The State-of-the-Art: Harvesting in the Nordic Countries[1]

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Summary

Forest management systems in the Nordic countries are generally characterised by repeated selective thinnings from below. An increasing share of thinning cuttings and mechanised harvesting, plus the increasing importance of environmental aspects are common features to logging in the Nordic countries. Log-length method is used almost entirely. Despite attempts to mechanise forest work, motor-manual cutting still has its place in modern forestry.

The one-grip harvester is the most common multi-function machine type. It can be used both in thinnings and clear cuttings. Two-grip harvesters are not equally capable of working in thinnings, where the damage to the remaining trees is to be minimised. The role of processors in cutting is rapidly getting smaller. The dominating machine in off-road transportation is the wheeled forwarder.

Farm tractor-based machinery still has a remarkable role in logging. Light tracked machinery has been developed for early thinnings and poorly bearing sites. These two groups form a minor, yet important part of the logging machine fleet.

In the near future, early thinnings with low productivity in mechanised harvesting and high costs in motor-manual harvesting will be the main question to be solved in the field of harvesting. The development of light machinery and multi-tree processing technology is therefore likely to take a remarkable step forward. Environmental aspects also have a strong influence in machine development.

1. A Brief Glimpse of Forestry in the Nordic Countries

Nordic countries, although often considered as an homogenous group, in terms of landscape and forestry differ a lot from each other. Landscape varies from Denmark's flatland through Finland's softly rolling hills to the mountains of Norway. Finland, being the most forested country in Europe, has 66% or 20.1 million ha of the total land area covered by forests, whereas the corresponding figure in Denmark is 12% or 512,000 ha (Fig. 1) (Anon.

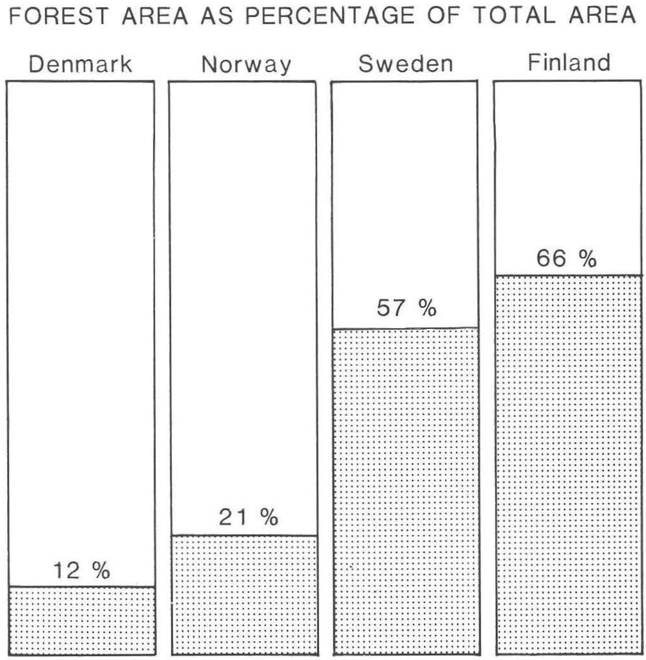

Figure 1: Forest area as a percentage of total area in some Nordic countries (Anon. 1982 and 1989).

1982 and 1989). Iceland, of course, is a very special case among the Nordic countries; it is a volcanic island with hardly any forests.

The selection of tree species varies as well. In the northern part of the area in question, including Finland, Norway spruce *(Picea abies),* Scots pine *(Pinus sylvestris)* and birch *(Betula pendula* and *Betula pubescens)* dominate. In Denmark, the most important coniferous species are: Norway spruce, Sitka spruce *(Picea sitchensis),* silver fir *(Abies alba),* Douglas fir *(Pseudotsuga menziesii)* and mountain pine *(Pinus mugo).* The most important broadleaved species are: beech *(Fagus sylvatica),* oak *(Quercus robur),* ash *(Fraxinus excelsior)* and sycamore *(Acer pseudoplatanus)* (Anon. 1982).

The rotation for conifers varies from 40 years in Denmark to up to 200 years near the northern tree limit. Forest management systems are characterised by repeated selective thinnings from below, except in Denmark, where row thinnings are used. An increasing share of thinning cuttings and mechanised harvesting, plus the increasing importance of environmental aspects are common features of logging in the Nordic countries.

The importance of forestry in the economy of the country is greatest in Finland and Sweden. Accordingly, specialised forest machinery is mostly used in logging. In Denmark and Norway a large share of logging machinery is farm tractor based. Also cable logging systems are widely used in the mountainous parts of Norway.

In the following, the description of current logging systems will concentrate on Finland and Sweden. These countries, however, represent the-state-of-the-art of mechanised tree harvesting in the Nordic countries. When it comes to future trends, the Nordic countries can more or less be considered as a group.

