SUSTAINABLE USE OF FOREST BIOMASS FOR ENERGY

Managing Forest Ecosystems

Volume 12

Aims & Scope:

Well-managed forests and woodlands are a renewable resource, producing essential raw material with minimum waste and energy use. Rich in habitat and species diversity, forests may contribute to increased ecosystem stability. They can absorb the effects of unwanted deposition and other disturbances and protect neighbouring ecosystems by maintaining stable nutrient and energy cycles and by preventing soil degradation and erosion. They provide much-needed recreation and their continued existence contributes to stabilizing rural communities.

Forests are managed for timber production and species, habitat and process conservation. A subtle shift from *multiple-use management* to *ecosystems management* is being observed and the new ecological perspective of *multi-functional forest management* is based on the principles of ecosystem diversity, stability and elasticity, and the dynamic equilibrium of primary and secondary production.

Making full use of new technology is one of the challenges facing forest management today. Resource information must be obtained with a limited budget. This requires better timing of resource assessment activities and improved use of multiple data sources. Sound ecosystems management, like any other management activity, relies on effective forecasting and operational control.

The aim of the book series ***Managing Forest Ecosystems*** is to present state-of-the-art research results relating to the practice of forest management. Contributions are solicited from prominent authors. Each reference book, monograph or proceedings volume will be focused to deal with a specific context. Typical issues of the series are: resource assessment techniques, evaluating sustainability for even-aged and uneven-aged forests, multi-objective management, predicting forest development, optimizing forest management, biodiversity management and monitoring, risk assessment and economic analysis.

The titles published in this series are listed at the end of this volume.

Sustainable Use of Forest Biomass for Energy

A Synthesis with Focus on the Baltic and Nordic Region

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PREFACE

From time immemorial, firewood has been a very important source of energy for mankind. Later in history, wood for energy decreased its importance because of other more convenient and cheaper sources, mainly fossil fuels. Today, focus is again on use of forests as a producer of energy with main drivers being climate change, shortage and increasing prices of fossil fuel sources, and safety in energy supplies. However, intensive use of forest biomass is questioned since fundamental ecological processes may be influenced negatively thus making up a trade-off with the benefits of using an otherwise sustainable source of energy.

In this book, selected aspects of intensive use of forest biomass for energy is treated with main focus on *ecological aspects* like maintenance of soil fertility, recycling of the combustion ash, influence on biodiversity and pests, and *economical aspects* both at forest owners level and for society. Another focus point is the implementation of this knowledge into decision support, recommendations and guidelines. The geographical scope is mainly the Nordic and Baltic region.

The EU-financed project "*Wood* for *En*ergy, - a contribution to the development of sustainable forest *Man*agement" (WOOD-EN-MAN)[1], make up the frame for the book. Seven partners participated in the project: Forest & Landscape Denmark, Swedish University of Agricultural Sciences, Finnish Forest Research Institute, Norwegian Forest and Landscape Institute, Lithuanian Forest Research Institute, Latvian State Forestry Research Institute, and Estonian University of Life Sciences with Forest & Landscape Denmark as coordinator. The work was financed by EU and the seven partners, and Nicholas Clarke made the linguistic revisions. All contributors are gratefully thanked.

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[1] Contract No QLK5-CT-2001-00527, EU FP5 Quality of Life.

It is our hope that the book can contribute to the debate and further development of using forest biomass as an energy source in a sustainable way.

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Chapter 1

INTRODUCTION TO SUSTAINABLE UTILISATION OF FOREST ENERGY

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1.1 Introduction

There are several reasons for enhancing the use of forest biomass for energy in Europe. Global considerations of climate change play an important role, together with also European and national considerations. Forest biomass is considered to be a sustainable source of energy, since the CO_2 released during combustion is later taken up from the atmosphere by the vegetation to produce new biomass. Furthermore, release of CO_2 to the atmosphere would alternatively take place as a part of the mineralisation. Biomass is also a domestic and distributed fuel, meaning increased local security of energy supplies, increased activity, income and employment in rural areas and a possible reduction of costs for agricultural overproduction in Europe. However, these views need a more detailed examination as many

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forest biomass production systems also needs inputs from fossil energy, and it has also been questioned if negative impacts on e.g. biodiversity and long-term soil fertility more than counteract the positive effect of this CO_2-neutral energy source.

Forest bioenergy utilisation is closely related to issues of pronounced political importance such as energy policies and the international processes for sustainable development, especially climate change and sustainable forest management.

1.2 Energy policy

Energy policy is a very important policy field in all European countries. The energy crises in the 1970s demonstrated the connection between energy prices and economic growth, and this gave a very strong argument for national energy policies. Increased domestic use of bioenergy was seen as a means to reduce dependency on imported fossil fuels and reduce the uncertainty and fluctuations in energy prices. Later, the use of bioenergy also became an important measure to reduce emissions of greenhouse gases (GHG). The EU has committed itself to reducing greenhouse gas emissions in the first commitment period of the Kyoto Protocol (2008-2012) by 8% compared to the reference year 1990 (EC 2004a). It has furthermore decided to make an independent commitment that EU countries will reduce their emissions by at least 20% in 2020 compared to the reference year 1990. If a larger, global agreement should be signed, and other developed countries commit themselves to reduce their emissions with comparable amounts, EU countries are willing to reduce their GHG emissions by as much as 30% by 2020 (EC 2007a).

The target of the European Union is to increase the share of renewable energy in energy consumption to 12% by 2010. Progress has been made, but the 12% target will not be met (EC 2007b, EC 2004b). Nevertheless, in the Commission's roadmap, the target is 20% of energy consumption by 2020. In regards to the increased use of biomass, the EU's Biomass Action Plan suggests that the use of biomass should increase by 80 Mtoe by the year 2010 (EC 2005). Specifically, the target share of biologically based fuels for transport is 5.75% by 2010 as compared to 10% by 2020 in the Commission's road map (EC 2007b). These targets call for increased production of biomass on the EU's own territory, but evidently a large part of the biomass will have to be imported. However, the EU's own forest energy resources enable the extraction of one third of the target in the Biomass Action Plan, requiring however establishment of large scale production and supply chains for forest energy (Asikainen et al. 2007). The Nordic and Baltic countries have already made progress in the use of renewable energy and, in particular, forest biomass: its gross inland consumption from forest biomass (EC 2007b). In Estonia, Denmark, Lithuania and Norway the share of wood based biomass is around 10%.

The EU has no commonly accepted agreements or binding means to promote bioenergy, and energy policies vary among countries. The Nordic and Baltic countries too have chosen different ways to promote bioenergy. These differences can be explained by very different energy systems in these countries, differences in political awareness, and status of knowledge about bioenergy. The decision to close nuclear power stations in Sweden in 1980 certainly helped launch a large forest bioenergy program (Björheden 2006). The Norwegian situation is somewhat the opposite. With a large supply of domestic energy sources like hydroenergy and oil there was not room for a large program on bioenergy. Finland has developed intensive harvesting, transport and combustion technologies for all solid biofuels with the emphasis being on the cost competitiveness of feedstock supply. Forest biomass (primary residues) has been in focus and its use has grown from about 0.5 mill. m^3 to 3.4 mill. m^3 from the 1990s to 2006, with the aim to reach 5 mill. m^3 in 2010 (Hakkila 2006). In Denmark the use of forest biomass for energy has intensified since the 1980s due to energy policy and the desire to create a better economy for forestry, which suffered from decreasing prices for pulpwood (Møller 2000). As such, considerations of energy policy, the environment, resources, and support for agriculture, forestry, economy and employment in local communities led to the broadly supported 'biomass agreement' of 1993. The agreement was committed to increasing the use of agricultural and forestry biomass in power generation to 1.4 mill. tons yr^{-1}. The Baltic States had a large and reliable supply of oil and gas from Russia until 1990.

After 1990 the situation has gradually changed, and we can observe a growing political interest for domestic energy sources (Silveira et al. 2006).

Forest bioenergy needs a favourable political framework to be competitive. In a world with discussion of liberalized markets this might seem odd, but the fact is that all energy markets are more or less regulated in all countries. However, the intense debate about the mix of markets and regulations in the energy sector is ongoing in most European countries, with one example being the policy of deregulation in the electricity sector.

1.3 Sustainable development and forest policy

Forest bioenergy chains must be managed in a sustainable way, and the production in the forest, transport, combustion, and distribution must be performed in line with principles of sustainable development. Many of the international developments related to sustainability are relevant to forest bioenergy production and utilisation (Table 1.1). A general basis for these international developments is the definition of sustainable development from the Brundtland report: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Another general basis is the precautionary principle, as for example recognised in Principle 15 of the Rio Declaration (UN 1992): "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason of postponing cost-effective measures to prevent environronmental degradation". Especially relevant in the context of this book is the often quoted definition of sustainable forest management from the Helsinki resolutions, H1 (MCPFE 1993): "sustainable management means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, and productivity, regeneration

Table 1.1. Sustainable development internationally in relation to forest bioenergy.

Issue	Agreements	Relevance to forest bioenergy
Climate change	- Convention on Climate Change (UNFCCC) - The Kyoto Protocol (KP)	Parties commit themselves to work for reduction and prevention of anthropogenic emissions of GHG in for example the energy and transport sectors.
Sustainable forest management	For example: - Statement of Forest Principles, United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 (Earth Summit). - Ministerial Conferences on Protection of Forests in Europe (MCPFE) - Montreal Process	The extraction of forest bioenergy should comply with the principles of sustainable forest management to maintain forest productivity, health and vitality, and the protective functions of forest in relation to adjacent ecosystems, mainly soil and water. The increased use of forest products for energy is addressed e.g. in the First Lisbon Criterion and in the Fifth Vienna Resolution of MCPFE.
Biological diversity	- Convention on Biological Diversity (CBD)	Forest bioenergy harvesting might jeopardize biodiversity values in some forests, but the convention makes no direct reference to bioenergy utilisation.
Desertification	- United Nations Convention to Combat Desertification (UNCCD).	The convention encourages use of alternative energy sources, particularly renewable energy resources, aimed at reducing dependence on wood for fuel in areas sensitive to desertification.
Emissions and long-range transboundary pollution	- United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP)	Some protocols are concerned with atmospheric emissions from combustion of wood even if the main concern was initially emissions from combustion of fossil fuels.

capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems”. The main concerns in relation to harvesting of forest residues are adverse effects on long-term site fertility due to increased extraction of nutrients and organic matter, and adverse effects on biodiversity due to removal of important breeding and feeding material for organisms living on dead wood. Gradually, the principles of sustainable development have been made more operational through legislation, certification, recommendation and guidelines at different levels. Some of these have been elaborated to develop sustainable utilisation of forest biomass for energy specifically, while others are indirectly relevant, e.g. regulations on wood ash use in forest, environmental legislation, or legislation for working conditions.

1.4 The WOOD-EN-MAN project

Apart from global considerations of climate change, there are good socio-economic reasons to support forest bioenergy. The implications of these are important research topics. This is also the case for different environmental effects of forest bioenergy utilisation, and it is a task for research to document such effects and to communicate the results to policy makers and practitioners. To bridge the gap between complex and uncertain research results and practical advice, interpretation based on experts’ opinions and best guesses are often needed.

This book aims at presenting the complex of research knowledge, but also at bridging the gap to practising sustainable harvesting of forest biomass for energy. The book is a dissemination product from the project ‘*Wood* for *en*ergy – a contribution to the development of sustainable forest *man*agement (WOOD-EN-MAN, QLK5-CT-2001-00527)’, which was funded by the EU’s 5th Framework Programme under ‘Quality of life and management of living resources’. Seven partners from seven Nordic and Baltic countries were involved in the work: Forest & Landscape Denmark (co-ordinating institute), the Swedish University of Agricultural Sciences, the Finnish Forest Research Institute, the Norwegian Forest and Landscape

Institute, the Lithuanian Forest Research Institute, the Latvian Forestry Research Institute SILAVA, and the Estonian University of Life Sciences.

The main objectives of WOOD-EN-MAN were to contribute to the development of management guidelines for sustainable utilisation of forest biomass for energy, and to provide policy recommendations for the further development of sustainable forest management in Europe and for achieving desired goals in the use of wood-based biomass for energy. To reach these objectives, the work within the WOOD-EN-MAN project was performed within five key topics, i) nutrient balances (Chapter 3), ii) wood ash recycling (Chapter 4), iii) biodiversity and pest insects (Chapters 5 and 6), iv) economics and policy (Chapter 8) and v) recommendations and management (Chapters 7 and 9). The project aimed at filling in knowledge gaps within these topics, presenting the state-of-the-art, and providing synthesis across disciplines.

Apart from the book, one of the main products from the project is the PC tool EnerTree, which is intended to aid decision making by for example forest owners, forest managers, and forestry extension. The tool can also be used for educational purposes. EnerTree is presented in Chapter 9.

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Chapter 2

FOREST ENERGY RESOURCES AND POTENTIALS

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2.1 Introduction

Forests provide an abundant, locally available and environmentally renewable source of fuel. However, their utilization has to be sustainable on an ecological, economic and social basis to ensure that future generations can utilize the forest resources with the same intensity. The benefits of wood as a fuel have been known throughout history and forests have undergone periods of heavy exploitation. Today, attitudes towards the forest have changed considerably, and in developed countries the health of the forest ecosystem has become an important topic on the agenda of environmentalists, politicians and society at large.

The Nordic and Baltic countries have a high share of forest and other wooded land per capita, 2.8 and 1.1 ha per capita respectively. In Europe as a whole the share of forest and other wooded

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land per capita is even smaller at 0.7 ha. This illustrates the large amount of resources available within the region.

In developing countries the utilization of wood based fuels is much higher merely because it is the only source of energy available to a large part of society. Hakkila and Parikka (2002) note that biomass from forestry and agriculture in developing countries supplies about one third of the primary energy consumption, whereas the contribution in the developed world is less significant. In the EU the primary energy consumption in biomass represents only 3% of total energy consumption (Hakkila & Parikka 2002). However, in the Nordic countries the contribution of biomass, and wood fuels in particular, to the total energy consumption is much higher. Finland, for example produces 20% of its total energy consumption from wood products (Statistics Finland 2005). In the Baltic countries wood fuels are also becoming increasingly imporant. Lithuania, for example, increased local fuel utilization of which wood represent about 85% from 3% of the total fuel balance in 1990 to 8% in 2002 (Kairiukstis & Jaskelevicius 2003).

