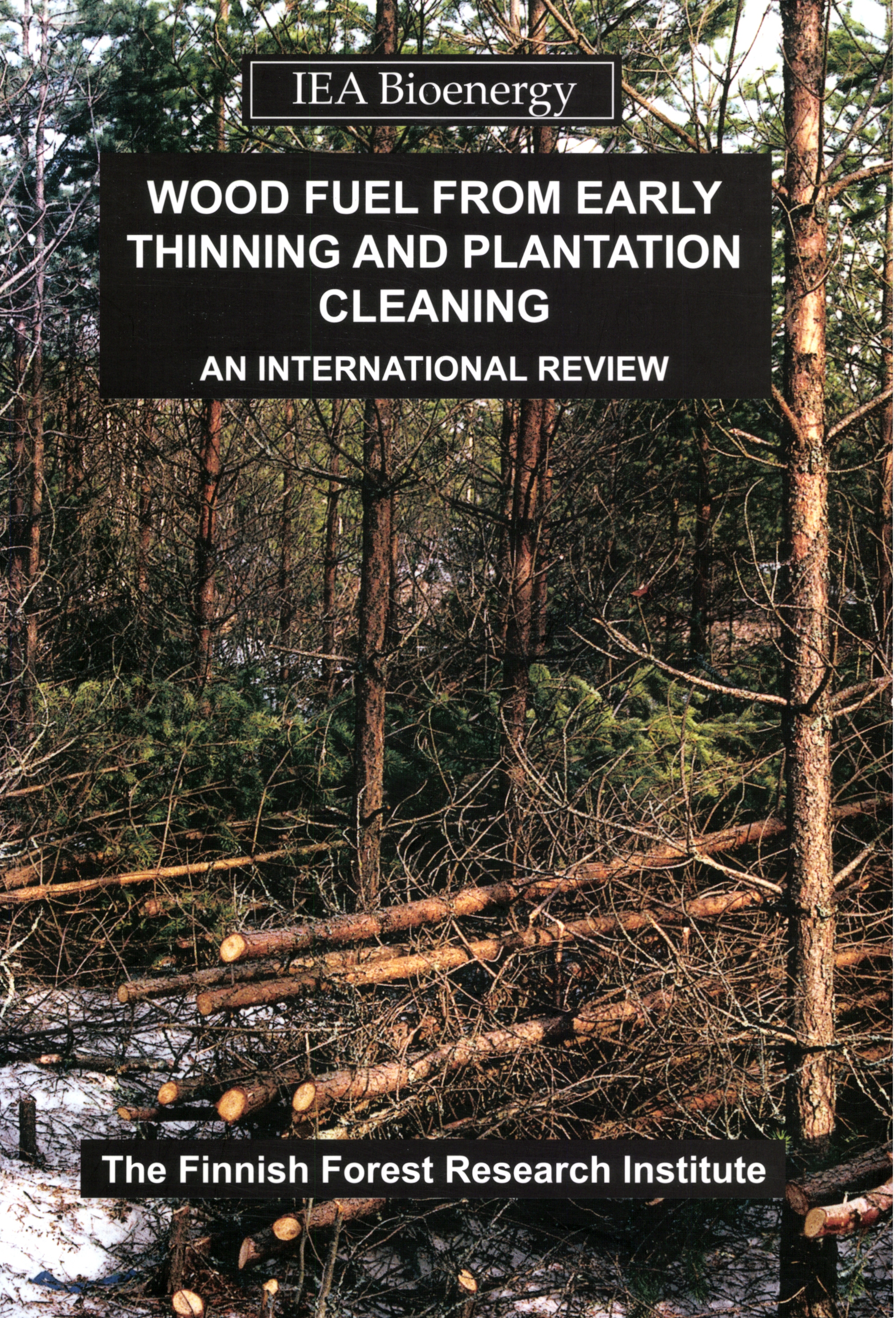
IEA Bioenergy

WOOD FUEL FROM EARLY THINNING AND PLANTATION CLEANING

AN INTERNATIONAL REVIEW



The Finnish Forest Research Institute

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IEA Bioenergy

WOOD FUEL FROM EARLY THINNING AND PLANTATION CLEANING

AN INTERNATIONAL REVIEW

Edited by
David Puttock and Jim Richardson

Activities 1.1 (Forest Management) and
1.2 (Harvesting)/Task XII/IEA Bioenergy

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Activities 1.1 (Forest Management) and 1.2 (Harvesting) of Task XII/IEA Bioenergy Agreement carried out an international review of wood fuel from plantation cleaning and early thinning. The participating countries were Canada, Denmark, Finland, the Netherlands, New Zealand, Sweden and the United Kingdom. The individual country reviews and an international summary are presented in this paper. Each report gives country-related background information on forestry and wood fuel utilization, energy potential from plantation cleaning and early thinning, environmental considerations from the viewpoint of wood fuel recovery, silvicultural systems and methods, cost of wood fuel, and knowledge gaps and problems.

Key words: IEA Bioenergy, wood fuel, early thinning, plantation cleaning, energy potential, environment, fuel cost

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Table of contents

PREFACE

Conventional forestry offers numerous opportunities for increasing the availability of woody biomass for renewable fuel. Much of this material can be realized through modification of present silvicultural and harvesting systems.

The efficiency and effectiveness of biomass recovery from conventional forest stands depend largely on the methods and logistics of forest management and harvesting. Efficiency in its broad sense means not only low costs and high productivity of work, but also enhancement of the growth of industrial wood, and sustainable and environmentally friendly operations. Although the goal is integrated production of raw material and energy, it is self-evident that high-quality industrial wood remains the main product whereas renewable energy is a by-product of conventional forestry.

Treatments such as plantation cleaning and early thinning are of utmost importance for further development of a forest stand. Unfortunately, their high cost results only too often in serious delay or total neglect of tending. A possibility to use low-quality biomass from young stands for the production of energy offers significant silvicultural benefits. Consequently, this concept is given a high priority in the research cooperation program within the frame work of the IEA Bioenergy Agreement.

Activities 1.1 (Forest Management) and 1.2 (Harvesting) of Task XII/IEA Bioenergy carried out an international review of Wood Fuel from Early Thinning and Plantation Cleaning in 1997. The objectives of the study were:

— To investigate the environmental and economic availability of biomass from plantation cleaning and early thinning
— To identify and analyze felling, extraction and comminution systems for producing wood fuels from these treatments
— To identify knowledge gaps, problems and potential solutions for economical and environmentally compatible wood fuel production

The project was undertaken by Dr. David Puttock, Silv-Econ Ltd, Ontario, Canada, assisted by experts from seven IEA countries: Canada, Denmark, Finland, the Netherlands, New Zealand, Sweden and the United Kingdom. The country reviews, preceded by an international summary, are presented here. We express our warmest thanks to Dr. David Puttock and the authors of the country reports for their contribution. We hope that this exchange of information between the participating countries will help to promote the utilization of unmerchantable biomass from young forest stands as a source of clean and renewable energy.

December 1997

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Wood fuel from early thinning and plantation cleaning
Summary of an international review

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Abstract

This paper summarizes the results of an international review of wood fuel from early thinning and plantation cleaning. The economic and biological benefits from early thinning have been well documented. However, removing forest biomass during the early stages of stand development from sites which are low in one or more nutrients may contribute to a loss of nutrients and organic matter. Depending on the pre-thinning density and the thinning intensity, the potential yield of wood fuel from early thinning may be as much as 70 dry tonnes per ha. Thus, wood fuel from the thinnings could be an important source of revenue to forest owners and would contribute to domestic energy requirements. Motor-manual felling predominates in early thinning, mainly due to the lack of appropriate technology for thinning small trees. However, the productivity of motor-manual felling is greatly affected by the initial stand density and declines dramatically at densities greater than 10 000 stems per ha. Under these conditions, purpose-built wood fuel harvesters with small-tree harvesting capability offer the greatest potential for increasing felling productivity and reducing the cost of wood fuel. The cost of wood fuel from early thinnings varies widely between countries from $US 25.00—87.50 per dry tonne depending on stand conditions, harvesting system, transport distance, domestic tax rates, and stumpage prices. At the low end of this range, wood fuel chips from early thinning are competitive with wood fuel produced from mill waste, the residues from clearfell operations, or from later thinning.

1 Introduction

In 1997, the International Energy Agency/ Bioenergy Agreement Task XII Conventional Forestry, Activity 1.1 Forest Management and Activity 1.2 Harvesting undertook a review of wood fuel from early thinning and plantation cleaning. The objectives of the review were to assess the status, energy potential, harvesting systems, and cost of wood fuel from these and other sources of wood fuel. Seven countries, Canada, Denmark, Finland, the Netherlands, New Zealand, Sweden, and the United Kingdom, participated in the review.

For purposes of this review, *early thinning is defined as a spacing operation to reduce stand densities in immature naturally-regenerated stands or plantations. Plantation cleaning is normally undertaken to remove competing hardwood natural regeneration from softwood plantations.* In some countries, there is no distinction between these two silvicultural activities and they are simply referred to as ‘stand cleaning’.

2 Energy potential

Early thinning and plantation cleaning are well-established practices in the countries which participated in this review. The area subject to stand cleaning has increased steadily from the 1950's through the 1960's but rose sharply during the late 1970's and 1980's in response to increased forest management activity, increased forest planting, and more recently, the desire to reduce or eliminate the use of chemical herbicides for controlling undesirable woody vegetation in plantations. The trend in Sweden (Fig. 1) is typical of the rate of increase in early thinning experienced elsewhere. The area which is cleaned varies from country to country but ranges from 2 500 to 200 000 ha per year. Most of this activity is in commercially planted forests except in Canada where early thinning is predominantly carried out in naturally regenerated softwood stands.

Thinning typically commences when the stand is 2—7 m in height and at pre-thinning densities of 4 000 stems per ha in plantations and 20 000 to 40 000 or more stems per ha in naturally regenerated stands. This often occurs when the stand is between 8 to 20 years of age. Post-thinning densities average 2 000 stems per ha in plantations and significantly greater in naturally regenerated stands. The yield of wood fuel from stand cleaning is expected to vary according to the initial stand density and thinning intensity. Potential yields vary from a low of 1 tonne dry weight per ha to as much as 70 tonnes dry weight per ha. For most countries, wood fuel from early thinning and plantation cleaning would provide less than 1 % of total energy requirements.

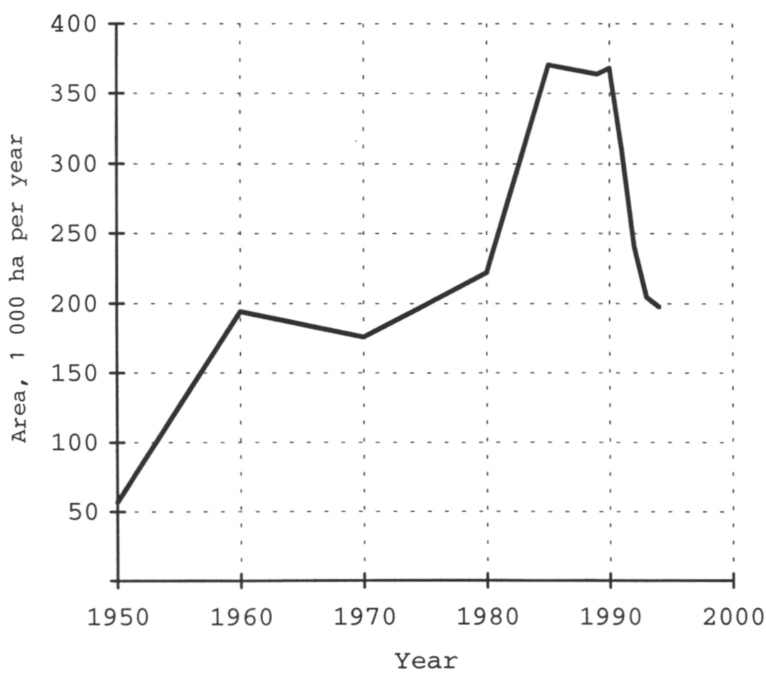

Figure 1. Area of precommercial thinning and stand cleaning in Sweden: 1950—1995.

3 Benefits and environmental considerations

Early thinning and plantation cleaning are important activities in sustainable forest management. Increased growth rates of residual trees, improved timber quality, and shorter rotation lengths, are some of the benefits from early thinning. Early thinning also facilitates the mechanization of subsequent commercial harvesting operations during the later stages of stand development. Thinning also provides an opportunity to sanitize the stand, improve the ability of the stand to resist windthrow and snow, enhance opportunities for non-timber forest uses such as outdoor recreation, and enhanced habitat for moose and deer and some other wildlife species.

Young trees are seldom of sufficient diameter to be used for pulpwood or other industrial forest products. Thus the potential of producing wood fuel from early thinning is of particular interest to forest owners. However, the lack of markets for wood fuel in most countries has limited its production from early thinning.

Harvesting small trees is also expensive and, in many countries, first thinnings are being delayed until the trees are of sufficient size to make harvesting for pulpwood economical. Delaying the initial thinning promotes self-pruning thereby improving the quality of sawlogs. However, delaying the first thinning may make the residual stand more susceptible to damage from wind and snow.

Many forest sites are marginal or low in one or more nutrients and removing forest biomass from those sites for fuel may contribute to a loss of nutrients and organic matter from the ecosystem, especially if branches and needles are also harvested. This could result in small reductions in growth. Application of chemical fertilizers may compensate for the nutrient losses however will not replace the loss of organic material.

A reasonable level of biomass removal has only moderate effects on smaller organisms, and is probably reversible. However some biotopes require special attention. These include forest edges, shorelines, islands, and remnant habitats on forest land. Although some species of wildlife benefit from thinning, others such as snowshoe hare and some species of songbirds may be adversely affected by the increased spacing.

Soil compaction due to the loss of the residual slash mat on strip roads and the loss of productive forest to strip roads, and damage to the roots and stem of residual trees are also of concern. On the other hand, recovery of biomass from plantation cleaning and thinnings reduces the risk of forest fire.

4 Silvicultural systems and cost of wood fuel

There is very little production of wood fuel from early thinning and plantation cleaning in the countries involved in this study. However, all countries have conducted field trials of wood fuel harvesting systems in early thinning. There is general consensus that whole tree harvesting and chipping would be the most cost effective wood fuel harvesting system for early thinning. If the trees were of sufficient size for pulpwood, then an integrated harvesting system might be more appropriate.

Motor-manual felling predominates in early thinning, mainly due to the lack of appropriate technology for thinning very small trees. When young stands are thinned or cleaned and the biomass is recovered for fuel, 4 m wide strip roads are opened at 20—25 m intervals to facilitate extraction of the biomass by forwarder to roadside or landings. Chipping usually takes place at roadside or at landings using mobile chippers.

The productivity of motor-manual felling is greatly affected by the initial stand density and declines dramatically at densities greater than 10 000 stems per ha. Consequently, the cost of producing wood fuel from early thinning is often prohibitive. Mechanized treatments offer the most practical alternative to motor-manual thinning in high density stands. Purpose-built wood fuel harvesters with small-tree harvesting capability offer the greatest potential for increasing felling productivity and reducing the cost of wood fuel. Criteria for economical wood fuel production from early thinning include: multi-tree handling capabilities, capability of reaching between the strip roads to do selective thinning, felling as a distinct activity in the harvesting system, and low ground pressure for machines in the system.

Biomass from early thinnings might economically be harvested using single-grip harvesters, but for efficient operation it may be necessary to delay the thinnings in order to increase the size of the trees. Although delaying early thinning would promote self-pruning, it would also increase the risk of windthrow and damage from snow and ice to the residual crop with corresponding loss of value .

The cost of wood fuel from early thinnings varies widely between countries from $US 25.00—87.50 per dry tonne depending on harvesting system, transport distance, domestic tax rates, and stumpage prices. At the low end of this range, wood fuel chips from early thinning are competitive with wood fuel produced from mill waste, the residues from clearfell operations, or from later thinning. However, for most countries, the cost of wood fuel from early thinning exceeds target prices by 20—50 % or even more.

5 Conclusions

The benefits from early thinning on stand development and other forest uses have been well documented. However, the long-term effects of biomass removal on the nutrient balance, site fertility, and organic matter require further investigation. Certain ecosystems such as shorelines, islands, and remnant habitats also require special consideration.

