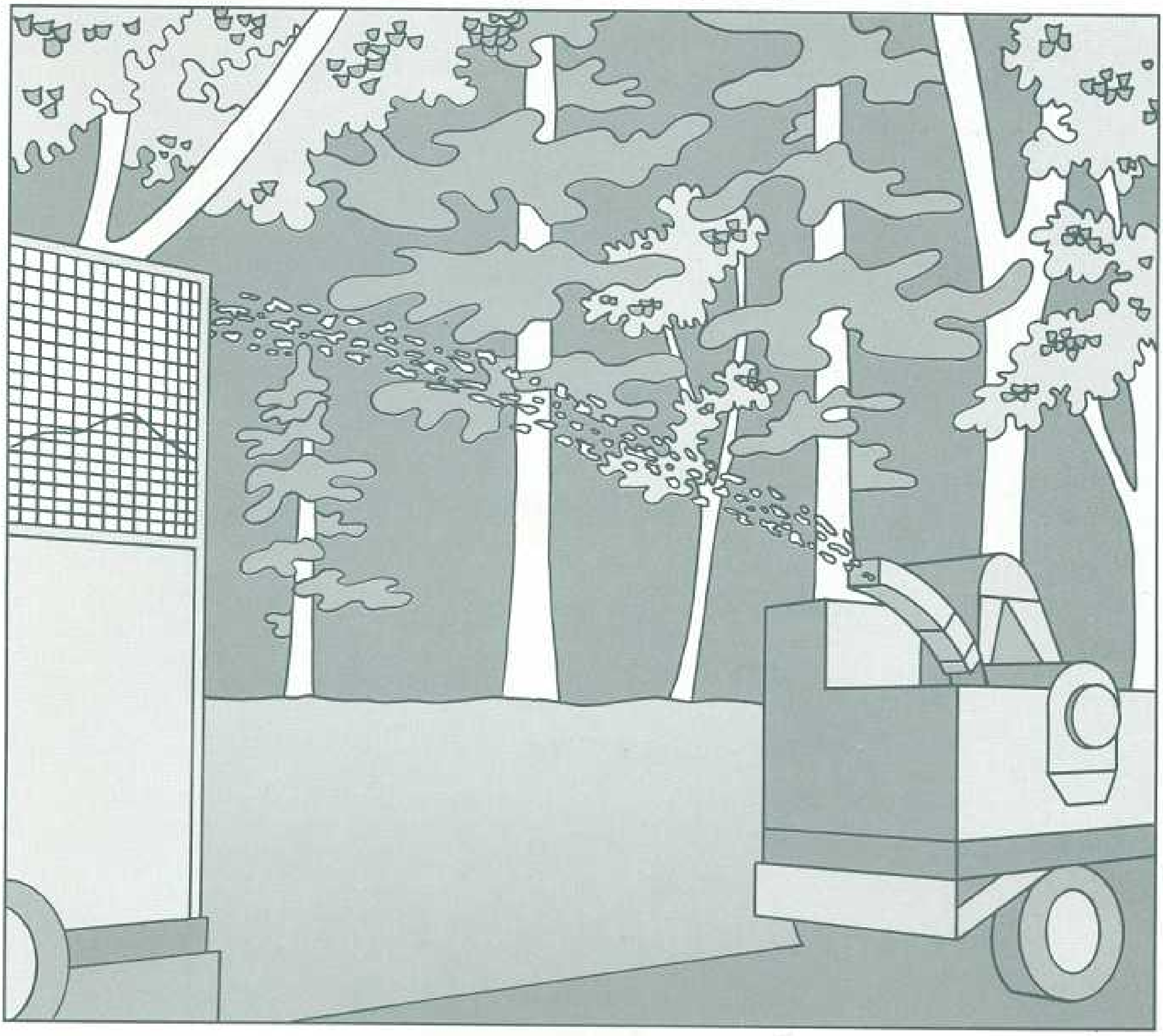
Proceedings of a workshop on forest energy production as a means of improving silvicultural practice

Edited by J. Richardson, Science Directorate, Forestry Canada



Forestry Canada Forêts Canada

Canada

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- il favorise les occasions d'emploi et de formation universitaire et technique dans le secteur forestier
- il encourage les Canadiens à prendre conscience de tous les aspects du secteur forestier.

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International Energy Agency
Bioenergy Agreement, Task VI
Activity 1, Conventional Forestry Systems

Fredericton, New Brunswick, Canada
September 25, 1989

Catalogue No. Fo18-15/1989E
ISBN 0-662-18816-0

Copies of this publication may be obtained free of charge from:

Forestry Canada
Science Directorate
Ottawa Ontario
K1A 1G5

A microfiche edition of this publication may be purchased from:

Micromedia Ltd.
165 Hôtel-de-Ville St.
Hull, Quebec
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Printed on recycled paper

Cover: A Mor-bark 22-inch disc chipper producing "whole-tree chips".

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Preface

Task VI of the International Energy Agency's Bioenergy Agreement is concerned with biomass supply from conventional forestry. Within that context, a number of international collaborative projects (or Activities) have been undertaken. Activity 1 focuses on Conventional Forestry Systems from a silvicultural and forest management perspective.

The objective of Activity 1 is to develop a state-of-the-art review of current forest management strategies and techniques used by participating countries to produce wood for energy in conventional forestry systems. The term "conventional forestry systems" defines systems designed primarily with forest management objectives other than energy production. Specific emphases include:

- forest energy production as a means of improving silvicultural practice;
- changes to forest management and silvicultural techniques necessitated by consideration of forest energy production; and
- silvicultural and management concerns of small woodlots.

A workshop on the first sub-theme—forest energy production as a means of improving silvicultural practice—was held at Fredericton, New Brunswick on September 25, 1989. Six papers were presented by participants from Canada, Sweden and the United Kingdom. These papers have been lightly edited for inclusion in these proceedings.

Additional copies of this publication may be obtained on request from:

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Avant-propos

La tâche VI de l'accord sur la bioénergie de l'Agence internationale de l'énergie traite de l'approvisionnement en biomasse provenant de la foresterie traditionnelle. Dans ce contexte, quelques projets (ou activités) internationaux ont été entrepris en collaboration. L'activité 1 porte sur les systèmes de foresterie traditionnels du point de vue de la sylviculture et de l'aménagement forestier.

L'activité 1 a pour objectif d'établir un aperçu de la situation des stratégies et des techniques d'aménagement forestier utilisées par les pays participants pour la production de biomasse forestière destinée à des fins énergétiques, et ce dans des systèmes de foresterie traditionnels. L'expression « systèmes de foresterie traditionnels » désigne les systèmes ayant pour objectif l'aménagement forestier non consacré à la production d'énergie.
On souligne les sous-thèmes suivants :

- la production de biomasse forestière à des fins énergétiques comme moyen d'améliorer les techniques sylvicoles;
- les changements vers des systèmes d'aménagement forestier et des techniques sylvicoles en réponse aux exigences de la production de biomasse forestière à des fins énergétiques; et
- les intérêts des propriétaires de petits terrains boisés en termes de sylviculture et d'aménagement.

Le 25 septembre 1989, un atelier traitant le premier sous-thème—la production de biomasse forestière à des fins énergétiques comme moyen d'améliorer les techniques sylvicoles—a eu lieu à Fredericton, au Nouveau-Brunswick. Des participants venus du Canada, de la Suède et du Royaume-Uni ont présenté six communications portant sur ce sujet. Ces communications ont été sommairement révisées avant d'être incluses dans le présent compte rendu.

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Acknowledgments

The leader for Activity 1 (and editor of these proceedings) wishes to express his sincere thanks to the local organizer of the workshop in Fredericton, Mr. Gerrit van Raalte, Maritimes Region, Forestry Canada; the management of Maritimes Region, Forestry Canada, for providing workshop facilities in the Hugh John Flemming Forestry Centre; the Scientific and Technical Publications Division, Science Directorate, Forestry Canada for undertaking the publication of this document; the International Energy Agency, Bioenergy Agreement, Task VI; and the Science Directorate, Forestry Canada, for the funding that made this publication possible.

Remerciements

Le chef de l'activité 1, et le rédacteur du présent compte rendu, tient à remercier les personnes et les groupes suivants : l'organisateur de l'atelier qui s'est tenu à Fredericton, M. Gerrit van Raalte, Région des Maritimes, Forêts Canada; la haute direction de la Région des Maritimes, Forêts Canada, qui a offert des locaux pour la tenue de l'atelier au Centre de foresterie Hugh-John-Flemming; la Direction des publications scientifiques et techniques, Direction générale des sciences, Forêts Canada, qui a assuré la publication de ce document; l'Agence internationale de l'énergie (tâche VI de l'Accord sur la bioénergie); et la Direction générale des sciences, Forêts Canada, qui a fourni les fonds nécessaires pour la réalisation de cette publication.

Forest energy production as a means of improving silvicultural practice: The Canadian context

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Abstract

The potential silvicultural benefits of biomass harvesting for energy within a conventional forestry system are explored within the Canadian context. The present level of silvicultural activity in Canada is considered to be at a low intensity, and unused biomass is widely available. Topics for further discussion are presented, including the effects of different types of biomass harvesting, the improvement of the symbiotic relationship between silviculture and bioenergy production, the potentially negative silvicultural aspects of biomass harvesting, and regional differences in silvicultural benefits.

Résumé

Ce document examine les avantages potentiels, pour la sylviculture au Canada, de la récolte de la biomasse destinée à des fins énergétiques, et ce dans un système de foresterie traditionnel. Le niveau actuel de l'activité sylvicole au Canada semble bas; en outre, une grande quantité de biomasse demeure inutilisée. D'autres sujets de discussion sont également suggérés : les effets de différentes méthodes de récolte de la biomasse, l'amélioration du rapport symbiotique entre la sylviculture et la production de la bioénergie, les aspects négatifs possibles de la récolte de la biomasse sur la sylviculture ainsi que ses avantages relatifs pour la sylviculture pour diverses régions.

Forestry production, whether it be for lumber, pulp and paper, energy, wildlife, or recreation, can be considered from a systems perspective. Forest energy production may involve one of two principal systems: short-rotation intensive culture (SRIC), or conventional forestry. The former system is normally dedicated exclusively to energy production. In the latter, bioenergy is normally a by-product, utilizing stand components which would not otherwise be of commercial value. In the conventional forestry system, trees are grown in plantations or naturally regenerated stands for 50 to 100 years or longer at more or less "natural" growth rates. They are harvested by traditional logging techniques, nowadays largely mechanized.

The objectives of growing forests in conventional systems may be timber production, sawlogs or pulpwood, wildlife, recreation, bioenergy, watershed management, or other ends. In any particular situation, one objective may be exclusive. Alternatively, there may be several, of which one may be major and the others of subsidiary interest or importance.

For example, in eastern Canada, a mixed spruce-fir-birch stand of natural origin may be managed primarily for production of spruce pulpwood; but it may also be an important wildlife habitat for deer and moose, with recreational hunting values. The birch component may also be a source of domestic woodfuel or fuel chips for industry. It is in this context that we view forest energy production: as a minor objective within a conventional forestry system.

The purpose of this paper is to explore the potential silvicultural benefits of biomass harvesting for energy within a conventional forestry system. This is done within the Canadian context of widespread availability of unused biomass, and the need for intensified silviculture. Topics for further discussion are also presented.

Forest biomass as a potential energy source in Canada

Canada is a forest nation. Its forests occupy a total of 441 million ha, or about 44% of the total land area (Canadian Forestry Service 1987). The forest types vary according to the geographic region and growing conditions. Boreal coniferous forests predominate in the North and East, with mixed hardwood and coniferous forests in the Maritime Provinces on the Atlantic coast and in the central parts of Quebec and Ontario. Very little remains of the former temperate hardwood forests of southern Quebec and Ontario. West of the Rocky Mountains, coniferous species dominate. These western forests are composed for the most part of species different from those in the East, and are also by far the most productive in the country (Rowe 1972).

The majority (94%) of Canada's forest land is owned by either the provincial or federal governments. Overall, only 6% is privately owned, though the proportion is much higher in the eastern provinces than in the West (Canadian Forestry Service 1987). Forest industry companies generally operate under some form of long-term agreement whereby they obtain the rights to harvest the timber in a specified area in return for payment of a stumpage fee and some arrangement for sustained forest management.