Wood has traditionally been a major source of fuel in households. However, after the discovery of oil the use of wood as fuel decreased in developed countries. The need for more research into alternative energy sources became obvious during the energy crisis in the 1970s, when the shortage of energy showed how vulnerable the economy was. An excess of raw materials, higher energy demand, political considerations and pressures from international environmental non-governmental organizations eventually opened the way for national policies for biomass energy production with economic and strategic issues as driving forces (Hall & Coombs 1987).

In the last years, the benefits of using wood energy have been rediscovered, particularly in the light of global warming and limited fossil fuel resources. As wood has a relatively low energy density, cost-efficient intensive utilisation depends highly on availability of local forest biomass resources. This chapter describes the natural conditions, suitability of different tree species and potential resources within the Nordic and Baltic countries, together with present utilisation intensity and practices.

2.2 Natural conditions

In the Nordic and Baltic countries, seven different ecological regions can be found. They range from Scandinavian montane birch forest and grassland in northern Norway, Sweden and Finland (especially at higher altitudes) to Central European mixed forests in Lithuania. Finland and most parts of Sweden are within the Scandinavian and Russian taiga region, where pine, spruce and birch dominate the forests. Spruce and pine also dominate the forests in much of Norway with Scandinavian coastal coniferous forests being found along Norway's west coast.

Sarmatic mixed forests dominate in the Baltic countries and southern Sweden. The range of Central European mixed forests reaches into the southern parts of Lithuania. Baltic mixed forests and Scandinavian coastal coniferous forests are commonly found in Denmark. The most notable change when moving south is the increasing share of hardwood species such as birch, alder, beech, oak, ash and aspen (European Environmental Agency 2006). As a result of the great ecological diversity within the Nordic and Baltic countries, the preconditions for forest energy utilization vary significantly.

Apart from natural conditions, development of forest resources depends on shifts in the policy and market framework. Forest resources react with quite a high inertia to changes in the relationship between society and forestry (Karjalainen et al. 2004). Development of average growing stock and increment depend mostly on the age class structure of forests. At the same time, on a European scale, forest resources have been increasing during the last 50 years (Kuusela 1994, Gold 2003). The forest cover has increased steadily by about 8%, the average growing stock by about 10%, and the average net annual increment by as much as 25%. The forest areas in the Nordic and Baltic countries are presented in Table 2.1. Growing stock (living trees) is about 7 698 million m^3 in the Nordic and Baltic countries (Table 2.1). Approximately 78% of the growing stock in forests is dominated by coniferous tree species (Karjalainen et al. 2004). Studies have revealed that site productivity has increased on numerous sites, in particular in many southern regions of northern Europe, most regions of Central Europe and in some areas in southern Europe (Spiecker et al. 1996). The causes of this trend are not clear, but a wide range of alternatives are possible, including nitrogen deposition, elevated CO_2 content of the atmosphere, land use history, changes in tree species and improved forest management (Spiecker et al. 1996). Development of average growing stock and increment depend mostly on the age class structure of forests. The age class structure can be changed significantly by cuttings, afforestation, large-scale calamities, etc. (Björheden 2005). Growing stock further depends on removals (thinnings and final fellings) and the growth in forest stands.

The increasing density of the growing stock poses a risk for more damages by insects, fungi, wind and other natural causes, and these developments are likely to also affect forest management practices in the future (Spiecker et al. 1996). As a result, lowering the density of the growing stock by increased harvesting of forest biomass for energy production decreases the risk of calamities and improves the overall health and stability of forest ecosystems (see Chapter 5 & 6).

Table 2.1. Total land area and forest area in 1000 ha and growing stock in million m^3 over bark of all living trees (United Nations 2005).

	Total land area	Forest area	% of total land area	Growing stock
Denmark	4 309	500	11.8	76
Estonia	4 523	2 284	53.9	447
Finland	33 814	22 500	73.9	2 158
Latvia	6 460	2 941	47.4	599
Lithuania	6 530	2 099	33.5	400
Norway	32 376	9 387	30.7	863
Sweden	44 996	27 528	66.9	3 155

2.3 Types of forest bioenergy

Most wood-based fuels originate from trees growing predominantly in forests. An exception is short rotation forestry, in which fast growing species are grown in short rotations mainly on former agricultural land, but forest biomass remains the prevalent source of wood based energy (Fig. 2.1). It can be divided into three groups:

primary, secondary and tertiary residues (Berndes 2001). The main sources of primary forest residues are the logging residues that are a by-product of conventional forest operations. Hakkila & Parikka (2002) defined forest residues as "all above-ground biomass left on the ground after timber harvesting operations, and pre-commercial thinnings of young stands". Sources of forest chips include residues from forest fellings, small diameter trees and non-marketable species from thinnings of young forests or seedling stands, and chips made from stemwood, branches, needles and stumps. Additionally 'traditional' (chopped) firewood is used for energy production. Industrial residues or secondary residues are by-products of forest industrial processes, including bark, sawdust, shavings and chips, endings, cross-cut ends and black liquor (Ranta 2003). Recycled wood or tertiary residues which are another source of biomass for energy consist predominantly of by-products of demolition, construction and packaging processes, offering a significant and inexpensive source of energy.

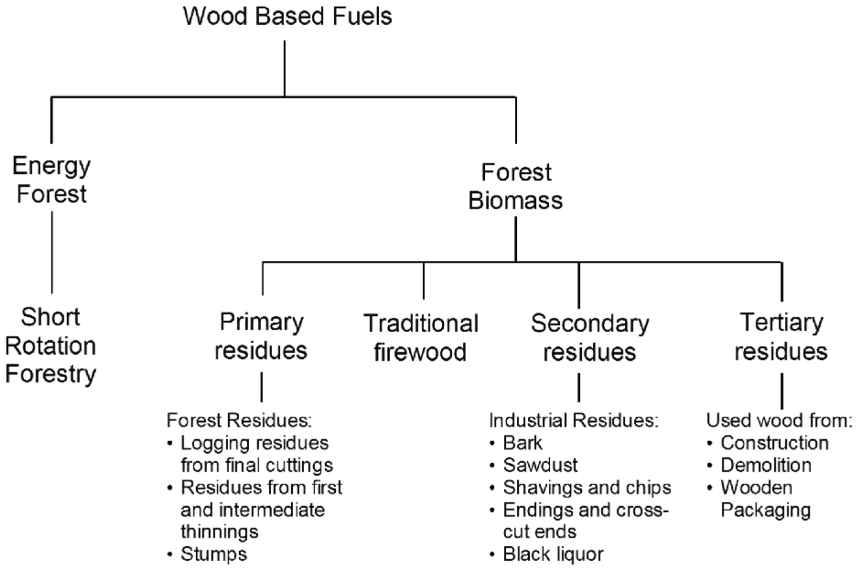

Fig. 2.1. Classification of wood based fuels.

All components of a tree can be used for energy production. However there are large differences between the different tree species and tree components with regard to availability and quality. Due to the lack of a common terminology for biomass components of a tree (Figure 2.2), this book uses the same classification as described in Hakkila & Parikka (2002);

- Complete tree refers to the entire above-and belowground mass of a tree.
- Whole tree (full tree) refers to the mass of a tree above the stump. Stem and crown mass is included but the stump-root system is excluded.
- Stem includes stem wood and stem bark, and is divided into marketable and unmarketable portions. Stem does not include the stump and its underground continuation.
- Unmarketable top (sometimes simply ‘top’) is the upper section of the stem that is left unused in logging operations due to its small diameter and high degree of branching. The size of the unmarketable top is defined by local logging practice. In industrialized countries, the bottom stem diameter of the unmarketable top is typically 6 - 8 cm, but may in some species be 20 cm. In natural tropical forests it may be even greater.
- Crown includes all living and dead branches, plus all the foliage and reproductive organs. However, in some studies, dead branches are not included in the crown mass.
- Branches include wood and bark of living and dead branches, but not the foliage, shoots and reproductive organs.
- Foliage refers to all leaves or needles, new shoots and reproductive organs. In some studies, reproductive organs are considered to be a separate biomass component.
- Stump is the unused above-ground biomass below the bottom of the marketable stem, and its underground projection including the taproot. Lateral roots are excluded.
- Stump-root system is the stump below the marketable stem, and all roots.
- Roots include all side or lateral roots, but not the taproot.

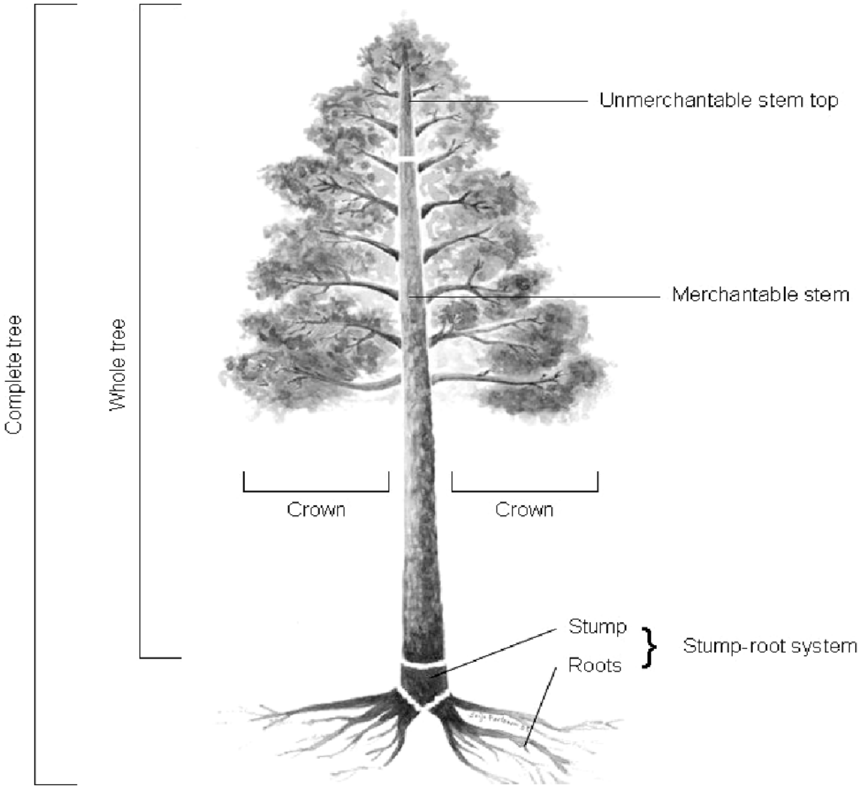

Fig. 2.2. The biomass components of a tree (redrawn from Hakkila & Parikka (2002).

2.3.1 Forest types

The actual forest type sets limitations for forestry since different site characteristics and species require different management techniques to optimise harvesting systems and generate high yields. Natural and well managed forests with a high timber value have a low potential for bioenergy production except for logging residues. In the case of unmanaged dense stands with relatively low timber value, the potential for bioenergy is much higher since small diameter material can be harvested for energy production. Growth of biomass for energy as the major objective is achieved in plantations with short rotations (Andersson et al. 2002).

2.3.2 Differences among tree species

From an economic standpoint, Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) are the most important species for forestry in the Nordic and Baltic countries as a whole. Their main utilization is in the production of sawn timber and in the pulp and paper industries. In addition, the importance of logging residues of spruce in particular as a source of fuel for heat and power generation has been widely recognized in recent years.

Considerable differences in the crown mass among species and within the different development stages of the stand can be found. Crown mass in relation to stem is in general larger in younger trees, caused by ample light infiltrating the stand (Hakkila 1989). Consequently, the crown mass and foliage are related to the shade tolerance of different species. Fir, being the most shade tolerant, has the largest share of crown mass and foliage followed by spruce and pine. As trees mature, light becomes insufficient for branches located on the lower part of the stem, causing them to die and fall off. As this process continues, the relative mass of the crown constantly decreases. From a management point of view, it is therefore important to know the mass distribution towards the end of the life cycle of a tree when harvesting of residues takes place (Hakkila & Parikka 2002). The share of crown mass and foliage is an important factor with respect to the amount of biomass available after conventional harvesting operations. If more biomass is available per hectare, the yield of the forest residues harvest is much larger, which results in lower unit costs.

There are large differences between different species in the amounts of residues per hectare, due to substantial variations in the relative quantity and composition of crown mass. For spruce the amounts of residues per hectare are considerably larger than for pine, owing to the larger share of crown mass. Foliage represents a large part of the crown, amounting to approximately 26% in mature Scots pine and up to 38% in Norway spruce (Hakkila 1991). This variation is caused by different factors such as shade tolerance, thickness of branches and bark, endurance of foliage, durability of dead branches, the form and shape of the stem and the basic density of the different biomass components of a tree (Hakkila & Parikka 2002).

2.3.3 Physical properties

Different species also vary in fuel characteristics such as energy content and heating value. The heating value describes the amount of energy released per unit mass (MWh kg^{-1}) when the fuel is combusted. The heating value can vary depending on the species, due to the density, moisture and ash content of the wood. The energy in 100% dry wood is approximately 5.3 kWh kg^{-1} for all species. In general, heating values are a little higher in softwoods because of the resin content and lower ash content, and lower in hardwoods. However, the density of hardwood species is higher, as is the dry weight of the wood per m^3. Consequently, the amount of energy per m^3 hardwood is higher that that of softwoods (Table 2.2).

Tree components naturally differ in their heating values as well. The heating value of stem, branch and root is highest in coniferous trees, due to the high resin content. The heating value of the stem or the whole tree biomass is, however, only to a small extent affected by the tree species. From the consumer's point of view the moisture content and quantity of available woodfuel are more important factors than the species, since they directly affect the economics of the operations (Nurmi 1993, 1997).

The weight of the woodfuel increases with moisture content, while the amount of cubic units is only marginally influenced by the

Table 2.2. Heating values of stem wood for various tree species at 50% moisture content (Schmidt 2003, Pirinen 1997).