2. Current Logging Methods in Finland and Sweden

2.1 General aspects

Finland and Sweden, though very much alike, have some differences which strongly influence logging. First of all, the share of peatlands of the total land area is significantly greater in Finland (32%) than in Sweden (22%) (Heikurainen, 1984). In fact, Finland is one of the world's richest countries in peatlands. Moreover, the share of drained peatlands is much greater in Finland compared to Sweden. According to Kuusela (1978), 43.6% or 4.1 million hectares had been drained by 1976.

Table 1: Some figures of logging by forest industry companies in Finland and Sweden (Puun, 1990).

	Finland		Sweden	
	1987	1992	1987	1992
Annual drain, mill. m^3	28	34	41	44
Clearfelling, %	61	61	77	73
Thinning c., %	39	39	23	27
Degree of mechanisation, %				
clearfelling	55	72	78	88
thinning	8	25	47	69
all	35	53	71	83
Average stem size, m^3				
clearfelling	0.26	—	0.26	—
thinning	0.11	—	0.11	—
Average removal, m^3/ha				
clearfelling	168	—	189	—
thinning	64	—	52	—
Average off-road haul. dist., m	315	—	400	—

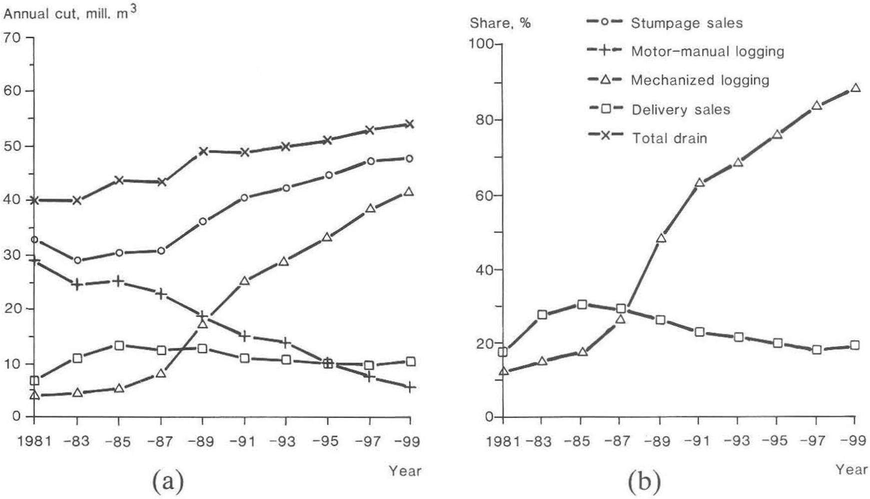

Figure 2: Development of logging in Finland (a) and the share of mechanised logging and delivery sales (b) in 1981-99 (Örn, 1990).

Another important factor is the difference in the basis of forest work payment, with Finland having a piece rate system and Sweden a time rate or a combination of piece and time rate. Nearly all forest machines in Finland are owned by private contractors, whereas in Sweden forest industry companies own 35% of the machines. The share of company-owned forests is clearly greater in Sweden. Environmental restrictions on logging are stricter in Sweden, but in both countries the condition of the site after logging must be good in order to keep private forest owners, who own a large proportion of forests, willing to sell wood in the future.

Table 1 gives an overview of logging in Finland and Sweden, excluding logging done by private landowners (Puun, 1990).

The degree of mechanisation in Finland, although one of the highest in the world, lies well behind Sweden due to, among other reasons, the differences in forest work payment system and forest land ownership (Figs. 2a, 2b, 3a and 3b). The share of mechanised logging is expected to rise rapidly. The log-length method is used almost entirely and rack distance usually varies between 20 and 30m. The selection of trees to be removed is done increasingly by the logger or machine operator.

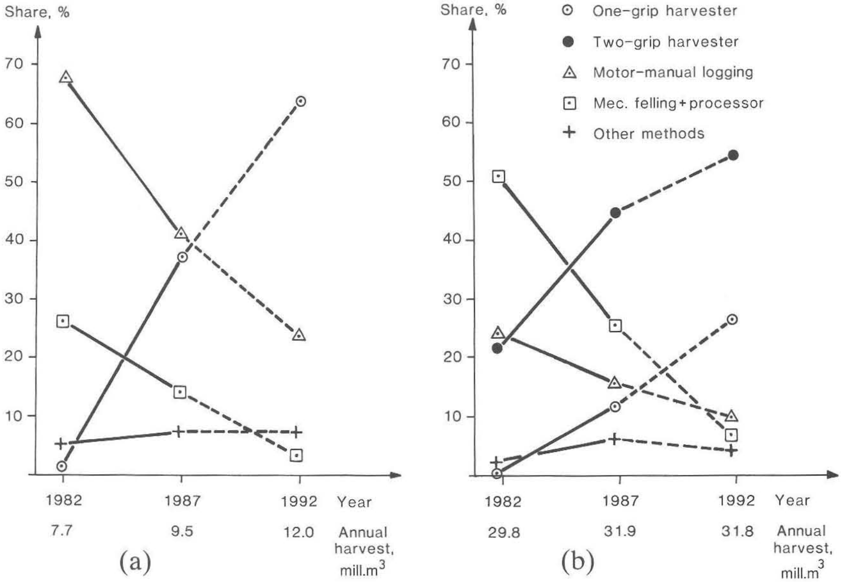

Figure 3: Logging methods in Sweden in thinnings (a) and clear cuttings (b) in 1982-1992 (Freij and Tosterud, 1988).