Canada's vast resources of virgin timber are a thing of the past. Most forest resources are now based on second-growth forests or forests which have been already harvested for selected products such as large sawlogs. On these lands more intensive forest management practices are being adopted.

The responsibility for forest management in Canada rests with the provincial governments. The federal role in forestry is one of research and financial support to the provinces to assist them in forest management.

In any consideration of the forest resources of Canada as a potential energy source, it is important to note that the majority of the population of the country which would use the energy is not located close to the source. The vast majority of the Canadian population of 26 million is located within 150 km of the border with the United States, or precisely in the part of the country where there are no forests. The forests that exist in this southern belt tend to be privately owned or reserved for some use other than timber or biomass production.

A national forest biomass inventory was completed in 1985. This included estimates of biomass on less productive or unproductive (in a commercial sense) forest areas, but excluded biomass on lands reserved for purposes other than wood production and harvesting (such as national parks, for example). In total, Canada has at least 26 billion oven-dry tonnes of forest biomass - the equivalent of 82 billion barrels of oil, or enough to meet all of the country's energy needs for 55 years (Bonnor 1985).

Renewable energy accounts for 6% of Canada's current primary energy needs and includes energy produced from forest biomass, the largest single contributor to that category. This is double the estimate of just 10 years ago. The bulk of Canada's energy needs is supplied from the country's large non-renewable energy sources of oil, natural gas and coal (Office of Energy R&D 1985).

Short-rotation intensive culture for bioenergy production has been studied experimentally in Canada, but virtually all forest biomass production for energy comes from conventional forestry systems. As a bioenergy source, SRIC may be an option in the southern parts of the country (or in other localized areas) where energy demand is high and concentrated, suitable land is available, and biomass is not available from conventional systems.

Silviculture in Canada

Intensive silviculture is a relatively new phenomenon in Canada. As recently as 10 or 15 years ago much less site preparation, stand establishment and stand tending were practised than today. The following tables provide a general picture of the present scale and types of activities. The statistics presented in Table 1 are derived from Kuhnke (1989).

Table 1.
Site preparation in Canada (1983-85 annual average)

Method	Area (ha)
Scarification	174 000
Prescribed burning	47 000
Herbicide	10 000
Other	29 000
TOTAL	259 000
(Total area harvested	877 000)

Scarification is the most common form of site preparation. Only 30% of the harvested area receives site preparation. The remainder either regenerates naturally without treatment, is planted without site preparation, or falls into the backlog of unregenerated forest land. Site preparation methods listed as "other" include windrowing, crushing, draining, and lopping and scattering of slash.

Table 2.
Stand establishment in Canada (1983-85 annual average)

Area planted	239 000 ha
Area seeded	32 000 ha
Planting stock production	450 000 000 seedlings

The total area of stand establishment (Table 2) is equal to the area site-prepared annually. Of the seedlings planted, slightly more than half (55%) are bare-root; the remainder are container stock. The most common species planted are white spruce, black spruce, jack pine, lodgepole pine, Douglas-fir, eastern white pine and red pine.

Table 3.
Stand tending in Canada (1983-85 annual average)

Method	Area (ha)
Chemical weeding	102 000
Mechanical or manual weeding	27 000
Thinning	45 000
Pruning	3 000
Fertilization	500
TOTAL	177 500

Although use of chemical herbicides (Table 3) was the most prevalent form of stand tending during the reporting period, the trend is toward greatly decreased use of this type of treatment because of environmental concerns. The thinning statistics refer to pre-commercial thinning or "spacing," which is by far the most important stand tending operation conducted in the eastern provinces, primarily in overdense young stands of natural regeneration. Use of fertilization in forest stands has declined considerably in recent years, largely for economic reasons.

Silvicultural benefits of biomass harvesting

There are a variety of forest management or silvicultural practices which may form part of a conventional forestry system and may be affected positively or negatively by considerations of bioenergy production. Forest management practices include site preparation, stand establishment by seeding or planting, stand tending (including competition control, thinning and fertilization), damage control (whether insect, disease, or fire damage) and harvesting. Only two of these operations and practices normally represent sources of biomass for energy—thinning and harvesting.

If energy production is a minor goal within a conventional forestry system, however, it can lead to a number of potentially significant silvicultural benefits. This is primarily because forest biomass for energy generally comes from stand or tree components which would not be utilized or removed from the site for other uses, and which, if not removed, would represent an impediment or potential hazard for the major objective of the system.

The potential silvicultural benefits of biomass production in conventional forestry systems are many and include:

- slash reduction;
- site preparation;
- control of species composition;
- removing "green junk";
- fire hazard reduction;
- insect and disease control;
- improved economics; and
- improved utilization.

Slash from harvesting, thinning or pruning, when left on the forest floor, is an impediment to further silvicultural treatments. It can be a particular problem after logging, if site preparation and planting are intended. Biomass harvesting for energy often involves the collection and chipping of such material. This process is made much easier and more economical if the slash has already been concentrated at roadside, as in whole-tree harvesting systems. Removing the slash facilitates subsequent access by equipment or planters and often results in improved restocking of the stand. Removing slash from the site, however, has long-term nutritional implications which are not well understood, but could have a negative impact on site quality and should not be ignored.

Several of the other silvicultural benefits of biomass harvesting in conventional forestry systems are related to the reduction of slash. One of these is site preparation, which is implicit in slash removal. In addition, any dragging of tree crowns in whole-tree harvesting, or movement of equipment to collect the distributed logging slash, may create a light scarifying effect on the forest floor, and thus improve seedbed conditions for regeneration.

Removal of all or part of the slash will also improve forest protection conditions. Less dead woody material on the forest floor means a lower fire hazard, a reduced food supply or breeding medium for destructive insect pests which might attack the remaining or new tree crop, and a reduced availability of substrate for fungi.

In some situations, biomass harvesting in conventional forestry systems may go beyond the utilization of slash and include the removal of standing woody vegetation of no "conventional" economic value. Most natural and many managed stands in eastern Canada include species of trees or woody shrubs which are of no value as timber. These might be white birch in Newfoundland, where there is no forest products industry that uses hardwood species. They might be immature dead white spruce stands on Prince Edward Island or low-quality hardwood stands in Nova Scotia or New Brunswick located at uneconomic distances from pulp mills which accept such material. They might be shrubs such as alder or mountain maple in any part of the region. Any or all of these species are candidates for energy chipping.

These stands of low-quality, non-commercial trees and shrubs are sometimes referred to by foresters as "green junk," a term that is apt, in a timber production context. Such stands may have resulted from years of neglect, high-grading or other mismanagement, fire, insect attacks or disease outbreaks. The best way to rehabilitate the site is usually to remove the stand and start with a clean site—a costly operation in most cases. If utilizing green junk for energy is an option, the operation becomes more economically viable, thus creating another silvicultural benefit of biomass harvesting.

Although the complete removal of non-commercial green junk stands does occur in eastern Canada, the more common practice is to harvest non-commercial species together with the commercial ones in the same stand. When, as often happens, the non-commercial species regenerate prolifically if left standing, the integrated harvesting operation may result in the reduction of unwanted competition in the subsequent stand. This is vegetation management without the use of chemical herbicides, a clear silvicultural benefit.

The more general benefits of improved economics and improved utilization are common to all biomass harvesting situations in conventional forestry systems. Whether the combined operation can be justified on economic grounds alone is still a debatable point in eastern Canada; but biomass harvesting could be the difference between success and failure for a marginal operation. When the silvicultural benefits are also included, even though it may not be possible to quantify them in economic terms, the balance will be even more positive.

Topics for discussion

There are a number of questions that need to be considered in the discussion of the silvicultural benefits of biomass harvesting in conventional forestry systems. First, are there benefits other than those discussed above? The preceding paragraphs describe the primary benefits in the eastern Canadian context. There may be further silvicultural advantages evident in other regions or countries. One objective of the present International Energy Agency (IEA) Activity is to determine and assess all the benefits in the participating countries.

Second, are all types of biomass harvesting equally beneficial? Whether it is whole-tree harvesting, integrated harvesting, or residue collection, each type of biomass removal affects the forest stand and site in a unique way. Each has its own merits. In general, the silvicultural benefits will likely be only a secondary consideration in the selection of the harvesting system, with the primary management objectives of paramount concern.

A third intriguing question, which may be of considerable interest, is whether forestry techniques can be modified to improve the positive symbiotic relationship between silviculture and bioenergy production. Clearly, if a silvicultural treatment can be adjusted to enhance the production of biomass for energy purposes without detracting from its forest management goal, this adjustment would be beneficial. Similarly, it may be possible to change biomass harvesting and collecting strategies and again enhance the silvicultural advantage. Such issues remain to be explored in the course of this IEA Activity.

The potentially negative silvicultural aspects of biomass harvesting must not be overlooked. Excessive removal of slash over an extended period can result in a deterioration in site nutrient status. The effect of such removal could be reduced by waiting until foliage has dropped from the slash before removing it; but the long-term effects are not well understood. For species that normally regenerate from seed in logging slash, biomass harvesting may mean a reduction in the amount of natural regeneration. On some sensitive sites, removal of all biomass may expose the forest floor to unwanted soil erosion.

As well as the negative silvicultural considerations, there may be economic disadvantages. Even when potential revenues from the sale of biomass for energy are taken into consideration and the silvicultural benefits quantified, a biomass harvesting operation within a conventional forestry system may still be uneconomical.

Finally, it is necessary to look into differences in silvicultural benefits between countries and regions. Since tree species, stand and site characteristics, as well as silvicultural and forest management practices vary considerably among countries and regions, some of these benefits are likely to appear in a more positive light than others. To add to these physical and management factors, variations in economic conditions, particularly in relation to the feasibility of bioenergy use, bring another element to any consideration of the viability of biomass harvesting.

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Biomass supply from conventional forestry

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Abstract

This paper describes briefly the forests and forest industry of the Maritime Provinces of Canada—New Brunswick, Prince Edward Island and Nova Scotia— indicating the potentially available forest biomass. Operational systems which might be used to obtain energy fiber include silviculture in young stands, early thinnings from plantations, clearing of derelict stands, and conventional harvesting operations. The economics of energy supply will determine how biomass for energy will be produced by means of conventional systems.

Résumé

Cette communication présente brièvement l'état des forêts et de l'industrie forestière des provinces Maritimes du Canada—le Nouveau-Brunswick, l'Île-du-Prince-Édouard et la Nouvelle-Écosse—et elle apporte des précisions sur la quantité de biomasse forestière potentiellement disponible. Les systèmes opérationnels qui pourraient servir à obtenir les fibres à des fins énergétiques comprennent la sylviculture dans les jeunes peuplements, les éclaircies hâtives dans les plantations, le dégagement des peuplements abandonnés et la récolte conventionnelle. L'économie de l'approvisionnement en énergie déterminera le mode de production de biomasse à des fins énergétiques à adopter en ayant recours à des systèmes conventionnels.

First of all, let me welcome you to the Forestry Canada Maritimes Region facilities in Fredericton. The Maritimes Region includes the Canadian provinces of Nova Scotia, Prince Edward Island and New Brunswick. The following is some background on the forests and forest industry in each province.

Nova Scotia

Productive forests cover about 4 million hectares of the province. Thirty percent of this total belongs to the provincial Crown; about 21% to "large" landowners (those owning more than 400 ha each); and 47% to "small" landowners (who own less than 400 ha). The forest industry comprises one pulp mill, three paper mills, one panel board mill, and more than 300 sawmills. Principal species used are red, white, and black spruce (*Picea* spp.) and balsam fir (*Abies balsamina*). The principal silvicultural activities in 1988 were the reforestation of 8000 ha and stand improvement (primarily early cleaning and spacing) of 7000 ha.

Prince Edward Island

Fully one-half of the Island or 270 000 ha is covered with forests. Small landowners, primarily farmers, own 93%; the provincial Crown holds the remaining 7%. The principal species is white spruce, growing primarily in pure stands on old, abandoned farmland. Both spruce and balsam fir are exported overseas as pulpwood. They are also sold to Nova Scotia and New Brunswick as pulpwood, and used in the many part-time small sawmills on the Island. The principal silvicultural activities include reforestation of about 600 ha per year and stand improvement of about 400 ha per year.