Species	Density	Heating value	
	kg (dry matter) m^{-3}	kWh kg^{-1}	kWh m^{-3}
Spruce	379	2.26	1713
Pine	431	2.26	1948
Beech	558	2.16	2411
Oak	571	2.16	2467
Aspen	353	2.16	1525
Birch	495	2.32	2296

moisture content. The moisture content also has a significant effect on the fuel quality since energy is needed to evaporate the water. In the large-scale combustion of wood chips, the moisture content of the fuel is however becoming less significant since modern combustion technologies are able to combust effectively a wide variety of fuels at different moisture contents due to e.g. flue gas condensation units.

2.4 Present use of forest biomass for energy

Hakkila & Parikka (2002) pointed out that currently no country in Europe is utilizing its full potential in regards to the use of forest fuel. Today, in the Nordic and Baltic countries, close to 100% of industrial residues are used and further growth from this source can only come with an expansion of the forest industries themselves. The situation is different with regard to forest fuels, which have a large potential in the future.

In the Nordic and Baltic countries in particular, the use of firewood is very common and contributes significantly to total energy consumption. In the Nordic countries firewood is commonly used to supplement the main heating systems. In the Baltic countries firewood accounts for the major part of forest energy (Röser et al. 2003).

2.4.1 Firewood

Firewood is produced from virtually any species of timber, with preference given to hardwood species due to the higher density of the wood (Table 2.2). Traditional firewood is usually produced from whole stems, stem tops and branches left after logging operations, or from stems that don’t fulfil the requirements for industrial roundwood (species, qualities, dimensions). Commercial firewood, however, is mainly produced from pulpwood logs (Seppänen & Kärhä 2003).

In Finland, for instance, more than 1 m^3 of firewood is used per capita each year, equal to 5.75 million m^3 annually (Sevola et al. 2003). This makes firewood the most important source of wood energy after industrial wood residues. However, in western societies nowadays, the utilization of firewood is not restricted to domestic heat production but also contributes to the standard of living in countless fireplaces, ovens and sauna stoves. After a long, constant decline, the use of chopped firewood started to increase during the 1990s and is almost twice as large as the total use of forest chips in Finland. Traditionally, energy wood in the Baltic countries comes from early thinnings and intermediate cuttings of mixed softwood-deciduous stands, and is consequently made up of different species and age classes. The species mix of these stands is favourable to firewood production as the share of non-timber species is relatively high.

2.4.2 Primary residues

Primary forest residues have become an important source of forest fuel in Finland and Sweden, where the largest share of energy from forest biomass is produced from logging residues of final fellings. However, in Denmark, Norway and the Baltic countries at present, logging residues are not commonly used due to economic and technical constraints (Röser et al. 2003) or ecological concerns, but the potential exists.

Precommercial and early thinnings remain a challenge in practically all countries as a result of the low profitability of operations or technological barriers. However, Denmark produces the largest share of woodfuel in thinnings of immature stands and this resource is now almost fully utilised (Nord-Larsen & Heding 2003). The use of wood chips in Norway has also increased over the past decade: they are also mainly produced in conifer thinnings and to a lesser degree from clear-cuts. The production of forest fuel from intermediate cuttings also competes with the production of pulpwood. However, the current low price of pulpwood leads to its being, to some degree, used for the production of fuel chips. Depending on market conditions this might become more common in the future. In Finland, stumps have been recently rediscovered as a source of energy, and interest is also emerging in Sweden. The development of the harvesting system has been rapid. The stump-root system can, at the moment, only be extracted from spruce clear-cut areas, because it is not anchored to the soil by a taproot. The harvesting of spruce stumps therefore makes only a shallow hole in the ground. In addition, the harvesting of the stump-root system makes site preparation for regeneration easier and prevents establishment of the root rot fungus (*Heterobasidion annosum*). Modern comminuation and combustion technology is able to handle different qualities of raw material, which is in favour of utilizing stumps.

The more intensive use of primary residues has been limited by the fact that they are only competitive on the market if industrial residues are utilized to their full potential. Industrial residues are available at a lower price, being a by-product of industrial processes. Furthermore, forest residue utilization for energy is at the beginning of its development, and at present there are limitations with regard to procurement technology, social acceptance and ecological sustainability (Röser et al. 2003, Röser et al. 2006, Muiste & Kakko 2004, Nurmi & Kokko 2001, Richardson et al. 2002, Egnell et al. 1998, Egnell et al. 2006). In particular, transport of logging residues has been a limiting factor caused by the low energy density of the fuel (Andersson et al. 2002). However, technological development has been rapid over the past decade and more cost effective solutions become available continually.

2.4.3 Secondary residues

Secondary residues are currently the most important source of wood fuels and their use is very common. The production of secondary residues is closely linked to the output of forest industries. Many forest industries utilize their own residues such as sawdust, bark and black liquor very effectively for the production of heat and power (Hakkila & Parikka 2002). Black liquor, in particular, is a usable fuel produced by the pulp and paper industrial processes. In Finland and Sweden the forest industries are the largest consumers of bioenergy, with the major share derived from black liquor (Röser et al. 2003). The pulp and paper industry is also the largest producer of secondary residues in Norway and as a result the bioenergy production of the Norwegian pulp and paper industry is estimated to be 45% of total bioenergy consumption in Norway (Röser et al. 2003). In Denmark and the Baltic countries secondary residues consist mainly of sawdust, cutter shavings and residues form the furniture industries. At present Denmark is facing a shortage of industrial residues due to an increase in the demand for pellets. In the Baltic countries there has been no tradition of utilizing industrial residues; however, their utilization has increased considerably in recent years. In Lithuania for example, the main wood residues originate from the mechanical wood processing industry and about 75% are used for fuel at present (Kairiukstis & Jaskelevicius 2003).

Secondary residues such as sawdust can be further refined into pellets or briquettes, transforming them into a fuel with improved handling and combustion properties. Pellets have gained in importance over the last decade. They are a fuel product compressed from milled wood. The use of wood pellets has increased significantly since the 1990s, particularly in Sweden, Denmark and Austria, and even earlier in North America (Alakangas & Paju 2002). Today, pellet systems offer a convenient and efficient form of heating, competing primarily with oil and electric heating systems. Additionally, pellets offer competitive alternatives in district heating and power plants.

2.5 Estimation of woodfuel potential

2.5.1 Net annual increment, fellings, and roundwood balance

Net annual increment (NAI) is calculated as the difference between gross annual increment (GAI) and natural losses (NL). Gross annual increment includes total increase of stem volume during a year. It includes both trees that are part of the growing stock and trees that have died or been removed during the year. Natural losses include the volume of trees that have died naturally during a year and are not included in fellings. NAI in the Nordic and Baltic countries is approximately 210 million m^3 per year measured over bark in forest available for wood supply. Fellings are approximately 150 million m^3 per year. Based on the difference between NAI and fellings, i.e.

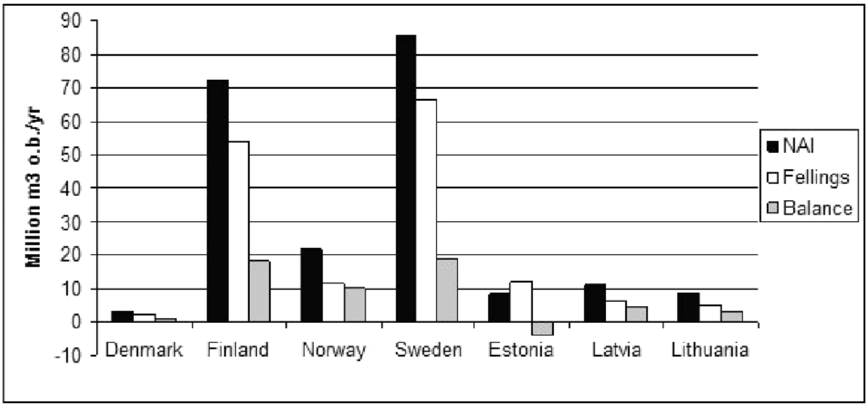

Fig. 2.3. NAI, fellings, and roundwood balance in forest available for wood supply in the Nordic and Baltic countries (Karjalainen et al. 2004).

roundwood balance, approximately 60 million m^3 per year or 28% of the NAI is left in the forests.

The roundwood balance is clearly positive in the Nordic and Baltic countries, except for Estonia (Figure 2.3). This balance can be regarded as a kind of surplus or reserve that is left in the forests. Nevertheless, competition for wood resources is increasing, and fulfilment of the demands for industrial use, energy production and environmental protection would obviously require compromises. Increased industrial use of wood will cause part of the wood to end up in the energy sector, the share depending on the use of wood in different processes (sawmills, chemical and mechanical pulp, different paper grades etc.). Use of roundwood directly for energy purposes would depend on the prices of roundwood, sawnwood, pulp, paper and energy. It is difficult to estimate how much of the unused increment could and will be utilised in the future for energy purposes, but most likely more than today.

In the Nordic and Baltic countries, NAI, fellings and roundwood balance vary significantly among countries. Most of the NAI can be found in Sweden and Finland, where the fellings and roundwood balance are also highest. In Latvia and Lithuania the balance is also relatively high compared to the NAI. However, in Estonia fellings are higher than the NAI, resulting in a negative balance. An overview of NAI, fellings and balance is given in Figure 2.3 and Table 2.3.

Table 2.3. NAI, fellings, and roundwood balance in the Nordic and Baltic countries in million m³ yr^{-1} over bark (Karjalainen et al. 2004).

Country	AI			Fellings			Balance between NAI and fellings		
	Coniferous	Broad-leaved	Total	Coniferous	Broad-leaved	Total	Coniferous	Broad-leaved	Total
Denmark	2.20	1.00	3.20	1.47	0.73	2.19	0.73	0.27	1.01
Estonia	4.40	4.20	8.60	8.30	3.90	12.20	-3.90	0.30	-3.60
Finland	56.65	15.82	72.47	43.50	10.80	54.30	13.15	5.02	18.17
Latvia	6.42	4.63	11.05	3.61	2.96	6.57	2.81	1.67	4.48
Lithuania	5.27	3.24	8.50	3.41	1.83	5.24	1.86	1.41	3.26
Norway	17.51	4.53	22.04	10.29	1.34	11.63	7.22	3.19	10.41
Sweden	71.51	13.92	85.43	57.28	8.84	66.12	14.24	5.08	19.32

2.5.2 Residues from fellings and roundwood balance

The potential sources of forest fuels are residues from the felling of roundwood (branches, needles, top stem wood, offcuts of stem), roundwood balance (NAI – fellings) and stumps and coarse roots. To estimate the shares of biomass components (stem & bark, branches, needles, top stem wood and stump wood), tree species were grouped into three groups: a spruce group (including Picea spp., Larix spp. and Abies spp.), a pine group (Pinus spp.) and a broadleaved group (beech, oak, birch and other broadleaves). The proportion of each species group in the growing stock was primarily based on volume statistics. If this estimate was not available, proportions of forest area dominated by certain species groups were used to define the proportions of the species groups.

Table 2.4. Theoretical felling residue potential in the Nordic and Baltic countries in million m^3 over bark annually (Karjalainen et al. 2004).

Country	Stem wood loss	Stem	Branches	Tops	Needles	Roots
Denmark	0.18	2.02	0.65	0.06	0.25	0.56
Estonia	0.32	3.71	0.88	0.10	0.22	0.27
Finland	4.34	49.96	14.44	1.47	4.80	15.77
Latvia	0.53	6.04	1.49	0.16	0.40	1.23
Lithuania	0.42	4.82	1.20	0.13	0.33	1.47
Norway	0.93	10.70	3.24	0.32	1.14	3.49
Sweden	5.29	60.83	18.97	1.84	6.88	19.87
Total	**12.01**	**138.08**	**40.87**	**4.08**	**14.02**	**42.66**

Table 2.5. Theoretical potential of the balance (NAI – fellings) in the Nordic and Baltic countries in million m^3 over bark annually (Karjalainen et al. 2004).

Country	Stem	Branches	Tops	Needles	Roots
Denmark	0.93	0.30	0.03	0.11	0.26
Estonia	-	-	-	-	-
Finland	16.72	4.83	0.49	1.61	5.28
Latvia	4.12	1.01	0.11	0.27	1.25
Lithuania	3.00	0.75	0.08	0.20	0.92
Norway	9.58	2.90	0.29	1.02	3.12
Sweden	16.85	5.54	0.54	2.01	5.81
Total	**51.20**	**15.33**	**1.54**	**5.22**	**16.64**

In the Nordic countries, the largest biomass reserves can be found in Finland and Sweden, and in the Baltic countries the biggest potential is in Latvia and Lithuania. Total volumes of different biomass components and theoretical forest fuel potential in the Nordic and Baltic countries are presented in Tables 2.4 and 2.5. However, there are some limiting factors that have to be taken into consideration in order to estimate the technically harvestable potential. In this study, availability reductions applied to the total potential were similar to factors commonly used in Finland (Asikainen et al. 2001a, Asikainen et al. 2001b, Laitila & Asikainen 2004, Hakkila 2004). It was assumed that 75% of clear-cuts and 45% of thinnings are technically available for supply.

Shares of timber from clearcuts and share of mechanization in the Nordic and Baltic countries are presented in Table 2.6. The actual amount of material taken out of the stand was estimated to be

Table 2.6. Shares of clear-cuts and mechanization degree in the Nordic and Baltic countries (Karjalainen et al. 2004).

Country	Share of timber from clearcuts (%)	Share of mechanization in cuttings (%)
Denmark	70	50
Estonia	73	55
Finland	79	97
Latvia	76	5
Lithuania	50	0
Norway	70	80
Sweden	70	98

Table 2.7. Volumes of available logging residues in the Nordic and Baltic countries (Karjalainen et al. 2004).

Country	Residues (fellings)	Residues (balance)	Roots (fellings)	Roots (balance)
Denmark	0.4	0.3	0.1	0.0
Estonia	0.6	-	0.2	-
Finland	10.7	6.3	2.2	0.7
Latvia	0.9	1.5	0.3	0.2
Lithuania	0.6	1.1	0.2	0.1
Norway	2.3	3.7	0.5	0.4
Sweden	14.1	6.6	2.8	0.8
Total	**29.6**	**19.5**	**6.3**	**2.2**

65% in mechanized cutting and 50% in manual cutting. The smaller recovery percentage in manual cutting results from the fact that residues are scattered over the whole stand, whilst in mechanized cutting, material can be stacked during cutting. The technical availability of felling residues in the Nordic and Baltic countries, including 25% of the balance, is shown in Table 2.7.