The results from this study suggest that wood fuel from early thinning and plantation cleaning can be recovered economically using current mechanized harvesting systems. However, in many countries, early thinning is the most expensive source of wood fuel. Work is underway to develop more economical silvicultural and harvesting systems for producing wood fuel from early thinning. In certain countries, wood fuel production is supported by public policy and programs. However, in most countries public support for wood fuel as an alternative to fossil fuels and support policies are necessary to establishing markets and an economical supply of wood fuel from early thinning and other sources of supply.

Review of wood fuel from precommercial thinning and plantation cleaning in Canada

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Abstract

Precommercial thinning and plantation cleaning offer opportunities for increasing the availability of wood fuel in Canada. In 1992, approximately 130 000 ha were treated with precommercial thinning or stand cleaning. Manual methods predominate in these silvicultural activities; however at stand densities greater than 10 000—15 000 stems/ha, mechanized systems are more economical. Recovering this biomass for wood fuel would require changes to silvicultural systems and harvesting technology.

1 Introduction and background

Precommercial thinning (PCT) and plantation cleaning are important activities in the sustainable management of Canadian forests. For purposes of this review, precommercial thinning (PCT) is defined as a spacing operation to reduce stem densities in immature stands approximately 1—6 m in height and less than 10 cm in diameter. PCT is normally carried out in naturally regenerated softwood stands 10-20 years old, however stands as old as 40 years have been subject to PCT. Plantation cleaning is normally undertaken to remove competing hardwood natural regeneration from softwood plantations, usually less than 1 m in height and 2—5 years old.

Although thinning has been carried out in Canada for more than 65 years (Schenstrom 1931), it is only recently that PCT in juvenile stands (6—20 years of age) has become a well-established practice. The area of PCT has increased steadily to approximately 117 000 ha annually (Fig. 1) (Canadian Council of Forest Ministers (CCFM) 1996). PCT in Canada is most commonly used in the Atlantic Provinces and its use decreases towards the west. This may be related to the predominance of overdense balsam fir regeneration in the Acadian and Boreal forest regions of eastern Canada (Farrar 1995) which benefits quite dramatically from PCT.

Environmental concerns have also prompted forest managers to consider non-chemical methods of controlling undesirable woody vegetation in softwood plantations. Motor-manual and mechanical cleaning to remove competing deciduous vegetation in conifer plantations are gaining acceptance as alternatives to aerial herbicide spraying. In 1995, approximately 31 000 ha were cleaned using motor-manual or mechanical methods (Fig. 1).

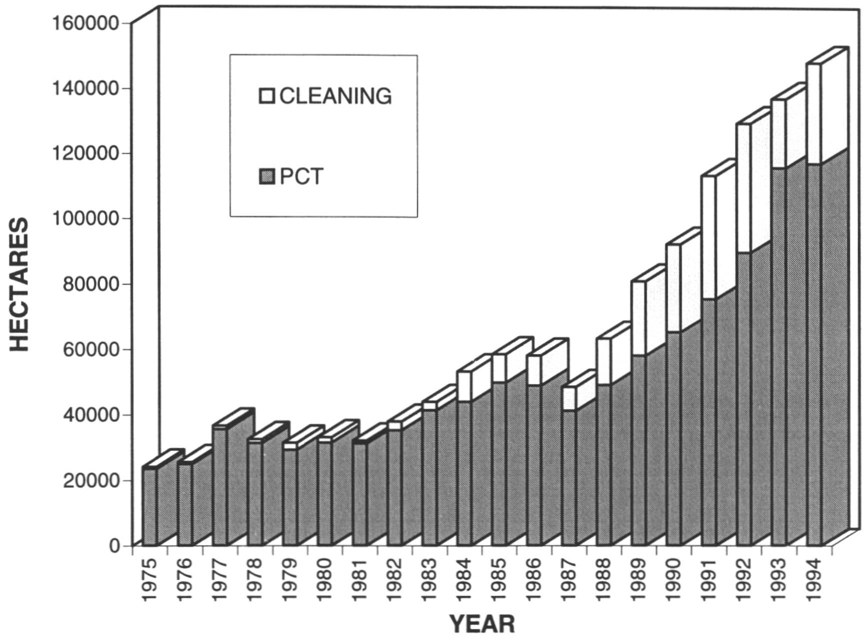

Figure 1. Precommercial thinning and cleaning in Canada.

During the 1970's, Canadian timber production increased significantly in response to world demand for forest products. Unfortunately, regeneration efforts did not keep pace, resulting in substantial areas of understocked sites. After 1980, provincial planting and seeding programs were increased to address these problems. By 1992, planting programs had largely eliminated the backlog of understocked sites. Several provinces began scaling back their planting programs in the early 1990's and established programs and regulations to encourage natural regeneration on approximately two-thirds of harvested areas with the remaining third to be restocked by planting, seeding, or scarification (CCFM 1996). Efforts to achieve natural regeneration on two-thirds of harvested areas continue. However, in 1994 approximately 487 800 ha were regenerated through planting or direct seeding, the equivalent of 51 % of the area harvested during the previous year.

Of the 236.7 million ha of productive forest land in Canada, approximately 5.6 million ha are in the 1—20 year age class (Gray 1996). Canada's forest inventory does not identify areas which may require tending. However, approximately 50 % of the regenerated area in this age class is fully stocked (Gray 1996). Assuming that this area would benefit from tending, some 140 000 ha might be subject to PCT or stand cleaning each year. This is the equivalent of approximately 14 % of the area harvested annually and is comparable to present levels of PCT and stand cleaning.

2 Energy potential from PCT and plantation cleaning

The amount of potential biomass from PCT varies depending on the species, origin of the stand, density, age, height of dominant trees and basal area (Bella & De Franceschi 1980). Pre-treatment densities of 10 000—50 000 stems/ha at 10—15 years of age are common (Hosick 1991; Bella & De Franceschi 1980) and in some cases, densities as high as 214 000 stems/ha have been reported (Hedin 1988; Smith 1987; Ryans 1995). Tree diameters range from 2—10 cm and typical tree height is 1.7—4.6 m (Brown 1992; Nova Scotia... 1992). Target post-treatment densities vary from 1 700 — 5 000 stems/ha (Hosick 1991; van Raalte 1991). Thus, some 10—60 odt/ha of biomass might conservatively be available for recovery following PCT (Singh 1982; Bella & De Franceschi 1980; MacLean & Wein 1976).

Information on the potential biomass from juvenile stands 2—5 years old is limited. Bella & De Franceschi (1980) have estimated dry weights of 5—13.4 odt/ha in naturally regenerated aspen stands up to 5 years old in Alberta and Saskatchewan where stand density varies from 35 000—389 000 stems/ha and averages 134 600 stems/ha. Aspen stands experience very high mortality in the first 5 years resulting in a significant reduction in stand density (Bella & De Franceschi 1972). Stand densities from 21 000 — 40 000 in naturally regenerated aspen stands 6—10 years are typical. The dramatic decrease in stand density is often accompanied by an increase in biomass with dry weights ranging from 4.2—26.9 odt/ha (Bella & De Franceschi 1980).

In most cases, the biomass which is felled during PCT and cleaning is left on site because of inherently high handling costs associated with small timber and the low recovery value of such wood for pulp furnish (Brenoe & Kofman 1990). Attempts have been made in Atlantic Canada to collect this biomass but costs have proved to be much greater than its value as an energy source (van Raalte 1991). Recovering the biomass would, in many cases, require changes in current silvicultural practices and tending and thinning systems, and would have implications for reforestation, growth and yield, nutrient levels, and environmental quality (Sabourin et al. 1992; Richardson 1991; Mård & Tham 1991; Hakkila 1989). Felling, extraction, and comminution systems would also require modification (Verkasalo 1994). A variety of motor-manual and mechanized systems have been evaluated for wood fuel recovery and new systems are continuously being developed (Puttock 1989; Watson et al. 1986).

3 Environmental considerations

The biological benefits from PCT have long been recognized (Oliver & Larson 1990). Thinning has been shown to increase the growth rates of residual trees (Brix 1981; Ginn et al. 1991; Lavigne 1988). However, the magnitude of increase is highly dependent on initial stand structure, intensity and frequency of thinning, thinning method (McCreary & Perry 1983), and soil drainage class (Briggs & Lemin 1994). Seasonal photosynthesis (Donner & Running 1986), soil moisture, and leaf hydration (Sucoff & Hong 1974) are higher following thinning. Although the specific physiological processes responsible for increased growth are not well known, the benefits appear to persist into subsequent growing seasons (Wang et al. 1995).

Enhanced habitat for some wildlife species is another benefit from early thinning. By opening up dense juvenile stands, thinning increases opportunities for movement of moose and deer, and it increases light penetration for the production of deciduous browse species. There also appears to be an increase in the availability of food for black bear (Racey & Pletch 1990). Although, species such as snowshoe hare, which depend upon dense juvenile conifer stands for winter cover may be negatively affected by increased spacing (Waterhouse et al. 1988), the negative impact on most wildlife is minimal unless stand density is reduced to less than 50 % crown cover (Telfer 1991).

PCT also provides an opportunity to sanitize the stand. However certain pathogens such as Annosus root rot (*Heterobasidion annosum*) can cause considerable damage in thinned stands (Gross 1991). Treatment of cut surfaces with borax or sodium nitrate is practiced after PCT in red pine in southern Ontario (Myren & Punter 1972). However, on most PCT operations, cut surfaces are not treated. Opening up stands by spacing and thinning also has the potential to reduce stand susceptibility to spruce budworm (*Choristoneura fumiferana*) defoliation (Crook et al. 1979). However, thinning may contribute to increased incidence of attack from some other insects (Bella 1985; Alfaro & Omule 1990).

The most problematic aspect of the removal of biomass for wood fuel from PCT and plantation cleaning is the risk of excessive losses of nutrients and the effect this has on future stand growth (Van Hook et al. 1982; Hakkila 1989). The risks are exacerbated with PCT and plantation cleaning because nutrients are concentrated in the tissues of plants of smaller diameters (Van Hook et al. 1982) and because nutrient demand is usually at its greatest soon after the first thinning (Mälkönen 1977 *in* Hakkila 1989). Another area of concern is damage to crop trees (New Brunswick... 1992).

4 Silvicultural systems and methods

Chainsaws or brushsaws predominate in PCT in Canada. Generally equal productivity seems possible with either chainsaws or brushsaws, and the choice seems to depend on operator preference and experience (De Franceschi & Bell 1990; Smith 1987). In stands with crop trees 1.5—6 m in height, worker productivity increases dramatically as stand density decreases (Fig. 2) (Nova Scotia... 1992).

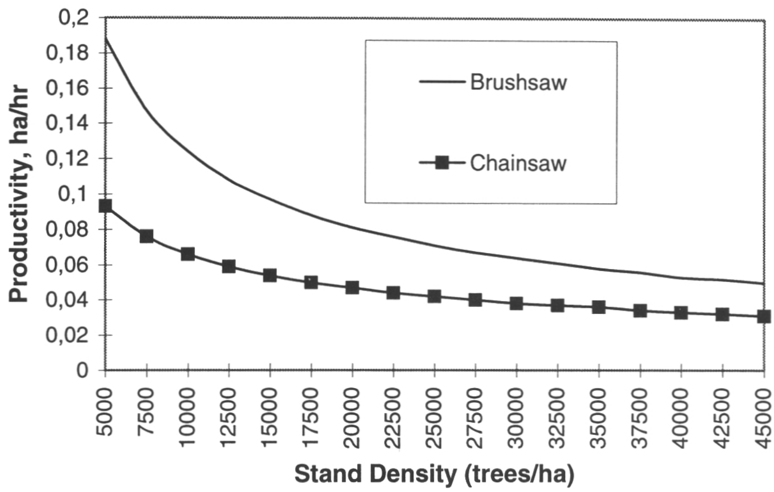

Figure 2. Comparison of PCT Productivities Between Brushsaws and Chainsaws.

In stands with crop tree height 6—9 m, productivity is significantly reduced but is not strongly affected by higher density. The productivity of motor-manual cleaning operations is similarly affected by stand density. Results from plantation cleaning trials in New Brunswick suggest that the production rate is approximately 3—6 % higher for plantation cleaning than for PCT using brushsaws in stands with comparable density (New Brunswick... 1992). On most PCT and plantation cleaning operations, workers are paid according the area treated and piecework rates are density-dependent (Brown 1992).

Motor-manual felling in PCT is expensive, costing on average CAD 700/ha (Nova Scotia... 1994) and double that amount when bucking and manual piling are included. Mechanical treatments offer the most practical alternative to motor-manual PCT in high density stands because machinery is less affected by increasing stand density. Although interest in mechanized PCT began in the late 1940's in Canada, it was not until the mid-1960's that the first mechanized operational-scale PCT projects were undertaken (Bella 1966). Mechanized PCT generally involves mowing strips in dense young stands using a variety of powered cutting heads. This approach leads to two concerns. The leave strips still require motor-manual thinning to release crop trees and there is always damage to crop trees on the edge of the mechanically cleared strips. In addition, most of the thinnings are macerated by the cutting action making recovery for wood fuel impossible (Ryans 1988; Ryans & Cormier 1994; Ryans 1995). PCT machines must be capable of working in stands with densities greater than 20 000 stems/ha and trees 1.5—6 m in height. Units must be capable of manoeuvering around up to 200 trees/ha larger than 15 cm in diameter (Smith 1987). At present, little consideration is given to developing mechanized PCT systems capable of felling and recovering early thinnings for wood fuel. However, the development of small single-grip harvesters offers new opportunities for recovering wood fuel and conventional products from mechanized PCT (Araki 1994).

Equipment designed specifically for plantation cleaning was developed in the 1980's in Sweden, where mechanized systems are currently in widespread use (Hellstrom 1992). These systems have been tested across Canada since 1990 (St-Amour & Ryans 1992; Hunt 1993; Mitchell & St-Amour 1995). There are now two Silvana Selective/Ford Versatile systems working in Atlantic Canada. Key features of these and other plantation cleaning equipment include precise control of the boom offering selective cleaning capability and carriers with high ground clearance.

One of the most problematic aspects of biomass harvesting is wood fuel storage. Long term storage of comminuted biomass either at the wood burning site or at roadside can amount to significant dry matter losses and reductions in net energy content (Thörnqvist & Jirjis 1990). Leaving the fuelwood in the forest before it is forwarded and processed significantly improves the drying of the biomass especially during the summer, and the leaves and needles, the nutrient-rich fraction of the biomass, are left in the forest (Jirjis 1996). This appears to be the most economical storage alternative for wood fuel from PCT because no additional handling of the biomass would be required. However, it also exposes the wood burning facility to potential delivery problems (Folkema 1989).

5 System performance and cost of wood fuel

The results from one Nova Scotia study provide some useful comparisons of motor-manual PCT and merchantable thinning systems for producing both pulpwood and wood fuel biomass (Annex 1) (Nova Scotia... 1988). Pulpwood and fuelwood were manually piled beside extraction trails cut 20 m apart. A small forwarder was used to extract both products to roadside landings where the fuelwood was chipped with a trailer-mounted disc chipper. The diameter of the fuelwood was suitable for the chipper, however the short length (2—5 m) made continuous feeding difficult. Total cost of wood fuel chips including transportation was estimated at CAD 62.31/gt and CAD 57.56/gt from the PCT and merchantable thinning respectively (Annex 1). Assuming target prices of CAD 23—28/gt delivered (Folkema 1989), the results indicate that harvesting unmerchantable biomass from thinning operations is impractical with the harvesting system used. A possible alternative would be an integrated operation involving full tree extraction with product separation at roadside. This would significantly reduce extraction costs.

A modified PCT system, combining mechanical row or strip thinning with selective motor-manual release, is considered the most effective approach for achieving desired biological and economic objectives (Smith 1987; Hedin 1988). To meet the spacing prescriptions for much of the boreal forest, the width of the cut strip should ideally be 1.8—2.4 m. However, most off-the-shelf brush cutters were designed for applications where a narrow width of cut is a detriment to productivity. Other constraints include potential damage to residual crop trees, incomplete mortality within cut strips, and difficult site conditions (Ryans & Cormier 1994). Modified PCT systems have been used in Nova Scotia since 1993. Row-thinning (mowing) productivity ranges from 0.33—0.75 ha/hr. The productivity of motor-manual thinning with brushsaws in the leave strips is 0.11—0.33 ha/hr (Nova Scotia... 1994) and is consistent with the productivity achieved during other field trials at comparable stand densities.