New Brunswick

The forests of New Brunswick cover 6 million hectares, of which the provincial Crown owns 50%, large landowners 20%, and small owners the remaining 30%. The forest industry is very important to the economy, employing one out of seven people in the province. The industry comprises five pulp mills, seven paper mills, three panel board mills, and more than two hundred sawmills. The spruces and balsam fir are the backbone of the raw material source, although one pulp mill uses primarily hardwood species. In 1988, 22 000 ha were under planting and stand improvement, primarily in early spring; cleaning was done on an additional 13 000 ha.

Wood for energy production

To date, very little has been done in the Maritimes to produce wood for energy in conventional forestry or harvesting systems. While the potential to do this is very high, as will be illustrated later, the main deterrent is the cost in relation to the price of oil. If oil again rises to $40 (U.S.) per barrel, the interest in wood energy will lead to the development of systems to produce wood for energy as well as for conventional products.

To illustrate the potential, Forestry Canada, under the Energy from Forestry Program (ENFOR), undertook a

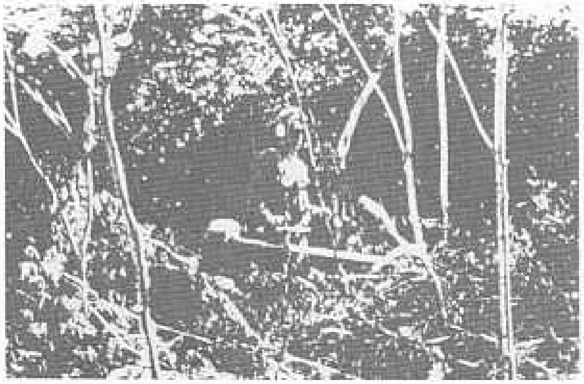

Figure 1. Spacing a 10-year-old northern hardwood stand.

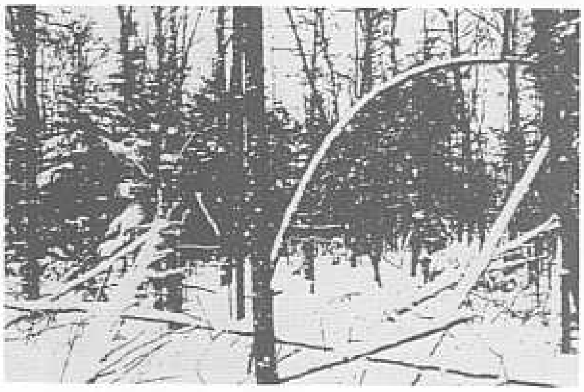

Figure 2. Poorly stocked mixed-wood stand.

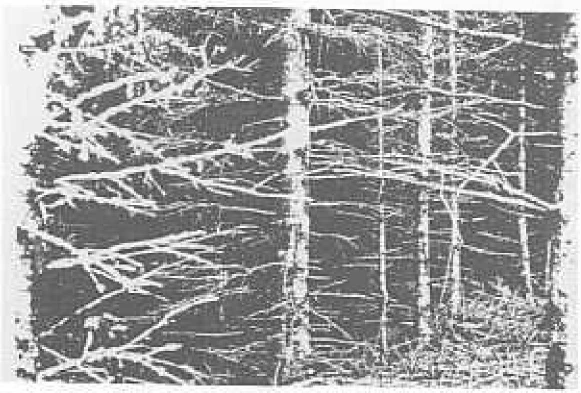

Figure 3. Poor quality "old field" white spruce.

biomass inventory for Canada in the early 1980s. The data presented in Table 1 for the Maritime provinces is from Bonnor (1985).

Table 1.
Biomass inventory in the Maritime Provinces

Biomass Type*	Nova Scotia	Prince Edward Island	New Brunswick
Productive land (t/ha)	88	105	86
Non-productive land (t/ha)	22	56	38
Total non-merchantable (millions of tons)	48	6	85
Total (millions of tons)	325	30	542

* All figures in oven-dry tonnes (ODT).

As can be seen from the table, between 16 and 20% of the total biomass in each province consists of non-merchantable trees. This non-merchantability is due to one or more of the following: small size, non-operable volume per hectare, or species of no present commercial value.

A great deal of forest biomass is produced but left on site under most of the currently used forestry and harvesting systems. In the Maritimes, there are at least four current operational systems that would readily lend themselves to yielding fiber for energy purposes. They are described below.

Silviculture in young stands

In the Maritimes, approximately one-third of the areas harvested regenerate to commercial species but are grossly overstocked. Tallies of over 200 000 stems/ha have been recorded but 20 000 stems/ha is quite normal. To reduce the rotation age, select for desired species and increase individual tree volume, spacing or cleaning (to a management target of 2500 - 5000 trees/ha) is done at an early age, usually 10-15 years (Fig. 1). A very large amount of biomass is thus cut and simply left on site. Attempts have been made to collect this biomass but costs have proved to be much greater than its value as an energy source. Still, the potential exists to mechanize this early spacing operation on suitable terrain and produce biomass for energy to offset the cost of the silvicultural operation.

Early thinnings from plantations

Many plantations are deemed to be overstocked by age 20 either because of initial tight planting, ingrowth of natural regeneration, or a combination of the two. Thinning at this early age yields some merchantable wood (primarily pulpwood) but up to two-thirds of the stems cut are non-merchantable. In fact, during most first thinnings at plantations, up to one-half of the biomass is left behind. This biomass could be easily utilized for energy purposes if the economics for doing so made it practical.

Derelict stands

Many of the forests, particularly in areas of the Maritimes that were settled first, have been subjected to some 300 years of selective cutting or "high-grading." This harvesting method (taking the biggest and best trees and leaving the rest) has resulted in stands of poor-quality, inferior species, and low stocking (Fig. 2). Abandoned farmland that has reforested naturally to "old field" white spruce also presents a problem of product quality (Fig. 3). As well, insects and diseases have played a major role in degrading forest stands and products. In particular, the spruce budworm has killed thousands of hectares of forests in Nova Scotia. Attempts at salvaging this huge volume of wood for fiber has met with diminishing success a few years after mortality.

Harvesting operations

Under the present economic circumstances, the only affordable wood for energy must be produced at the same time as the conventional products. Under the short-wood system up to 30% of the biomass is left on site (Fig. 4). With the full-tree system, the whole tree is transported to roadside (Fig. 5), where it is either trimmed and loaded, with the tops and branches discarded at the roadside (Fig. 6), or processed in its entirety as whole-tree chips for conventional use or for energy purposes.

In conclusion, the economics of energy supply determine when and how biomass for energy is produced through the conventional forestry and harvesting systems. Operational methods are to a large extent already in place under current harvesting systems. With modifications, these systems can and will produce wood for energy. If the price for oil increases again, emphasis will be placed on recovering biomass from silvicultural operations, although under present economic conditions and energy pricing in the Maritimes, this is not happening.

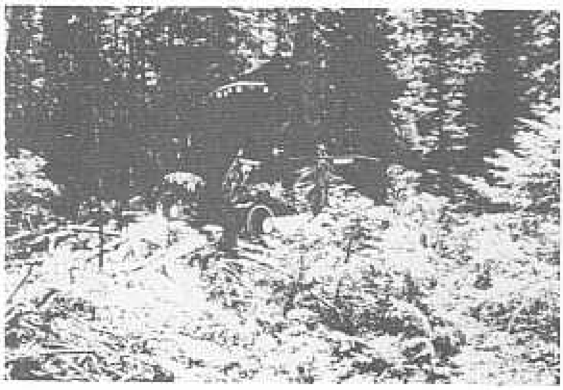

Figure 4. Short-wood felling and processing at stump.

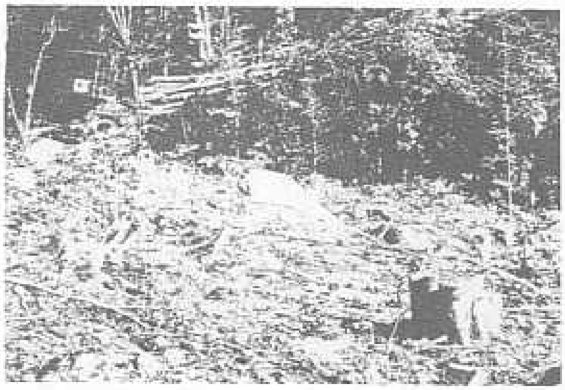

Figure 5. Koehring Feller-Forwarder: the whole tree is transported to roadside.

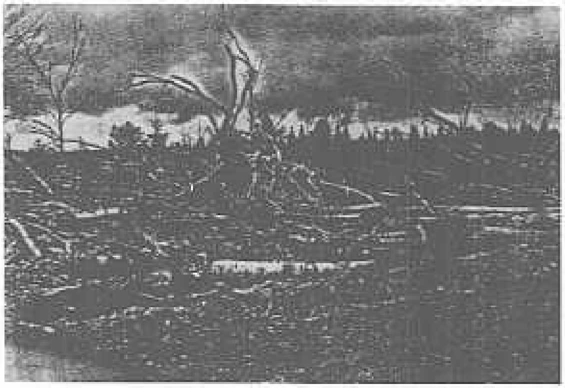

Figure 6. Hardwood tops and branches are left at roadside.

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Forest bioenergy developments and silviculture benefits in Newfoundland

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Abstract

An historical review of government-sponsored incentive programs in support of forest bioenergy developments in Newfoundland is provided. The silviculture benefits derived from whole-tree biomass harvesting operations in stand conversion areas are substantial. The availability of forest biomass for woodfuel and the potential for an expanded woodfuel industry in support of intensive silviculture programs is discussed.

Résumé

Il s'agit d'un compte rendu des programmes d'aide gouvernementaux destinés aux projets de développement de la bioénergie forestière à Terre-Neuve. Les avantages sylvicoles découlant des activités rattachées à la récolte de la biomasse par arbres entiers sur les terrains de conversion des peuplements sont considérables. Le document traite également la disponibilité de la biomasse forestière destinée au secteur du bois de chauffage et de la possibilité d'un développement accru de l'industrie du bois de chauffage lié à des programmes sylvicoles intensifs.

The use of wood as a source of energy is as old as colonization and the development of the fishing industry in Newfoundland. In the 1800s, the value of this resource for fuel and building construction was considered important enough to warrant the establishment of a three-mile limit which reserved the forests within three miles of the coast for use by fishermen. These limits were eventually incorporated into management units and are now subject to provincial management regulations.

The use of fuelwood in the home gradually declined with the advent of cheap oil and a better transportation infrastructure. Not until the energy crisis of the mid-1970s was there a renewed interest in wood as an energy source. At that time, various government programs were initiated to encourage consumers to consider alternative energy sources. They provided grants to homeowners for the installation of solid-fuel stoves. At the same time, pilot projects and studies were undertaken to encourage the industrial sector to convert to wood.

Today, more woodfuel is consumed annually in this province than ever before. The most recent figures estimate that roughly 710 000 m^3 of solid wood and sawmill residue is consumed for fuel, of which approximately 90% is for residential use (Northland Associates Ltd. 1988). Commercial whole-tree chipping operations are presently producing approximately 60 000 m^3 annually. This figure is expected to double with the start-up of a 5Mw wood-fired electrical generating station in Roddickton.

The forest management and silviculture benefits of the industrial woodfuel industry are significant. In remote regions of the province alienated from the pulp and paper industry foresters have been able to integrate biomass harvesting with conventional sawmill operations to utilize both mill and logging residue. The biomass woodfuel industry also has been able to use non-merchantable timber from "junk" stands, enabling foresters to clear these areas cheaply and convert them to high-value spruce plantations. These benefits neatly complement improved utilization efforts made difficult by extensive forest management in the past, coupled with ravages by insects, disease and fire. These events have created a forest resource of poor fiber quality, which to some degree is not usable by conventional forest industries.

Government-sponsored incentive programs

The energy crisis of the mid-1970s sparked a major effort of the Canadian government to reduce Canada's dependency on imported oil. Through departments such as Energy Mines and Resources (EMR) and the Canadian Forestry Service (CFS), programs were established to encourage large industrial, institutional and residential fuel consumers to consider wood as an alternative energy source. These federal departments worked with provincial line departments like Mines and Energy, and Forestry, as well as the forestry industry, to develop a commercial woodfuel industry in the province. Over a period of years, a total of eight programs and funding sources were identified.

Each program had unique objectives directed toward research and technology transfer in specific areas. Of the eight available funding sources, two programs (FIRE and Class 34) were not accessed by the eligible parties. The most active and productive programs were CREDA, ENFOR, COSP and the Forestry Agreements. The RCDP and BDP provided some funding for demonstration projects in remote communities and two peat-related programs.