2.2 Motor-manual cutting

Despite attempts to mechanise forest work, motor-manual cutting still has its place in modern forestry. Even in the mid-90s its share is expected to be approximately 10 to 30% in company operations (Örn, 1990; Freij and Tosterud, 1988). Motor-manual cutting is most competitive in first thinnings. In Finland, it is considered the most economic method for first thinnings, whereas in Sweden it is no more cheaper than mechanised methods. In later thinnings and clear cuttings motor-manual cutting is usually the most expensive method. However, it is still profitable to cut the most valuable stems, such as big-dimensioned veneer birch, motor-manually to maximise the grade yield of the forest products.

Rationalisation has greatly improved the productivity of manual cutting. These measures include the lengthening of pulpwood logs to 3-5m and the relaxing of nominal length accuracy and delimbing requirements. In Finland, the average annual output of a chainsaw worker is 2,500-3,000m^3 (Hakkila 1989), whereas, due to the time rate system, it is somewhat lower in Sweden.

Motor-manual cutting has therefore reached the stage where its productivity cannot be significantly increased. The labour force of forestry is continuously decreasing and the timber demand of the pulp and paper

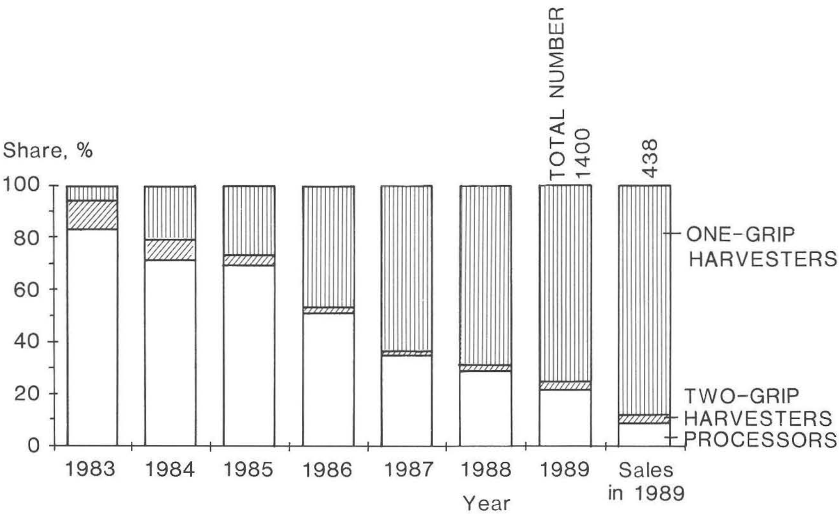

Figure 4: Cutting machine fleet in Finland in 1983-89 (excluding machines older than 6 years) and cutting machine sales in 1989 (Metsäkoneiden, 1989).

industries increasing, creating increasing pressure to replace chainsaw work with multi-function machines.

Since a majority of silvicultural operations is still performed by labour-intensive methods, it is important to maintain a significant share of motor-manual cutting to ensure the availability of a manual labour force for seasonal operations, such as planting and pre-commercial thinnings. In addition, private forest owners often consider motor-manual cutting to be silviculturally and ecologically the best harvesting method, especially in Finland. It is also always a safe cutting method for poorly-bearing peatlands.

2.3 Mechanised cutting

The one-grip harvester is the most common multi-function machine type. In Finland, for example, over 80% of the multi-function machines sold in 1989 (including the ones sold without a base carrier) were of this type (Metsäkoneiden, 1989) (Fig. 4). It has developed to an all-round machine, which can be used both in thinnings and clear cuttings, yet there are also more specialised models for early thinnings. One-grip harvesters, like all logging machines excluding small ones, work mostly from racks. The trees in the middle of the section between the racks have to be felled maunally if the machine cannot reach them. The reach of one-grip harvester cranes is usually about 10m.

At first one-grip harvesters were usually built on a new or used, shortened chassis of a mid-sized forwarder. Today, most of the units have a chassis especially designed for the purpose, which has improved their suitability for thinnings. The weight of the most common types varies from 9 to 15 tonnes and their price is between 1 to 1.5 million Finn marks (FIM) (1 FIM=0.16 Irish £). Annual output in thinnings is between 20,000 to 30,000m^3 and in clear cuttings up to 50,000m^3. Technical availability is up to 85%.

One reason for the rapidly increasing degree of mechanisation is the flexibility of the present one-grip harvesters. Conifer stands and the trees are quite easy from the mechanisation point of view: the initial density of man-made stands is approximately 2,000 trees per hectare, and stem form is generally good and they usually do not have thick difficult branches. The properties of broadleaved species, birch being the most important in this context, are less suitable for mechanised cutting, and especially one-grip harvesters often encounter difficulties in feeding and delimbing.