With the above-mentioned reductions taken into consideration, it was estimated that felling residues amounted to a total of 71 million m^3 annually in the Nordic and Baltic countries. Annual harvestable residues were estimated to be 30 million m^3. In addition, about 6 million m^3 of stump wood, out of a total potential of 44 million m^3, could be used for energy production. If, for instance, 25% of the balance should be directed to energy use, 20 million m^3 of above ground biomass and about 2 million m^3 of stump wood could be used for energy. Thus, the available forest fuel totals about 58 million m^3, which corresponds to about 116 TWh of energy.

The volume of technically available forest fuels in the EU 25 is 140 million m^3, of which 72 million m^3 are felling residues from current fellings and 68 million m^3 are roundwood and felling residues from unutilized increment or roundwood balance. This also in cludes 13 million m^3 of stump wood. The Biomass Action Plan, published by the Commission of the European Communities (2005), aims to raise the production of bioenergy from biomass and waste from 67 Mtoe in 2003 to 143 Mtoe by 2010. One third of this increase could be covered by forest biomass. In the Nordic and Baltic countries in particular, the use of forest biomass for energy could be increased substantially.

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Chapter 3

EFFECTS OF VERY INTENSIVE FOREST BIOMASS HARVESTING ON SHORT AND LONG TERM SITE PRODUCTIVITY

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3.1 Introduction

Intensified forest biomass utilisation causes export of substantial amounts of nutrients from the forest ecosystem. Compared to conventional stems-only harvesting, the most intensive biomass scenario causes increases in nutrient exports of up to 6-7 times whereas the biomass export increases only up to 2 times (Stupak et al. 2007a). High concentrations of nutrients in small branches, twigs, and leaves compared to stems are the main reason. The extensive export of nutrients related to intensive biomass extraction have for many years

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caused concern for the long-term fertility of the system among forest ecologists (Burger 2002, Blanco et al. 2005, Dyck et al. 1994, Egnell et al. 1998, Egnell et al. 2006).

Whole-tree harvesting experiments have demonstrated decreases in increments in the short term. In Fennoscandia, Jacobson et al. (2000) demonstrated growth decreases in the first 10 years after intensive harvesting in thinnings of Norway spruce and Scots pine stands. The decrease was about 10% compared to conventional thinnings. The growth reduction observed during the first 10 years could be neutralised by nitrogen fertilisation and they concluded that the growth reduction was initialised by induced nitrogen deficiency. Comparable results have been found in the UK by Proe and Dutch (1994) in second generation Sitka spruce after clear-cutting including removal of residues. To our knowledge no experiments have been conducted for a longer period than about 30 years, corresponding to less than one tree generation. In agriculture, such exhaustion experiments have been conducted for more than 160 years at Rothamsted Experimental Station. The productivity of wheat is now almost constant, but only about one third of the optimal fertilised level (Vance 2000).

In order to assess long-term sustainability the output and input fluxes of nutrients from and to the system can be measured and a balance calculated, i.e. the nutrient balance approach. If the balance is negative, export exceeds import and the system will be unsustainable over time. The nutrient balance approach has been used to quantify the effect of intensified biomass extraction on the ecosystem nutrient status by e.g. Adams et al. (2000), Boyle et al. (1973), Huntington (2000), Likens et al. (1998), Watmough & Dillon (2003) and Weetman & Webber (1972). Such studies have shown a biomass export related decrease in soil stores of nutrients, often calcium. A decrease in soil stores may not *per se* be critical as long as the level is far above a critical low level but the negative nutrient balance may be interpreted as a warning for the long-term effect.

Nitrogen has often been in focus in nutrient balances since growth is often limited by nitrogen and positive effects of nitrogen fertilisation are common. However, phosphorus, calcium or potassium may become a problem in areas with significant nitrogen deposition (George & Seith 1998). Magnesium deficiency may occur in some areas, for example as induced by acid rain in parts of Central Europe (Evers & Huttl 1990, Katzensteiner et al. 1995).

Fertilisation with nitrogen can compensate for nitrogen related growth rate decrease, at least in the short term (Jacobson et al. 2000). Documentation for similar effects of the other nutrients is lacking although hypothesised (Scott & Dean 2006).

It has been suggested to bring back combustion ash to the forest in order to compensate for the nutrient export and to avoid deposition of the ash as waste. However, during the combustion process significant parts of some elements, mainly nitrogen, vaporise. Calcium, magnesium, potassium and phosphorus are retained almost completely in the ash. Much research has concentrated on the use of ash as a fertiliser and as a means to counteract soil acidification, see Chapter 4.

Guidelines for careful biomass harvesting taking the negative effects into account have been published. The most detailed are from Sweden (National Board of Forestry 2002) and Finland (Koistinen & Äijälä 2005). However, operational tools for estimation of compensation needs are few, see however Chapter 9.

Very intensive harvesting has also been claimed to have a negative influence on the organic matter content in forest soils due to a reduced input of dead biomass (Jandl et al. 2007). Since soil carbon only adapts slowly to reduced litter input it has been difficult to document a general trend in soil carbon content after intensive harvesting (Johnson et al. 2002).

In this chapter we focus on the nutritional consequences of intensified biomass utilisation by use of the nutrient balance approach. Specific attention is given to quantification of the nutrient export and to the soil nutrient release capability. We suggest distinction of sensitive and robust soils. Six case studies are used to exemplify the approach and illustrate the importance of deposition, harvesting and soil properties. The distinction of sites and the quantification of nutrient balances are used for compensation recommendations. We do not discuss effects like decrease in soil organic matter, or other indirect effects like soil compaction, weed problems, and microclimatic effects.

3.2 Nutrient fluxes to and from forest ecosystems

In the forest ecosystem nutrients are cycling in a relatively closed cycle. In the entire forest ecosystem a balance (Eq 3.1) almost exists between uptake and decomposition (Ulrich 1987):

$$CO_2 + H_2O + xMe^+ + yA^- + \text{energy} <\!\!-\!\!> (CH_2O)_n + (x\text{–}y)H^+ + O_2 \qquad (3.1)$$

where n, x, and y are constants, Me^+ are cations (Ca^{2+}, Mg^{2+}, K^+…) and A^- are anions (NO_3^-, $H_2PO_4^-$ …)

As a consequence of the cycle, *steady state* in element storage should be expected in natural forests. However, the cycle is not completely closed. Small amounts are deposited from the atmosphere and losses take place due to leaching or through gaseous output to the atmosphere. In managed forests, element export also takes place with biomass harvesting. The fluxes are illustrated in Figure 3.1. The fluxes of nutrients can be summarized in a mass balance equation (Eq 3.2):

$$\Delta\text{biomass} + \Delta\text{soil} + \Delta\text{atmospheric flux} + \Delta\text{runoff flux} = 0 \qquad (3.2)$$

Numerous balance accounts have been made for forest ecosystems. Several of these focus on the effect of biomass export, e.g. Adams et al. (2000), Boyle et al. (1973), Freer-Smith & Kennedy, (2003),

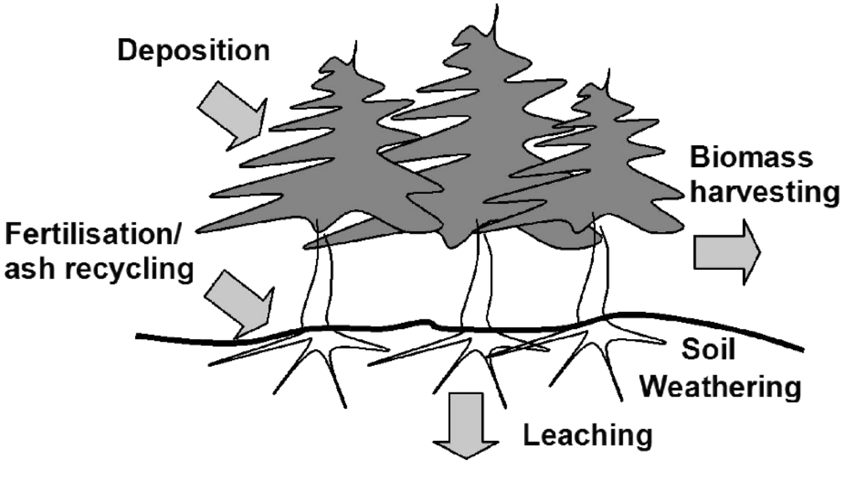

Fig. 3.1. Nutrient fluxes to and from a forest ecosystem.

Hutington (2000), Likens et al. (1998), Watmough & Dillon (2003) and Weetman & Webber (1972).

Nutrient balances should be interpreted carefully. Even the most sophisticated balances have a high degree of uncertainty. Among the uncertainties affecting the balances are:

- It is technically difficult to determine small but still significant fluxes, e.g. gaseous outputs.
- The spatial variation is very high.
- The temporal variation is also extremely high, and daily, yearly and tree generation cycles exist.

3.2.1 Deposition

Atmospheric deposition is a source of nutrient inputs to forests, and in some cases deposition might be sufficient to replace nutrients lost by intensive harvesting. Among nutrients in deposition are nitrogen, potassium, calcium, magnesium and micronutrients such as boron. In some areas, deposition can also cause increased nutrient export by leaching and subsequent decrease in pH, leading to decreased nutrient availability in the soil.

Deposition can be particulate or gaseous (dry deposition), or in solution (wet deposition). An overview of the factors influencing dry deposition is given by Erisman & Draaijers (2003). Dry deposition increases with natural factors such as increasing wind speed and decreasing surface wetness. It also depends on the canopy structure and the structure of the landscape. A ‘rough’ and tall canopy will increase the amount of dry deposition as will small needle-like structures compared to larger leaf-like structures. To illustrate this, the deposition of nitrogen was about 40 kg ha^{-1} yr^{-1} to Sitka and Norway spruce, and about 15 kg ha^{-1} yr^{-1} to beech at Lindet, located in a high ammonia deposition area in Denmark (Table 3.1). At the landscape level, dry deposition is higher where there are many forest edges and other transition zones. The contribution of dry deposition to total deposition varies: in clean areas the contribution is often small while in more polluted areas and in areas subject to impact from desert dust or sea salt, it may be significant. As an example, dry sulphur deposition to the forests in southern Norway has been estimated as

Table 3.1. Deposition and leaching to and from Nordic and Baltic forested sites.

Site	Species	Year	Deposition					Depth	Element output in seepage water				
			N	P	K	Ca	Mg		N	P	K	Ca	Mg
			kg ha^{-1} yr^{-1}					cm	kg ha^{-1} yr^{-1}				
Denmark:													
Lindet[1]	N. spruce	1988-91	39.4	0.0	6.5	7.1	11.9	90	1.4	0.0	6.1	3.2	6.6
Lindet[1]	Beech	1988-91	15.2	0.0	6.6	5.6	8.3	90	0.2	0.0	6.4	2.2	5.4
Lindet[1]	Sitka spr.	1988-91	39.8	0.0	4.7	6.3	12.5	90	5.7	0.0	7.7	10.0	10.9
Stenholt Vang[1]	Sitka spr.	1988-91	22.3	0.0	3.3	4.2	5.8	40	48.4	0.0	1.9	113.9	4.9
Ulborg[1]	Sitka spr.	1988-91	24.7	0.0	5.5	6.5	15.6	90	1.4	0.0	3.2	7.9	12.1
Norway:													
Nordmoen[2]	N. spruce	1986-88	10.9		2.5	2.2	0.6	60	0.7	0.1	1.4	3.6	1.8
Birkenes[3]	N. spruce	1980-90	26.0		4.4	4.2	3.6	Weir	2.1		2.6	12.6	4.7
Sweden													
Gårdsjön[4]	N. spruce	1989-1991	14.4	0.2	5.1	5.2	8.6	?	0.1	0.02	3.1	7.1	10.4
Finland:													
Mekrijärvi[5]	Scots pine	1985-1986	2.0	0.0	4.6	2.8	0.7	24	0.2	0.0	3.4	0.7	2.1
Lithuania:													
Kacergine[6]	Scots pine	2001	10.9		14.8	3.1		20-50	4.4		1.8	3.1	

[1]Pedersen (1993), [2]Johnson and Lindberg (1992). Only inorganic N is included, [3]Kvindesland et al. (1994). Only inorganic N is included, [4]Moldan & Wright (1998b), [5]Helmisaari (1995), [6]Stakenas (2004). Only inorganic N is included.

20–50% of total deposition (Aamlid et al. 2000). The size of the wet deposition depends both on the amount of precipitation and on elment concentrations in the precipitation. There is therefore considerable interannual variation. Often, what is measured is bulk deposition, which includes wet deposition but only part of the dry deposition.

Deposition that reaches the forest floor and thus enters the soil consists of throughfall (deposition measured below the canopy) plus stemflow. Trees tend to act as particle collectors, so for those elements that occur in dry deposition, concentrations may be higher in throughfall than in bulk deposition. Canopy exchange processes and the production of dissolved organic matter in the canopy also affect element concentrations in throughfall. Especially for potassium, canopy leaching is an important pathway into forest soils (Langusch et al. 2003). Stemflow may represent a significant input to the forest floor in some forests, for example in beech forest. In mature Norway spruce and Scots pine forests, the contribution from stemflow is normally small.

Nitrogen deposition in throughfall is highest in Denmark, south–western Sweden and southernmost Norway (Lorenz et al. 2005, 2006). The northern parts of Fennoscandia have very low throughfall nitrogen deposition, <3.6 kg $ha^{-1}yr^{-1}$ (Lorenz et al. 2005, 2006). In addition to long-range transboundary deposition, animal husbandry may be important in some areas as a source for ammonium. For example, 98% of ammonia emissions in Denmark are from agricultural sources, predominantly livestock manure (Heidam & Illerup 2003). Trends in throughfall deposition of inorganic nitrogen are very variable. In Sweden, most ICP Forests Level II sites showed an increase in nitrate in throughfall between 1998 and 2003, while most Finnish, Norwegian and Estonian sites showed a decrease (Lorenz et al. 2006). In the same period, ammonium in throughfall deposition mostly decreased in Estonia and Finland, while patterns in Norway and Sweden were variable (Lorenz et al. 2006). However, few of the observed trends in nitrate or ammonium throughfall deposition were significant.