There are no examples of the use of single-grip harvesters in PCT. A Valmet 901 single-grip harvester fitted with a Valmet 955 cutting head was evaluated for merchantable thinning in Nova Scotia in 1989. The method of operation was similar to the modified PCT. Thinning productivity with the Valmet system was inversely related to stand index, i.e. trees per m^3. Average productivity for combined trail cutting and thinning operations was 3.3 m^3/PMH (approximately 2.7 gt/hr). Production rates for forwarding were also influenced by stand conditions and averaged 5.3 m^3/hr (approximately 4.3 gt/hr) (Nova Scotia... 1991). The results suggest that small harvesters could be a practical alternative to motor-manual and conventional row thinning systems and would facilitate wood fuel recovery from PCT (Folkema 1989).

In Atlantic Canada the price of whole tree chips produced by large scale integrated harvesting systems is within the CAD 23—28/gt target price (Folkema 1989; Puttock 1995; Gingras & Favreau 1996). Wood fuel from logging residues can also be produced within the same price range (Desrochers et al. 1993). A full tree harvesting system such as that described by Gingras & Favreau (1996) consisting of feller bunchers, grapple skidders, a mobile chipper, and 14.8 m chip vans might be economical for producing wood fuel from PCT. For example, the estimated cost of producing wood fuel chips with this system using a modified PCT approach is CAD 24.88—27.02/gt assuming that (i) feller buncher productivity in PCT would be 40 % of the production rate achieved during final harvests, and (ii) production rates for the other machines in the system would be comparable for PCT and final harvest.

Perhaps the ideal system for harvesting biomass for energy from modified PCT would be to combine strip cutting and chipping in the same machine. Forwarding the energy chips could also be integrated or treated as a distinct operation. The leave strips would be selectively thinned by a motor-manual system and no attempt would be made to recover biomass from that part of the operation. This would ensure that reasonable amounts of biomass were left on site for nutritional purposes and would simplify the extraction of wood fuel. Another advantage is that removing biomass from the cut strips would improve access for the subsequent motor-manual thinning stage.

In mechanical plantation cleaning with the Silvana Selective/Ford Versatile system, the normal mode of operation consists of straddling the centre row of trees and cleaning the plantation in a semicircle in front and to the sides of the machine in one pass - cleaning 9.5—11 m wide swath. On most operations, the felled trees remain on site in whole tree form and could potentially be recovered for wood fuel. Productivity ranges from 0.09—0.35 ha/hr (St-Amour & Ryans 1992; Mitchell & St-Amour 1995). Comparisons with motor-manual cleaning methods suggest that the break-even point for mechanized cleaning is 10 000—15 000 trees removed per ha (Ryans & St-Amour 1994).

6 Knowledge gaps and problems

While the benefits from early thinning on stand development are generally acknowledged, the long-term effects of biomass removal on the nutrient balance and site fertility are not yet fully understood. The problem is exacerbated with early thinning because nutrient demand is at its greatest soon after the first thinning. Another area of concern is damage to crop trees. Mechanized systems appear to offer the greatest opportunity for economical wood fuel production from PCT, particularly in the small diameter, dense stands experienced throughout much of the commercial forest regions of Canada. Mechanized techniques must meet both economic and biological objectives. None of the existing systems meet the present economic criteria for wood fuel production from PCT. A long-term commitment will be required for the development of suitable machines and systems for producing wood fuel from PCT and plantation cleaning.

7 Conclusions

In addition to the many biological benefits from early spacing and cleaning, PCT and plantation cleaning offer opportunities for increasing the availability of wood fuel in Canada. Although there are numerous benefits from early thinning, the long-term effects of biomass removal on site fertility are not fully understood. Recovery of biomass would require changes in current silvicultural practices and tending and thinning systems, as well as modifications to felling, extraction, and comminution systems. Motor-manual methods predominate in these silvicultural activities however at stand densities greater than 10 000—15 000 stems/ha, the cost of wood fuel from these systems is excessive. A mechanized cutting and chipping strip thinning system might be the most economical method for producing wood fuel from PCT. However a long-term commitment will be required for the development of suitable machines and systems.

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Annex 1. Estimated wood fuel cost (CAD); Nova Scotia thinning trials 1988.

Treatment	Stand conditions			Volume harvested		
	Average Diam, cm	BA m^2/ha	Volume gt/ha	Pulp	Chips	Total
Precommercial thinning	8.0	30.1	121.9	36.9	18.0	54.9
Commercial thinning	12.4	47.2	263.0	32.3	18.5	50.8

Treatment	Felling		Forwarding		Chipping		Transp.	Total cost
	Prod. gt/hr	Cost CAD/gt	Cost Pulp CAD/gt	Cost Biomass CAD/gt	Prod. gt/hr	Cost CAD/gt	Cost CAD/gt	fuel chips Cost CAD/gt
Precommercial thinning	0.29	25.72	8.00	16.00[1)]	5.8	12.59	8.00[1)]	62.31
Commercial thinning	0.43	21.97	7.49	16.00[1)]	6.3	11.59	8.00[1)]	57.56

[1)] Estimated based on 50—60 % equivalent volume of pulpwood.
[2)] Transport cost is estimated for conventional chip vans.

Review of fuelwood from early thinnings in Denmark

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Abstract

Most stands in Denmark are planted, but a tendency to use natural regeneration during reforestation can be noted. This means however that cleaning is usually not a problem. A first thinning is carried out in two steps with an initial row thinning followed by a selective thinning. Pulpwood prices are so low that that chipping the wood for energy is the only economical alternative, where a positive net return per hectare can be achieved.

Research questions are no longer focused on improving productivity of the chipping operation, but should now be focused on the consequences of harvesting fuel chips. These consequences are: soil fertility, humus layer and ground pressure problems. Also the problems connected to returning wood ash to the forest should be investigated. Storage of wood fuels should also be investigated further.

1 Introduction and background

In Denmark afforestation only takes place by planting. Reforestation has usually taken place by planting in coniferous stands, but in recent years, natural regeneration methods are being used more frequently. In deciduous stands it has been more common to rely on natural regeneration, however a large proportion of the areas are planted.

It is the intention to increase the forested area in Denmark by 100 % over the next 50 years to a total of about 24 % of the total land area. The Danish Forest & Landscape Research Institute has produced a report (Gamborg 1996), which indicates methods to increase the production of wood for energy from these new plantations.

Most forests in Denmark are rather young and date from the period between the two world wars, when large areas of heath were reclaimed and either used for agriculture or planted with conifers. Since most forests are planted, there is only a limited need for cleaning of the stands. Usually the stands are thinned by the time they are 7—8 metres high at the age of 15—20 years.

In the naturally regenerated stands there is often a need for cleaning. However since the areas are limited and the problem has only recently been identified, there is little information on thinning requirements for these areas. Also, given the trend away from even aged forests to multiple-aged stands, a greater need for cleaning can be expected in the future.

Denmark is a very windy country, so gales in spring and autumn are common. Two types of stands have shown the best resistance against windthrow - those which are not thinned and those which have been heavily thinned at an early stage of development. Stands which are thinned at a later age are more subject to windthrow.

Economically it has become increasingly difficult to harvest the first thinnings for anything but energy. Pulpwood prices are extremely low and the demand for roundwood for the fibreboard industry has almost disappeared.

2 Energy potential from early thinnings

The energy potential in stands that are in need of cleaning is very limited. The high proportion of small trees make this operation near impossible to perform economically. However in the case of first thinnings, the situation is different. Many first thinnings which previously would be pre-commercial thinnings are now commercial because of the harvesting of wood for energy. The forest owner cannot expect a large revenue or any at all, but the thinning is carried out.

In a typical first thinning about 120—160 m^3 loose fuel chips can be expected. These chips will weigh about 40—53 tonnes with a moisture content of about 45 %. The chips are produced from whole trees, including branches and tops. However, most of the needles remain in the forest because summer drying is used for nearly all wood for energy.

In the period 1990—2000 some 2500 ha of conifers are in need of first thinning with an additional 800 ha/year of deciduous forest. In the period 2000—2010 the amount increases to 3600 ha/year and 950 ha/year respectively. This amounts to ca 1—2 % of the total forested area. A report on the availability of fuel chips from the forest has been produced (Lind 1994). Not all the areas can be harvested for energy, since many small areas are not suitable and not all terrain lends itself to the chipping process.

In 1997 about 600 000 m^3 loose of chips will be harvested in the Danish forests, amounting to almost 10 % of the total annual harvest. Most of these chips (60—70 %) originate from thinnings. It is expected that the amount will rise within the next few years to approximately 1 million m^3 loose. A political decision will force the electricity companies to consume 200 000 tonnes (600 000 m^3 loose) for the generation of electricity. When this increase has been effected in a few years time, between 30—40 % of the total wood harvest in Denmark will be used for energy purposes, whether as town heating or as firewood to heat individual houses.

Lind (1994) calculated that around 300 000 tonnes per year of wood are available from the Danish forests if many reducing factors are taken into account. This means that fuelwood chips would need to be imported, since the expected consumption will be larger than the available amount.

3 Environmental considerations

Chipping of first thinnings has both a positive and a negative effect on the stands. The positive effect is that all unwanted trees can be removed. The stand is cleaned of all dead, diseased and crooked trees with or without double stems. The remaining crop is evenly spaced and of a much improved quality.

The negative impact might be that an increased amount of nutrients is removed from stand. The humus layer might also be affected, since all logging residues are removed. Research into this aspect of thinning is much needed. The impact of removing whole trees by chipping is somewhat mitigated by the method applied in Denmark, whereby the trees are left to dry during summer. This drying causes most of the needles to drop of prior to or during the chipping operation. The needles remain in the forest or around the skidtrails.

Another problem connected to the harvesting of energy chips from thinnings is the rather intensive traffic in the stand with relatively heavy machines. The effects of this traffic in the stand is another subject that needs more research.

The impact on wildlife is rather diverse. Thinning opens the stands with skidroads and the stem number is reduced drastically so that less shelter can be found. However, the canopy openings might favour the production of forage, thus increasing the feeding possibilities. Another problematic aspect involves the removal of all the dead and diseased trees during chipping thus reducing the amount of dead wood on which many species of fungi and insects thrive and thereby reducing the natural biological diversity in the stands.

4 Silvicultural systems and methods

The chipping method is mainly used in coniferous stands, since the first thinnings in deciduous stands are mainly carried out by people who want firewood. The first thinning in coniferous stands is carried out at the age of 15—20 years. The stem number before thinning is usually between 3000 and 4000 trees per hectare and the thinning intensity is about 45—50 % of the stem number. The first thinning is carried out in two steps with about one year between the steps. The method and machines are described in Kofman (1993). The amount of chips harvested per hectare in the first thinning is about 150 m^3 loose volume of summer dried chips, or about 50 tonnes.

During the first step, every 6th or 7th row is felled by chainsaw in a rooftile fashion. The felling is carried out in the period December to April and the trees are left to dry in the stand until after summer, when the chipping starts with a terrain chipper in August-September. The chipping is carried out the year-round, but only taking trees that have had at least one summer period to dry.

The second step is the selective thinning of the strips in between the skidtrails. This selective thinning is usually carried out with a feller-buncher that can accumulate several trees in the felling head before it dumps the bunches in the skid trail, again in a rooftile fashion. The machine can thin 3—4 rows on either side of the skidtrail. These trees from the selective thinning are also left to dry in the stand during summer and are chipped by the same machine as before.

The chipping is carried out in all cases by a terrain chipper. The trees remain in the stand and the chipper drives to the trees. A second machine, the chip shuttle, is used to transport the chips from the chipper to the containers at the roadside. In this way the chipper can continue without interruptions for the transport phase of the operation.

In first thinnings these two machines usually have a productivity of 300—400 m^3 loose per workday of 8—9 hours. The felling machine can fell and bunch about 250—300 trees per hour or only half the amount the chipper can comminute. The motor manual felling of the row trees can be carried out at a rate of about 120—150 trees per man-hour.

About 80 % of the chips are delivered straight to the heating plant in containers. This is possible because of the summer drying. The remaining 20 %, harvested in August and September, is stored for delivery during winter. This is possible because the chippers operate year-round. Their production is almost the same every month, but the consumption of chips during summer is considerably lower than in winter. The chips are stored in large piles of several thousand m^3. Some of the piles are left open to the elements, others are covered with plastic. In both cases problems arise, since the moisture redistributes in the piles. The outside layer will absorb the condensing water which is evaporated or generated in the centre of the pile. At the time of delivery there thus exists a very wet outer layer (MC 60 % or more on wet basis) while the centre of the pile is dry (MC 25—30 %). The chips are all filled with fungal sporesi and bacteria and can be a health risk.

5 Cost of wood fuel

The costs of harvesting wood fuel in thinnings includes:

	DKK/ m^3 loose volume
• felling	20
• chipping	45
• road transport for maximum 50 km	20
• stumpage	10

Table 1. Harvesting costs of fuel chips and pulpwood in Denmark.

	Fuel chips	Pulpwood
Harvested amount	50 tonnes/ha	25 tonnes/ha
Felling, harvesting & chipping	216 DKK/tonne	163 DKK/tonne
Terrain transport		75 DKK/tonne
Total cost at roadside	216 DKK/tonne	238 DKK/tonne
Selling price	260 DKK/tonne	200 DKK/tonne
Net return	2200 DKK/ha	-950 DKK/ha

The price is about DKK 100/m^3 loose volume depending on the moisture content of the chips. The price is usually fixed in DKK/GJ. The present price varies between DKK 35 and DKK 37 per GJ. The price for wood fuel from clearcuts cannot be given, since very few clearcuts are used for energy. The final price for wood fuel from logging residues is the same as for the chips from thinnings, where the costs for felling are transferred to the chipping costs. Usually the stumpage price is also assessed to the chipping. The owner gets his land cleared free of charge. In Denmark wood for fuel is mainly economical due to the high taxes on all fossil fuels. It has been a political decision to apply taxes on fossil fuels, which has made biomass a competitive fuel for town heating.

In thinnings the alternative to fuel chips would be to harvest pulpwood; on clearcuts the alternative to chipping the slash would be windrow and leave it. Both alternative systems are more expensive than the fuelwood system.

Pulpwood prices are very low at the moment with only DKK 160/ m^3 solid. In Table 1 the harvesting costs and yields of fuel chips are compared to harvesting pulpwood. It is clear that harvesting pulpwood is not a good alternative at the moment. Also the table shows that harvesting fuel chips yields the double amount than harvesting pulpwood. Not only are tops and branches included in the fuel chips, but also all unmerchantable trees.

6 Knowledge gaps and problems

The effects of harvesting fuelwood on the stand are not much studied and unknowns include the effect of removing large amounts of biomass from the stands on the soil fertility and the humus layer. Returning the wood ash might be a solution, but this question needs more research. It has been shown that wood ash contains relatively large amounts of heavy metals (Kofman 1987). It might be possible to separate the ash at the heating plant into one fraction which contains most of the heavy metals and one which does not. The application of ash is not without problems. The ash contains much dust and the total ash is very basic. These problems should be solved.

Further research on the storage of fuel chips from summer to winter is also needed. A method should be developed to prevent the redistribution of moisture in the piles and to reduce fungal attack on the chips.

The chipping methods in Denmark are quite mature and highly productive. The main problem is now not to increase the productivity further, but to improve the logistics and to reduce the costs.

7 Conclusions

Wood fuel is a normal product from Danish forestry. At the moment about 10 % of the annual harvest is used as energy chips. A very large proportion of these chips originates from early thinnings. The harvesting methods are well developed and mature. Special machines have been developed and are operated year-round.

The increase in fuelwood production has only been possible because of a political decision to tax fossil fuels in order to reduce the consumption. Biomass is still exempt from tax.