Two-grip harvesters are not as capable of working in thinnings where the damage to the remaining trees is to be minimised. Most of the present models are rather big and heavy and competitive only in clear cuttings with a large stem size. The weight of two-grip harvesters varies from 16 to 20 tonnes, and their price is almost 2 million FIM.

In Finland, less than 3% of the multi-function machines sold in 1989 were two-grip harvesters (Metsäkoneiden, 1989). In Sweden, where the proportion of clear-cutting is larger, 34% of cuttings made by forest industry companies in 1987 was done with the machine type in question (Freij and Torsterud, 1988). Their share is, however, diminishing, as can be seen in Fig. 3.

The role of processors in cutting is rapidly getting smaller (Figs. 3 and 4).

Light, farm tractor-mounted cutting units have also developed a lot during recent years. Orginally, farm tractor based logging machinery was simple and designed for the self-employed forest owners. The price of a modern farm tractor based logging machine is around 400,000 FIM. From the economic point of view, purchase of auxiliary equipment such as a boom-mounted one-grip harvester head is feasible only if it can be employed during 8 to 11 months of the year. This presupposes contractor type operation and puts new requirements on the farm tractor (Hakkila, 1989).

In professional cutting the ergonomic level of a farm tractor may be inadequate, though there are some improvements in the latest models. Among the private forest owners, farm tractor based machines have a reputation of being a smaller and lighter alternative to real forest machines, an alternative that is more gentle on the forest. This, however, may not always be the case since in forestry use, a farm tractor, initially meant to be used on a field, is closer to its limits of mobility than a forest machine.

In Denmark and Norway, farm tractor based logging machines are popular. In Finland, most of the processor-type units sold in 1989 were for farm tractors. The trend in new models is towards one-grip harvesters. The reach of the crane is usually limited to 5 to 7m, so a large share of the trees between the strlip roads may have to be felled manually. The productivity is very much dependent on conditions. According to Heikka (1988) the output of some farm tractor-mounted processors varied from 2.1 to 12.2m^3 per effective hour.

Light cutting machines were developed to solve the problems of first thinnings such as, the high cost of manual cutting, strict environmental requirements and the harvesting of light material from Finland's drained peatlands. At first, these machines were rubber-tracked and their weight was around 5 tonnes. Some of the later versions weigh up to 8 tonnes and some have steel tracks or wheels. At present, most of these machines are single-grip harvesters.

In small multi-function machines, the reach of the crane is limited to 6 to 7m, so light harvesters normally have to open an additional passage, a so-called ghost rack, in between the racks to reach all the trees. Thanks to

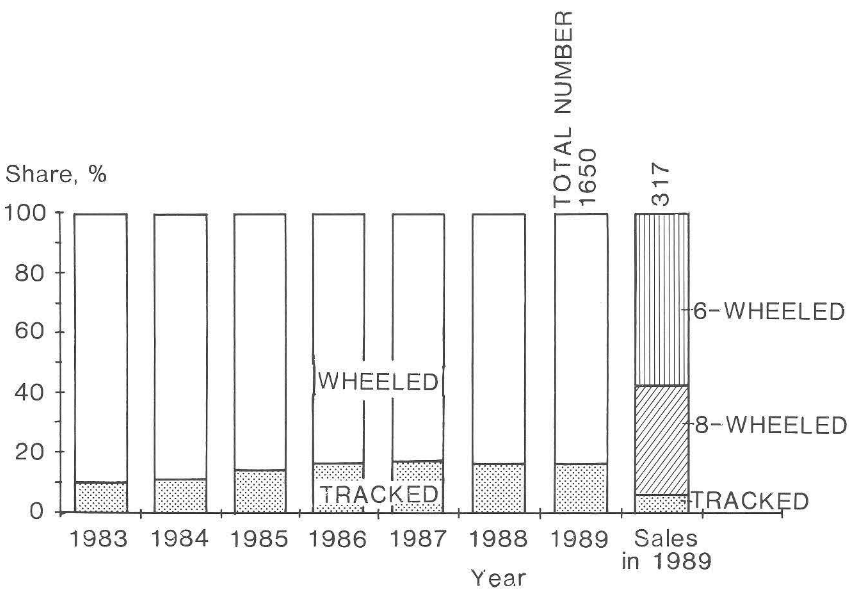

Figure 5: Forwarder fleet in Finland in 1983-89 (excl. machines older than 6 years) and forwarder sales in 1989 (Metsäkoneiden, 1989).

the small dimensions of the machines, the ghost rack can be narrow and winding, thus allowing removal of the lowest possible number of trees.

The price of light harvesters varies from 700,000 to 900,000 FIM. According to Sirén (1989), the smallest harvesters with rubber-tracked base carriers may produce 4 to 5m^3 timber per operating hour under difficult conditions of early thinnings with an average stem size of 0.04m^3. The optimum stem size was found to be between 0.05 and 0.15m^3. In 1989, this machine type accounted for about 9% of the cutting machine sales in Finland (Metsäkoneiden, 1989).