Sulphuric acid or sulphur dioxide deposition is relevant to nutrient cycling because of its acidifying effect. In the Nordic-Baltic area, throughfall deposition of sulphate sulphur is generally highest

(>4 kg ha^{-1} yr^{-1}) in Denmark, southernmost Norway, some areas of coastal Norway (due to sea salt deposition), much of southern Sweden, southernmost Finland and Estonia (Lorenz et al. 2005, 2006). Sulphate in throughfall deposition has generally decreased in the whole region, in many places significantly (Lorenz et al. 2005, 2006), due to reductions in emissions, although there is some variation due to temporal variation in throughfall amounts and sea salt inputs.

The deposition of nitrogen and sulphur cannot be seen solely as a supply of nutrients but also in terms of acidification. Acid deposition may lead to nutrient imbalance, or deficiency, by depleting the stores of base cations in the humus layer, in particular magnesium, as shown in the experiments of Abrahamsen et al. (1994). The acidifying effect of precipitation is often expressed in its pH, although a high concentration of ammonia in precipitation can also have a significant acidification potential, despite the high pH. In the Nordic-Baltic region, the highest pH values in precipitation (>5.2) are found in the relatively pristine areas of northern and mid-Norway and there is a pH decrease to 4.4-4.8 towards the south and east (Hjellbrekke 2003). The pH of precipitation has shown an upward trend in much of the Nordic-Baltic area (Heidam & Illerup 2003, Kvaalen et al. 2002, Lövblad et al. 2003, Ruoho-Airola et al. 2003, Schaug et al. 2003, Sopauskiene & Jasineviciene 2003), although no significant trend was found for Latvia (Lyulko et al. 2002) and a decreasing trend in parts of Estonia due to reduced emission of alkaline dust (Pajuste et al. 2003).

Concentrations of base cations in deposition can be due to anthropogenic emissions (e.g. burning of oil shale and cement production in the Narva region of Estonia, Schaug et al. 2003), to dust inputs or to sea salts. Dust emissions have generally been reduced in the last decades, leading to decreases in calcium and magnesium deposition (Langusch et al. 2003). Calcium concentrations in bulk/wet precipitation are generally low (<0.2 mg l^{-1}) in most of Norway, Sweden and Finland (Hjellbrekke 2003). Concentrations in Denmark, the Baltic States, south-western Sweden and the extreme south of Norway are higher, but annual mean values remain under 1 mg l^{-1} (Hjellbrekke 2003). In Latvia, changes in the concentrations of base cations in precipitation have followed the decline in sulphate concentrations (Lyulko et al. 2002). There have been decreased concentrations of non-sea salt calcium and potassium in precipitation in southern parts of Finland (Ruoho-Airola et al. 2003), Latvia (Lyulko et al. 2003) and Norway (Moffat et al. 2002, Schaug et al. 2003), of potassium in Estonia (Pajuste et al. 2003) and of calcium in Scania (Lövblad et al. 2003).

Sea salt input may be particularly important for magnesium and micronutrients such as boron. Sea salt deposition is highest in coastal areas of Norway and on the west coasts of Sweden and Denmark (e.g. at Lindet and Ulborg in Denmark, Table 3.1). It decreases exponentially with distance from the coastal zone. The gradient of magnesium input from the sea may extend as far as 200 km inland (Armbruster et al. 2002). There is also smaller scale variation: in Norway, the sodium and chloride concentrations in conifer needles have been related to distance from the nearest fjord (Aamlid & Horntvedt 2002). In some inland areas of Norway such as Ottadalen, which lies in a rain shadow, boron deficiency may occur (Brække 1979, Kohmann 1997). Boron deficiency is also known from Finland (Tamminen & Saarsalmi 2004). The amount of sea salt deposition depends on the frequency of westerly winds, in particular in the form of autumn and winter storms. The Baltic is low in salts (average surface salinity range 3-10‰, compared to the global oceanic average salinity of 35‰), so sea salt deposition is likely to be less important along Baltic coasts. In the Norwegian fjords, the salinity of the deeper layers is similar to the global average, while thin surface layers may have lower salinity during periods of freshwater outflow. Surface salinity at the head of the fjord may be very nearly fresh.

Heavy metal deposition is one source of heavy metals in biomass, and thus in wood ash that is recommended as a means of counteracting acidification and nutrient removals due to harvesting. Concentrations of lead and cadmium in precipitation are lowest in northern Fennoscandia and increase towards the south (Ilyin et al. 2003). Emissions of these elements have decreased in Europe in recent years (Ilyin et al. 2003). In Latvia, concentrations of lead and cadmium in precipitation have tended to decline in recent years (Lyulko et al. 2002, 2003). Heavy metal deposition can be severe in areas near heavy industry, for example nickel in eastern Finnmark (Aamlid 2002).

In conclusion, nutrient concentrations in forest soils are affected by both natural and anthropogenic deposition. Anthropogenic deposition is especially important for nitrogen in the southern parts of the Nordic-Baltic area. In these areas, deposition may in itself be sufficient to replace nitrogen lost in intensive harvesting. Deposition can also affect the acidification status of the soil and heavy metal concentrations. Sea salt input can be especially important in areas near the Atlantic coasts (less so near the Baltic coasts), for example for magnesium and boron. However, deposition is often insufficient to replace base cations lost through harvesting (cf. Section 3.4).

3.2.2 Leaching

The major natural export of nutrients from the forest ecosystem is for most nutrients through leaching with the seepage water out of the rooting zone. In addition, harvesting itself affects nutrient export in leaching. Thus, leaching has to be considered when calculating nutrient balances in order to evaluate the necessity for nutrient addition using wood ash or fertilisers. Output nutrient fluxes depend on both water fluxes through the soil profile and nutrient concentrations in the seepage water.

It has been hypothesised that unpolluted old-growth temperate forests should exhibit minimal net uptake or accumulation in biomass (Hedin et al. 1995): thus, leaching losses should be roughly equal to input in deposition. This has been found to be the case for base cations and inorganic nitrogen (Hedin et al. 1995). Developing forests, on the other hand, tend to retain added nutrients, so that losses in leaching would tend to be reduced. This would be the case especially for nitrogen, as this is normally a main limiting factor for forest growth in Scandinavia. Anthropogenic nitrogen deposition may lead to increased retention of nitrogen in the ecosystem and, in some areas, leaching of excess inorganic nitrogen (Dise et al. 1998). In a forest that is not nitrogen-saturated, leaching of inorganic nitrogen is insignificant (e.g. at Mekrijärvi, Finland, Table 3.1), while in a nitrogen saturated system it can be significant (Gundersen et al. 2006). In most of the Nordic area, forest ecosystems are not nitrogen-saturated but nitrogen-limited, but even in these leaching of organic nitrogen occurs naturally. Leaching of inorganic nitrogen in nitrogen-limited forest ecosystems is generally very low, although it can be exported during periods of high flow, especially outside the growing season when uptake is low (e.g. due to snowmelt or storms, Mulder et al. 1997, Moldan & Wright 1998a), or by leaching after clear-cutting, when uptake is low and runoff high (Hu 2000). Not only overall nitrogen deposition but also tree species appears to be relevant: in Denmark, higher nitrate leaching rates were found under conifers (Sitka spruce, Norway spruce and Douglas-fir) compared with deciduous trees (beech and oak) (Hansen 2003, Table 3.1).

Leaching of base cations is influenced by both natural weathering rates and deposition patterns. For example, stands on a calcium rich site in Denmark (Stenholt Vang, parent material mixed quaternary deposits) could leach about 100 kg Ca ha^{-1} yr^{-1} (Pedersen 1993, Table 3.1). The leaching of magnesium in forests in western Denmark is influenced by deposition of sea salts (e.g. at Ulborg and Lindet, Table 3.1).

Both the amount and the chemical composition of seepage water are influenced by harvesting. Harvesting decreases evapotranspiration and thus increases runoff quantity. Haveraaen (1981) estimated that clear-cutting might increase runoff by up to 30%, equal to 200-250 mm yr^{-1}, in an area of eastern Norway with shallow soil. Increased leaching of all main forms of dissolved nitrogen (nitrate, ammonium and organic nitrogen) has been observed after harvesting (Haveraaen 1981, Nieminen 2004). Haveraaen (1981) found that loss of total nitrogen increased from 1.5 kg ha^{-1} yr^{-1} to 7-9 kg ha^{-1} yr^{-1} (including 6 kg ha^{-1} yr^{-1} of NO_3-N) after harvesting in eastern Norway. Uptake of nitrate is low due to lack of vegetation, and this nitrate will therefore be largely leached, together with base cations. However, small clear-cuts on a nitrogen-saturated site in Germany did not appear to increase the risk for increased nitrate concentrations in seepage water (Huber et al. 2004). For phosphorus the situation is less clear: P concentrations did not significantly increase, while P leaching increased only slightly after harvesting (Haveraaen 1981, Nieminen 2004). Base cation fluxes in runoff may increase after harvesting (e.g. potassium loss increased from 2 kg ha^{-1} yr^{-1} to 12-13 kg ha^{-1} yr^{-1}

in eastern Norway, Haveraaen 1981), as increased decomposition of organic matter may lead to increased concentrations of base cations in runoff water. Piirainen et al. (2004) observed only slightly increased fluxes of P and base cations from below the B horizon after clear-cutting, despite increased fluxes from the O horizon. Thinning has been found not to exert much influence on concentrations of ammonium, nitrate, potassium and magnesium in soil water, while the effect on calcium concentrations was variable (Hu 2000).

In summary, leaching of inorganic nitrogen in the Nordic-Baltic area is high only in areas impacted by high nitrogen deposition. Unlike nitrogen, leaching of base cations is influenced by both soil pH and deposition. Leaching of nitrogen as well as other nutrients may increase temporarily as a result of harvesting. To what extent compensation using fertilisers or wood ash is necessary after harvesting will depend on the ability of weathering and deposition in combination to replace nutrient losses in both harvesting and leaching.

3.2.3 Nutrient removals in forest biomass harvesting

Nutrients in biomass are not readily available for nutrient uptake, but they constitute a significant pool of the nutrients in the ecosystem. Part of the nutrients in biomass is recycled relatively quickly through decomposition of litterfall and fine roots (Parton et al. 2007) and a part is released more slowly after decomposition of coarse woody debris (Laiho & Prescott 2004) and other more recalcitrant parts. Due to harvesting in a managed forest, a large part of nutrients in the biomass are output fluxes from the ecosystem. This output is concentrated to cleanings, thinnings and clear-cuts taking place at intervals of several years or decades. As such, the largest single nutrient removal with harvestings might take place only once per rotation in the clear cut. From a long-term perspective it is however relevant to look at the average yearly nutrient removals over the whole rotation, rather than the actual fluxes in single years. This quantity can be compared to other inputs and outputs more evenly distributed between years. Model calculations for Norway spruce,

Table 3.2. Description of utilisation alternatives, cf. Figure 3.2 and Table 3.1.

Utilisation intensity	Description
ST	Removal of stems only in all thinnings and at clear cut
TH1	ST + removal of fresh whole-trees in the 1st thinning
TH1-3	ST + removal of fresh whole-trees in the 1st–3rd thinnings
LR	ST + removal of logging residues after clear-cutting
AG	Removal of all above ground material in all thinnings and at clear cut
AG+BG	AG + removal of stump and root systems after clear-cutting

Scots pine and birch in monocultures show that the size of the biomass and nutrient removals may vary considerably (Stupak et al. 2007a, Infobox 3.1 and Table 3.2). Considering all scenarios, the biomass removals varied by 20 times (0.7 to 12.5 t ha^{-1} yr^{-1}), and nutrient removals even by 100 times (0.6-48.9, 0.1-6.9, 0.2-21.9, 0.6-46.8, and 0.1-6.2 kg ha^{-1} yr^{-1} for nitrogen, phosphorus, potassium, calcium and magnesium, respectively). *Site productivity* and *utilisation intensity* are the most important factors to explain the variation (Figure 3.2).

Infobox 3.1. Details for modelling of biomass and nutrient removal scenarios.

Average yearly removals of biomass and nutrients were calculated for several scenarios by combining:

- Two growth models for Norway spruce, one for Scots pine and one for birch, which gave diameters, heights and stem numbers as output
- Biomass equations giving the biomass of different tree compartments with diameter and height as input
- Three levels of nutrient concentration in the different biomass compartments

Site index (height at the age of 100 years for spruce or pine) varied from 16-36 m, corresponding to production classes (maximum average yearly yield) of 2 - 20 m^3 ha^{-1} yr^{-1}.

Table 3.3. Ranges of relative average yearly biomass and nutrient removals for different utilisation scenarios (Table 3.2). ST, stem harvesting only = 1.00 For birch, no scenarios include extraction of foliage or the stump and root system.