Research is needed into the effects on the soil fertility and the humus layer of harvesting biomass from thinnings. Methods to apply wood ash to the forest should be developed and the effects of this application on the soil fertility and the ground water require further study. Further research into the storage of wood fuels is also needed.

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Review of wood fuel from precommercial thinning and plantation cleaning in Finland

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Abstract

The paper deals with the biomass potential, silvicultural considerations, cost of recovery and environmental aspects in conjunction with the energy use of small trees from plantation cleanings and early thinnings in Finland. Repeated thinnings from below are an essential characteristic of the Finnish forest management system. Due to the high operational costs, plantation cleanings and first commercial thinnings are currently a critical link in the management chain. These young forests possess a high potential as a source of renewable energy, 4 to 6 million m^3 or 8 to 12 TWh per year. Utilization of small-treè biomass for energy is constrained by the high costs compared to peat, coal, oil or even wood chips produced from residues such as bark, sawdust or logging slash from clearcuts.

1 Introduction and background

The area of productive forests in Finland is 20 million hectares. The annual increment of stemwood is 80 mill. m^3 and, including crown mass, the above-ground tree biomass increment is 110 mill. m^3. The annual drain is 62 mill. m^3 stemwood and 85 mill. m^3 biomass (Statistical yearbook... 1995).

Selection cuttings in uneven-aged stands were rejected in favour of growing even-aged stands in the early 1950s. Natural or manual seeding or planting of relatively small (2—3 ha) clearcut areas is considered to be a nature-oriented type of regeneration. In the natural development cycle of Nordic boreal forests, fire or storm damage would provide spaces at intervals of 60—100 years for regeneration of light demanding pioneer tree species, such as Scots pine (*Pinus sylvestris*) and birch (*Betula pendula* and *Betula pubescens*). Norway spruce (*Picea abies*), as a shade-tolerant species, has a slower start.

Finnish forests are managed under a rotation regime of 70 to 120 years. Some 200 000 ha or 1 % of the area are regenerated annually either naturally or artificially. It follows that in the long term, the areas of both unmerchantable plantation cleanings and first commercial thinnings should also be annually 200 000 ha. Unfortunately, these targets are not met.

Plantation cleaning at the age of 8—15 years is important for biological reasons. After cleaning, the production potential of the site is shared by a lower number of faster growing stems of better quality (2000—2500 trees per ha). Cleaning is also needed in order to regulate the composition of tree species towards healthy mixtures and economically profitable growing stock.

The cleaning of young stands has an impact on the economy of subsequent commercial thinnings. Fully-mechanized first commercial thinning at the dominant height of 11—14 metres allows the maximum density of about 2000 trees before thinning. Higher densities tend to result in logging costs greater than the revenues.

The area of cleaning and tending of young stands in Finland was highest in the mid-1970s, temporarily more than 500 000 ha annually. During the last decade, the area has decreased to an annual level of 200 000 ha or less. This amount is about the same as the total area of regeneration.

The annual area of first commercial thinnings at the age of 25—45 years, about 70 000 ha, is only one third of the silvicultural need. For an area of 400 000 ha it is already too late to carry out the first commercial thinning, since delayed thinning contains an increased risk of storm and snow damages.

Wood from first thinnings is primarily designated for the pulp and paper industry. Cleaning and first-thinning stands also contain a high fuel potential, but a serious constraint of using that potential is the high cost compared to competing fuels such as coal, peat and oil.

2 Energy potential from early thinning and plantation cleaning

The recovery of biomass from cleanings is not feasible unless the tree height is at least 5—7 m. The yield should be at least 20 m³ solid of biomass per hectare. If a commercial demand for fuel chips arises, one third of the annual cleaning area or 65 000 ha could meet there requirements (Fig. 1). It is to be emphasized that presently the cost of recovery of whole-tree chips from plantation cleanings far exceeds the solvency of chip-fired heating plants.

Because of the larger tree size, the biomass potential from the first commercial thinnings is considerably greater. However, for national economic considerations, wood from commercial thinnings should first and foremost be used for the production of pulp and paper. The distribution of biomass between fiber and energy depends primarily on the minimum diameter of pulpwood, which is presently 7 cm for Scots pine and 8 cm for Norway spruce. Were pulp mills to establish special debarking lines for small-sized logs so as to reduce breakage and loss of wood, the minimum diameter of pulpwood could be decreased to 5 cm. The biomass potential of the first commercial thinnings would then be shown in Table 1.

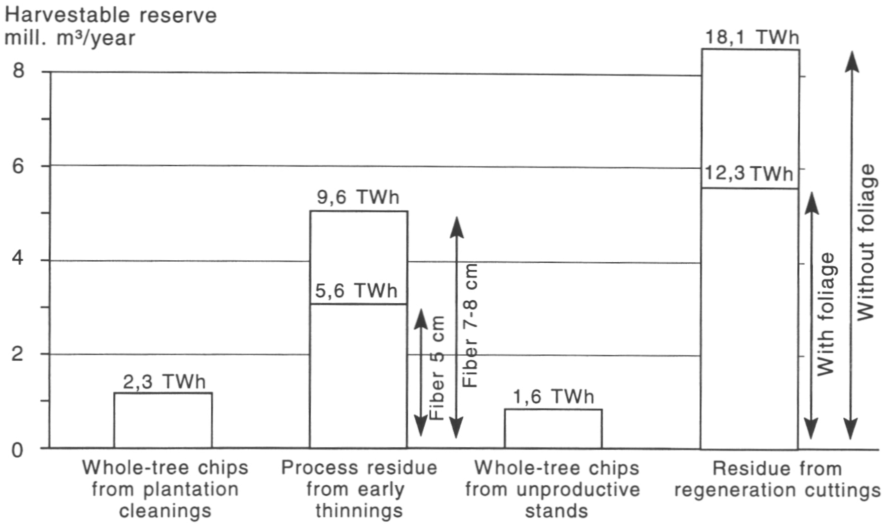

Figure 1. The harvestable forest energy reserve in Finland. The minimum diameter of pulpwood alternatively 5 or 7—8 cm (Hakkila & Fredriksson 1996).

The biomass from the first commercial thinnings should therefore be used partly for fiber and partly for energy. Consequently, integrated harvesting followed by subsequent segregation of the fiber component from the energy component at the pulp mill or terminal is an attractive proposition. The distribution of biomass between fiber and energy is strongly affected by the minimum diameter requirement for pulpwood.

Table 1. Biomass potential of first commercial thinnings in Finland (Hakkila et al. *1995).*

	m^3/year
Biomass by tree component	
Stem, including bark	9.7
Crown mass, including needles	3.0
Total biomass	12.7
Biomass by product	
Pulpwood over 7 (8) cm	5.7
Pulpwood 5—7 (8) cm	2.0
Fuelwood	3.1
Residue to be left in the forest (recommendation)	1.9
Total biomass	12.7

The quantity of technically harvestable biomass from plantation cleaning and first commercial thinnings is compared in Fig. 1 with the logging slash harvestable from regeneration cuttings, composed primarily of branches and tree tops. The proportion of logging slash which is classified to be harvestable is only one third of the total amount left from commercial cuttings, since many technical and environmental considerations restrict total recovery. Nevertheless, more fuel is available from regeneration cuttings than from plantation cleanings and early commercial thinnings.

3 Environmental considerations

Cleaning and thinning reduce competition between roots and crowns of individual trees. Light penetration into the lower canopy layers strengthens the vigour of the crowns. The optimal crown length for tree growth is 40—50 % for Scots pine and birch and 60—70 % for Norway spruce. Higher soil temperature also enhances the availability of nutrients. Releasing nutrients from logging residues stimulates the growth of the remaining trees.

Decreased competition resulting from cleaning and thinning shortens the rotation time of stands by 20—30 years in southern Finland, when the rotation length is determined by diameter (dbh). Thinned stands are also more popular for hiking, picking berries and mushrooms, and for hunting. Generally, thinning does not reduce biodiversity, if stands are grown as mixtures and if dead and rotting trees are left uncut in the stand. However, animals and plants favouring untouched, old forests need a network of strict nature reserves.

Removing forest biomass from a site causes loss of nutrients from the ecosystem. This is especially the case if branches and needles are also harvested. Branches and needles contain a considerable part of the nitrogen (N), phosphorus (P), kalium (K) and magnesium (Mg) reserves of trees. Full-tree harvesting would increase the future risk of nutritional imbalances attributable to increased nitrogen deposits from atmospheric pollution. The nutrient balance of forest soil must also be taken into consideration when harvesting biomass for fuel on poor soils.

4 Silvicultural systems and methods

When young stands are cleaned or thinned and the biomass is recovered for fuel, 4 m wide strip roads must be opened at 20—25 m intervals. Cutting is made with a chainsaw, which is sometimes equipped with a felling frame to allow an erect work position and facilitate the bunching of small trees. The performance of the chainsaw operator varies from 1.5—4 m^3 solid of undelimbed trees per hour, depending on tree size, tree species, undergrowth, terrain, snow cover etc. When the tree size is very small, 0.01—0.04 m^3 , mechanized felling is not competitive. When the tree volume exceeds 0.06—0.07 m^3 one-grip harvesters become competitive against chainsaw operators.

Chipping usually takes place at the road side. Undelimbed trees or 5—7 m tree sections are hauled to road side by conventional forwarders. The average load size for undelimbed tree sections is about 6 m^3 solid for Scots pine and 5 m^3 for Norway spruce. The productivity of forwarders is 6—8 m^3 solid per hour.

At the moment, there are four Chipset terrain chippers in Finland. To make feeding from both sides possible, the chipping device is positioned in the front of the unit. The productivity in small-tree operations, including the transportation of chips to the roadside and tipping the chips onto a chip container on the ground, is about 8 solid m^3 per hour. Currently, these machines work primarily in regeneration areas due to the more competitive chip costs.

A majority of whole trees, tree sections and delimbed stems are chipped for fuel at the road side. In non-commercial operations by farmers, chipping is made with light farm tractor-mounted disc chippers. Heavy truck-mounted chippers are common in commercial operations due to their good performance and mobility from site to site. Including the idle time used for waiting for chip trucks, the productivity of chipping is 15—30 m^3 solid per hour. When fully employed, a heavy truck-mounted whole-tree chipper has an annual capacity of 40 000—50 000 m^3 solid.

Some modern chip-fired heating plants can burn fresh biomass with a high efficiency, whereas some require dryer chips with a moisture content less than 40 %. Both transpiration drying in the forest and the drying of whole trees and tree sections in uncovered roadside piles are used to lower the moisture content of chips.

5 Cost of wood fuel

The Finnish Forest Research Institute and Wood Energy Association studied the prices of wood fuels at chip-fired heating plants in 1995. Price data were received from 50 out of the country's 102 forest chip-fired heating plants.

The price of forest chips exceeds the price of industrial process residue such as bark, sawdust and unbarked chips at the heating plant. The chips reduced from logging slash at regeneration cutting areas are only slightly more expensive, whereas the price of chips reduced from small-sized trees is considerably higher. To be competitive against fossil fuels and peat, the price of chips should not exceed 40—45 FIM/MWh. However, if the direct and indirect effects on rural employment are recognized, prices as high as 50—80 FIM/MWh could be justified in different heating and co-generation plants.

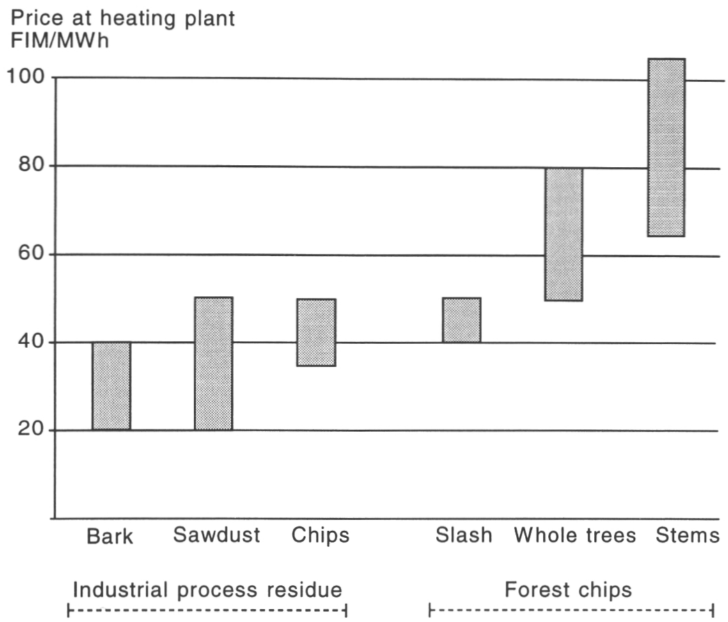

Figure 2. The price of wood fuels at forest chip-fired heating plants in Finland in 1995 (Hakkila & Fredriksson 1996).

There is no established cost level for chips produced from small-sized trees from plantation cleanings and early thinnings. Technical conditions such as tree size, yield per hectare and transport distance greatly affect both productivity and costs. However, the price range of chips made from whole trees and delimbed stems shown in Fig. 2 is fairly representative of early thinnings.

Table 2. Average price of wood chips at the heating plant in Finland in 1995 (Hakkila & Fredriksson 1996).

	FIM/MWh	US$/MWh
Industrial process residue:		
Bark	32	6.4
Sawdust	33	6.6
Chips from wood residue	44	8.8
Forest chips:		
Chips from logging residue	46	9.2
Chips from small whole trees	62	12.4
Chips from small delimbed stems	89	17.8
Average for forest chips	58	11.6

Chips from cleaning represent the top prices of the range and in most cases would probably be even higher. Table 2 gives the average price of various types of wood fuels at the heating plant in 1995. The energy content of a solid m^3 of chips is about 2.0 MWh and that of a loose m^3 of chips about 0.85 MWh, depending on tree species, moisture content etc. In March 1997, the exchange rate was 5 Finnish marks (FIM) to 1 US dollar.

6 Knowledge gaps and problems

The total consumption of wood-based energy in Finland corresponds to 25 mill. m^3 solid wood annually. Most of this production is based on burning solid and liquid waste materials in the wood-processing industry. The aim of the state's energy policy is to increase the production of wood-based energy by one third in the 1990s. This is possible from the point of view of the biomass potential, because there is a remarkable fuelwood reserve standing in Finnish forests.

The major problem in the utilization of wood for energy is the high cost of recovery. At the existing price level of the competing energy sources it is practically impossible to use wood from cleaning of young stands for energy in commercial operations. In first commercial thinnings, the stumpage price paid by the pulp and paper industry is superior compared to that paid by energy producers. This situation can only be changed by increasing the environmental taxes of fossil fuels. In practice, fuelwood harvesting from first commercial thinnings may in some cases be profitable, because all the small-sized wood coming to the market is not needed by the forest industry for pulp and paper making. As mentioned before, the biggest and most profitable supply of wood for energy comes from clearcut areas of Norway spruce stands.

The long-term effects of nutrient losses must be carefully studied to determine the guidelines for the large scale utilization of logging residues or whole trees from cleaning and thinning operations. This is especially important on the poorest soils, where the risk of acidification and nutrient imbalance is the greatest.

Once such problems have been solved, the increased use of wood for energy will be beneficial for the environment. The closed circulation of CO_2 between the atmosphere and the forest will have little effect on global warming as well-managed vigorous young forests with high growing stocks, act as carbon sinks.

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Review of wood fuel from early thinning and plantation cleaning in the Netherlands

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Abstract

Discussion regarding the use of wood fuel for commercial energy production in the Netherlands began in the 1990's. The main reasons for using wood fuel are: the political demand for using renewable energy, the need to reduce CO_2 emissions, and the lack of markets for surplus timber. Only 10 % of the area of Holland is forested. Therefore, early thinning and cleaning are important management tools for improving growth and producing better quality timber. The energy potential from early thinning and plantation cleaning could be between 400 000 and 570 000 dry tonnes annually. The Netherlands does not have experience with harvesting energy wood. However, through the International Energy Agency/ Bioenergy Agreement, knowledge gained in other countries, especially Denmark, Sweden, and Finland, is being transferred to Holland. In 1996, there have been field trials with Danish equipment. Although there are few technical barriers to wood fuel in the Netherlands, the economics of wood fuel consumption are affected by the low cost of fossil fuels and the high natural gas reserves. This is changing however, due to political concerns over the balance of greenhouse gases. In 1996, a small energy tax on fossil fuels was introduced and electricity suppliers are now selling an environmentally friendly "green electricity". Energy wood has a future in the Netherlands, although the total forest reserves would satisfy only a small percentage of energy requirements.