Table 1.
Government-sponsored incentive programs

Acronym	Program	Duration
CREDA	Conservation and Renewable Energy Demonstration Agreement	1979 - 1985
ENFOR	Energy from the Forest Program	1978 - present
COSP	Canada Oil Substitution Program	1980 - 1985
FIRE	Forest Industry Renewable Energy Program	1979 - 1986
RCDP	Remote Community Demonstration Program	1982 - 1989
Class34	Tax Incentive Program	1976 - present
BDP	Bioenergy Development Program	1984 - 1988
FSA I	Regional Development and	1974 - 1980
FSA II	Subsidiary Agreements	1981 - 1986
FRDA	Federal/Provincial Forestry	1986 - 1990

The accomplishments of the most active programs are described below.

- CREDA Provided $1.8 million in funding toward technology transfer creating job opportunities, education and construction of at least three major pilot conversion programs.

- ENFOR Provided $2.2 million for research and development and technology transfer in the field of biomass supply. Initiated by the Canadian Forestry Service (now Forestry Canada), this program has funded 54 contracts under 19 identified projects.

- COSP Provided $10.0 million for grants to homeowners toward the purchase of solid-fuel units and home insulation improvements.

- FRDA FSA I FSA II The Federal-Provincial Forestry Agreements provided funds for numerous trials to assess the operational and economic aspects of forest biomass harvesting systems.

As a result of the combined effects of these programs, an industrial woodfuel industry has been established and continues to expand despite much lower oil prices in recent years. At present, six industrial and commercial establishments are burning approximately 50 000 green tonnes of whole-tree woodchips annually (Table 2). A third hospital and the 5Mw electrical generating station mentioned above were scheduled for start-up in late 1989 (Figure 1). They will create an additional demand for 54 000 green tonnes annually.

Figure 1. Location of industrial woodchip biomass users in Newfoundland.

Table 2.
Industrial and commercial woodchip fuel consumers in Newfoundland (Northlands Associates Ltd. 1988)

Sector	Facility	Approximate annual consumption (green tonnes)
Public	Western Memorial Hospital	10 000
	James Paton Hospital	3 000
	Central Regional Hospital*	4 000
	Eastern Community College	480
Commercial	Newfoundland Hardwoods Ltd.	4 000
	Natural Enterprises Ltd.	25
	Roddickton Electricity Generation Station*	50 000
Forestry Industry	Abitibi-Price Inc.	33 000
Total		104 505

* In start-up phase at time of writing.

Forest biomass harvesting operations

The first whole-tree chip-harvesting operations in the mid-1970s were carried out by the pulp and paper industry in pure and residual stands of white birch. These were large operations consisting of 28-inch Mor-bark disc chippers supplied primarily by cable skidders hauling whole trees to roadside. These operations supplied the large fuel demand of the pulp and paper industry at that time.

In more recent years, the advent of smaller woodchip-burning facilities has seen the introduction of scaled-down operations suited to the needs of smaller markets. These operations utilize both smaller chippers and smaller-dimension wood residue. Many have been integrated with conventional sawlog and pulpwood harvesting operations utilizing small stems, tops and branches as a by-product. Only the larger facilities such as the Abitibi-Price mill at Grand Falls, the hospital at Corner Brook and the generating station at Roddickton derive a portion of their fuel supply from independent harvesting operations where non-commercial or junk stands are utilized.

Availability of forest biomass

In response to concerns by the forest industry over interim wood supplies during the next 20-40 years in Canada, one prominent Canadian forester, Dr. Gordon Baskerville, recently commented that in Canada we do not have a fiber shortage, we have a "quality fiber" shortage. That is, even though economic softwood supplies of spruce and fir feeding conventional sawmills and pulp mills are in short supply, supplies of biomass fiber from non-conventional sources such as hardwoods, tops, branches, and small stems are more abundant.

The forests in Newfoundland and Labrador are similar to those in many other boreal regions of Canada. These forests have been affected by a range of natural phenomena such as fire and insects, as well as by several decades of extensive forest management practices. Until recently, the forest industry relied solely on natural regeneration to restock its cutovers. This reliance has resulted in greater species diversity and generally poorer quality stocking than existed in original stands which evolved over long periods of time. The uncontrolled mix of natural and artificial phenomena has reduced the quality of the forest resource significantly and created a resource that is increasingly unusable by conventional forest industries. It is, however, ideally suited for use in biomass woodfuel industries.

Although no province-wide survey to determine the volume of the available biomass in Newfoundland has been carried out, a 1985 survey conducted by Woodlot Services (1978) Ltd. identified large volumes of economic biomass within an 80-km radius of four major centres. On the basis of probable demand levels for each centre, the survey identified standing biomass volumes of more than 5.4 million green tonnes which could supply each centre for periods ranging from 15 to 65 years (Woodlot Services Ltd. 1985). These estimates did not include annual growth increments or logging residues from conventional harvesting operations.

Many foresters feel that the results of this survey closely depict the situation in many areas of the province; however, because of the remoteness of many rural areas, the economic availability of these resources is questionable. Experience has shown that the most economical sources of biomass woodfuel are pure stands of hardwood close to the conversion facility. Lower-volume stands (insect-damaged, high-graded, residual) are less economical. Logging slash left on cutovers is the most costly to recover.

Silviculture benefits

The development of the existing biomass woodfuel industry in Newfoundland and Labrador has been rationalized by the need to find new and cheaper energy sources and, most important, by the need to create employment in one of the less developed regions of the country. The silviculture and forest management benefits derived from such an industry have not been a significant factor in rationalizing conversions to woodfuel; and although the silvicultural benefits have been discussed from time to time, the economic value of these benefits has not been identified.

Nonetheless, foresters are generally aware of these benefits when trying to cope with regeneration problems imposed by large volumes of slash left on cutovers or very large volumes of residue on potential site rehabilitation areas. Alternative silviculture treatment options to deal with these problems are often logistically complex and very expensive.

Because the forest industry derives its wood supply from natural stands, and because provincial stumpage and merchantability policies provide little incentive to use fiber fully, many cutovers are left with large volumes of slash and non-merchantable residual stems. Cutovers that require immediate treatment must be either slash-raked (cost: approximately $280/ha) or broadcast-burned (approximately $150/ha). The latter treatment is the only option on rough ground, but is also unreliable because of its dependency on favourable weather conditions as well as its relatively higher element of risk.

The most difficult and expensive siliviculture treatment practised in the province is the clearing of junk stands and their conversion into spruce plantations. Since 1979, approximately 14 000 ha have been cleared at a cost of roughly $16 million (Alexander 1989). Additional site preparation treatments like slash raking and window burning on these cleared areas added costs of more than $3 million before they could be planted. This total investment of roughly $19 million (or about $1357/ha) represents the cost incurred to prepare those lands for planting.

Full-tree biomass harvesting operations produce equivalent clean cutovers for few or no silvicultural costs. A comparison of several treatment options for reclaiming backlog forest lands has shown that biomass harvesting is the least expensive option (Alexander 1989). The irony is that the current lack of markets for biomass woodfuel in many areas keeps full-tree biomass harvesting from being an option.

Future forest biomass utilization

Bioenergy developments are difficult to predict because of uncertainty over future world energy production and demand. Even if energy prices rise in the next few years, they may not spark the worldwide search for alternative energy sources of the mid-1970s. In all likelihood, future increases will be more gradual. Therefore governments are unlikely to sponsor these kinds of incentive programs for conversion to woodfuel.

Future forest biomass developments will be more difficult to justify on the basis of fuel prices alone. For this reason, other factors such as employment generation and forest management benefits will have to be included in the overall analysis.

In recent years, reforestation efforts on Crown land have relied on site clearing of backlog areas to accommodate more than 50% of the annual planting program. Given the need to continue site reclamation programs, solving the problem of how to clear these backlog sites and, in particular, how to cope with their large volumes of unmerchantable residue, is one of the major challenges facing foresters.

One solution would be to find new markets for the biomass. It is only logical for the forestry sector to make known the benefits of biomass woodfuel harvesting and encourage the development of biomass markets. Financial incentives similar to those provided for job creation programs would have a significant effect on the overall cost-benefit analysis of woodfuel burning installations. The many benefits—year-round employment opportunities, dollars kept in the provincial economy as opposed to invested in foreign oil, and rehabilitation of productive forest lands—provide a strong argument for continued investment in the biomass woodfuel industry.

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Restocking of conifer clearfell in the United Kingdom

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Abstract

Restocking methods from the 1950s through to the present time are described. Treatments have changed from hand heaping and burning to the current intensive use of Scandinavian scarifiers and mounders.

Current restocking programs involve 8500 ha of Forestry Commission land and 4800 ha of private woodlands. These are dealt with in a variety of methods dependent on the harvested conifer species, terrain type and size of area.

Mechanized systems are generally in use for site preparation, and stock is principally bare-rooted and planted by hand.

Résumé

Le texte passe en revue les méthodes de reboisement utilisées depuis les années 50 jusqu'à aujourd'hui, de l'empilage-brûlage à main de rémanents à l'utilisation intensive de scarificateurs et de machines à buttage scandinaves modernes.

Les programmes actuels de reboisement touchent annuellement 8 500 ha des terres de la *Forestry Commission* et 4 800 ha de terrains boisés privés. Les techniques utilisées varient selon les espèces de conifères récoltées de même que le type et la superficie du terrain à reboiser.

En général, le terrain est préparé au moyen de systèmes mécanisés, et le matériel de plantation est habituellement à racines nues et planté à la main.

Introduction

In the 1950s clearfelled conifer sites were cleared of brash (slash) by heaping it up by hand and burning it. Mechanical assistance was used very occasionally. In general, the areas were small (under 10 ha), and had mostly Scotch pine or larch as the first crop. This method was very expensive, so that as the areas to be worked increased in size, and Sitka spruce, with its greater weight of brash, became a larger percentage of the species area, the need for clearance was questioned.

The loss of nutrients, the danger that newly planted stock could be destroyed by browsing, the increased weed growth and the possibility of creating disease centres on the fire sites had to be balanced against the advantages. These were the reduction in insect pests, ease of access for cultivation and more successful cultivation. By the end of the 1960s and early 1970s, debris was no longer burned. Pine sites were treated by brash chopping or ploughing through, and spruce brash was windrowed to create clear ground for planting as well as an extraction route on wet sites. On spruce sites, planting was carried out with bare-root stock straight through the brash; there was also some container planting of Scotch pine and Corsican pine.

On many upland and lowland sites the results of restocking were unacceptable. Survival was poor and several beating-up (replanting) operations were necessary. Delayed establishment of the new crops increased the weeding costs and the potential for browsing so that restocking became a very expensive operation. Research investigations indicated numerous causes for these crop failures and an upland restocking group was formed in 1982.

Subsequently, a special project team was formed answering directly to a [Forestry] Commissioner. It consisted of a silviculturalist, and entomologist, a physiologist and a workstudy team member. The restocking work was given the highest priority. Some old truths were recognized and reinforced, and everything from plant quality, storage and packing of plants, to site treatment and protection methods against insects and browsing animals, was investigated. Standards were decided upon and brought into force through special support training sessions (Tabbush 1988). A test of the results was to be carried out in 1989: but a subjective assessment of an area where crops were poorly stocked after six years, found crops to be thriving in half that time.

Current methods will be described for the two principal site types: dry East-coast pine and upland gley Sitka spruce. Supporting evidence from experience and comments on the potential are given where complete harvesting of biomass takes place, as described by Hudson et al. (1989).

Dry East-coast pine sites

Brash

Pine brash (Scotch, Corsican and lodgepole) is brittle and easily chopped by low-powered machinery such as the Wilder Rainthorpe. Some commercial harvesting of the brash has taken place in the largest lowland pine forest, Thetford Chase. Relevant details are given by Hudson et al. (1989). In certain sections of the forest, where a butt rot (*Heterobasidion annosum*) has caused severe damage in the previous crops, the stumps have been extracted. Both stumps and brash are stacked in windrows. The stumps are not harvestable because of their high silica content and the flints embedded in their root systems.

Cultivation

Dry heathland sites are easily cultivated, either with or without brash treatment, either by means of conventional afforestation ploughs (Tailor, G. G. M. 1970), or, as at Thetford Chase, a shallow screefing plough. On the lowland heaths, Corsican pine is the main replacement species. It is grown in Japanese paper pots and planted by machine (Finnplanter).