	Norway spruce	Scots pine	Birch
Biomass			
TH1	1.0-1.2	1.0-1.1	1.0-1.1
TH1-3	1.0-1.4	1.0-1.2	1.0-1.1
LR	1.1-1.7	1.1-1.5	1.0-1.2
AG	1.3-1.8	1.2-1.5	1.2-1.2
AG+BG	1.6-2.3	1.5-2.0	-
Nitrogen			
TH1	1.0-2.4	1.0-2.0	1.0-1.2
TH1-3	1.0-3.6	1.0-2.4	1.1-1.5
LR	1.4-5.4	1.3-4.5	1.2-1.6
AG	2.1-5.8	1.8-4.5	1.5-1.8
AG+BG	2.5-6.3	2.1-5.0	-
Phosphorus			
TH1	1.0-2.6	1.0-2.0	1.1-1.4
TH1-3	1.0-4.1	1.0-2.5	1.2-1.8
LR	1.3-6.1	1.3-4.8	1.2-1.9
AG	2.0-6.6	1.7-4.8	1.6-2.3
AG+BG	2.4-7.2	2.0-5.2	-
Potassium			
TH1	1.0-1.9	1.0-1.8	1.0-1.2
TH1-3	1.0-2.6	1.0-2.2	1.1-1.4
LR	1.3-3.8	1.3-4.1	1.1-1.4
AG	2.0-4.0	1.8-4.1	1.3-1.6
AG+BG	2.3-4.6	2.1-4.5	-
Calcium			
TH1	1.0-1.8	1.0-1.3	1.1-1.2
TH1-3	1.0-2.5	1.0-1.5	1.1-1.5
LR	1.3-3.5	1.2-2.2	1.2-1.6
AG	1.9-3.7	1.4-2.2	1.5-1.8
AG+BG	2.3-4.2	1.7-2.6	-
Magnesium			
TH1	1.0-1.9	1.0-1.4	1.0-1.2
TH1-3	1.0-2.7	1.0-1.5	1.1-1.3
LR	1.3-3.9	1.2-2.3	1.1-1.4
AG	2.0-4.2	1.4-2.3	1.4-1.6
AG+BG	2.3-4.7	1.7-2.8	-

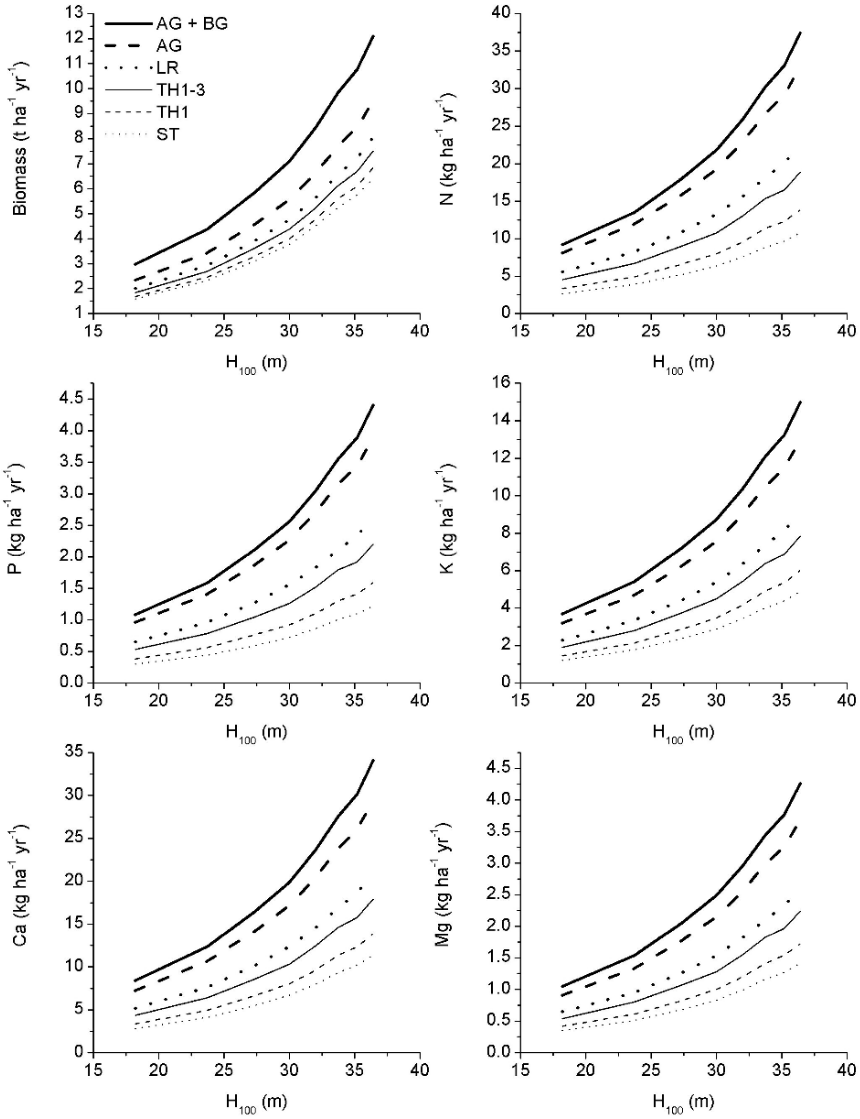

Fig. 3.2. Average yearly biomass and nutrient removals for Norway spruce versus of productivity (H_{100}) for the different utilisation scenarios described in Table 3.2.

The utilisation intensity can also be described as the relative increase in removals compared to the situation where only stems are harvested. This relative increase depends on the element and the species, with the largest increases being for nitrogen and phosphorus in spruce (6-7 times, Table 3.3).

For potassium, calcium, and magnesium in spruce and nitrogen, and phosphorus and potassium in Scots pine, increases were up to 4–5 times for the most intensive scenarios, while for calcium and magnesium in Scots pine increases were up to about 3 times. Correspondingly in birch, increases were up to 2 times for all nutrients (for birch, no scenarios included removal of leaves or stumps and roots). In comparison, the increases in biomass removals were only up to 2 times.

When only stems are harvested, the biomass and nutrient removals are only slightly influenced by *species*, while for more intensive utilisation scenarios, the nutrient removals are substantially lower for Scots pine and birch compared to Norway spruce. The pattern is shown for nitrogen in Figure 3.3, but it is similar for all nutrients. The main explanation is that Scots pine has a smaller crown share than Norway spruce, and birch harvesting is simulated without leaves. As such, differences among species seem to originate mainly from differences in productivity and crown share (see also Chapter2).

The effects of *target diameters* (or rotation age) are limited. For each scenario on the more productive sites, a maximum was reached (Figure 3.4). Such patterns are in agreement with well known patterns for stem wood growth as described in growth models and traditional production tables (Ekö 1985, Leary et al. 2007a, Leary et al. 2007b, Nabuurs & Schelhass 1997, Skovsgaard 1995). For the lowest site productivities, the biomass and nutrient removals only increased with increasing target diameter. *Initial planting distances* might also influence biomass and nutrient removals. For example Gamborg (1997) found by model calculations that the yield of wood chips from thinnings can be increased by 30-40% when initial plant densities are increased from 2500-4500 plants ha^{-1} to 6500 plants ha^{-1}, and when whole-tree harvesting is performed in all thinnings. The *thinning regime* is not likely to have substantial effects unless the share of removed stems is large enough to affect stand productivity. The model calculations were not verified by field observations, and a number of factors reduce the biomass and nutrient removals in practice. First of all, the most intensive utilisation scenarios are seldom applied. As described in Chapter 2, the present practices in the Nordic and Baltic countries comprise harvesting of

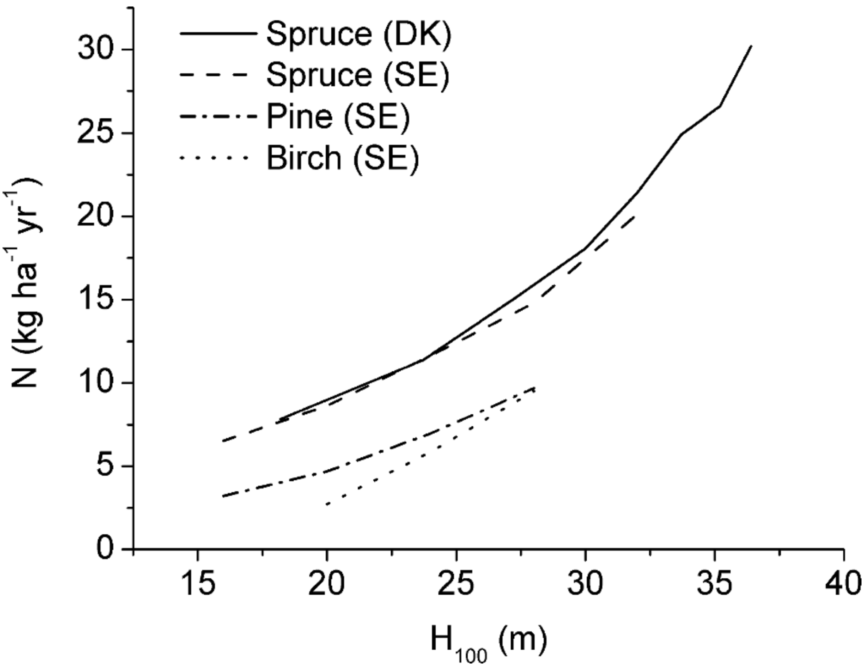

Fig. 3.3. Average yearly nitrogen removals for spruce, pine and birch when all above ground biomass is removed (AG, Table 3.2). For spruce two different growth models, a Danish (DK) and a Swedish (SE), were used.

whole trees in pre-commercial and first thinnings, sometimes after pre-drying, and removal of logging residues after clear-cutting. A part of the biomass is often left in the forest either as recommended by authorities in some countries, or because it is not profitable to remove everything. Different methods are proposed by various guidelines to reduce the removals in the attempt to balance the trade-off between high biomass yields and low nutrient removals (Chapter 7). It has been proposed to leave some trees or tree parts in the forest, or to let the needles shed by pre-drying. The larger part of Norway spruce needles are usually shed during such drying (Flinkman et al. 1986, Mäkelä 1997, Thörnqvist 1984) while Scots pine needles are more resistant to shedding (Simola & Mäkelä 1976). By pre-drying thinned whole-trees, Møller (2000) and Stupak et al. (2007b) found that 30-60% of the nitrogen, phosphorus, and potassium and 20-30% of the calcium and magnesium could be kept in the forest. The corresponding decrease in biomass yield was less than 20%.

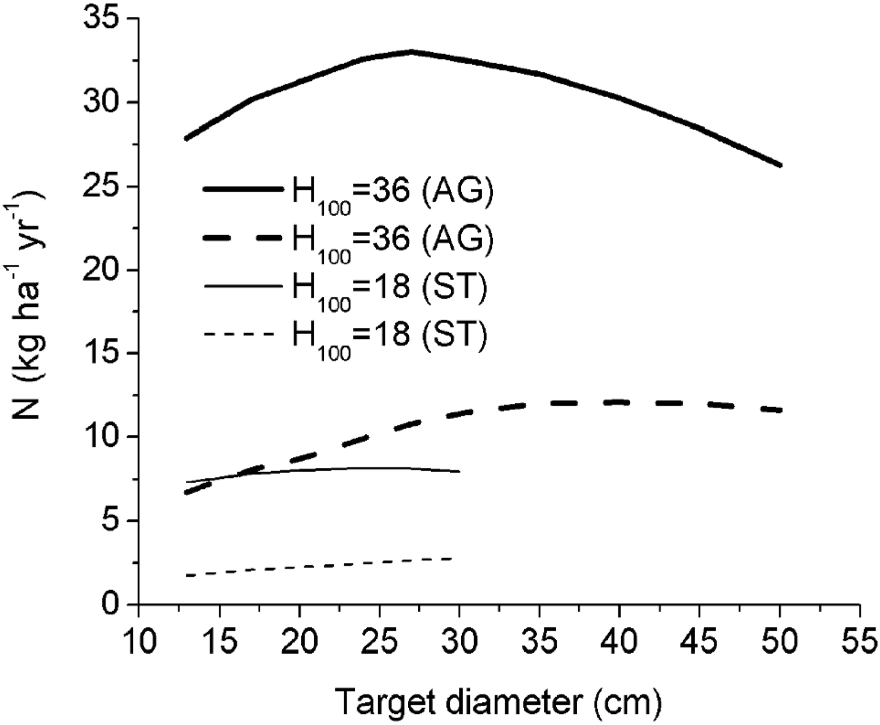

Fig. 3.4. Average yearly nitrogen removals for spruce versus target diameter for two different site productivities and two different utilisation scenarios: harvesting of stems only (ST), and removal of all above ground biomass (AG), see also Table 3.2.

Similarly, it is not practically feasible to gather all logging residues from a clear cut. The part that can be recovered depends on the density of the residues (see also Chapter 2), and on how well the material has been piled by the harvesting machinery. Typically about 70% of the logging residues can be recovered (Hakkila 2004). For whole-tree harvesting in thinnings, it might be possible to obtain recovery rates close to 100%. On the other hand, it is impossible to remove biomass without also removing a part of the top soil. To our knowledge, no investigations have been performed to quantify this effect.

Removal of stumps, often together with removal of logging residues, is of increasing interest. Based on the conservative assumption that nutrient concentrations in stump and root systems are the same as in stems, the additional removal of stumps and roots after clear-cutting increased biomass and nutrient removals by about 30 - 50% compared to harvesting of stems only (Stupak et al. 2007a). In practice removals will be less due to roots being broken off during extraction. Guidelines for forest fuel harvesting might also recommend actively leaving a certain part of the stumps in the forest (Egnell et al. 2007).

Estimates of nutrient removals can be used in nutrient balances, or for estimating compensational amounts of wood ash. Factors that reduce the actual removals should be taken into account.

3.2.4 The soil as a source and a store of nutrients

The soil contains different pools of nutrients ranging from readily available ions in the soil solution to nutrients in poorly soluble minerals or in recalcitrant organic material that are practically unavailable to plants. The major part of plant nutrients needed for forest growth is taken up by the root system from the soil solution. The availability of nutrients is dependent on physical and chemical soil properties. Due to the ability to bind and release nutrient ions, the soil acts as a buffer in the nutrient cycle. The buffer properties arise from different processes like ion exchange, immobilisation and mineralisation of soil organic matter and mineral transformations. Some buffer systems, e.g. the exchangeable pool of ions, respond quickly to changes in the soil solution and may provide plant nutrients on demand in the short term. Other processes may be slower.

The net release of available nutrients in the soil mineral pool is the sum of the single components of the equation (Eq 3.3):

$$\begin{aligned}\Delta\ \text{available soil nutrient pool} = {} & \text{chemical weathering} \\ & + \Delta\ \text{exchangeable pool} \\ & + \Delta\ \text{other sorption/desorption} \\ & + \text{net mineralization/immobilization from} \\ & \quad \text{organic matter}\end{aligned} \tag{3.3}$$

During the life span of a forest rotation the available pool may fluctuate. After a clear-cut, a large amount of the nutrients are normally transferred to the soil component. The largest demand for nutrients from the soil is when the tree crowns are expanding fast around canopy closure.

Weathering of soil minerals is the main source of nutrients obtained from the sediments or the bedrock that constitute the parent material. The exchangeable pool, other sorption and desorption and changes in the stock of organic matter may be sources or sinks for available soil nutrients. Over the time span of a forest rotation, changes in the exchangeable soil pool arise from the balance between losses and gains of nutrients due to growth, decomposition, weathering, deposition and leaching.

The balance between these processes may influence the acidity of the soil and the soil water chemistry. Depending on the cation exchange capacity (CEC) and the base cation saturation the soil buffer for base cations may be small or large. CEC is correlated with soil texture and content of organic matter. Sandy soils have low CEC and loamy soils high CEC, and CEC increases with increasing amount of organic matter in the soil.