1 Introduction and background

1.1 Biological and economic rationale for early thinnings and plantation cleaning

In the Netherlands, early thinnings and cleanings contribute to sustainable forestry. Without thinnings, both quality and growing capacity of young forests are reduced. Because of the negative cash-flow of early thinnings, many forest owners are postponing early thinnings. As well, nature conservation and recreation are becoming increasingly important forest management considerations. Although multi-purpose urban forestry includes timber production, harvesting is not currently popular, especially when it contributes to changes in forest aesthetics. When timber prices are low, harvesting is not economically justifiable and when prices increase, special efforts are required to gain enough public support for timber harvesting.

The environmental function of the forest and the possibilities for substituting native timber for timber from tropical rainforests and for replacing fossil fuels gives harvesting and timber production a new chance in public opinion. Environmental issues such as the greenhouse balance and climate changes with consequences for sea-level rising and dike-building, the CO_2-fixing of forests, and the possibilities for renewable energy from energywood have assumed a prominent place in national environmental politics.

1.2 Historical perspective of forests

Since the last century, natural forests no longer exist in the Netherlands. All forests are planted, the oldest being 150 years old, primarily Scots pine and some broadleaved forests. In the beginning of this century the total amount of woodland was less than 2 % of the land surface. There were significant reforestation during the 1920's and 1930's, especially on so-called waste grounds like heathland and both inland and coastal sand dunes. The principal species were spruce and pine. There was more reforestation in the 1950's and 1960's in which Douglas-fir and larch were also planted.

After the 1970's it became clear that outdoor recreation was the primary reason for government support of new forests. From this perspective, the best locations for new forests are in the vicinity of the large cities in the western part of the country where forests have been relatively sparse. During the past ten years, thousands of hectares of new forests have been established, mainly consisting of broadleaved species such as oak, beech, ash, and some poplar.

A special type of new forest is the large plantations in the newly-made polders in the former Souther Sea in the centre of the country, just east of Amsterdam, where three new polders of approximately 40 000 ha each have been constructed since the Second World War. On this new land, approximately 20 000 ha is forest, primarily broadleaved species, including initially poplar and willow and later oak, beech, ash and hawthhorn. These forests, which are planted on very fertile clay soils, are experiencing very high growth rates between 15—20 m^3/ha/yr for poplar and willow and 12—15 m^3/ha/yr for other species.

1.3 Status of forest area, growing timber and harvesting

The total forest area is now approximately 340 000 ha, or almost 10 % of the land surface, more than double the forest area that existed at the beginning of the century. The government plans a further increase of 75 000 ha over the next 25 years. The total volume of timber is about 50 million m^3 with annual growth of 2.2 million m^3 (6.5 m^3/ha/year). The total harvesting is decreasing and at the moment less than 1 million m^3/year. Since 1988 the annual harvest has decreased by 25 % from 1.3 million m^3 to less than 1 million m^3 in 1994, mainly due to lower timber prices (Stichting Bos en Hout 1997).

Forests in the Netherlands have three main functions: nature conservation, recreation, and timber production. One quarter of the forests have an exclusive nature function. The forests in the Netherlands are owned by the State Forest

Service (30 %), NGO's for nature conservation (15 %), local and regional authorities (20 %), and private persons (35 %)

2 Energy potential from early thinning and plantation cleaning

The total energy potential from early thinnings and plantation cleaning is estimated to be 260 000 to 320 000 dry tonnes per year. New sources of woodfuel such as logging residues, some energywood plantations, harvesting a greater portion of the annual growth, and wood collected from city parks and gardens are expected to provide another 140 000 to 250 000 dry tonnes per year by the year 2000. Therefore the total potential by 2000 could be between 400 000 and 570 000 dry tonnes (Vis 1996). Not considered in these estimates are other sources of woodfuel including used lumber from buildings and other biomass products from agriculture. Agricultural biomass has the potential to double the total amount of biomass which is available for renewable energy.

3 Environmental considerations

Early thinnings and cleanings are important forest management tools for improving growth and producing better quality timber. Dutch forestry tradition in mainly based on German experience with broadleaved trees such as oak and beech. In this tradition, it is essential to have a relatively high level of management during the first 10 years of the plantation. The cost of this intensive management should be recovered during harvesting at latter stages of stand development. Because most of the biomass in this period will be left in the forest (in fact most early thinnings are not removed) there has been no discussion about impacts on nutrient levels.

Trials to undertake the first thinning when the sale of the timber from the thinning has a positive cash flow (after at least 15 years) have determined that this approach has no negative impacts on the sustainability of the stand. Also, in mixed forests it is generally not difficult to maintain the different tree species without early thinnings.

First thinnings are mainly done by motor-manual operations. Recently there have been some pilot studies of thinning with small scale processors. The results of these operations are promising, due to reduced thinning costs and the fact that damage in dense stands has been much less than expected.

When harvesting a greater portion of the biomass from early thinnings, such as when whole-tree harvesting methods are used, there is a chance of nutrient depletion on some poor sandy soils. A study by the Dutch Forest Research Institute in 1996 (unpublished report) and a review of the literature indicates that on these poor soils, whole-tree harvesting should be used for first thinning only. For all other thinnings the logging residues should be left in the forest to provide the necessary nutrient levels.

4 Silvicultural systems and methods

Only a small amount of the Dutch forest i.e. approximately 5 % is older than 100 years. In fact more than 60 % of the area is younger than 60 years. From the middle of last century, the area of forest has declined, with only 3—4 % of the land now covered with woodland. There have been three periods of reforestation, beginning in 1870—1900 mainly with Scots pine with the main goal of stabilizing the numerous drifting inland and coastal sand dunes which became a danger for the growing population. The second period, in 1920—1930(—40), larch and spruce were used, mainly on heathlands, to make these waste grounds more useful.

With the change in farming methods associated with the use of fertilizers, the heathlands were no longer farmed. The third period was in 1950—1960, with spruce as main species but also Douglas-fir, larch, and oak. After cultivation wet heathland systems could also be reforestated. During the last decade there have been three ongoing programs for planting new forests: (1) urban forests near the densely populated areas mainly in the western part of the country ('randstad'); (2) large plantations of poplar and willow and broadleaved species such as oak, beech, maple and ash on land reclamation projects in the former Souther Sea, and; (3) reforestation of agricultural fields with short rotation plantations, mainly poplar and spruce. The target for establishment of new forests is 75 000 ha in 1990—2015.

Because of the climate, the natural woodland vegetation in Holland is a mixed forest with broadleaved species. In fact, conifers are not native, except perhaps some pine on bog systems. Today, 70 % of the total forested area is conifer forest and only 30 % is broadleaved species (Tables 1 and 2).

Approximately 30 % of the forests in the Netherlands are designated for nature conservation with only few possibilities for harvesting. The other 70 % are multifunctional. Because most of the Dutch forests are relatively young, there is not much harvesting activity. On average approximately 1500 ha (less than 1 %) is harvested annually. Of this 1500 ha, approximately 1000 ha is clearfelled, the remainder are small-scale felling operations. Planting and seeding accounts for 80 % of forest regeneration while the remaining 20 % is regenerated naturally.

Table 1. Comparison of natural forest with reforested species in the Netherlands.

Natural forest type	Soil type	Soil moisture	Primary species in reforestation
Oak-birch	Sand	Very dry	Scots pine
Oak-beech, spruce	Sand/loam	Dry	Pine, larch, Douglas-fir
Oak-hornbeam, spruce, beech	Loam	Dry to wet	Douglas-fir
Ash-elm	Clay	Wet	Poplar, beech, ash, maple
Alder	Peat	Very wet	Poplar, spruce
Willow	Clay	Very wet	Poplar, willow

Table 2. Distribution of tree species in the Dutch forest.

Species	Percent of total forest area
Scots pine	39
Oak	16
Larch	6
Spruce	4
Douglas-fir	5
Poplar	5
Birch	6
Beech	3
Other coniferous spp.	6
Other broadleaved spp.	10

There are trends in reforestation towards using more Douglas-fir instead of spruce and pine, greater use of broadleaved species, in particular oak and beech, and establishing more mixed forests with different layers.

5 Cost of wood fuel

Calculations of cost of wood fuel are based on the following three sources:

1. Data collected by Danish forestry and research institutes and published in different papers, some of them part of IEA Bioenergy activities (Hakkila et al. 1997; Hudson & Kofman 1996, and information provided by Pieter Kofman and his colleagues when we visited Denmark and during study tours in 1995 and 1996.
2. Some field trials in the Netherlands with Danish harvesters and chippers and Danish operators in autumn 1996 and spring 1997 with first thinnings in young stands (20 year old) of beech, ash, maple and oak and also in normal thinnings in spruce and pine in the Flevoland region.
3. Our 'own' data from normal harvesting of roundwood for industrial pulp and paper purposes.

Prices vary with the origin of the wood. Roundwood is the most expensive. When using an integrated harvesting method the cost is 120 dfl/odt. Wood from first thinnings is somewhat less expensive due to whole-tree harvesting: 108 dft/odt. Logging residues from clearfelling, e.g. poplar, can be acquired for approx 100 dfl/odt. The stumpage price in these calculations is 10 dfl/m^3. This is adequate to offset administration costs and provides a small revenue for the forest owner. Residues from the paper industries (bark) and sawmills cost 113 dfl/odt while residues from city parks and gardens are the least expensive at 64 dfl/odt.

In a recent study for a 20 MW wood-fired biomass plant in the southern part of the Netherlands, the average price, based on a mix of different kinds of available chips, was calculated at 107 dfl/odt.

6 Knowledge gaps and problems

There are no technical barriers to woodfuel in the Netherlands. The experience in Denmark is more than enough to help us build a energywood market. However, because of their relatively low prices, fossil fuels are too competitive for the development of a commercially-based energywood market. Political intervention is therefore necessary. In the Netherlands, energy taxes on fossil fuels are under discussion. The government decided to impose a small tax in 1996. Energy suppliers have also started selling and promoting an environmentally friendly product called green electricity. Individuals and factories pay a premium for their electricity and the higher prices make it possible to produce more electricity from sun, wind, and biomass. Currently, 2 % of the clients have chosen this possibility. After further promotion and marketing it is expected that at least 5 % of all users will purchase this environmentally friendly product.

There is sometimes negative public opinion about harvesting timber which is often considered to be an affront to nature. Forest owners and government will invest in public education and information to foster public support. Fortunately, the discussion of the greenhouse effects from using fossil fuels and the positive contribution when using biomass including wood, makes it possible to convince people of the necessity of harvesting wood.

7 Conclusions

Energy wood has a future in the Netherlands, although the total amount of timber is only sufficient for a small percentage of the total energy consumption. Due to political decisions, it is expected that wood-fired electricty plants will be constructed in the next 2—5 years. The energywood market in the Netherlands is too small for the country to develop the entire system itself. Major parts of the system will be undertaken in cooperation with foreign companies. Most favorable are Danish and Finnish harvesting companies, in particular when they are able to undertake small-scale harvesting operations.

Forest owners are interested in the potential for improving forest management by producing energywood. The primary markets for forest products are in Germany and Belgium and because of the high costs of transport, it is not profitable to export low- value timber. A domestic energywood market will stimulate forest management and economic returns.

Because of the surplus of agricultural area in some parts of the Netherlands it is possible to develop some 10 000 hectares of energywood plantations. Currently farmers have a set-aside agreement with the European community for this land. Changing set-aside to short-rotation forestry has two advantages: it produces "non-food" for a real market and it contributes to renewable energy.

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Review of wood fuel from precommercial thinning and plantation cleaning: New Zealand opportunities and experience

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Abstract

There are currently no precommercial thinning operations harvesting wood fuel in New Zealand. Precommercial thinning of New Zealand's planted production forests for wood fuel could, however, provide over 7 % (~ 400 PJ) of New Zealand's energy needs between the years 2000 and 2010. The dispersed nature of the resource, the likely environmental impacts (nutrient removal and soil damage), availability of substantial quantities of lower cost residue from clearfell harvesting operations and the competition for the resource from conventional fibre users may result in the potential not being quickly realised.

1 Introduction and background

New Zealand has approximately 7.9 million hectares of forest (~ 29 % of land area) of which 1.5 million hectares (17 %) is planted production forest and the remainder (83 %) is natural forest. The natural forest is predominantly tied up in conservation estate. Timber harvest from natural forests has been decreasing for the last four decades, both in real terms, and relative to the harvest from planted production forests. It currently provides 1 % of the nation's timber production. Natural forests in New Zealand are excluded from this review.

Most of the forest management and harvesting activity is taking place in the planted production forests. Through new planting these forests are currently expanding at the rate of about 75 thousand hectares per year. Radiata pine (*Pinus radiata*), Douglas-fir (*Pseudotsuga menziesii*) and other introduced softwood species account for 97 % of planted production forest area. It is in these forests that there is the greatest *opportunity* for obtaining wood fuel from precommercial thinnings.

At the time of establishment, or re-establishment, more trees are planted than will be needed for production thinnings or for the final crop at the time of clearfelling. This is done to allow for mortality and other losses during the early growth of the forest and to allow for selection of trees with the best form, vigour and economic potential. The unwanted trees are thinned to "waste" usually before the trees are 10 years old. The thinned trees are left on site to decay and return their nutrients to the nutrient pool.

In this paper the term "precommercial thinning" will be used to refer to harvesting and *removing* trees from the forest which would normally be thinned to "waste". There are currently no operations in New Zealand which use precommercial thinnings for wood fuel. Most interest in bioenergy is focused on using "waste" from milling operations or residue from around landings in clearfelling operations.

2 Energy potential from precommercial thinning

Fourteen years ago Everts (1983) estimated that the projected biomass yields from precommercial thinnings would be 1.3 million od tonnes per annum by the year 2000 and 1.5 million od tonnes per year by the year 2010. These figures are now out-of-date. A rapidly expanding planted production forest estate and better estimates of individual tree biomass require that the potential yields be revised.

Table 1. gives the annual biomass and energy potential for the periods 2001—2005 and 2006—2010. The estimates are based on many assumptions, including:

- only trees planted in the past five years will be eligible for precommercial thinning in the period 2001—2005; the 1995 National Exotic Forest Description (Anon 1995) indicates that there are approximately 340 000 hectares in this age class.
- only trees planted in the next five years will be eligible in the period 2006—2010; an estimate of the area that will be in this age class is 550 000 hectares.
- only ground-based (i.e., non-cable) logging terrain will be suitable for precommercial thinning for wood fuel and this comprises about 63 % of planted area in New Zealand.
- the four broad classes of management practice described in the 1995 National Exotic Forest Description (Anon 1995) can be allocated on a pro-rata basis to recent and new planting. The classes are "Intensively tended with production thinning" (IPT), "Intensively tended without production thinning" (INPT), "Minimum tended with production thinning" (MPT) and "Minimum tended without production thinning" (MNPT).
- an energy conversion factor for softwoods of 19.2 MJ per kilogram of oven dry wood is appropriate.

Because of the broad assumptions made in the projections it is probably prudent to say that the potential yields for the period 2001—2005 are somewhere between 1.5 and 2.5 million od tonnes per annum (30—50 PJ per annum) and for the period 2006—2010 somewhere between 2 and 4 million od tonnes per annum (40—80 PJ per annum). New Zealand currently consumes about 665 PJ of total energy per annum. The biomass estimates above are considerably higher than those of Hall & Wylie (1996) but only 4—6 year old trees were included in their 0.3 million od tonnes per annum estimate.

Table 1. Annual biomass and energy potential from precommercial thinnings in New Zealand.