In the 1970s, upland heaths were frequently completely ploughed, or ploughed and ripped, and replanted with Sitka spruce. The numerous types of disc or hoe-type scarifiers imported from Scandanavia deal easily with pine brash (Nelson and Quine 1989, Chadwick 1989a).

Other treatments

Grass is the principal weed on lowland heaths. Because of the easy access, tractor-mounted boom sprays are used for the application of herbicides.

Upland heaths revert quickly to heather (*Calluna vulgaris*), which induces nitrogen deficiency if the heaths are replanted with spruce. This condition can be alleviated through the application of either the herbicide glyphosate (to kill the heather), or a nitrogenous fertilizer (usually prilled urea).

An attempt to convert nutritionally poor upland heaths, which have grown low-yielding Scotch pine as a first crop, to high-yielding spruce sites through deep, complete cultivation, has led to expensive ameliorative treatments. The rapid mineralization of the thin organic layer, followed by a re-invasion by heather, has produced chronic nitrogen deficiency in these soils.

Apart from the use of nitrogen described above, there is generally no requirement for fertilizers. Even when the first crop may have required phosphate at planting it is not necessary to monitor crop deficiency for 8-10 years (Taylor, C.M. 1989).

Upland gley Sitka spruce sites

Introduction

Nearly all of the crops now being restocked on this site type were planted on ground ploughed either at a 4.5-m spacing and turves spread, or at a spacing of 1.5 m. The introduction of the Cuthbertson drainage plough in the mid-1940s led to deeper furrows and larger ridges. While this type of ground preparation resulted in improved early growth we now know that it also produced laterally restricted root systems (Booth 1974; Saville 1976). This problem, combined with the shallow rooting on these gleyed soils, produced crops prone to windthrow and shortened rotations.

Ploughed ground, wet sites and frequently upturned rootplates hinder access and greatly affect future management systems.

Brash

The quantity of brash varies according to the age and stocking of the previous crop and the method of working. A recent study in Kielder Forest of an unthinned Sitka spruce crop, with 4500 stems/ha and a standing volume of 330 m^3/ha, gave the following yield (48% moisture content) of residues after harvesting:

- material for chipboard, top diameter 3 cm (includ ing dead trees), 100 tonnes/ha;
- material for pulp, 3 m x 6 cm mean top diameter (no dead trees harvested), 135 tonnes/ha; and
- simulated mechanized pulp harvesting (trees less than 10 cm dbh were not processed, nor was dead material), 200 tonnes/ha (Chadwick 1989).

Studies in which the brash was chopped up were never satisfactory. A wide range of equipment was used, and either traction was a problem or the chopping blades could not deal with the dense, springy, tough spruce brash. The felling system windrowed the material to give access routes to harvesting machinery; the timber was stacked in the alternating bare strips.

Planting in the brash zones was extremely difficult. Stocking densities as low as 1000 plants/ha were recorded when the aim was 2000 to 2500 plants/ha. A large-scale beating up operation was frequently necessary in year 3 when the brash had settled.

An experiment to examine the effects of planting in the bare strips, in the brash zone, or with complete removal of the brash, gave the following mean heights after 3 years:

Falstone experiment 7 P 81

Brash strips	Clear strips	Complete clean
0.86 m	0.76 m	0.68 m

Cultivation

After clearfelling, these upland gley sites rewet, producing anaerobic conditions very close to the surface. Drying and warming frequently start in May; rewetting occurs in September. The Research Branch has always recommended planting on a raised site and mound planting for improved root architecture (Tabbush 1988). The improved aeration and warmer temperatures encourage root growth and better survival (Ray and Nelson 1989).

In an attempt to increase the plant stocking, to provide easier and cheaper planting in the brash zones, and also to produce the recommended mound size, numerous pieces of equipment have been tried in recent years. A paraphrase of Chadwick (1989a) summarizes the trials to date:

> Machines capable of producing such mounds (Tabbush 88) are: backhoe diggers, used to drain and spread drain spoil as mounds and continuously acting mounders such as the Sinkkila, Bracke and Donaren mounders. These three machines work well on clear ground, but in dense slash they simply rearrange it and expose natural raised sites such as plough ridges and the stumps of the previous crop.
>
> Workstudy has evaluated machines in field trials, operational costs are likely to be around £100/ha for a combination of mounding plus exposing natural planting spots in patches of dense slash.

An example of the effect of cultivation on planting is given in the same paper (Table 1).

With a labour cost of 6.0p per standard minute and a labour on cost of 100%, using drain and mounded area planting times as standard, the *additional* costs of planting various site types are:

Sinkkila mounded site	£16.20/ ha
TTS Delta scarified site	£19.00/ ha
No ground preparation	£75.00/ ha

Table 1.
Effect of cultivation on manual planting of Sitka spruce on restock sites

Ground preparation pattern	Planting time in standard minutes/ha (2500 trees/ha at 2 x 2 m spacing)
No preparation (1)*	1479
No preparation (2)*	1411
Scarified with TTS Delta (3)	980
Scarified with TTS Delta (2)	962
Drain and mound (Backacter)	811
Sinkkila mounded area (2)	946

Notes:
(1) Times from Replanting Output Guide 1.
(2) Times from studies undertaken during project.
(3) Times from Replanting Output Guide 4.

* Ground approximately 50% under moderate brash, 50% timber zones.

Other treatments

There has been no need to apply fertilizer at planting on the gley sites. Where it has been applied experimentally it has increased weed growth, particularly of willowherb (*Epilobium* spp.) In brash-free zones and where all brash has been removed experimentally, weed growth has been heavier. On peaty gleys heather has reinvaded, necessitating control measures.

General comments

Improvement of the quality of planting stock by methods such as precision sowing and undercutting (Mason 1987), the increased knowledge about cold-storage regimes, and the provision of cold stores (Tabbush 1987) have all helped survival and early growth on restock sites. Even Douglas-fir, which so often is a difficult species to handle, responds to undercutting (Mason 1987).

Complete harvesting of biomass

There are very few studies to date on which to reach conclusions. The energy experiments reported by Hudson et al. (1989) are the only sources, other than experimental trials, from which we can obtain evidence.

On the lowland heaths at Thetford Chase, apart from minimal increase in weed growth, the effects appear to be negligible. On upland sites, as long as the needle litter is left on site, again there appears to be no detrimental effect.

Chadwick (1989a) concludes that "collecting and extracting residues solely as an aid to restocking would be unacceptably expensive (trial area average cost: £510/ha)."

As there is no major energy market available, the only market potential appears to be the screening of the chipped end product and the provision of the material for a range of uses.

Conclusion

Restocking in the United Kingdom has moved to widespread use of Scandinavian scarifiers and mounders for ground preparation in the past five years. While mounding is completely accepted for the drier sites, there is still discussion on its value on the wet gleys.

Improved plant production methods, storage, and handling of plants have led to better stocking densities and quicker establishment of plantation conditions.

Natural regeneration occurs on less than 5% of the restock area, but is of increasing interest.

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Residue harvesting systems

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Abstract

Residue harvesting systems have been examined in a series of field trials in conifer clearfell crops in the United Kingdom. Both landing and terrain chipping systems have been shown to be effective in the removal of residues, enabling more efficient restocking.

Landing chipping systems are considered appropriate to wetter upland spruce sites. Extraction of the residues has been shown to be feasible and economic, but chipping of the residues at the roadside or landing requires further investigation.

Terrain chipping systems in commercial operation in pine crops on drier sandy soils have been monitored and found to be economically viable over short extraction distances.

Résumé

Au Royaume-Uni, on a évalué des systèmes de récolte des rémanents dans le cadre d'une série d'expériences sur des récoltes de conifères ayant fait l'objet d'une coupe à blanc. En ce qui a trait au retrait des rémanents, les systèmes de mise en copeaux sur le premier dépôt transitoire et sur le terrain se sont révélés efficaces; ils accroissent donc l'efficacité du reboisement.

Les systèmes de mise en copeaux sur le premier dépôt transitoire conviennent aux peuplements d'épinettes de hautes terres humides. L'extraction des rémanents s'est révélée faisable et économique. Toutefois, les systèmes de mise en copeaux des rémanents le long des routes ou sur le premier dépôt transitoire devront faire l'objet d'autres études.

On a évalué des systèmes de mise en copeaux sur le terrain d'entreprises commerciales pour des récoltes de pins sur des sols sablonneux secs. Ces systèmes ont été jugés rentables lorsqu'il s'agit de courtes distances d'extraction.

Introduction

The predominant harvesting system for conventional conifer forestry in the United Kingdom is the shortwood method. In addition, tree-length systems are common and becoming increasingly popular with the demand for longer timber lengths at the sawmill. Felling and processing is generally carried out manually, but mechanisation is increasing because of a lack of chain saw operators, and the demand of the wood processing industry to increase output from the expanding timber resource.

Neither the shortwood nor the tree-length system uses the residues left in the stump area. In upland spruce areas the residues are often used to form a brash mat to aid extraction. The accumulation of residues can hinder restocking, but the removal of the residues can reduce restocking costs and allow a higher proportion of the land area to be restocked.

The potential of the residues for energy production has been recognised by the UK Department of Energy. A series of field trials of residue extraction and landing chipping in upland spruce areas have recently been completed by the University of Aberdeen in collaboration with the Forestry Commission. In addition, monitoring of terrain chipping systems has been carried out in conjunction with two commercial chipping operations.

The resource

Wood production in the United Kingdom was some 6 million m^3 over bark (ob) in 1987, of which 80% was from conifers, with 58% of that total in Sitka spruce and Scotch pine. Production is predicted to rise some 60% over current levels in the next 15-20 years. Present annual felling in clearfell operations is 2.74 million m^3 ob (Forestry Commission 1988).

Field trials of residue harvesting systems in unthinned upland spruce crops indicate a potential for some 68% in additional biomass. Trials in pine crops indicate a lower potential of about 20%. The recovery of residues from clearfell operations assessed on an overall percentage of 35% of the total stem volume of 2.74 million m^3 ob would give an additional recoverable yield of 960 000 green tonnes per annum (Mitchell et al.1989).

Harvesting trials

In general, the upland forests in the United Kingdom are predominantly Sitka spruce crops on peaty gleys and surface water gleys. These wet sites restrict access and favour the use of landing chipping residue harvesting systems, under which the residues are extracted by forwarder to the forest road or landing for chipping.

Scotch and Corsican pine crops are grown on the lower, dryer sandy loam soils in the East of the country. The higher load bearing soils allow the use of heavier forwarder-mounted choppers, and thus make the use of terrain chipping methods possible.

A number of field trials have been carried out with both the landing chipping and terrain chipping systems in the United Kingdom over the past three years. They are summarised below.

Landing chipping

Crop Description

This trial was carried out in Kielder Forest, England (Forestry Commission 1989). The residues remained from the shortwood clearfell of a 28-year old unthinned crop of Sitka spruce and Sitka spruce/lodgepole pine mixture. Terrain classification was 2.3.3. Soils were peaty gleys and surface water gleys. Information from sample plots located within the trial area is summarised below in Table 1.

Table 1.
Sample plot data

Age (yrs)	Species	Average volume (m^3)	Trees/ha	YC
28	SS (SS&LP)	0.100	2500	14

Machine specifications

A Bruunett 578F forwarder was used for residue extraction. The base machine was modified with the addition of a Clark Brash Grapple. The standard bunk was replaced with a wider bunk with a solid base and without bolster pins. The rear wheels were replaced with 600-mm diameter wheels, while the front wheels were fitted with lightweight tracks.

The chipper was a Bruks 1000 CT drum chipper complete with a chop bin mounted on a Volvo SMV 2115T forwarder, weighing a total of 25 tonnes. The chipping unit consisted of two knives mounted on a drum 1000 mm wide. A horizontal feed table and two horizontal hydraulically powered spiked feed rollers were used to assist in feeding the residues into the chipper drum. The feed table was equipped with five chains driven by a hydraulic motor. The feed mechanism was automatically controlled to prevent the chipper drum from overloading. Chips were blown directly into the 17 m^3 chip bin.

Method

Harvesting of the site had taken place approximately one year earlier. The residues had then been extracted by the modified forwarder and stored in roadside heaps for 2-4 months.

The Bruks forwarder-mounted chipper was situated on the road beside the residue heaps. The chipper then self-fed the residues, exhausting the supply within reach of the grapple before moving along the road.

