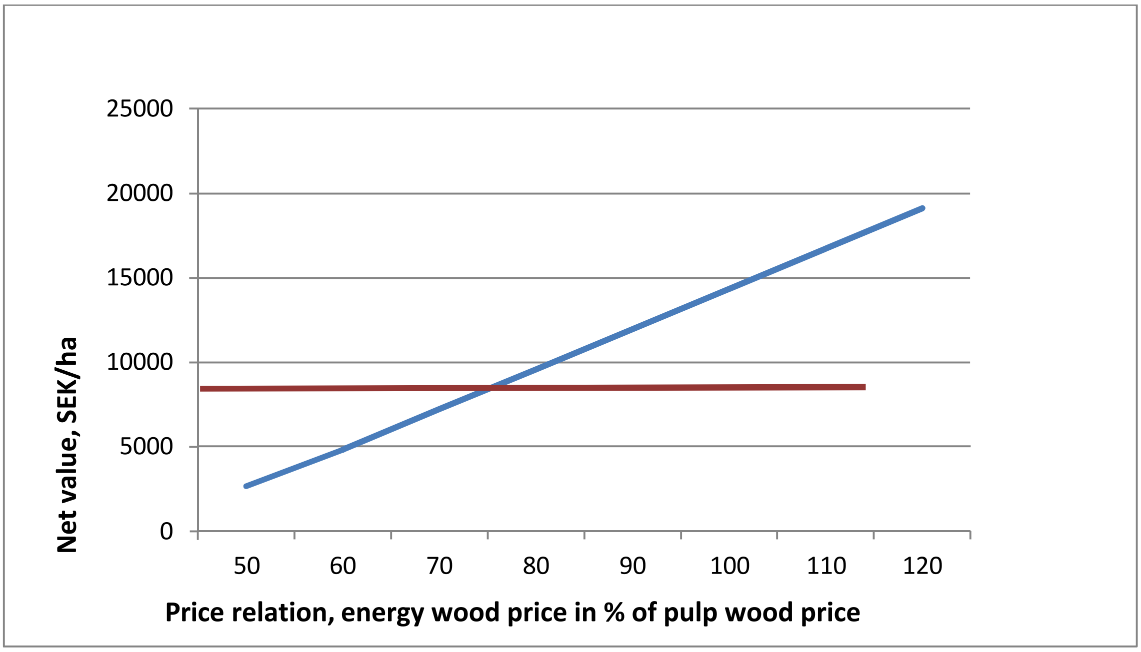

Figure 1: With today's costs in the harvesting of mixed coniferous stands at 0.05 m³ (removal), is the breakpoint at an energy price that is higher than 76 percent of the pulpwood price (SEK / m³)

If the mean stem volume is weaker the break point will occur already at a larger difference in the assortments prices, since a larger amount of the harvest will not have reached pulp wood dimensions. In parts of Sweden one also has to calculate a cost reduction because of long transports, especially for pulp wood. One also has to calculate that some parts of the volume, normally 3-5 percent, will be rejected, especially from weak thinning. In energy wood harvest one gets paid for the full volume.

In integrated harvest the productivity is low for the weakest stems, where all of the volume goes to energy. In the energy removal from the top sections though, where the other part of the stem goes to pulp wood, the productivity is very high (Laitila et al 2010).

Integrated harvest of pulp and energy wood might be of interest if the total removal per hectare is at least 35-40 m³ and the harvest of the smallest assortment is higher than 10 m³ per hectare (Kärhä 2010, Iwarsson Wide and Fogdestam 2011). But the more assortments the higher the costs for forwarding, and in these type of stands one should only harvest two assortments. We also has to calculate that some of the pulp wood volume will end up in the energy wood piles, since they will be harvested together with surrounding energy wood trees to optimize the crane cycles. This volume is normally about 10-15 percent (Iwarsson Wide and Fogdestam 2011).

The productivity in the harvest decides the profitability. With today's machine costs the limit for profitability in energy wood harvest is about 9-10 m³/E_0-h (Bergström 2010). Depending on the mean stem diameter the driver has to handle a given amount of stems per E_0-h to reach that limit. The weaker the diameter, the more stems has to be handled. If the mean diameter in the removal is 8 centimeters, one needs to handle 200 stems per E_0-h, and if the mean diameter is 6.5 centimeters 400 stems has to be handled per E_0-h.

Pre-clearing of the weakest stems, typically up till 5 centimeters in diameter breast height, can raise the mean stem volumes and thereby also the productivity in the harvest. But it will probably cost about € 150-200 per hectare, and when it comes to pine and birch, it is sometimes not worth the cost, when looking at it strictly economically.

Multi-tree handling is vital for a profitable harvest and handling of small dimension stems, especially in stands with a low mean stem volume and a big removal per hectare. Productivity can rise with 20-50 % in the dimension typically harvested from these stands, 0.03-0.06 m³ per stem. Improved working methods can also help to increase the productivity – mainly by decreasing the crane movements, which also decreases the stress on the driver.

5 Conclusions

Rising prices on bio fuel has created new assortments that can compete with pulp wood in weak early thinning. The price relations decided what assortment will generate the best net value in the harvest. In stands with a mean stem volume larger than 0.05 m³ in the removal pulp wood is normally the best outcome. In really weak stands, with a mean stem volume of 0.02-0.03 m³, one get the best net value if everything is harvested as forest fuel. In coniferous stands with a mean volume over 0.035 m³ it is often more profitable to harvest for pulp wood, since soft wood pulp wood often give a better price. But if the proportion of hard wood pulp wood is greater than 50 percent in the removal, or if the mean stem volume is less than 0.035 m³ one should consider an energy wood removal instead. This is because of the higher energy content and slightly lower prices for hard wood pulp. In the southern parts of Sweden though, the prices and price relations look a little different, with higher prices on hard wood pulp and lower prices on energy wood compared to the central and northern parts (2012), which leads to other optimal removals.

A great challenge and problem for persons that plans these thinning is to estimate the possible volumes to harvest, and thereby estimate revenues and cost in the operation. Today estimates, if any are done, are very rough are often built on experience or guessing. When deciding what assortment to harvest and what technology and method to use we need to look at the whole handling chain, harvesting, storing, transportation and chipping. Also the price relations between the different assortments are crucial and decides that should best be harvested.

To be able to calculate and compare different alternatives depending on the stand data, Skogforsk has developed a volume and cost calculation tool. With a tool that can calculate assortment volumes and takes into account different prices on the assortments and also calculate the cost for harvesting and forwarding of the different assortments, using models for time consumption per hectare it becomes easier to compare the outcomes of the different options. A more advanced version will also calculate costs for chipping, storing and transporting the material to the industry.

Software like this leads to increased profitability in early thinning and higher precision in analyses of different systems and their economical outcome in early thinning. The possibility to make a simple calculation to compare the outcome of harvesting pulpwood, forest fuel or a combination harvest in each stand provides a good decision support and increase the possibility to reach a profitable result in the operation.

6 Literature

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