Management practice classes	Yields from all thinnings odt/ha	2001—2005			2006—2010		
		Area ha x 10^3	Biomass yields odt/ ha x 10^6	Energy PJ/ha	Area ha x 10^3	Biomass yields odt/ ha x 10^6	Energy PJ/ha
Intensively tended with production thinning	10	49.3	0.1	2	79.7	0.2	3
Intensively tended without production thinning	50	98.5	1.0	19	159.4	1.6	31
Minimum tended with production thinning	0	10.7	0.0	0	17.3	0.0	0
Minimum tended without production thinning	70	55.7	0.8	15	90.1	1.3	24
Total		214.2	1.9	36	346.5	3.1	58

In comparison, Hall & Wylie (1996) estimate there will be a potential wood fuel resource from *residues* left on clearfell cutovers of about 560 000 od tonnes by the year 2005. Sims et al. (1990) estimate that there will about 2.5 million od tonnes per annum of cutover residues by the year 2010.

3 Environmental considerations

Nutrient depletion and soil damage by heavy harvesting equipment would probably be the two greatest environmental concerns resulting from removing precommercial thinnings for wood fuel. Many of New Zealand's planted production forestry sites are marginal or low in one or more nutrients (Will 1985) and precommercial thinning for fuel wood could result in the need for additional fertilizer application. For example, Hunter et al. (1989) found from research on three trial sites in the North Island of New Zealand that removing precommercial thinnings would remove between 105 and 240 kg of nitrogen (N) per hectare, depending on the site. At the poorest N site this loss represented a high percentage

of the total N on site. Removal of significant quantities of other nutrients such as phosphorus, magnesium and potassium would also occur (Frederick et al. 1985).
To achieve precommercial thinning at an acceptable cost, purpose-built mechanised harvesting systems will be required. Stem and root damage to the remaining trees and soil compaction and disturbance have been reported in many studies of thinning operations (e.g. Murphy 1982) and could be expected from equipment used for precommercial thinning of wood fuel.

4 Silvicultural systems and methods

Research carried out by the New Zealand Forest Research Institute and forest companies over the past fifty years has lead to a detailed understanding of the effects of different silvicultural systems on forest growth and profitability. This research has been incorporated in powerful computer tools (e.g. STANDPAK) which enable forest managers to design and evaluate the silvicultural regimes which are best suited to their particular situations (Maclaren & Knowles 1995). This has lead to a wide range of regimes being used in New Zealand.

Initial densities typically range between 600 and 1000 trees per hectare and final crop densities at clearfelling between 200 and 350 trees per hectare. The potential number and timing of precommercial thinnings, as well as the yield, will depend on the regimes followed. For the analyses used to derive the yields in Table 1, it was assumed that there would be no precommercial thinnings for the MPT regimes, a single precommercial thinning at age 5 and age 9 for the IPT and MNPT regimes respectively, and two precommercial thinnings at age 5 and age 9 for the INPT regimes.

The average stem volume for a first precommercial thinning would be between 0.01 and 0.05 m^3, depending on age of thinning, and between 0.1 and 0.15 m^3 for a second precommercial thinning.

As noted in the introductory section, there are currently no operations which are harvesting precommercial thinnings for wood fuel in New Zealand. Hall (1995a), however, has recently described a system which has been used to harvest 10 year old thinnings for fibre for a medium density fibreboard plant. The forest owner had previously thinned trees of this age to "waste". The system comprised three fallers who manually felled trees with chainsaws and a 63 kW Lamborghini 4WD agricultural tractor towing a two-axle FMV forwarder-trailer fitted with a crane and grapple. The average tree size harvested in this operation was 0.11 m^3 and daily production for the system was 40—45 m^3.

It is expected that such a system would be unsuited for early precommercial thinnings where tree sizes would be much less than 0.1 m^3 (e.g., 0.01—0.05 m^3). For very small tree sizes a precommercial thinning system would need to be fully mechanised, highly productive to keep costs low, and highly manoueverable to minimise the damage to the final crop element. Sims et al. (1990) have suggested that a specialised biomass harvester would need to be developed for trees less than 0.1 m^3.

In the late 1980s a Bruks whole tree chipper mounted on an Osa forwarder with a 17 m^3 bin was used for a short time by Handifuels Fuel Systems in thinnings (Mead 1987) but this unit is no longer operational. Hall & Wylie (1996) suggest that a small feller/chipper/forwarder with a bin capacity of 8—9 m^3 could be used in early precommercial thinnings.

5 Cost of wood fuel

Conventional clearfell harvesting costs for skidder/tractor logging terrain in New Zealand are NZ$8—NZ$12 per m^3 or about NZ$20 per od tonne (NZ$1 = US$0.7). Precommercial thinning costs for wood fuel could be expected to be higher than this.

For the thinning operation described by Hall (1995a), where the average tree size was 0.11 m^3, harvesting costs were NZ$35—NZ$40 per m^3 of stemwood (~ NZ$85 per od tonne). Costs would be NZ$10—NZ$20 per od tonne lower than this (i.e., NZ$65—NZ$75 per od tonne) for a precommercial thinning because the cost of manual delimbing would not be incurred. Similarly, Hall & Wylie (1996) estimate that the costs of a small feller/chipper/ forwarder operating in early precommercial thinnings would be NZ$30—NZ$35 per green tonne on truck (NZ$70—NZ$85 per od tonne).

To these precommercial thinning costs must be added chipping costs (NZ$10 to NZ$15 per od tonne) and transport costs (NZ$0.5/km/ od tonne) (Hall & Wylie 1996). Assuming an average transport distance of 100 km, transport costs would be about NZ$50 per od tonne. Delivered costs of wood fuel from precommercial thinning could then be in the order of NZ$125 per od tonne.

In comparison, Hall (1995b) describes a range of residue recovery systems which can deliver solid wood, collected from around the edges of landings as part of integrated harvesting systems, for costs ranging from NZ$24 to NZ$70 per m^3 (NZ$55—NZ$160 per od tonne).

When looking at the costs for precommercial thinning for wood fuel it is important to remember that New Zealand forest owners will incur thinning to "waste" costs of about NZ$0.30 per tree if the material is to be left on the ground to rot. This would equate to NZ$15 per od tonne for early precommercial thinning tree sizes and NZ$2—NZ$3 per od tonne for late precommercial thinning tree sizes.

As an additional consideration, Mead (1987) estimated that the cost of replacing nitrogen fertilizer after full-tree harvesting of 8 year old radiata pine precommercial thinnings would be about NZ$200 per hectare (~ NZ$8 per od tonne) and would require about 7 GJ per hectare (vs ~ 450 GJ per ha removed).

There are currently no incentives, grants, or taxation effects that would be available to New Zealand forest owners for supplying precommercial thinnings for wood fuel. However, there is the possibility of a low-level carbon emission tax on industry being imposed before the end of the millennium which would effectively be to the advantage of bio-fuels.

6 Knowledge gaps and problems

Research into the environmental impacts of using precommercial thinnings for wood fuel appears to be well underway in New Zealand. Having little precommercial thinning operational experience within New Zealand, however, means that there are large knowledge gaps in relation to what are the most appropriate systems to use - particularly for early precommercial thinnings - and what are the overall economics of such operations. Sharing knowledge through the IEA project may be the most appropriate way for New Zealand to easily acquire this experience. On the other hand, as long as there is likely to be lower-cost wood available from integrated clearfell harvesting operations and clearfell residue recovery operations, it may be some time before the potential for using precommercial thinnings for wood fuel is realised.

Competition for the precommercial thinning resource from conventional fibre recovery operations may also limit the opportunity for using it as wood fuel. In recent years a number of markets have sprung up for what were once considered to be waste products (e.g., bark).

7 Conclusions

Precommercial thinning of New Zealand's planted production forests for wood fuel could provide over 7 % (~ 400 PJ) of New Zealand's energy needs between the years 2000 and 2010. The dispersed nature of the resource, the likely environmental impacts, the availability of substantial quantities of lower cost residue from clearfell harvesting operations and the competition for the resource from conventional fibre users may result in the potential not being quickly realised.

8 Acknowledgements

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Review of wood fuel from early thinning and plantation cleaning in Sweden

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Abstract

Cleaning is carried out in order to influence the competitive situation in a stand with the aim of controlling the distribution of volume growth and the quality of timber. Today, cleaning is conducted on about 200 000 ha per year in Sweden, most of which is cleaned motor-manually. The degree of mechanization is less than 1 %. The biomass content of a cleaned stand is generally low, ranging from 1 to 2 tons dry matter per ha, but in certain stands it can amount to over 20 tonnes per ha. The main motivation for removing biomass from a cleaned stand is the possibility of reducing overall cleaning costs. Few studies have been made on the environmental effects of the biomass removal in connection with cleaning. Studies made in connection with thinning, primarily of conifers, indicate that negative effects such as increased soil acidification, reduced pools of base cations and nitrogen losses, can occur. It should be possible to compensate for these undesirable effects through measures such as fertilization or ash recycling. Estimates of impacts on the flora and fauna suggest that effects are small and reversible. However, certain biotopes require special attention. Cost and performance studies indicate that it can be profitable for individual landowners to remove biofuel from very tall, dense stands, whereas better technology is required for more commercial operations. The development of such techniques is under way today. For large-scale removal of biofuel in connection with cleaning, simple forecasting tools will have to be developed that can help in determining when and where biomass should be removed. The decision should be based on economic, ecological, and technical considerations. Furthermore, thorough analyses of the effects on the nutrient balance need to be made, and any reductions in the quality and growth of timber need to be quantified.

1 Introduction and background

The terms "precommercial thinning" and "plantation cleaning" have traditionally referred to thinning a young stand without utilizing the stems removed. The term "commercial thinning" generally refers to thinning operations carried out in older stands where the timber removed is utilized. *In the following text the term "cleaning" refers to both plantation cleaning and precommercial thinning while the term "thinning" refers to commercial thinning.*

The tree species under consideration are Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and birch (*Betula* sp.). Conversion figures for assortment transformations are given in the following table:

	Loose m^3	Dry tonnes	MWh	Solid m^3
1 loose m^3	1	0.17	0.8	0.4
1 dry tonne	5.9	1	4.72	2.36
1 MWh	1.25	0.21	1	0.48
1 solid m^3	2.5	0.42	2.1	1

2 Biological and economic motivation for cleaning

Plantation cleaning primarily aims at reducing the negative effects of birch competition in the future stand, which generally consists of pine and spruce. Cleaning is carried out before serious damage occurs to the conceived future stand and sometimes needs to be repeated one or several times during the rotation. In connection with the cleaning of pine or mixed stands, hardwood species are generally left in openings and in wet areas. In cases where plantation cleaning is carried out with the aim of favouring the spruce component, a larger proportion of hardwood is often left to provide a nurse stand for the spruce seedlings. This shelter protects the seedlings against frost and inhibits stump sprouting. Such a nurse stand is initially relatively dense, approximately 4 000 stems per ha, but thins out with increasing age. Stems removed from the nurse stand can provide a substantial amount of biofuel.

Precommmercial thinning (in the following text called cleaning) is generally carried out once the stand has reached 2 to 3 m in height. This type of treatment aims, among other things, to enhance growth and increase the mean dimensions of the residual stand, favour trees of superior quality and increase the ability of the stand to resist windthrow and snow. The point in time at which the cleaning is carried out and the number of stems left will vary depending on the types of trees present, the site quality and future intentions regarding the stand. In general, spruce is less sensitive to competition than pine, and the density of trees that can be tolerated increases with site quality. If one aim is to produce high quality wood, cleaning is often carried out in several steps, after each of which many trees are left, and the final cleaning is made late in the rotation. In general, the stand density ranges between 2 000 and 3 000 stems per ha after the final cleaning. Fig. 1 exemplifies the consequences of various cleaning regimes. The figure shows the volume distribution in a model stand of pine at a dominant height of 12 m after cleaning to 2 500 stems/ha and after cleaning to 5 000 stems/ha. As shown in the figure a light cleaning results in the volume being distributed among a large number of smaller stems. This leads to higher cutting costs and greater risks for wind and snow damage in connection with the first commercial thinning, but often results in better quality trees, especially in pine stands. The figure is based on Petterson's (1992) functions predicting stand development after cleaning.

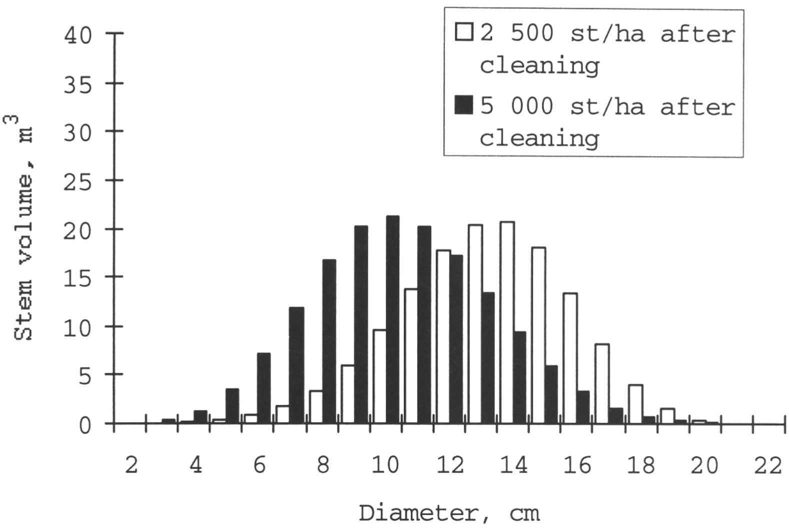

Figure 1. Distribution of volume among diameter classes in a typical stand of pine at a dominant height of 12 m for different cleaning regimes in Sweden.

The trend within Swedish forestry during recent years has been to clean at a later stand age, leaving more trees per ha and an increased admixture of hardwood.

3 Historical perspective

From 1950 to 1980, the area cleaned in Sweden increased relatively slowly but then rose sharply in the 1980s. This sharp rise has several explanations, the most important of which is probably that the use of chemical herbicides for hardwood control was forbidden by law. In 1990, the cleaned area began to drastically decrease, and by 1994 it was back to the level existing prior to the herbicide prohibition (Fig. 2). This reduction can be attributed partly to increased efficiency and cost-consciousness in forest management, as well as to changes in objectives. The decrease is also related to the amount of area subjected to final cutting: In the latter half of the 1970s, the total area on which final cuttings were made decreased from approximately 300 000 ha per year to 200 000 ha per year. This affected the amount of area cleaned after a delay of about 10 years.

Table 1. Height distribution of the stand area subjected to cleaning in Sweden (Bjurulf 1991).

Stand type, mean height	Proportion of area, %
Seedling stage < 1.3 m	23
Thicket stage 1.3—3 m	32
Thicket stage > 3 m	45

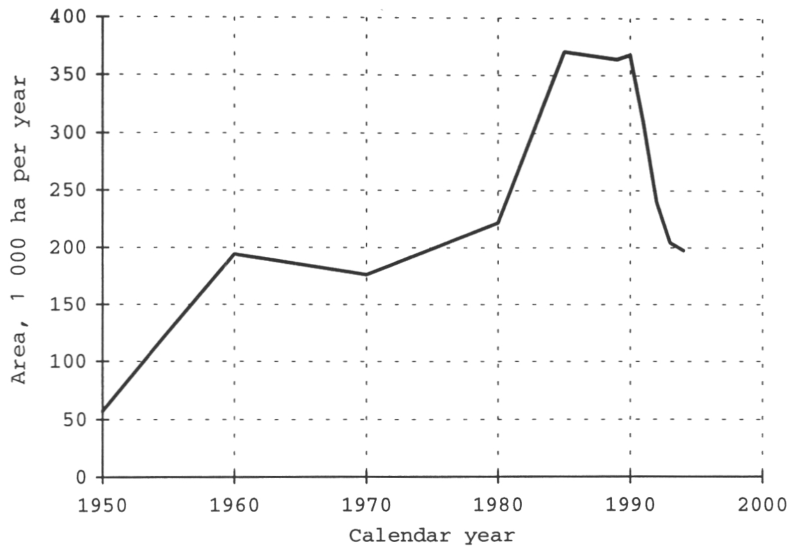

Figure 2. Total area cleaned in Sweden between 1950 and 1994 (for 1950-1970 the figures also include chemical control). Source: Skogsstatistisk årsbok, 1996.

In an analysis of the characteristics of stands in need of cleaning (Bjurulf 1991) the stand types where distributed as shown in Table 1.