A lorry was provided during the trial to shuttle chips to a nearby storage area.

Results

The amount of additional above-ground biomass obtained from whole-tree utilization was calculated (Table 2).

Productivity for residue extraction with the modified Bruunett forwarder was 8.65 *t58*/productive machine hour (pmh), over an extraction distance of 100 m. Residue chipping at roadside with the Bruks 1000 CT chipper had a productivity of 3.5 *t58*/pmh. With freshly felled material, chipping productivity rose considerably, to some 8-9 *t58*/pmh.

Table 2.
Additional above-ground biomass

Whole tree weight (*t58**)	Stem weight (*t58**)	Additional weight (*t58**)	Above-ground biomass %
0.168	0.100	0.068	68

*Tonnes at 58% moisture content.

Harvesting equipment costs included labour and new equipment. The capital cost of the modified Bruunett forwarder was given as £90 000, and the Bruks 1000 CT forwarder mounted chipper as £220 000. Labour costs were £6.00/smh for the machine operators. This cost has been subjected to a 50% on-cost for overhead. Total operating cost is expressed in £/pmh for each item of equipment. The utilization rates used in the costings are based on a combination of the trial findings and levels achieved in the industry, loss of time due to weather, breakdowns and movement between sites.

Harvesting element costs are based on the hourly rates per productive machine hour and the productivity results for each element. For chipping, a mean productivity of 6 *t58*/pmh has been used for costing purposes.

Harvesting system costs in relation to the energy value of the chipped material are based on a net calorific value of 6.73 gigajoules/*t58* (Table 3).

Table 3.
Harvesting system costs

Operation	Cost £/pmh	Output *t58*/pmh	Unit cost £/*t58*
Extract	38.08	8.65	4.40
Chip	75.76	6.00	12.63
Total			17.03
£/*t58*	17.03		
£/GJ	2.53		

Terrain chipping

Crop description

This trial was carried out in two locations.

1. Kinloss, Scotland.
Terrain classification was 1.1.1., with sandy loam soils. The Scotch pine and lodgepole pine residues were from conventional clearfell operations. The residues had been bulldozed into piles and were badly contaminated with sand and stones.

2. Brandon, England.
The trial took place at three separate locations in Thetford Forest. The terrain classification on all sites was 2.2.1. and all soils were sandy loams.
2a and b. Corsican pine residues following premature clearfell due to windblow damage.
2c. Corsican pine whole trees following premature clearfell clearing due to windblow damage.

Machine specifications

1. Bruks 800CT drum chipper (complete with chip bin) mounted on a Kockums 84-31 forwarder: The chipper unit has two horizontal, hydraulically powered, spiked feed rollers and a chain feed table. It is powered by an integral 165-kW diesel engine. The chips are blown directly into a 14-m^3 chip bin.

2a. Bruks 1001 CT drum chipper (with chip bin) mounted on a Volvo BM SM971 forwarder: The chipper unit has two horizontal hydraulically powered spiked feed rollers and a chain feed table. Power is supplied by an integral 195-kW diesel engine. The chips are blown into an 18-m^3 chip bin.

2b. Siba 7/45 RCX drum chipper (with chip bin) mounted on a Bruunett 578F forwarder: The chipper unit has two horizontal feed rollers and two vertical compressible feed rollers, all hydraulically powered. Power is provided by an integral 156-kW diesel engine. The chips are blown into a 14-m^3 chip bin.

2c. Siba 7/45 RC drum chipper (with chip bin) mounted on a Bruunett 578F forwarder: The chipper unit has two hydraulically powered horizontal feed rollers. Power comes from an integral 125-kW diesel engine. The chips are blown directly into a 14-m^3 chip bin.

Method

The techniques for terrain chipping were similar at all sites. The forwarder-mounted chipper moved along an edge of cleared ground feeding the chipper, exhausting the supply of residues within reach of the grapple before moving forward. Residues were dropped onto the feed table of the chipper. In the case of the Bruks, the chain-feed table moved the material to the chipper drum. The Siba chippers had no chain-feed table, the grapple being used to introduce the residues to the chipper drum. As soon as the chip bin was full the units returned to the landing to off-load the chips.
At 2c, a high-quality white wood chip was required. The operator fed the whole trees butt first into the chipper, stopping and ejecting the remaining top once the first live branch had been reached. The tops were chipped in another operation at a later date.

Results

Table 4.
Trial results

Trial	Species	MC * (%)	Extraction distance (m)	Cycle time (hr)	Productivity (t/pmh)
1	SP/CP	43	450	0.75	4.19
2a	CP	55	145	1.10	6.28
2b	CP	56	1150	1.66	2.68
2c	CP	59	300	0.91	4.96

* Moisture Content.

Harvesting equipment costs included a labour element and new equipment. The capital cost of the harvesting equipment is summarised below (Table 5).

Table 5.
Harvesting equipment costs

Equipment	Cost (£)
Bruks 800CT	200 000
Bruks 1001CT	220 000
Siba 7/45RCX	145 000
Siba 7/45RC	134 000

Labour costs have been taken at £6.00/smh for the chipper operator. This cost has been subjected to a 50% on-cost for overhead. Total operating cost is expressed in £/pmh for each item of equipment. The utilization rates in the costings are based on a combination of field trial findings and levels achieved in the industry, taking into account loss of time due to weather, breakdowns and movement between sites.

Harvesting element costs are based on the hourly rates per productive machine hour and the productivity results for each harvesting element.

Harvesting system costs in relation to energy of the chipped material are summarised in Table 6.

Table 6.
Harvesting system costs

Trial	Cost £/pmh	Output t/pmh	Unit cost £/t	Net calorific value	Cost £/GJ
1	69.96	4.19	16.70	10.02 GJ*t43**	1.67
2a	75.76	6.28	12.06	7.38 GJ*t55*	1.63
2b	56.63	2.68	21.13	7.17 GJ*t56*	2.95
2c	50.83	4.96	10.25	5.80 GJ*t56*	1.77

*Per tonne at 43% moisture content and other percentages, as indicated.

Discussion

Landing chipping systems removed the residues of upland spruce crops by modified forwarder without difficulty. The absence of the brash mat was offset by the low weight of the residue load (about 4 tonnes) and by the use of the wider tires and the tracks. The forwarder was able to traverse all of the site under trial. Productivity over the extraction distance of 100 m was acceptable although the high capital cost of the forwarder placed extraction costs at the upper limits of economic viability.

The wet residue material from the roadside stacks was difficult to handle; chipping was slow and chipping costs were high. Freshly felled material proved easier to chip, however, so that productivity increased. Output of the chipping unit must rise to about 10 tonnes per productive machine hour to achieve economic chipping costs.

The only major commercial residue harvesting operations in the United Kingdom use terrain chipping methods. Monitoring these operations at a number of locations has shown that there is potential for the systems where extraction distances can be minimised. While extracting the chips, the chipper unit is not operative and the high capital investment in the combined forwarder and chipper is under-utilized. At short extraction distances, the cost of £10.25/t59 is considered to be economical and would warrant further investigation of the systems. More research into chipping units suitable for landing chipping of residues is necessary.

Both residue harvesting systems will produce industrial raw material with high value potential in the form of white wood chip in addition to the energy chips. Screening to segregate the two products, with the possibility of offsetting the cost of production of the energy chip, is considered feasible.

Conclusion

Both residue harvesting systems were effective in removing the residues from the sites and gave a clear site for restocking.

Terrain chipping systems work best on firm level ground. With good planning to minimise extraction distances, they can offer potentially economical residue harvesting systems.

Extraction of residues on wet upland sites for landing chipping has also been shown to be a viable harvesting option, but more work is necessary to improve chipping productivity and reduce costs.

The potential of screening systems to increase the product range from residue chips is considered to be worthy of additional research. Investigations into improving the productivity of landing chipping systems, and into screening equipment, are to be undertaken in another series of field trials by Aberdeen University and the Forestry Commission.

Acknowledgements

This work was supported by the UK Department of Energy Biofuels Programme, by the Forestry Commission and by the CEC Energy from Biomass Programme. Thanks are due to the two commercial chipping operators, M I Edwards Engineering, Brandon and Fibroheat, for allowing monitoring of their chipping operations. The views expressed are those of the authors and not necessarily those of the sponsors.

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Forest energy production as a means of improving silvicultural practice: The Swedish experience

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Abstract

Since 1973, the year of the oil crisis, major efforts have been made in Sweden to find alternative domestic energy sources to replace fossil fuels and nuclear power.

The forest is possibly Sweden's most important renewable energy source. Calculations have shown that conventional forestry can produce approximately 15 million m³ (30 TWh) of tops and branches from the present harvest of sawmill timber and pulp wood.

At present, the annual harvest of tops and branches is approximately 4 million m³ of solid wood (8 TWh). The two major commercial woodfuel harvesting methods are the tree section method used in thinnings, and a separate operation for collecting residue after clearcutting.

No Swedish experiments have yet proved that there are any significant nutrient losses from long-term production. Results up to now imply that nutrient removal has only a slight effect on plant growth. The experiments also imply that the survival of plants in regenerated areas is improved by slash removal. In established stands there will probably be a slight negative effect, at least in stands of Norway spruce (*Picea abies* [L.] Karst.). Stands of Scotch pine (*Pinus sylvestris* [L.]) are not likely to be affected in the same way.

Silviculture benefits from the woodfuel harvest mainly in the following ways:

During thinnings:
- better economy in the important early thinnings;

At final harvest:
- opportunity to start regeneration measures at an earlier stage;
- easier and better soil scarification;
- easier plantation; and
- fewer problems with voles, insects and competing vegetation.

Résumé

Depuis 1973, année de la crise pétrolière, la Suède a déployé de grands efforts pour trouver des sources d'énergie qui pourraient remplacer les combustibles fossiles et l'énergie nucléaire.

La forêt est peut-être la plus grande source d'énergie renouvelable en Suède. En effet, il a été démontré que la foresterie traditionnelle peut produire environ 15 millions de mètres cubes (30 TWh) de houppiers et de branches, dont l'extraction pourrait être intégrée à la récolte actuelle de bois de sciage et de pâte.

La récolte annuelle actuelle de houppiers et de branches est d'environ 4 millions de mètres cubes de bois solide (8 TWh). La méthode d'éclaircie par sections d'arbres et la coupe à blanc suivie d'une opération de ramassage des rémanents sont les deux principales méthodes de récolte de bois de chauffage.

Aucune expérience menée en Suède n'a encore pu démontrer qu'il y aurait, à long terme, une diminution importante de la production en raison d'une perte des éléments nutritifs. Les résultats obtenus jusqu'à maintenant suggèrent seulement un léger effet sur la croissance des arbres. En outre, les expériences suggèrent que l'enlèvement des rémanents occasionne un meilleur taux de survie des plants sur les terrains de reboisement. Dans les peuplements bien établis, il y aura peut-être un léger effet négatif, au moins dans les peuplements d'épinettes de Norvège (Picea abies [L.] Karst). Les peuplements de pins sylvestres (*Pinus sylvestris* [L.]) ne seront probablement pas touchés de la même façon.

Les principaux avantages que procure la récolte de bois de chauffage à la sylviculture sont les suivants:

Éclaircies:
- rentabilité accrue des éclaircies hâtives importantes;

Coupes définitives:
- possibilité d'entreprendre le reboisement plus tôt;
- scarifiage plus facile et mieux réussi
- plantation plus facile;
- diminution des problèmes dus aux campagnols, aux insectes et à la végétation concurrente.

Introduction

The Swedish energy system has changed remarkably since 1973, the year of the oil-price crisis: we use less energy because of improved efficiency in the energy system and better conservation. Greater interest in environmental matters has also increased the use of wood fuels. In forestry, woodfuel is now regarded as the third most important forest product after pulpwood and saw timber. The accessible amounts of woodfuel largely depend on the timber consumption of the forest industry and the degree to which it uses woodfuel in connection with its logging operations. The only exceptions are woodfuel production from pre-commercial thinnings and cleaning of broad-leaved trees—which can be done separately, independent of conventional forestry practices.

Use and supply of woodfuel

In Sweden, the total use of bioenergy is 60 TWh/yr, which represents about 30% of total Swedish heat production. About 50%, or 30 TWh, of this total originates from woodfuels (Fig. 1). From the silvicultural point of view, the most interesting woodfuel is harvested as a complement to conventional logging operations, mainly tree tops and branches. This logging residue can be collected and used after a clearcut, or by using the tree-section method in thinnings.