In the long-term ecosystem perspective, elements like phosphorus, calcium, potassium, magnesium and many micronutrients are released in the soil by weathering of soil minerals. Newly deposited sediments with only limited biological activity, termed virgin soils, contain almost no nitrogen and the availability of elements like phosphorus, calcium, potassium, magnesium etc. is relatively low. Nitrogen enters the cycle due to biological fixation or deposition, whereas other elements mainly enter the system due to chemical weathering or deposition (Wardle et al. 2004). In the early biological succession stages soil fertility is low. In the late succession stages, soils get older and degraded, and fertility will again decrease mainly due to leaching losses and insufficient inputs of mainly phosphorus (Wardle et al. 2004).

The weathering rate is enhanced by biological activity generating acidity needed for the dissolution of the minerals (Raulund-Rasmussen et al. 1998). The weathering rate is an important component of fertility in forest soils. Considerable research effort has been conducted in order to understand the weathering process. However, determination of ongoing weathering rates is notoriously difficult and estimates are uncertain (Likens 2004). By use of empirical methods, e.g. monitoring of soil acidity or soil test assessments, relative differences between different soil nutrient release capabilities can be established.

The weatherability of the soil minerals can be relatively assessed by consecutive dilute nitric acid extractions at pH~1 as suggested by Callesen & Raulund-Rasmussen (2004). By use of this method, the vulnerability of soils against nutrient depletion can be assessed in a relative manner. The soils in Scandinavia and the Baltic Sea region are young on a geological time scale. Most of the area was glaciated in the Weichsel ice age and new parent material was mixed or deposited for the development of new soils. In spite of the young age, soils in the region show very high variation in nutrient release capability (Figure 3.5). Total release of phosphorus ranged from 20 kg ha^{-1} to 3.9 t ha^{-1}, potassium ranged from 80 kg ha^{-1} to 3.2 t ha^{-1}, calcium from 90 kg to 9.1 t ha^{-1} and magnesium from 100 kg to 7.3 t ha^{-1}. This high variability could not be predicted from soil variables like texture but was dependent on the mineral composition of the parent material (Callesen et al. 2005). Since nitrogen is not released from soil minerals due to chemical weathering and only enters the forest ecosystem via the atmosphere, other approaches must be used when assessing soil nitrogen supply. Indicators like C/N ratio or microbiological assessments trying to quantify the pool of easily mineralisable nitrogen have been suggested (Wilson et al. 2005). Although they have shown some success, none of these indicators have shown unambiguous usefulness. Fertilisation experiments seem to be the most relevant method, e.g. indicating Scandinavian soils as predominantly short of available nitrogen (Binkley & Högberg 1997) except in the south-western part where high deposition rates have saturated forest soils with nitrogen and increased leaching rates are frequently found (Callesen et al. 1999, Gundersen et al. 2006)

Organic soils are soils with a relatively high content of organic material, indicating no or only a limited content of mineralogical material prone for nutrient release by chemical weathering. Organic soils get their nutrients principally either via the precipitation, i.e. bogs, or via lateral water flows from other terrestrial ecosystems, i.e. fens. Fens may either be eutrophic or ombrotrophic depending on the concentration of nutrients in the incoming water. Mostly, organic soils are used for forest production following extended ditching which may increase both root depth and mineralisation, and for

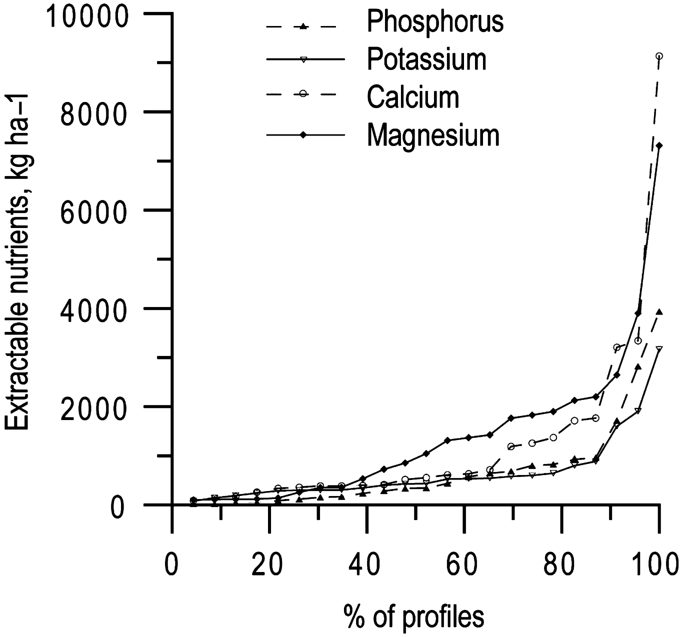

Fig. 3.5. Accumulated distribution of soil profiles in relation to extractable nutrients after 218 hours of extraction time (0.1 M nitric acid) in soil depth 0-50 cm, kg ha^{-1}. For example about 90% of all soil profiles have less than 1000 kg of phosphorus per hectare.

those reasons also growth rates at least in the short term (Westman & Laiho 2003).In the long term, most ditched peat lands will be vulnerable if the incoming flux of nutrients is insufficient to compensate the export.

The soil carrying capacity is the maintenance of forest productivity, soil quality and soil fertility at the same time. These terms are only connected in the context of the health and function of the ecosystem (forest productivity) or the soil as part of the ecosystem (soil quality and soil fertility).

The sensitivity of soils to nutrient export is dependent on the size of the soil nutrient buffer in the short term and in the long term. The soil volume that is exploited by roots, the texture and the content of weatherable minerals are important parameters. Fertile soils or robust soils possess a large nutrient buffer capacity and an ongoing rate of element replacement by weathering or deposition. Sensitive or poor soils have a low capacity for nutrient replacement by weathering or deposition. In a forest management context, a high level biomass harvest on sensitive soils requires a careful examination and management of the ecosystem nutrient balance. Robust soils with a large buffer can resist exploitation of biomass without consequences for productivity even for relatively long-term perspectives. We define:

Sensitive forest soils lose fertility, i.e. production capacity, as a consequence of element exports in biomass under the present forest production system within the relevant range of time. The decrease in fertility is caused by nutrient deficiency reducing the growth rate due to insufficient element replacement capability.

Robust soils are able to sustain productivity under the present forest production system following the export of elements in biomass within the relevant range of time. The replacement may take place either from the capital of available elements, or enter the cycle from outside sources, e.g. salt deposition, atmospheric deposition, biological fixation, or release due to chemical weathering of soil minerals.

These are theoretical considerations that cannot be applied directly in forest management due to the time span involved before negative effects of biomass export on growth can be observed. A highly practical approach and use of indicators are recommended.

Indicators for and classification of soil sensitivity

Soil pH or even better subsoil pH (between 50 and 100 cm) has been shown to be a good indicator of the weathering potential (Figure 3.6). High subsoil pH is maintained as a consequence of a sufficiently high weathering rate. *The mineralogy* of the parent materials has also been shown to be a very strong indicator for the weatherability (Callesen et al. 2005). The mineralogical composition can be assessed primitively by the presence of dark minerals in the fine sand fraction (Figure 3.7) or be indicated from maps of bedrock. *Soil texture* as an indicator may work in areas with homogeneous mineralogy (Callesen & Raulund-Rasmussen 2004), but in areas with different bedrock, geological mapping and expert evaluation on site are needed (Callesen et al. 2005).

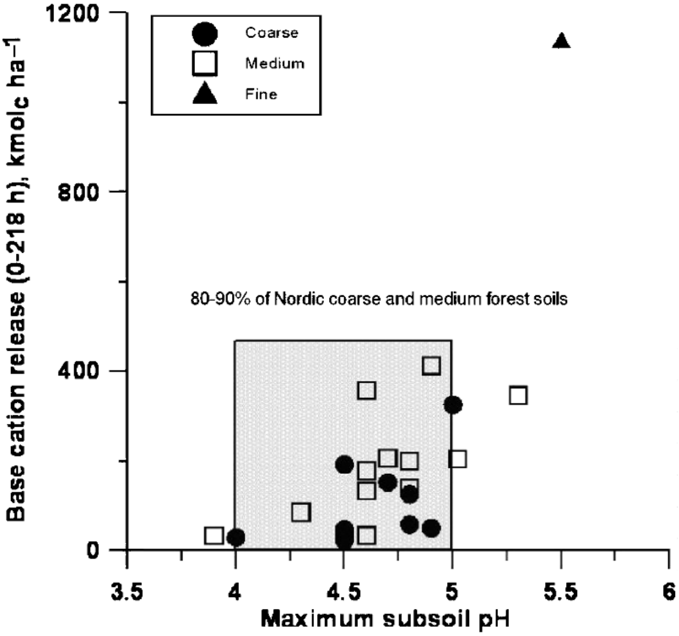

Fig. 3.6. Release of base cations after 218 hours of extraction in dilute nitric acid of 23 Nordic and Baltic forest soils of predominantly sandy soil texture versus subsoil pH in the profile. Texture class *fine*: >10% clay, *medium*: <5% clay and (>5% fine silt or >50% coarse silt + fine sand) or 5-10% clay, *coarse*: others. The shaded area represents the pH range in which 85% of all forest soils in a database with Nordic forest soils are found (unpublished).

Soil temperature strongly influences both the mineralisation rate (Wright et al. 1998) and the weathering rate (Gerard et al. 2002), and will therefore be a relevant indicator for soil sensitivity. Processes are slow at low temperature, and an annual mean temperature of less than 2°C in Scandinavia and the Baltic region corresponds with a short growing season.

Soil depth influences the available amount of nutrients to the roots. If the soil is shallow the volume of the rooting zone is low, and the nutrient supply from weathering will be limited. The 30 cm limit in Figure 3.8 is set somewhat arbitrarily.

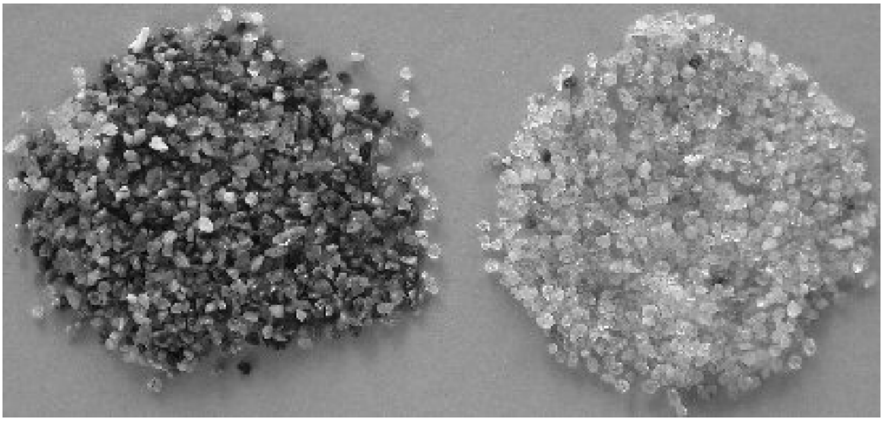

Fig. 3.7. Two very different sandy soils (B-horizons, sand fraction). The left one is from Nordmoen, Norway, containing mainly dark and greenish mafic minerals and the one to the right is from Ulborg, Denmark, containing mainly light acidic minerals. The different mineralogical composition can be assessed from the colour. The precise composition of the two soil samples may be found in Teveldal et al. (1990) and Raulund-Rasmussen (1993). Photo: Flemming Rune.

These indicators together with classification of a specific soil as organic or mineral are organised in a decision tree indicating the sensitivity of the soil (Figure 3.8). The sensitivity of the soil furthermore depends on atmospheric inputs and fertilisation might compensate negative balances on sensitive soils.

3.3 Assessment of long term productivity consequences of very intensive harvesting

Several approaches for assessment of long term productivity consequences of very intensive harvesting have been suggested (Wei et al. 2003). The *direct experimental approach* includes assessment of yield after a certain relevant time span of the considered treatment. For comparison, ‘no harvesting’ or ‘conventional stem harvesting’ treatments are necessary in an experimental design including sufficient repetitions. Numerous experiments of that type have been conducted in mainly Europe and North America. Several have shown negative growth response following very intensive harvesting, either after thinnings of varying intensity (Jacobson et al. 2000) or in the

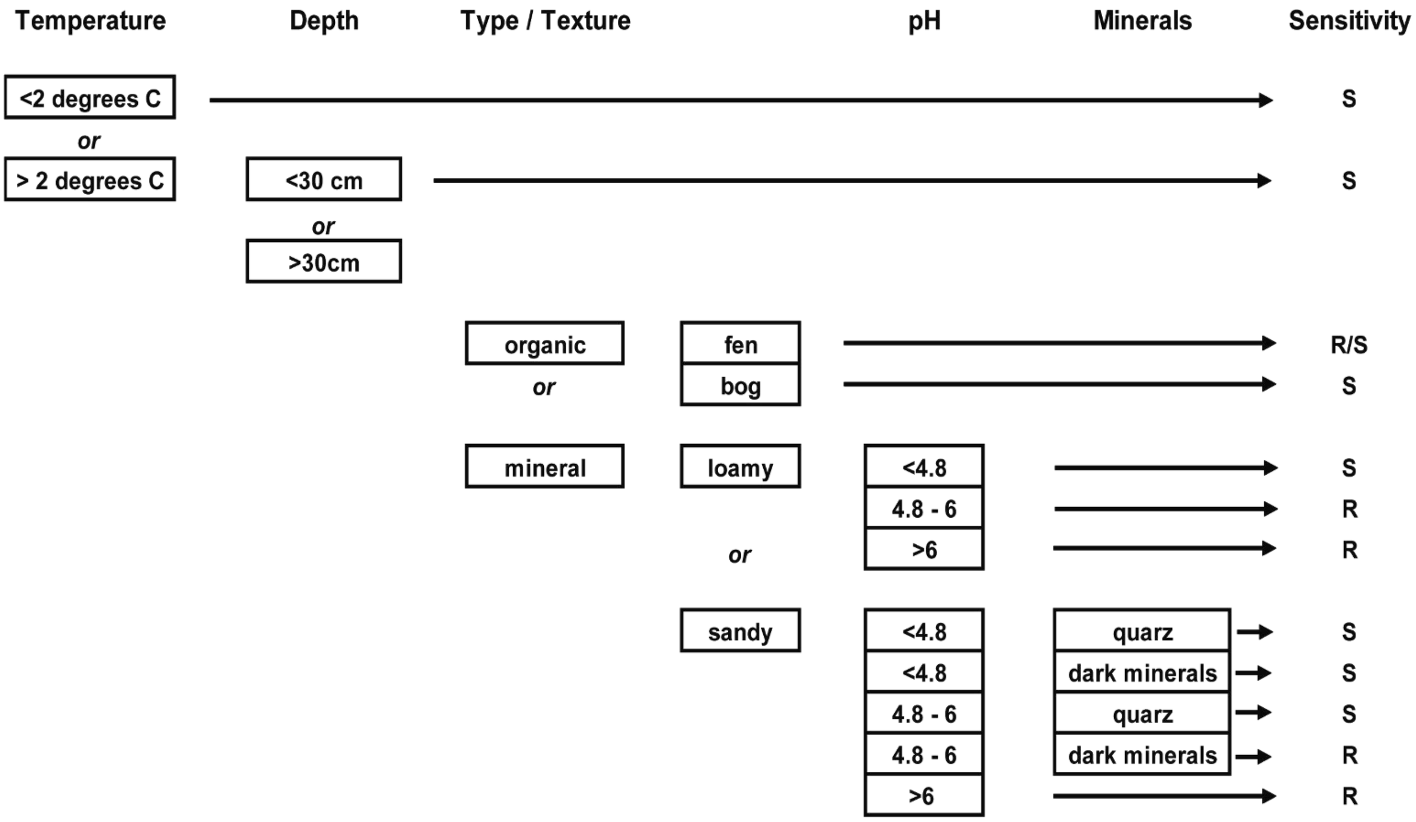

Figure 3.8. Classification of soils as robust (R) or sensitive (S) (see text for definitions).