Today cleaning is mainly carried out using motor-manual techniques. In the early 1990s, serious efforts were begun to develop mechanized methods, and by the late 1980s and early 1990s, mechanized cleaning accounted for 2—3 % of the total area cleaned. The dominant type of machine is a small thinning harvester with increased ground clearance and with the thinning unit replaced by a cleaning unit.

During the mid-1990s, reduced labour costs and increased availability of motor-manual working contractors resulted in the stagnation of cleaning-machine development, and the use of existing machines decreased. Today mechanized cleaning accounts for less than 1 % of the area cleaned in Sweden.

4 Energy potential from early thinning and plantation cleaning

The volume of wood in stands in cleaning-age is estimated to between 1 and 2 % of the total standing volume. This relation is also mirrored in the yearly cutting volume shown in Fig. 4. The yearly cutting volume in cleaning-stands here represents the potential volume and not the used volume which is much smaller (Berg et al. 1996).

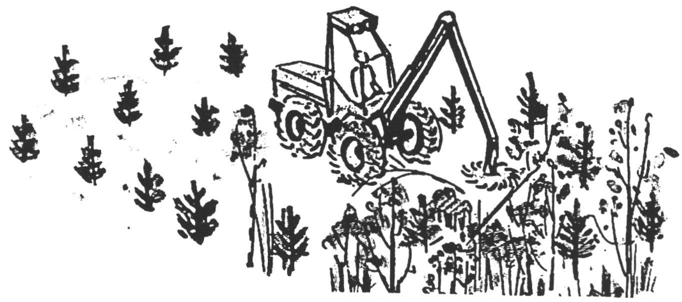

Figure 3. Today less than one percent of the total area cleaned in Sweden is treated with machines.

Marklund (1981) presented estimates of the biomass contents of cleaned stands based on the National Forest Inventory surveys from 1973 to 1977. According to these estimates stands with a mean height less than 1.3 m contain an average biomass of 0.6 tonnes dry matter per ha (these stands are probably of little interest as a source of harvestable biomass). The corresponding biomass in stands greater than 1.3 m in height was 6.0 tonnes per ha. It was assumed that, on average, 1.2 tonnes dry matter per ha cleaned would be available for utilization. Calculations based on the cleaning intensity for 1994 show that the gross amount of biomass removed in the country was approximately 240 000 tonnes dry matter per ha. This corresponds to about 1.1 TWh (0.2 % of the country's total energy consumption or 2 % of all forest fuel). Hektor et al. (1995) assumed that the quantity of wood available through cleaning amounts to about 3 TWh per year which corresponds to approximately 0.7 % of the total energy consumption in Sweden and 6—7 % of the total amount of forest fuel produced.

Recently, there has been a tendency in Swedish forestry to carry out fewer cleanings and to clean stands at a later age. Thus it can be assumed that the amount of biomass per hectare has increased and that the approximations above are too low. Estimates made for single stems indicate that dense stands on high quality sites in middle Sweden which have not been subjected to earlier cleanings can contain large amounts of biomass. According to estimates based on Marklund's formulas (Marklund 1988), and measurements of height and diameter, approximately 20 tonnes dry matter per hectare could be available for removal (Mattsson et al. 1996). Theoretical calculations based on a model stand of spruce, presented by Leijon (1996), indicated that the corresponding amount of biomass that could be removed in practice would amount to approximately 5 tonnes dry matter per hectare in connection with an early cleaning and 10 tonnes dry matter for a later cleaning.

5 Environmental considerations

Very few research findings confirming the environmental effects of biomass removal in cleaned stands have been published in Sweden. General, non-binding regulations concerning the removal of tree parts other than stem wood on forest sites advise that tree parts not be removed in connection with first thinnings on dry

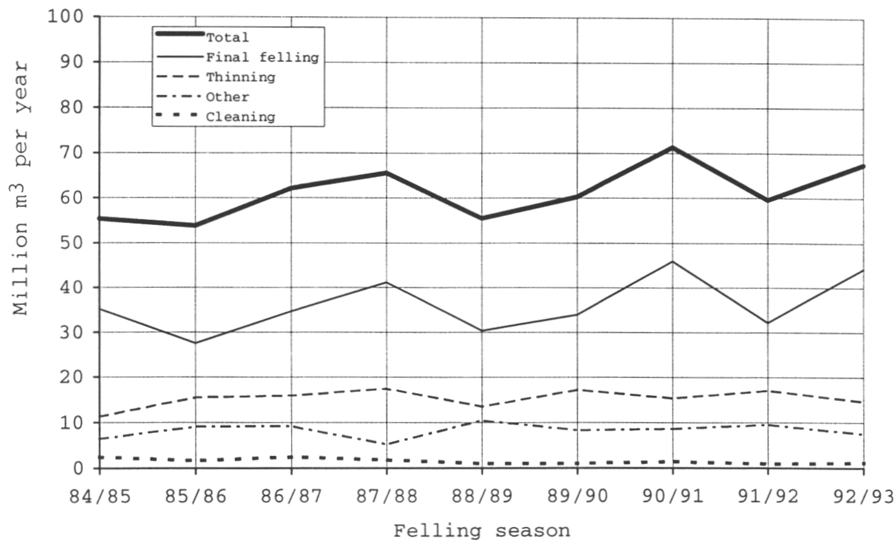

Figure 4. Cutting volume per cutting season (1984-1993) according to the National Forest Inventory stump survey. Source: Skogsstatistisk årsbok, 1996.

or mesic soil of low productivity. No limits are given for amounts of biomass removed in connection with cleaning. These recommendations, however, are being revised, and changes based on new research findings can be expected in the near future. It is likely that these changes will result in fewer restrictions, provided that measures are taken to compensate for losses of nutrients and base cations.

5.1 Growth reductions

Unpublished results indicate that in certain cases the removal of biomass can result in small reductions in the total volume growth of pine. Trials carried out in thinned stands indicate that growth can decrease somewhat 0—3 % (Leijon 1996). Growth reductions in research trials have been greatest on high quality sites and are assumed to be due to the removal of nitrogen (Jacobsson 1996). Taken together, these findings indicate that one can expect cleaning to negatively affect growth.

Growth reductions can also be caused by the introduction of strip roads as well as the use of machines in the stand. Strip roads reduce the amount of timber-producing area. A rough estimate based on Petterson's (1992) functions for stand development after cleaning indicate that strip roads can lead to production losses of up to 5—10 percent of the volume in connection with a first thinning (strip road area 16 %, thinning at 12 m dominant height, SI T-24/G-24, 2 500 stems/ha) after cleaning (SI = Site Index, the approximated height of pine, T, or spruce, G after 100 years).

Andersson (1980) presented an example where yearly growth losses of about 8 % resulted from strip roads combined with stem and soil damage. This effect can, however, be assumed to be less pronounced in connection with cleaning because of the less extensive root systems of the residual trees and the fact that current machines have less impact on the soil.

5.2 Nutrient balance

Effects on the nutrient balance of biomass removal in connection with cleaning have yet to be studied. Simulations and studies of the removal of biofuels in connection with thinning and final cutting indicate that such removal can, among other things, lead to increased soil acidification and a decreased pool of base cations. Therefore to achieve sustainable production compensatory measures are needed, e.g. compensatory applications of chemical fertilizer or ash recycling. In addition, the removal of forest biofuels results in a situation where exports of nitrogen from the stand exceed the amounts supplied through deposition (Olsson, M. et al. 1996).

5.3 Effects on flora and fauna

A reasonable level of biomass removal has only moderate effects on smaller organisms, and is probably reversible. However, some biotopes require special attention. These include abandoned pastures, forest edges, field islands, shores, islands and remnant habitats on forest land. These areas can locally contain large amounts of biomass. In such areas it is recommended that any treatment be made only after consulting with floral and faunal experts (Kruuse 1996).

6 Silvicultural systems and methods

6.1 Stand characteristics before and after cleaning

In general, stands that have been cleaned are often heterogeneous and difficult to describe, especially those subjected to plantation cleaning. An example of this is presented in Fig. 5. The figure is based on studies of automatic data collection in connection with mechanized cleaning (Mattsson 1997) and shows the numerical distribution of stems before subjecting an ordinary stand, with a mean height of 2—3 m, to plantation cleaning. The number of stems was measured in each of 131 sample plots, the positions of which had been determined using GPS. Thereafter the results were interpolated using GIS. The total area of the stand is about 3 ha. In this case there were approximately 10 000 stems per ha before cleaning and 2 250 stems per ha after cleaning. This type of cleaning generally also reduces the mean height of the stand.

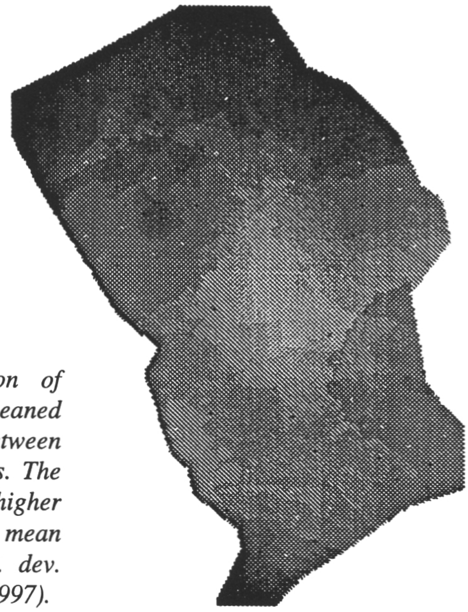

Figure 5. Numerical distribution of stems in a 3 ha stand to be cleaned according to interpolation between GPS-positioned sample plots. The darker the colour tone the higher the number of stems; mean =10 300 stems per ha, std. dev. =9 960 stems/ha (Mattsson 1997).

6.2 Existing technology

The methods used today are of the type where the stems are felled and then extracted manually. Chipping can be carried out on-site as well as at the roadside or at an industrial site.

Gullberg (1989) studied an MB-Trac agricultural tractor with a front-mounted chipper using three different working methods: manual collection followed by hand-feeding, manual collection followed by grapple-feeding, and felling with a felling device followed by grapple-feeding. Studies and operational statistics from a number of various stand types showed that performance varied from about 4 loose m^3/productive hour (felling with a felling device) to approximately 5 loose m^3/ productive hour (hand-feeding). This corresponds to approximately 0.7—0.9 tonnes dry matter/productive hour. The frequency of damage in the residual stand was 2 % with hand-feeding, 8 % for grapple-feeding, and 19 % for felling and feeding with a felling device. Economic analyses of typical stands showed that at 1995 cost levels the method can be profitable at mean diameters equal to and greater than 3.5 cm .

During 1996, the Forestry Research Institute of Sweden (Thor 1996) carried out studies with a Finnish-built chipper, Chipset 563. This chipper has the advantage that it can be fed from both sides as well as from the front. The study gave promising results in low-diameter thinnings. In a stand with a mean diameter of approximately 10 cm at breast height and with 2 700 stems/ha the machine's performance was 20 loose m^3/productive hour (approximately 3.4 tonnes dry matter). Felling and collection were carried out with a single-grip harvester. The results indicate that the technique has good potential even in dense cleaning stands with high average diameter.

Experience from thinning indicates that it is expensive to haul whole trees. Therefore, machines must have a large loading capacity. An increased loading height or extra wagons on standard forwarders (Brunberg 1996) can also provide satisfactory solutions in cleaned stands.

Unchipped material can be stored for up to one year. It is recommended that the stack be loosely packed and exposed to wind. A cover of reinforced paper can be suitable. If the material is to be stored in chipped form one should aim for an initial moisture content of 35 %, a homogeneous fraction size, pure assortments and 6—7 m high, non-compressed stacks (Wigren et al. 1993).

6.3 Future techniques

Future techniques should make it possible to carry out removal operations on a larger scale, with greater demands on profitability. Theoretical proposals and prototypes for development of such techniques exist today. The harvesting and collection of wood pose problems in the development of techniques to be used on a large scale.

Criteria that need to be met by any unit used for removing biomass from cleaned stands are as follows:

- The unit should be able to handle several trees at a time.
- The unit should be able to work continuously.
- The grapple must have a long reach in order to minimize the amount of strip-road area needed and driving-induced damage.
- Machines included in the system must have a low ground pressure.

Jonsson et al. (1992) developed and analysed a number of proposed techniques for harvesting wood in connection with mechanical cleaning. The techniques for cutting were divided up into three groups: (a) a continuous method where wood is directly chipped immediately after cutting, (b) a discontinuous method where wood is collected and chipped by the same machine and (c) separated functions where one machine cuts and collects while another machine chips the material and transports it away. The last two techniques were rejected owing to the risks of visibility problems, ground damage and stand damage as well as the high costs. The analysis resulted in a proposal for continually-operating chipping unit with the chipping unit mounted on the tip of a grapple (see Fig. 6). Theoretical sensitivity analyses of the net costs in relation to variables such as the amount of biomass available, level of efficiency, transport distance over the terrain, energy price and machine and personnel costs indicate that last two mentioned factors (machine and personnel costs) have, by far, the greatest effect on costs.

Work is ongoing to develop a multiple-tree handling unit for carrying out low-diameter thinnings/high-diameter cleanings. These units are to be included in a system with a Chipset chipper or with a slash forwarder.

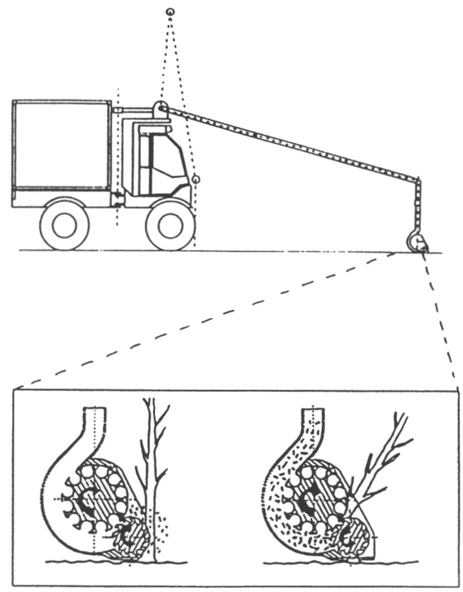

Figure 6. Proposed chip harvester built for use in cleaning (Jonsson et al. 1992).

7 Cost of wood fuel

Danielsson et al. (1990) presented cost calculations based on conditions in southern Sweden. At an arithmetic mean diameter of 5 cm and a transport distance of 30 km to the heating plant, a cost of 220 SEK/solid m^3 biofuel would be incurred which corresponds to a cost of approximately 110 SEK/MWh (cost level for 1990). Costs for less intensively cleaned stands are considerably higher. In Table 2 the costs are itemized.

Danielsson et al. (1990) compared various types of removal in southern Sweden in terms of cost (Table 3). According to this comparison, removal following cleaning is only marginally more expensive than removal following a final cutting. However, it should be pointed out that crushed fuel originating from the removal of whole trees (cleaning, thinning) has a higher moisture content and is therefore of lower quality compared with fuel obtained in other ways. The calculations are based on the following systems:

- Cleaning - motor-manual cleaning followed by chipping with a tractor-mounted chipper and container (MB-Trac.); transport to heating plant.
- Whole trees (early thinning) - felling and collection with machine (FMG 0410), the biofuel forwarded out of the forest and transported to the heating plant via a landing.
- Late thinning - felling and delimbing of trunks with a single-grip harvester; transport out of the stand with a grip-saw forwarder; transport to heating plant.
- Final cutting: Forwarding of slash, chipping and transportation to the heating plant.

Table 2. Distribution of costs by items (Danielsson et al. 1990).

Item	SEK/solid m^3 biofuel
Additional costs for felling	20.4
Removal and chipping	114.3
Transport and drop-off at heating plant	37.2
Financial compensation to landowner	27.5
Administration, 10 %	19.9
Total	218.9

Table 3. Comparison of different methods of biofuel removal in terms of cost to the user in Sweden (Danielsson et al. 1990).

Method	Cost to user SEK/ solid m^3 biofuel
Whole trees, early thinning	180
Final cutting	210
Cleaning ≥ 5 cm dbh	220
Late thinning	240

Prices for unrefined wood have decreased during the last few years. Fig. 7 shows commercial price levels, including tax, for unrefined wood fuel during the period 1985-1995. As shown in the figure, the real price during the period has decreased. According to NUTEK's price sheet nr 1/1997, the price for wood chips during 1996 was, on average, 105 SEK/MWh for industry and 112 SEK/MWh for heating plants.