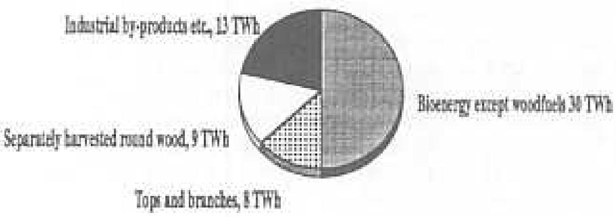

Figure 1. Total use of bioenergy in Sweden, 1985.

Today, logging residue contributes about 8 TWh, or the equivalent of 4 million m^3 of solid wood per year. The traditional cut of firewood by forest owners and small farmers for their own consumption is greater still —about 6 million m^3. Of this total 2 million m^3 can be regarded as slash; the rest is stem wood that normally would have been cut as pulpwood. The open market only deals with 1.5 million m^3; the rest is used internally by industries or private forest owners.

Potential supply

There are very large amounts of unused biomass in the Swedish forest. On average, it is possible to harvest 0.5 m^3 of discarded tops and branches for every cubic metre of timber and pulp harvested. The annual harvest of saw timber and pulpwood in Sweden is approximately 50 million m^3 of solid wood. Under ecological guidelines established by the National Board of Forestry, an estimated 15 million m^3 (30 TWh) of tops and branches could be harvested in Sweden every year: 19 TWh from final fellings and 11 TWh from thinnings (Fig. 2.) These ecological guidelines are preliminary, however, and still not very well supported, as most field experiments are too recent. Without the guidelines, the possible supply would be about 25 million m^3 (50 TWh). The logging residue is to a great extent an unutilized energy resource.

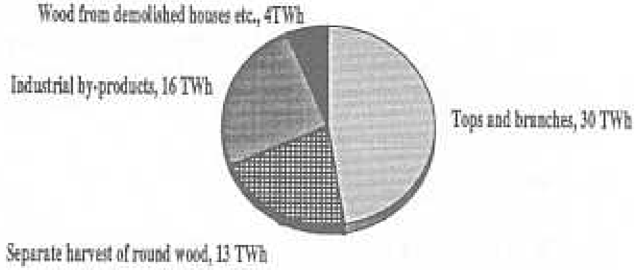

Figure 2. Potential supply of woodfuel in Sweden.

Future utilization

The extent to which the discarded tops and branches will be utilized in the future is difficult to predict. The critical factor is the cost of alternative energy sources, mainly coal and oil. The world price of coal and oil has been dropping in recent years. At present, woodfuel cannot compete with imported fossil fuels the way it could in the early 1980s, even though the state encourages the use of domestic fuels through taxation. Even with today's difficulties, the use of woodfuel has increased through the 1980s from approximately 8 million m^3 in 1980 to about 17 million m^3 in 1989 (Fig. 3).

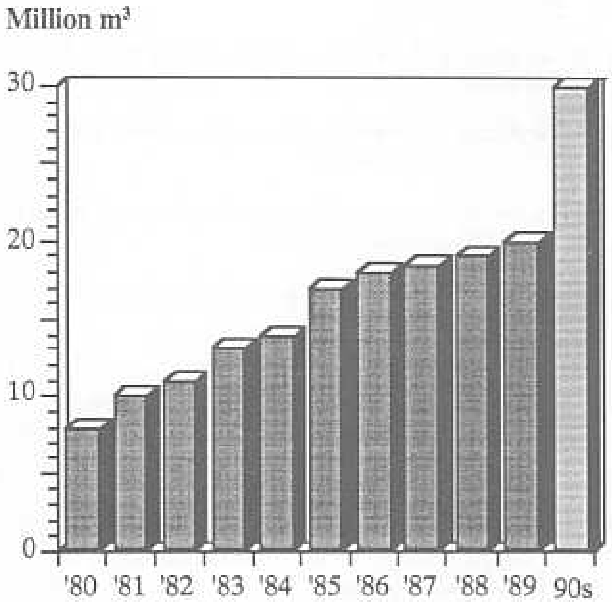

Figure 3. Use of woodfuels during the 80s and potential supply.

The elimination of nuclear power

As a result of a national referendum, nuclear power stations in Sweden are to be closed down by 2010 at the latest. The effects of this measure on the use of woodfuel are hard to predict. It will probably damage the electricity-intensive pulp and paper industry and decrease the price of pulpwood. In addition, it will influence the demand for woodfuel by raising interest in alternative energy sources. Almost half of all electricity consumed today is produced by nuclear power (65 TWh). The rest is produced mainly by hydro-electric power stations. Under present conditions it is not possible to produce electricity from woodfuel at a reasonable cost.

Harvesting fuelwood

Commercial harvests of woodfuel in Swedish logging operations are carried out by two major methods. The woodfuel is either produced from the residue left after a clearcut in a separate operation, or it is harvested during early thinnings which are part of the industrial wood harvest. It seems reasonable to harvest the woodfuel at the same time as the timber and pulpwood, but existing logging machines fell and delimb the trees at the clearcut area. In Sweden, it is very unusual to haul out the wood as whole trees or stems. The shortwood method, with the wood cut in pieces which vary between 3 and 5.5 m, is used for 99% of the cut volume. The harvest of woodfuel is therefore adjusted to fit the shortwood system.

Commercial methods

After a clearcut, the residue is usually left in large piles behind the logging machines which delimb and cut up the trees . It is then collected and chipped into woodfuel by special machines called "fuel harvesters." At the moment several different types of fuel harvesters are being used. The two methods of woodfuel production are illustrated in Figure 4.

The main difference between them is in how and where the chipping takes place. The most common method is to use a mobile chipper which chips the debris (1) right at the clearcut area, hauls the chips (2) to the landing and empties them into containers ready to be loaded onto trucks (5). The second method is to transport the debris on a forwarder (3) to the landing where it is chipped (4) and loaded into containers (5).

If a large user of woodfuel is located close to the forest, the residue can simply be transported (3,6) and chipped on the premises (7).

During thinnings, an integrated method called the "tree-section method" is used. The trees are felled and

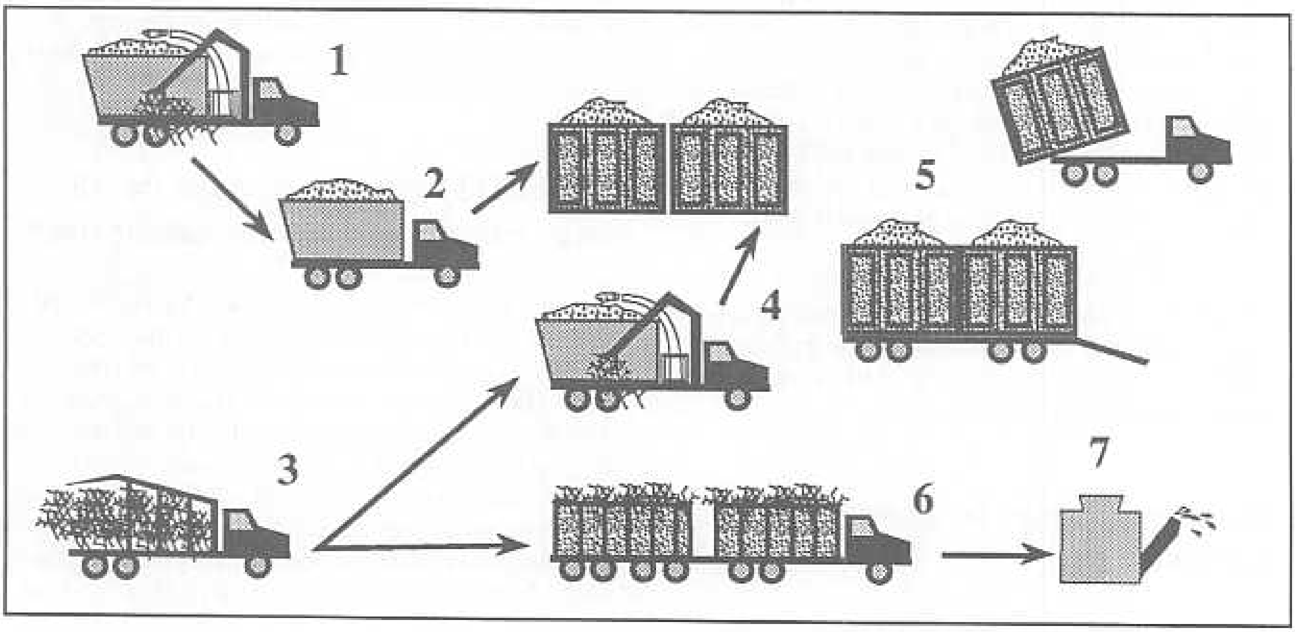

Figure 4. Systems for harvest of logging residue after final felling.

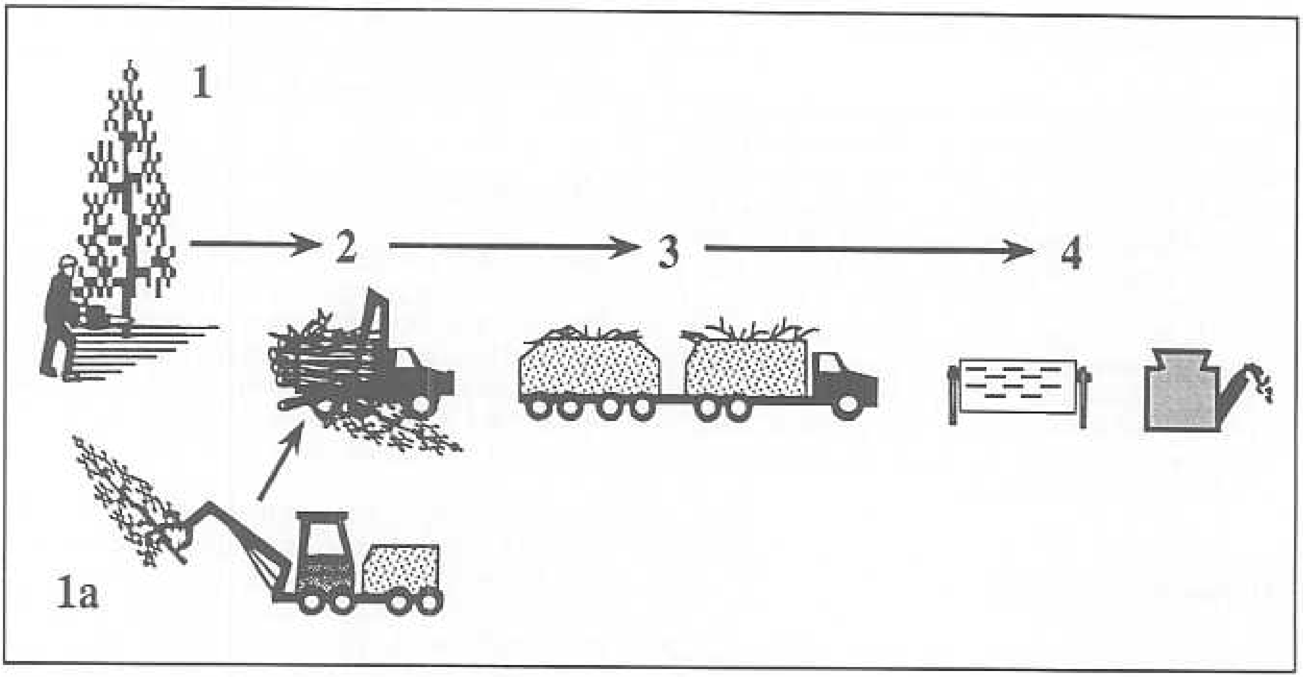

Figure 5. Systems for harvest of tree sections (Larsson, 1987).

cut into lengths of 5 to 6 m with the branches on. This method is the usual one for early thinnings of small trees, where the extra output of woodfuel, in addition to pulpwood, can make the thinning commercially viable. In many cases such thinnings (with tops and branches discarded) would represent a net loss to the forest owner. This method is illustrated in Figure 5.

The trees are generally felled manually by chainsaw (1) or, increasingly by a feller-yarder (1a). A special forwarder with a saw mounted on the grip cuts and hauls the trees (2) to the landing. The tree sections are hauled (3) on specially designed trucks . Tree sections are very voluminous so the floor and walls of these trucks are covered to maximize load volume. The trees are delimbed (4) in bunches, mainly at the industry site.