The combination of small size, low mass and rubber track running gear tends to limit the durability of a forest machine. However, when working as harvesters these small machines seem to have better chances to survive. Some organisatorial requirements are set, since these machines can compete with bigger ones only in early thinnings.

2.3 Off-road transportation

The dominating machine in off-road transportation is the wheeled forwarder. The development of forwarders began in the early 1960s in Sweden, and from the Nordic point of view their present level is quite satisfactory in terms of productivity, ergonomics and environmental aspects.

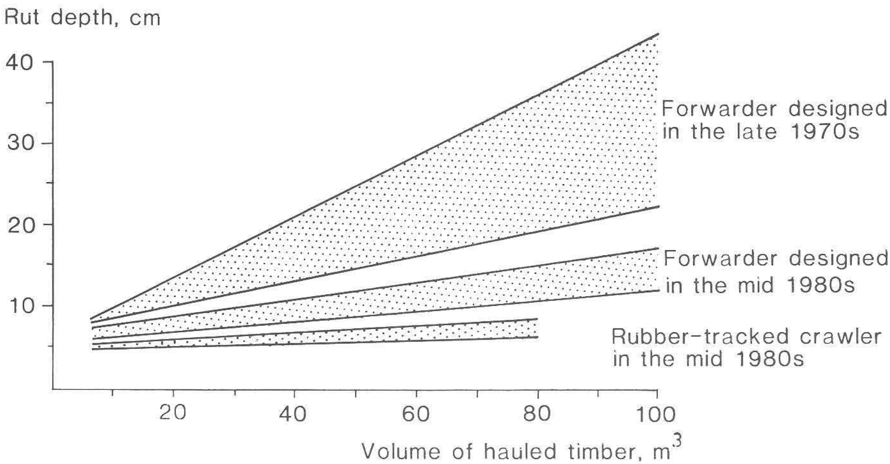

Figure 6: Rutting as a function of hauled timber volume and carrier type in an experiment on soft agricultural peat land (Sirén et. al., 1987).

In Finland, a typical forwarder purchased during the late 80s has six wheels, a net mass and load capacity of 10 to 12 tonnes and a crane reach of 10m. A forwarder of this size class is considered medium-sized. In Sweden, the variety is greater: there are more light and big units and also more eight-wheeled ones. Also in Finland the number of eight-wheeled forwarders is increasing mainly for their better flotation on poorly-bearing soils; about 40% of the forwarders sold in 1989 had eight wheels (Metsäkoneiden, 1989) (Fig. 5).

The weight of the models on the market varies from 8 to 22 tonnes, and prices accordingly vary from 750,000 to 1,500,000 FIM. Depending on the haul distance, terrain, site conditions, type of equipment and the skill of the driver the output in Finland varies generally from 8 to 15m^3 per operating hour, and with 2,000 annual operating hours the output of a medium-sized forwarder is between 15,000 and 20,000m^3 (Hakkila, 1989). In a Finnish follow-up study by Kahala and Kuitto (1986) the average productivity of a mid-sized forwarder was 10.3m^3 per effective machine hour, and the mechanical availability 93%.

On poorly-bearing soils and in snowy conditions the mobility of wheeled forwarders is improved by the use of steel tracks and chains. The state of the stand after mechanised logging is usually very acceptable. In various studies the percentage of damaged trees after cutting and forwarding has been found to be less than 5% and in many cases the size of the machinery did not affect the damage percentage, due to the differences in work methods. In the 1980s special attention was paid to reducing the damage that forwarders cause to the soil, yet a lot still remains to be done (Fig. 6). Some attempts have been made to equip a mid-sized wheeled forwarder with rubber tracks. So far the durability of the tracks has not been satisfactory, although at the moment the new Valmet system is still under investigation.

A farm tractor, when used for off-road haulage, is usually equipped with a bogie trailer. Loading is done with a simple cable-operated boom loader, with a hydraulic crane or, in case of small wood, even manually. A little under 30% of the total annual cut in Finland is delivered to the road side by self-employed forest owners working usually with chainsaw and farm tractor (Örn, 1990). In Denmark and Norway the farm tractor has an important role in off-road transportation.

The mobility and reliability of the best modern four wheel-drive farm tractors are also sufficient for contracting work when equipped with a powered trailer and an hydraulic crane. In permanent contracting the productivity is 6-7m^3 per effective hour for larger units, but considerably less, about 4-5m^3 per effective hour, for smaller ones (Mikkonen, 1984). In temporary operations of self-employed farmers, the productivity is lower. For example, for a unit with an unpowered trailer and a combination of winch and mechanical boom loader, the productivitiy is 2-5m^3 per effective hour over a haulage distance of 200m (Mäkelä, 1987).