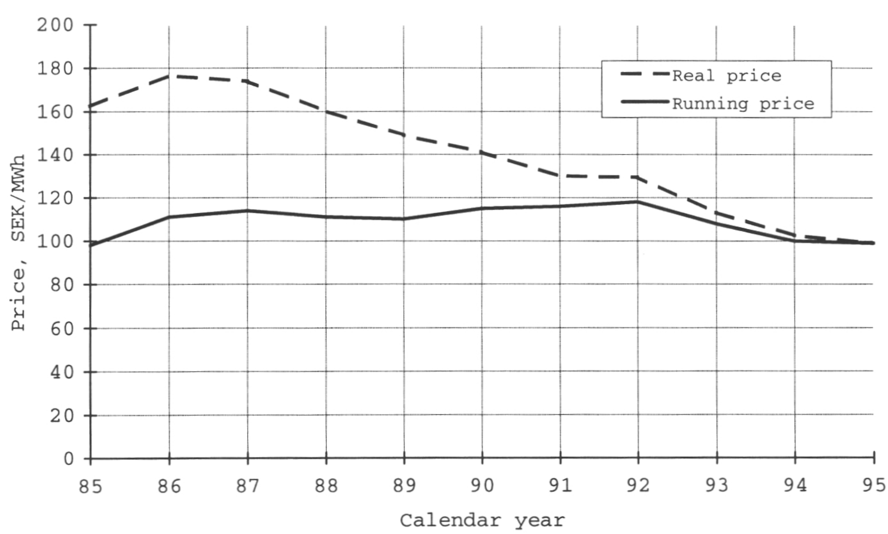

Figure 7. Running and real price, respectively, for unrefined wood fuel in Sweden, 1985-1995, SEK/MWh (Source: NUTEK 1996).

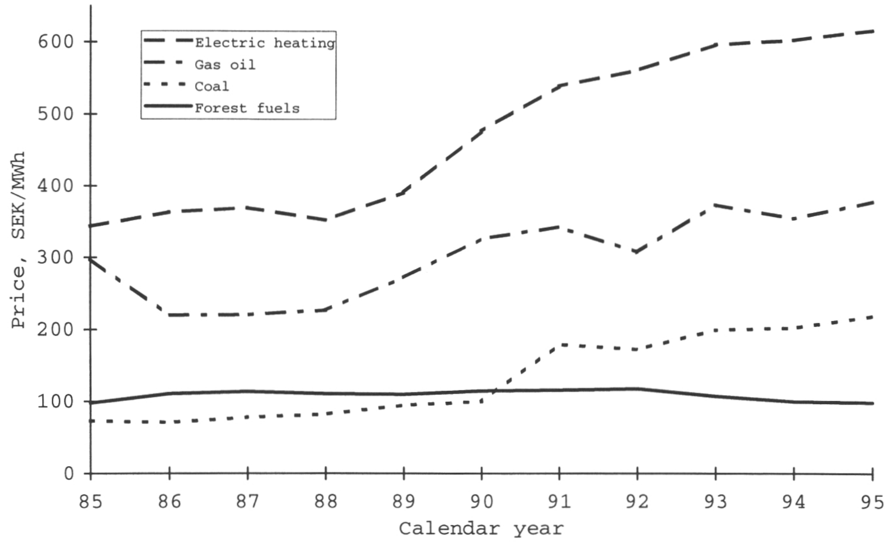

Figure 8. Running price in SEK/MWh for four types of energy sources in Sweden during 1985-1995 (Source: NUTEK 1996).

Fig. 8 shows the current commercial price, including tax, for four types of energy sources. As can be seen, the price trend has been most favourable for forest fuel.

All biofuels are exempt from taxation. In the case of electricity production, the end-user is taxed which is why all fuels used for producing electricity are not taxed. Up until the middle of the 1980s energy prices increased primarily due to price increases for oil. Thereafter taxes have accounted for an increasingly large part of the price (NUTEK 1996).

8 Knowledge gaps and problems

Techniques specially designed for the removal of biofuel in cleaned stands are lacking today. Improvements in techniques or changes in management strategies concerning cleaning will have to occur before the method can become widely accepted and used on a large scale.

Prior to any technique development work, it is important that a survey is made in order to provide the information needed to answer the following questions concerning the type and amount of biofuels that can be harvested:

- What objectives are suitable for biofuel removal?
- How should objectives be chosen in practice? (development of forecasting tools on a local basis)
- What consequences can biomass removal have on future management?

- What is the total amount of biomass that can be removed; what is the optimal amount? (more in-depth analyses on a local basis).

Nutrient balances constitute another important matter that needs to be addressed. The removal of biomass from cleaned stands can, in certain cases, be very large in both relative and absolute terms, and can even exceed the amounts removed in thinnings under some circumstances. The degree to which removing biomass can result in losses of base cations and nutrients in cleaned stands has yet to be determined. Therefore trials aimed at assessing such impacts should be carried out prior to increasing the intensity of removal.

Furthermore the consequences of any measures taken to compensate for losses of nutrients and base cations need to be evaluated. Would the costs for such measures (or, on the other hand, losses in growth caused by not taking those measures) cancel out the savings in cleaning costs gained through the removal of biofuel?

9 Conclusions

The greatest motivation for removing biofuels in connection with cleaning is the potential for the landowner to reduce net cleaning costs. Stands for which biomass removal is currently a viable option are generally dense, with large-diameter stems. Such stands are very expensive to clean; however, the profits from biomass removal can make such operations financially worthwhile. The contribution of biofuel to the total energy needs of the country is small. For the individual landowner, who does not value his work time in the same way as a company, it can be profitable to rely on existing techniques, whereas for removal on a larger scale, simple forecasting tools need to be developed in order to determine where and when removal can be profitable; in addition, effective and environmentally sound methods need to be developed. Effects of any potential removal on growth, quality and the nutrient balance should be analysed. The reduction in overall cleaning costs must be weighed against these impacts as well as against any possible costs resulting from requirements to return nutrients and base cations. In general, removal should not have any large negative effects on the flora or fauna, but on the local level consideration of endangered species and habitats may be required.

The trend today towards carrying out fewer cleanings later in the rotation as well as the admixture of hardwoods in young stands can, in combination with a favourable cost situation, lead to an increase in interest for biomass removal. However, in the foreseeable future, the greatest motivation for biomass removal in cleaned stands will probably continue to be the possibility to limit net costs of cleaning.

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Review of wood fuel from precommercial thinning in Great Britain

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Abstract

There is little wood fuel harvested on a commercial scale in Great Britain presently. This is likely to change in the future as a result of Government legislation. The results of Aberdeen University harvesting trials into wood fuel from early thinnings found that terrain-based whole-tree comminution gave the lowest harvesting costs, with landing-based whole-tree comminution being the next most cost effective method. Integrated harvesting systems are generally the highest cost system for harvesting wood fuel in early thinnings.

Once a stable market requiring a constant supply for wood fuel has been established within Great Britain, it likely that the wood fuel will be sourced from clearfell operations rather than from thinning operations due to lower harvesting costs and the subsequent reduction in future restocking costs.

1 Introduction

1.1 Thinning

The objective of British forestry is to grow high-value sawlogs. This is achieved by close spacing to minimise growth of side branches and ensuring a knot-free stem. As the trees within a stand grow, inter-tree competition restricts individual tree growth. When inter-tree competition begins to severely restrict tree growth at around age 15 to 25 years, thinning of the crop commences.

1.2 Economics of thinning

Thinning may provide income equal to or more than the final clearfell value of the crop within a shorter time period, but in theory this should be a secondary consideration (Hart 1994). Thinning is generally delayed until the trees are large enough to make thinning economical using present shortwood harvesting methods.

1.3 Biological considerations

Delayed first thinning has the danger of letting wind enter through the opened crop canopy with resultant damage to residual stems. Early precommercial thinning can often prevent or limit any wind damage.

1.4 History, current and future status of precommercial thinning for wood fuel in Great Britain

Due to lack of markets within Great Britain for wood fuel, the use of wood fuel from precommercial thinnings or indeed any harvesting operations has been minimal. The recent granting of seven licences under the Non Fossil Fuels Obligation (NFFO) legislation means that in the future there may be a potential market for wood fuel. However, due to the high production costs involved and the environmental implications, it is likely the wood fuel will be sourced from commercial clearfell harvesting operations.

2 Energy potential from whole-tree early thinning

Approximately 15 % of the area under conventional thinning has potential for wood fuel. This would give 7 500 ha/yr at a yield of 50 green tonnes/ha total biomass, resulting in a potential yield of 380 000 green tonnes/yr rising to an annual yield of 610 000 green tonnes/yr by the year 2010 (Mitchell et al. 1990). The greatest quantities of potential wood fuel from early thinnings exist in Scotland which has 45 % of total potential tonnage in the period 1987—1991 rising to 49 % in the period 2002— 2006 (Hudson 1993).

3 Environmental considerations

3.1 Silvicultural basis for thinning

Trees are planted sufficiently close together so that some will become suppressed by their neighbours and ultimately die. If the crop is not thinned this process will occur throughout the life of the stand. In the case of a normal rotation this would represent a considerable loss in volume of merchantable timber. Thinning is therefore required to reduce stand density, thereby reducing competition and providing more growing space for the remaining trees. Thinning also widens the range of choice of future silvicultural operations.

3.2 Environmental impacts

The removal of all above-ground biomass in whole-tree harvesting introduces a number of factors that can affect the long-term productivity of the site (Hudson 1997). Although these factors are greater in whole-tree harvesting in clearfell operations, they are still applicable to a lesser extent in whole-tree harvesting in thinning operations.

The most important factor is the increased nutrient losses. Although it is possible to compensate for nutrient losses by application of chemical fertiliser (Moller & Patterson, 1990), the loss of organic matter cannot be replaced with application of fertilisers (Maliondo et al. 1990). The supply of nutrients from atmospheric inputs and from natural weathering and mineralisation will replace some lost nutrients (Boyle 1976) but the buffering effect of the soil may be adversely affected which may result in reduced acid-neutralizing capability of a given site (Maliondo 1988).

Whole-tree harvesting in precommercial thinning can cause compaction and damage soils. This is due to the lack of the protective cover of the residue slash mat on extraction routes and thinning racks. Soil compaction can indirectly affect root growth by promoting surface runoff and soil erosion and by reducing soil aeration and increasing mechanical impedance (De Vries 1983).

4 Silvicultural systems and methods

4.1 Stand characteristics before thinning

Before thinning takes place the crop will have reached canopy closure, the trees will be approximately 8 m in height and will contain a certain amount of suppressed, dead or dying trees and 'wolf' (leaning or forked) trees. The thinning regime then has to be chosen.

4.2 Stand characteristics after thinning

The objective of thinning is to remove most of the suppressed and sub-dominant trees and also to open up the canopy by breaking up groups of competing dominant and co-dominant trees, thus encouraging the development of the better trees and leaving an open and uniform stand.

4.3 Methods

Due to the lack of markets for wood fuel in Great Britain there are few companies operating wood fuel harvesting operations. Research into wood fuel harvesting was conducted by the 'Harvesting Unit', University of Aberdeen during 1989—1992 with twenty-nine harvesting trials covering a range of tree species, tree size, terrain conditions, and harvesting systems in several geographical locations (Mitchell et al. 1990—1993). The following sections are based on the information and results obtained from these harvesting trials.

Whole-tree and integrated harvesting systems are the comminution systems which are most applicable to conifer early thinnings. Whole-tree comminution can take place at the landing site, with the whole-tree being extracted, or with the use of terrain chippers. Integrated harvesting is the extraction of whole-trees, with product separation at the landing site, with the limbs and tops comminuted for fuel. Both motor manual and mechanical felling are applicable. Extraction is by winch or grapple skidders, with secondary extraction by forwarder if the distance to the landing site is too great.

Table 1. Production rates for whole-tree to landing and terrain chipping systems in the United Kingdom.

Comminution unit	Output (green tonnes/pmh)	Output (green tonnes/year)
Whole-tree - landing:		
Tractor mounted	5.07	6 084
Self propelled	6.97	8 364
Heavy duty trailer	8.05	9 660
Chunker	15.31	18 372
Terrain chipping	9.83	11 796

4.4 Production rates

The limiting factor in productivity of wood fuel harvesting is the output of the comminution unit (Mitchell et al. 1990). Output per productive machine hour (pmh) and annual outputs have been tabulated for each category of unit (Table 1).

4.5 Drying and storage

Storage and drying of the wood fuel, both in the form of whole-trees and as comminuted material, have major implications in the utilisation of available energy (Mitchell et al. 1990).

Three trials of transpirational drying of whole conifer trees were carried out during the summers of 1987 and 1988. Two trials in Sitka spruce thinnings indicated a moisture content reduction of 12 % - 13 % over a 5-month period. A third trial, in lodgepole pine, indicated a moisture content loss of 17 % over a 13-month trial period. Assuming zero dry matter losses, the energy value of the felled whole-trees showed net positive gains of 10 to 14 % (Mitchell et al. 1990).

For a viable wood fuel supply chain, storage of comminuted wood fuel is necessary to give buffer stock for continuity of supply (Mitchell et al. 1990). The changes in energy value of the fuel during storage are influenced by particle size, moisture content, dry matter losses, and the length of storage. Storage has a monetary cost which reflects the method and period of storage. The cost of provision of a storage facility is largely offset by minimising energy loss. This is attributed to the drying effect, with consequent reductions in dry matter loss, achieved by covering the stack. Also, a fuel with a consistent moisture content is likely to reduce capital requirements and increase the efficiency of the boiler plant.

Table 2. Production costs - thinning and clearfell comparison in the United Kingdom.

System	Thinning, £/green tonne	Clearfell, £/green tonne
Whole tree comminution:		
Terrain	3.10 - 6.01	n/a
Landing	6.68 - 15.12	16.88 - 19.04
Integrated	8.41 - 13.94	5.51 - 13.77
Residue	n/a	13.82 - 13.87

5 Wood fuel cost

5.1 Production costs - thinning, clearfell and residue harvesting

In harvesting wood fuel from precommercial thinnings in comparison to clearfells, the price range is significantly different (Table 2). This is due to scale of operations, machine size, machine productivity, and level of operator skill required.

5.2 Incentives, grants and taxation effects

Wood fuel in England and Wales has recently received incentives under the Non Fossil Fuels Obligation (NFFO) legislation. Licences for seven new electricity generation plants (a total capacity of 62 MW) requiring some 700 000 green tonnes per year should result in a stable market for wood fuel. Timber outputs from Britain's forests are exempt from taxation. From the grower's perspective this will also apply to the wood fuel element harvested.

6 Discussion and conclusion

There is little wood fuel harvested on a commercial scale in Great Britain at present. This is likely to change in the future as a result of Government legislation. The results of the Aberdeen University harvesting trials of wood fuel from early thinnings found that terrain based whole-tree comminution resulted in the lowest wood fuel cost with whole-tree comminution landing-based being the next most cost effective method. Integrated harvesting systems are generally the highest cost systems for harvesting wood fuel in early thinnings.

Although terrain-based comminution systems gave the lowest harvesting costs, this is the type of system most dependent on terrain conditions. With much of potential thinnings occurring on the poorer sites within Great Britain, the most effective harvesting method would be whole-tree comminution at landing, as it is less dependent on terrain factors.

Production costs of wood fuel from thinnings will fluctuate throughout Great Britain as a result of variation in species composition and terrain factors. Whole-tree harvesting for wood fuel from precommercial thinnings offers no great economic advantage in cost reduction over the traditional shortwood method. From a silvicultural point of view precommercial thinning needs to be undertaken, but again whole-tree for wood fuel offers no great advantage over shortwood methods, as both aim to leave a open and fairly uniform stand, while traditional shortwood methods have fewer environmental implications.

Once a stable market requiring a constant supply of wood fuel has been established within Great Britain, it likely that the wood fuel will be sourced from clearfell operations rather than from thinning operations due to lower harvesting costs and the subsequent reduction in future restocking costs.

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RESEARCH PAPERS 667

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