The need to refine these woodfuel harvesting techniques is greatest in two areas: delimbing of tree sections in bunches and pressing of tree sections into piles for ease of transportation.

Small-scale methods for private woodfuel harvesting

Most wood used by private forest owners is conventional firewood. Much of this wood could actually be sold as pulpwood. The private owners cut trees, preferably broad-leaved trees, on forest land partly used for grazing and hay production, and along ditches. When private forest owners produce fuel chips they usually use wood from pre-commercial thinnings. The most common method is to fell the trees with a chainsaw or brush-cutter, chip them with a chipper mounted on a farm tractor, and haul the chips back to the farm for use at home. One method used by entrepreneurs for the pre-commercial thinning of hardwoods employs a chipper mounted on the front of a small tractor with a chip-container at the rear. A professional operator can produce 5 m^3 of fuel chips an hour (Filipsson 1984).

Removal of logging residues and the effects on growth and yield in the remaining stand

Conventional logging operations use the shortwood system: the trees are delimbed and cut into 3-m pieces. When the trees are being harvested for energy production they are removed whole. Stem, branches, needles and sometimes even stumps are utilized. The logging residue—the branches and needles—contains most of the nutrients. In fact, the slash contains all the nutritious substances needed by the remaining trees. Removing the slash risks decreasing the potential growth of the forest and thus the long-term yield of the land.

The effects of different kinds of "whole-tree utilization" on regeneration as well as growth and yield are being closely studied in a number of field experiments. In the Nordic countries there are about 50 such long-term experiments, most of them established during the past 10 years.

If the slash is removed after a clearcut, the survival rate of the planted trees is greater than if the slash is left on the regeneration area (Björkroth 1983; Leijon 1985, 1989; Kardell 1987). Removal of the stumps improves survival rates even more; best of all for the survival of the planted trees is removal of both slash and stumps (Kardell 1987).

Nevertheless, studies on the effects of slash removal on new plant growth are not conclusive. Lundkvist (1987) reports that the growth of Norway spruce (*Picea abies* [L.] Karst.) is affected negatively, while the growth of Scotch pine (*Pinus sylvestris* [L.]) is not affected at all by the removal of slash. On the other hand, Kardell (1987) found that the growth of both Norway spruce and Scotch pine is positively influenced by slash removal.

The causes of these different results may be numerous. Slash influences the environment of the plants in many ways: the soil scarification, for instance, will vary. The frequency of damage by insects and voles may differ. Differences in growth rates between clearcuts with and without slash have not yet been analyzed. One reason the newly established plants do not need the slash is that very large amounts of nutrients are released at final felling. Some surplus nutrients even leach away (Rosén 1982).

Established stands with higher growth rates have a greater need for nutrients. The earliest field experiment on removal of slash in the Nordic countries was carried out in 1928 at a Scotch pine stand. It consisted of two plots; the slash was removed from one plot and added to the other at every thinning. During the observation period of 32 years, the pines on the plot with all the slash grew 20% better than those on the plot without slash (Brantseg 1962). Similar results on thinnings of Norway spruce and Scotch pine are reported by Tveite (1983).

A Swedish experiment with three replications showed significant differences in growth during the 10 years after thinning between plots where slash had been removed and those where slash had been left in place. Where slash had been removed, the seedlings continued to grow more slowly than on plots where it had been left even during the subsequent 10-year period; but the differences in growth were not significant (Andersson 1988). The general growth loss after whole-tree thinning is estimated at 10%.

There is, however, a belief that Norway spruce may be more negatively influenced by whole-tree thinning than Scotch pine. The reason for this is that the amount of slash and removed nutrients are greater for a Norway spruce stand than for Scotch pine. Leijon (1989) reports that the decrease in production after 25 years in an experiment with Norway spruce corresponds to between 1 and 5 years' growth. He also found that the decrease in yield capacity between plots with and without logging residues ceases after 25 years.

Formal restrictions on woodfuel harvest

To prevent the removal of biomass and its nutrients from forest land, the Swedish National Board of Forestry has imposed guidelines limiting the use of tree-section methods and the harvesting of logging residue. These guidelines, which are not enforced by law, are based on the assumption that removal of biomass is harmful to the long-term productivity of the soil, mainly because of the removal of nutrients and organic material. The current (1985) restrictions are rather extensive and, as noted earlier, not very well supported; they are, however, soon to be replaced.

The main features of the guidelines are:

- no slash removal from dry or nutrient-poor sites;
- hardly any slash removal from sites with coarse soil texture; and
- severe restrictions on slash removal from peatlands.

In addition to these, there are special restrictions in areas with dry, early summers, at high altitudes or with a high deposition of acidifying substances. There are also special restrictions on the harvest of slash after clearcutting if the area is to be regenerated with spruce or if the humus layer is thin. Under no circumstances can tops and branches be harvested more than once during a rotation.

Woodfuel silviculture: the birch-shelter example

The number of broad-leaved plants per hectare has increased dramatically in young forests during the past 20-30 years. An important silvicultural question is this: how should these stands, in which numerous broad-leaved trees are mixed with conifers, be tended to produce a yield as high as possible under existing circumstances?

In Sweden, the two native conifers are Norway spruce and Scotch pine; the main broad-leaved species are birch (*Betula pubescens* [L.] Ehrh. and *Betula pendula* Roth) and aspen (*Populus tremula* [L.]). Broad-leaved trees like birch and aspen have a more rapid height growth than conifers during juvenile stages. This rapid height growth, together with the development of suckers, makes repeated early cuttings necessary if serious competition between suckers and conifers is to be avoided. When Mielikäninen (1985) found that a mixed stand of Norway spruce and silver birch achieved a higher total yield than Norway spruce alone, the silver birch was approximately seven years younger than the Norway spruce. Norway spruce, which are shade tolerant (Ståhlfelt 1931), can survive as suppressed trees under a dense shelter of broad-leaved trees (Tham 1987).

One management alternative in young even-aged mixed stands of Norway spruce and self-propagated birch is to grow them together during the first decades of the rotation period. This management method takes advantage of the differences in the growth rates of the two species. The birch, which is a pioneer tree, will dominate the spruce at the beginning of the rotation; then after the birch is thinned away the spruce alone will form the mature stand. The result of a yield prediction study (Tham 1988) shows that it is better to leave a shelter of 500-800 birches per hectare than to remove all the broad-leaved trees. If a high yield is desired, it is important for the Norway spruce to reach a height of 1-2 m rapidly. When the spruce reach that height, the birches should be spaced to the desired number per hectare.

The number of naturally regenerated birch trees on a clearcut area after felling and soil scarification is usually much greater than 800 per hectare. Björkbom (1972) found 25 000 birch plants per hectare after soil scarification. To avoid serious competition between the birches and the Norway spruce it is necessary to reduce the number of birches dramatically. If the birches are spaced at about 500-800 per hectare before the Norway spruce is 1-2 m high, it will be necessary to cut the birch suckers several times (Andersson and Björkdahl 1984) to prevent them from reaching a height greater than the Norway spruce plants.

Instead of spacing the birch to the recommended 500-800 birches per hectare as soon as pre-commercial thinning is needed, the birch spacing can be done in two steps (Johansson 1983; Brunberg and Johansson 1984). At the first pre-commercial thinning, the birches can be spaced to 2500-3000 birches per hectare. Later, when the Norway spruce is 1.5-2 m in height, they can be thinned to the recommended 500-800. There are several reasons to thin the birches in two steps, but the most important is to protect the Norway spruce plants against frost.

If wood is needed for fuel, it is possible to utilize the birches felled during the second thinning. It is also possible to get a surplus from early thinnings if the birches are purchased as woodfuel instead of pulp-wood (Tham and Josefsson 1986). If the birch shelter is dense enough the birch-stumps may be too closely spaced to sprout (Andersson 1984); and it is considered easier to do the pre-commercial thinning in two steps than to cut suckers repeatedly. But it is not known how dense the shelter needs to be to prevent sprouting. Measurements of radiance in young broad-leaved stands indicate that if lack of light is the single factor that prevents the cut stumps from sprouting, as many as 1 million stems per hectare may be needed (Johansson 1989).

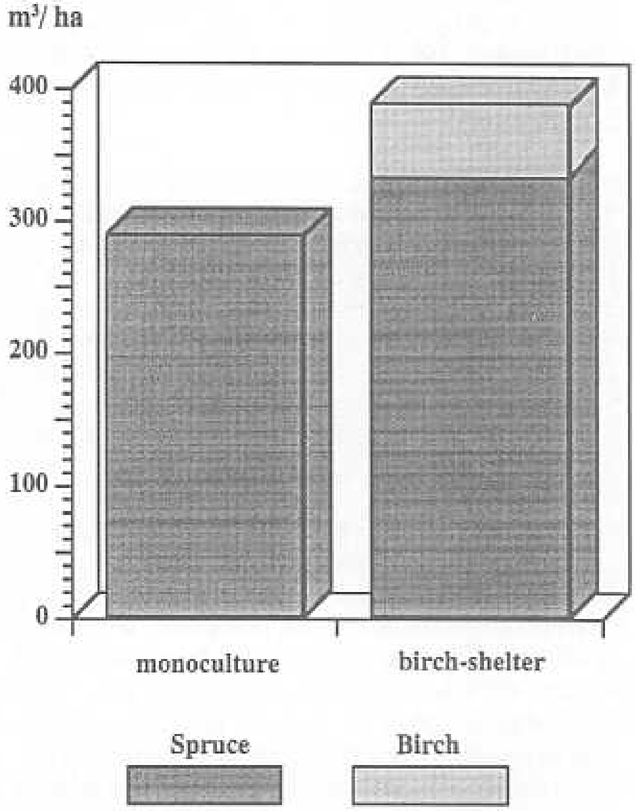

Figure 6. Total yield in stands of spruce with or without a shelter of self-propagated birches.

To date there are no long-term data available from stands that have experienced heavy early thinnings of birch in one or two steps. A model of how a mixed stand of spruce and birch might grow when given a few heavy thinnings is described by Tham (1988). The model illustrates, through examples from simulations, that the stand will produce a higher total yield if 500-800 broad-leaved trees are left as a shelter instead of being cut (Fig. 6).

Effects on silviculture of utilizing woodfuel

Hitherto the discussion of the utilization of tops and branches from a silvicultural point of view has been primarily concerned with the risks it may represent for long-term production. However, the use of this biomass also leads to several benefits for practical silviculture: some of them obvious, some of them debatable.

Early thinnings

One of the obvious benefits is the important contribution this third type of use can represent to the forest owner's income during early thinnings. To maximize the production of the main stems, it is often necessary to do the first thinning at a rather young stand age. Because of the small quantities of merchantable timber, these thinnings often involve financial losses. Under these circumstances the forest owner can very easily be tempted to postpone the first thinning to a stand age that is non-optimal from the silvicultural point of view. The extra income that the harvest of woodfuel can provide makes it possible for thinnings of rather young stands to be profitable. Early thinnings are in fact very suitable for the tree-section method. The large amounts of tops and branches in relation to stem volume and the high proportion of unmerchantable stems make harvesting for woodfuel a profitable activity.

Regeneration

As noted earlier, the removal of logging residue after a clearcut will probably have a negative effect on nutrition and the microclimate of the regeneration area. It will, however, also influence the practical regeneration work, mostly in a beneficial way.

The practical effects it will have are mainly the following:

- simplified, and thereby better, soil scarification;
- an opportunity to perform soil scarification immediately after the logging;
- easier planting;
- earlier planting; and
- perhaps a reduced need for control measures against competing vegetation.

The first of these effects, simplified scarification, may be the most important. In fact, this seems to be the reason why many forest owners keep on harvesting logging residues even though the profitability of the harvest may be in question. The simplified scarification and planting mean better performance, and thus improved survival of plants (Leijon 1989).

The fact that both soil scarification and planting can be performed sooner after logging means that the forest owner will gain perhaps two or three years in production, since it is necessary to wait this long if the residue is left. The reason for this is that soil scarification cannot be done as long as the residue is fresh and also because of the risk of insect damage to plants if they are planted in fresh residue.

The last point — reduced need for control measures against competing vegetation—is more debatable. Logging residue can reduce the growth of unwanted vegetation in the short run, but in the long run it will increase undesirable growth because of the release of nutrients. In addition, as noted earlier, removal of slash will reduce the numbers of voles and insects, which will also save the forester some trouble in tending the new stand.

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