Farm tractors are also frequently equipped with a skidding winch, the use of which allows wide spacing of racks. The productivity of skidding stems or logs over a distance of 200m is 1.5-3.0m³ per effective hour (Ryynänen, 1986; Mäkelä, 1987).

Light tracked forwarders were developed for early thinnings and poorly bearing sites. A common feature of these machines is a rubber track running gear, one model with steel tracks being an exception. These machines have been developed over the years and generally they have grown in size and mass. Their mobility on poorly bearing sites is good and the damage to the soil minimum (Fig. 6). So far, the durability of rubber tracks, especially on mineral soils, has been a problem. Preferably these machines should be used on peatlands. This may be difficult to arrange, since usually the landing sites are located on mineral soils, and thus maybe only a minor part of the haulage is performed on peatland.

The weight of the present models varies from 2 to 8 tonnes, and prices vary accordingly from 200,000 to 500,000 FIM. In the follow-up study by Eeronheimo and Heikka (1987) the productivity of a mid-sized unit in first thinning conditions with easy terrain over a haulage distance of 340m

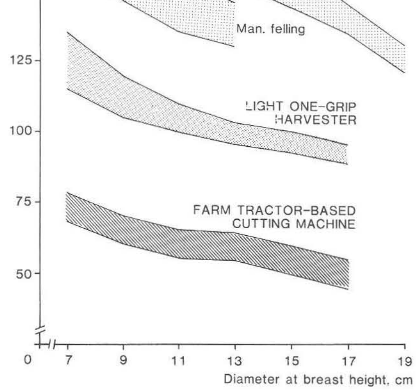

Figure 7: The productivity of different harvester types, pine (Mäkelä 1989a).

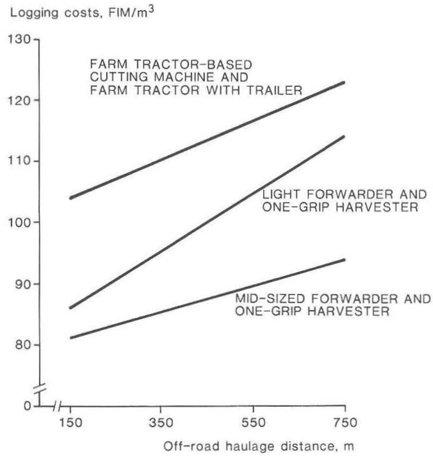

Figure 8: Logging costs of the studied machine combinations (Mäkelä 1989a) (1 FIM=0.16 Irish £).

Table 2: The relative productivity of the studied forwarders (Mäkelä 1989a).

	Relative productivity, %			
Haulage dist., m	Mid-sized forwarder (wheeled)	Light forwarder (tracked)	Light forwarder (wheeled)	Farm tractor
50	100	65-80	85-90	60
350	100	55-65	60-65	60
750	100	50-60	50	60

was 4.1m^3 per effective hour. In 1989, these machines had a 6% share of forwarder sales in Finland.

The tracked mini skidders, which do not carry the operator, were aimed for the use of the self-employed forest owner. In Sweden, they have had some commercial success, but in Finland, not more than 250 units have been sold to date, of which only 20 or 30 are used at least partly in logging. The average load size in first thinnings is about 0.5m^3 and productivity between 0.5 and 1.1m^3 per effective hour (Ryynänen, 1990).

3. Some Recent Studies of Mechanised Logging

3.1 Early thinning in pine and spruce stands

Mäkelä (1989a, 1989b) conducted a series of studies to determine the technical and economical feasibility of different harvesters and forwarders in first thinning pine and spruce stands.

In the pine stands, the machinery studied can be divided into three groups consisting of (1) mid-sized machines: five different wheeled, single-grip harvesters and two wheeled forwarders, (2) light machines: three tracked, single-grip harvesters (1 steel-tracked, 2 rubber-tracked), and three light forwarders (steel-tracked, rubber-tracked, wheeled) and (3) farm tractor-mounted processor with felling head or alternatively with trailer.

The average density of the stands was 1,780 stems per ha, the number of trees to be removed 580 per ha and the average size of thinnings 0.05m^3. Rack distance was 30m for group 1, 15m for group 2 and 25m for group 3. For groups 1 and 3 the trees outside the reach of the machine were felled manually. Main study results are presented in Figs. 7 and 8, and in Table 2.

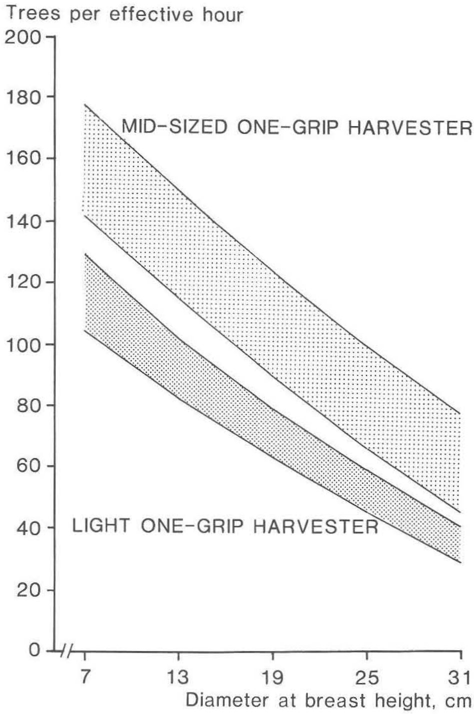

Figure 9: The productivity of different harvester types, spruce (Mäkelä 1989b).

In the spruce stands, the machine groups were: (1) mid-sized machines: four different wheeled single-grip harvesters and two wheeled forwarders and (2) light machines: three tracked harvesters (1 steel, 2 rubber) and two tracked forwarders (1 steel, 1 rubber).

The average density of the stands varied from 1,100 to 1,800 stems per ha, the number of trees to be removed from 400 to 900 per ha, and the average size of thinnings from 0.13 to 0.24m³. Rack spacing was 20m for group 1 and 30m for group 2. No trees were felled manually, since the light harvesters used additional racks. Main study results are presented in Figs. 9, 10 and 11.

The percentage of damaged trees was low for all machine combinations in both pine and spruce stands, 3.7% in the worst case.

Brunberg and Nilsson (1988) studied the FMG 0470 harvester, a wheeled machine weighing 4.6 tonnes and able to operate on ghost racks in early thinnings. Productivity was found to be strongly dependent on the difficulty of the terrain and properties of the stand. In the ecological sense the harvesting result was good, yet in the difficult terrain, the amount of damage to the remaining trees tended to increase. Only in early thinnings with easy

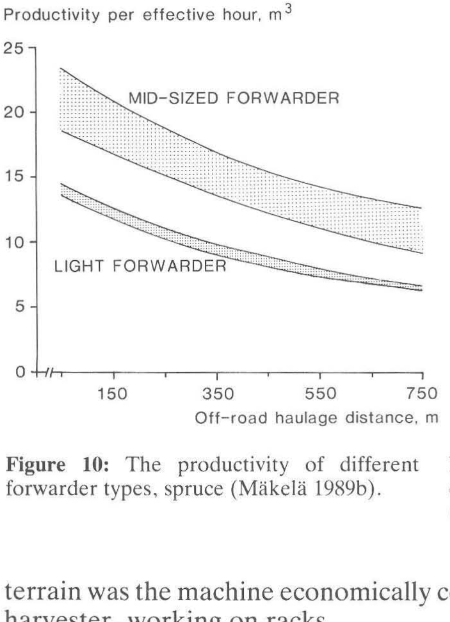

Figure 10: The productivity of different forwarder types, spruce (Mäkelä 1989b).

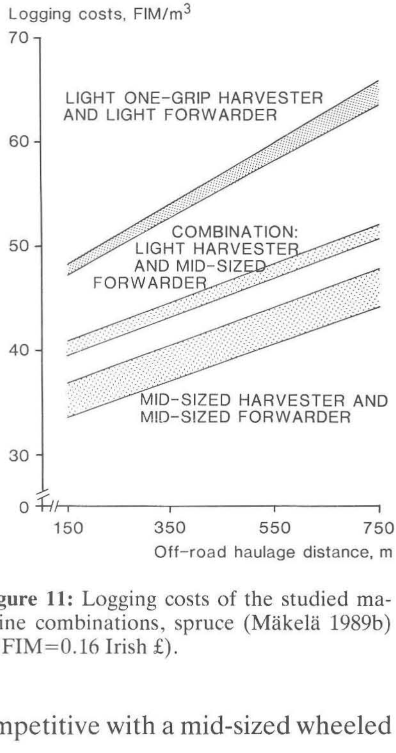

Figure 11: Logging costs of the studied machine combinations, spruce (Mäkelä 1989b) (1 FIM=0.16 Irish £).

terrain was the machine economically competitive with a mid-sized wheeled harvester, working on racks.

3.2 Multi-tree processing with cutting machines

Processing more than one tree at a time is an attractive possibility in early thinnings, where the tree size is small and a large share of the cycle time is spent on other work phases than delimbing and bucking, resulting in low productivity. To do multi-tree processing a harvester must be able to activate the feeding rollers and delimbing knives independently, so that a new tree can be grabbed and felled while the others are held between the rollers. If a processor is used for multi-tree processing, the trees are felled into piles beforehand.

As an example of the results of the various studies, the dependence of cycle time of a Valmet 892/955 harvester (Brunberg et. al., 1989) and the dependence of productivity of a Pika 45 processor (Lilleberg, 1987) on the number of trees processed at a time is presented in Figs. 12 and 13.

Generally, the trees to be processed at the same time should preferably be

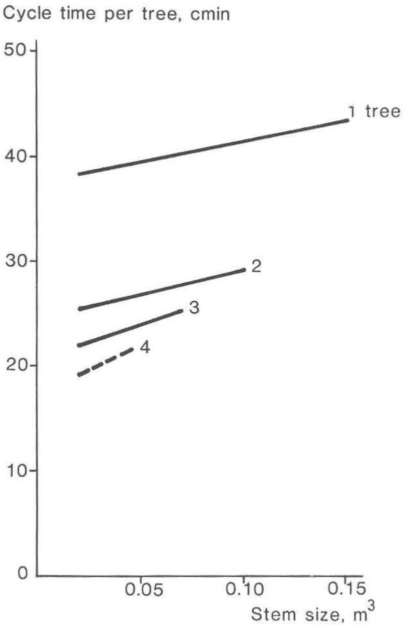

Figure 12: Cycle time per tree in multi-tree processing with Valmet 892/955 harvester (Brunberg, et. al. 1989).

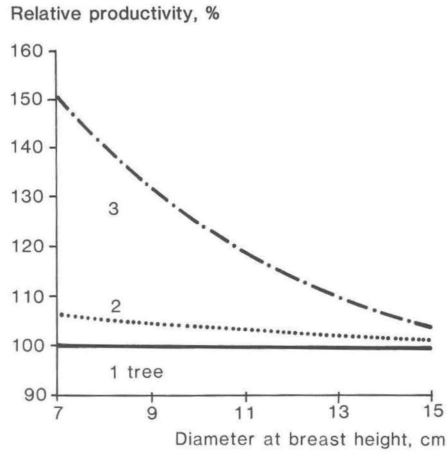

Figure 13: Productivity of Pika 45 processor in multi-tree processing (based on data of Lilleberg, 1987).

similar in terms of branchiness and size. The quality of delimbing is naturally lower than normally obtained, yet usually good enough.

Designing the feeding and delimbing devices especially for multi-tree processing will improve the results.

3.3 A combined harvester/forwarder

In the combined harvester/forwarder concept the same base machine is used for both harvesting and forwarding. The idea is to cut down machine transferring costs, when the individual stands to be harvested are small and the distances between the stands long. There are two variations of the theme. In the first, some machine elements, for example the grapple and the harvesting head, are interchangeable, and some are stripped off when not needed. The second alternative is to design the machine so that it can be used for both tasks without any modifications.

Lilleberg (1988) studied the Ponsse combine unit based on a standard forwarder chassis with interchangeable grapple/harvesting head and removable stakes. The productivity was 10-21% lower than the productivity of the standard single-grip harvester from the same manufacturer. This was due to the shorter reach of the crane and a limited working sector.

According to Andersson (1989) the productivity of the combine machine FMG 250 forwarder with IW-35 harvesting head, which is capable of doing both harvesting and forwarding without modifications, was 20-25% lower, than that of a conventional single-grip harvester. With a 15km distance between each stand, the cost of logging per m^3 was lower with the combine machine than with a single-grip harvester plus a forwarder, if volume removal was less than $125m^3$. With the distance of 5 and 25km, the breakeven point was respectively 100 and $150m^3$.

Valmet has recently introduced a combine machine, which can be equipped with a grapple saw or a harvesting head. The machine has a rotating cab and no modifications are needed when changing the type of work.

4. Future trends in harvesting

In the near future early thinnings with low productivity in mechanised harvesting and high costs in motor-manual harvesting will be the main question to be solved in the field of harvesting. The development of light machinery and multi-tree processing technology is therefore likely to take a remarkable step forward.

The present increasing trend in the degree of mechanisation will continue. Future harvesters will be more reliable, better suited for their task, easier to operate and more automated. Modern electronics and data based systems offer interesting possibilities. Concrete examples, which may be reality in the near future, are the single-lever to control the movement of the boom tip along straight lines in the horizontal and vertical planes (Löfgren, 1989), and go-home functions of the boom. The timber scaling devices of cutting machines are undergoing a rapid development and in Finland the measuring of timber will probably soon be largely based on them.

Environmental aspects also have a strong influence in machine development. The design of present-day forwarders are still based on very conservative concepts, although in the average site conditions in the Nordic countries they are environmentally very acceptable.

Bruun recently introduced a forwarder with steerable wheels on the front axle of the front bogie and on the rear axle of the rear bogie. The design reduces turning radius, and soil shear and motion resistance in curves. It is quite possible, that the future forwarders will have individual slip and torque control and active suspension of each wheel, and in addition to articulated frame-steering, the wheels will be steered in relation to the frames.

Unconventional vehicle running gear designs, such as the pneumatic mattress track (PMT) (Burmeister, 1989), would facilitate almost damage-free harvesting, as far as damage caused by the running gear is concerned. The PMT vehicle runs on tracks consisting of air-filled fabric bags joined one after another. The bags are pressurised only under the vehicle, which enables the track to "swallow" obstacles. Also, the application of light-weight structures could give interesting possibilities in developing forest machinery.

As a whole, the technology of harvesting certainly is far from the final stage of development, if anything like that even exists. The forest is, however, a harsh environment, so the machinery, besides being technically advanced, must, as well, be robust. This still today, tends to clip the wings of the wildest ideas.

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