second generation following clear cut (Egnell & Valinger 2003, Proe et al. 1996). Other experiments have shown no response in productivity following very intensive harvesting (Jacobson et al. 2000). Although the direct experimental approach gives the ultimate answer regarding productivity response, the approach conducted alone also has several weaknesses for prediction, mainly related to its retrospective character, the fact that the response is very site specific, and that the response to intensive harvesting may occur after very short to very long time spans of utilisation. Furthermore, direct experiments are very expensive and the timescale of the answers are limited to that of the experiments. Answers for longer time periods will be provided as experiments grow older, and as such it is of crucial importance to continue and expand the experimental basis. However, for answering questions about effects of intensive harvesting if practiced over several tree generations, we are very far from being able to use this approach. Notice that the situation is different for agriculture, where exhaustion experiments have been performed for more than 100 yearly cycles of wheat (Vance 2000).

Combination of harvesting and fertilisation experiments is obvious and has documented nitrogen deficiency-induced growth reduction following very intensive harvesting (Jacobson et al. 2000). However, to our knowledge no experiments including a combination of very intensive harvesting and wood ash application have been set up so far. Since wood ash recycling is expected to have long lasting ecosystem effects, balances may indicate possible deficiency induced by other elements than nitrogen (Saarsalmi et al. 2006).

Much relevant knowledge can be deduced from *general fertilisation experiments*. First of all they indicate any possible nutriationally related limitation in growth rate. Many experiments have shown that growth is often limited by availability of nitrogen (Binkley & Högberg 1997), although shortage of phosphorus has also been shown (Nilsen 2001). Direct shortage of potassium, as indicated by Dralle & Larsen (1995) and Stevens et al. (1993), is seldom. Direct calcium limited growth is also very seldom whereas indirect effects of low calcium concentrations like increased fungi sensitiveness (Anglberger et al. 2003) and decresed turn-over rate of organic matter (Vesterdal & Raulund-Rasmussen, 1998) have been shown. On sites where growth limitations due to nutrients have been documented, it is obvious to expect possible negative growth effects of very intensive harvesting.

The *nutrient balance approach* and *ecosystem modelling* in various combinations may be relevant complements to the experimental approaches (Kimmins et al. 1999). Although simple in principle, nutrient balances based on inputs and outputs are complicated to set up, first of all because important fluxes like deposition, leaching, and biomass export rates all need much monitoring and experimental work. Release rates of nutrients due to chemical weathering and mineralisation of organic matter are also part of the nutrient balances, but until now the ultimate methods for real *in situ* rates have not been suggested (Likens 2004). Anyhow, by use of simplifications and assumptions the nutrient balance approach is widely used and has proven useful. Concepts like the critical load concept rely on the nutrient balance approach, although the focus is on the carrying capacity of the soil against deposition of acidifying compounds (Rosén et al. 1992). More complicated bottom up ecosystem process models like FORECAST also include nutrient cycling and nutrient balances (Kimmins et al. 1999). The nutrient balance approach must have a time resolution relevant for the nutritional need of the stand. The more robust the soil, the lower will be the necessary resolution.

For specific recommendations we suggest an *expert approach* relying on interpretations of experiments including very intensive harvesting and fertilisation, nutrient balances and soil indicators (Figure 3.8, Infobox 3.2).

Infobox 3.2. Relevant expert questions for qualitative assessments of site vulnerability when practicing very intensive harvesting.

Do we have knowledge from similar sites about
– effects of very intensive harvesting?
– fertilisation response?
Does the nutrient balance indicate critical deficits?
Is the soil robust or sensitive (Figure 3.8)?

3.4 Case studies – examples of assessments of vulnerability and compensation recommendations

In order to demonstrate the use of the expert approach (Infobox 3.2) six case studies from the Nordic-Baltic region (Table 3.4) will be analysed and recommendations for very intensive harvesting and nutritional compensations will be discussed. In the case studies two harvesting scenarios are used: conventional stem harvesting (CH, identical to ST in Table 3.2) and whole-tree harvesting (WTH, identical to AG in Table 3.2).

Case 1: Stenholt Vang, Denmark

This site is fertile due to favourable soil conditions and the stand increment is high. No experiments including very intensive harvesting have been done on sites like Stenholt Vang. Neither have fertilisation experiments been done, but the soil conditions are far better than on soils where no yield response is found for any nutrient. Due to high productivity the export of nutrients is large (Table 3.5). The loss of elements due to leaching is also high. Nitrogen deposition compensates for losses through conventional biomass export. Presumably, the soil is nitrogen saturated judged by the high leaching rate. Despite the negative nitrogen balance following whole-tree harvesting we believe that the soil will for a long time sustain the production rate. Reduction in nitrogen leaching may be induced because of the negative balance as suggested by Gundersen et al. (2006). However, this hypothesis needs verification. The calcium leaching rate is extremely high due to dissolution of carbon dioxide and formation of carbonic acid due to the relatively high pH. Even whole-tree harvesting would contribute only modestly to the calcium depletion of the soil. The high leaching rate of calcium indicates a high calcium status in the soil in accordance with the soil analyses and the weatherability assessment. A similar interpretation can be made for magnesium and potassium. The phosphoros status of the soil is very high as well. The Stenholt Vang site can only be interpreted as relative robust against biomass export.

Table 3.4. Selected information on the six case study sites.

Site	Lat. (N), Long. (E)	Biome, annual mean temperature, annual precipitation	Soil	Tree species	Production class m^3 ha^{-1} yr^{-1}	Reference
Stenholt Vang, Denmark	55°57’ 12°22’	Nemoral 8°C 650mm	Hapludalf, loamy, fertile	Norway spruce	17	Hansen (2003)
Lammhult, Sweden	57°10’ 14°35’	Mid-boreal 5.5°C 688 mm	Typic haplorthod	Norway spruce	10	
Nordmoen, Norway	60°15’’ 11°06’	Mid-boreal 3.8°C 862 mm	Cambic arenosol, rich mineralogy, slightly podzolised	Norway spruce	9	Teveldal et al. (2000), Moffat et al. (2002)
Ilomantsi, Finland	62°47′ 30°58′	Boreal 1.9 °C 649 mm	Poor sandy till, iron podzol	Scots pine	4	Helmisaari (1995)
Rääkkylä, Finland	62°14′ 29°50′	Boreal 2.5 °C 620 mm	Poor ombrotrophic peatland	Scots pine	4	Finér (1992)
Kacergine, Lithuania	54°55′ 23°43′	Mid-boreal 6.5 °C 686 mm	Haplic arenosol	Scots pine	6	Ozolincius et al. (2005)

Case 2: Lammhult, Sweden

Lammhult represents a common site type in southern Scandinavia. It is a mesic site developed on a deep glacial till. The glacial till contains a mixture of different primary minerals in different grain size classes resulting in a comparatively high weathering rate for this soil. The forest stand is Norway spruce with a production class close to 10 m^3 ha^{-1} yr^{-1}. Normally a stand like this is thinned 2-3 times per rotation period. Nitrogen deposition is around 10 kg N ha^{-1} yr^{-1} and the deposition of base cations is an important supply of nutrients that makes up to around one third of the total supply of base cations. Fertilisation experiments on similar sites indicate that the forest is water and nitrogen limited (Nilsson 1997). Experience from harvesting experiments including conventional and whole-tree harvesting suggests that Lammhult is a robust site with respect to conventional harvesting. If whole-tree harvesting is practised the export of many nutrients will be close to the input. It is likely that the input of nitrogen will be too small to compensate for the export (Jacobson et al. 2000). Continued whole-tree harvesting may result in slight growth reductions caused by decreased nitrogen availability. Both nitrogen compensation and ash recycling is recommended when practicing whole tree harvesting.

Case 3: Nordmoen Norway

The Nordmoen site is a Norway spruce forest located on a relatively homogenous flat sandy plain, developed on glaciofluvial and aeolian deposits. The soil is a cambic arenosol. Mineralogically, the site is quite rich (Figure 3.7). Unweathered material consists of quartz (50%), potassium feldspar (18%), muscovite (13%), plagioclase (8%), chlorite (7%), biotite (2%) and amphibole (2%) (Teveldal et al. 1990). Nitrogen deposition is high enough to compensate for removal with conventional harvesting, but not high enough to compensate for whole-tree harvesting. Deposition of base cations is not high, partly owing to long distance from the sea. Weathering and deposition together appear unable to compensate for loss of potassium, calcium and magnesium through leaching and harvesting and it may thus be necessary to compensate these elements. However, it

Table 3.5. Soil nutrient contents and nutrient balance accounts for Stenholt Vang, Denmark. N.E. = not estimated.

	DW	N	P	K	Mg	Ca
Soil pool*, total, Mg ha^{-1}		6.8	N.E.	36	78	56
- available**, Mg ha^{-1}			2.6	1.1	1.7	12
Weatherability estimate***			Very high	High	High	Very high
Est. of weathering rate, kg ha^{-1} yr^{-1}			N.E.	N.E.	N.E.	N.E.
Deposition, kg ha^{-1} yr^{-1}		24	≈0	4	4	5
Leaching, kg ha^{-1} yr^{-1}		10	≈0	1	8	91
CH, export****, kg ha^{-1} yr^{-1}	6200	10	1	4	1	12
- , balance, kg ha^{-1} yr^{-1}		4	-1	-1	-5	-98
WTH, export****, kg ha^{-1} yr^{-1}	8700	28	3	13	2	26
- , balance, kg ha^{-1} yr^{-1}		-14	-3	-10	-6	-112

*0-100 cm, **0-100 cm, ammonium nitrate, ***Callesen & Raulund-Rasmussen, unpublished, ****Stupak, unpublished

Table 3.6. Soil nutrient contents and nutrient balance accounts for Lammhult, Sweden. N.E. = not estimated.

	DW	N	P	K	Mg	Ca
Soil pool*, total, Mg ha^{-1}		4.1	99	140	53	229
- available**, Mg ha^{-1}				0.011	0.060	0.045
Weatherability estimate***			High	Med.-high	Med.-high	High
Est. of weath. rate****, kg ha^{-1} yr^{-1}		-	N.E.	4.2	1.6	3.9
Deposition, kg ha^{-1} yr^{-1}		11.7	0	1.9	1.0	2.0
Leaching, kg ha^{-1} yr^{-1}				N.E.	N.E.	N.E.
CH, export*****, kg ha^{-1} yr^{-1}	2500	6.6	0.3	2.1	0.6	5.0
- , balance, kg ha^{-1} yr^{-1}		5.1	N.E.	4.0	2.0	0.9
WTH, export*****, kg ha^{-1} yr^{-1}	3300	12.7	1.2	5.2	1.7	12.5
- , balance, kg ha^{-1} yr^{-1}	111	-1.0	N.E.	0.9	0.9	-6.6

*0-100 cm, **0-100 cm, ammonium acetate, ***Sverdrup (pers. communication), ****Callesen & Raulund-Rasmussen, unpublished, *****Stupak, unpublished.

is possible that the long-term weathering rates used here underestimate current weathering rates. A long-term experiment at Bergermoen, near Nordmoen and with the same soil type, showed that total production fifteen years after whole-tree thinning was less than that after conventional thinning: compensation fertilisation was necessary to maintain growth (Norwegian Forest and Landscape Institute 2007). On Nordmoen and similar sites it is recommended to compensate for all nutrients when doing very intensive harvesting.

Case 4: Ilomantsi, Finland

This site is extremely poor due to the very low content of soil nutrients and a harsh, cold climate (Helmisaari 1995). The nutrient balance estimates show a balance in nitrogen because the limited export seems to be compensated by deposition. However, on nitrogen-deficient sites, whole-tree harvesting in particular means a loss of relatively easily mineralisable nitrogen compared to conventional harvesting. The site is in an area where tree growth in general is limited by deficiency of nitrogen (Kukkola & Saramäki 1983), and the export of nitrogen in whole-tree harvesting at thinning has been shown to cause nitrogen deficiency and growth depression (Jacobson et al. 2000), which is in accordance with the concept of nitrogen productivity (Ågren 1983). There is a small deficit of phosphorus and larger deficits of potassium and magnesium in both conventional harvesting and whole-tree harvesting. Weathering can partly compensate these deficits, but the contents of phosphorus and base cations in the soil are limited, and potassium and magnesium in particular are leached from the upper soil. In conclusion, this site seems to be very sensitive to whole-tree harvesting and compensation including nitrogen and other elements is recommended, especially after whole-tree harvesting.

Case 5: Kacergine, Lithuania

This soil is sandy and relatively poor in nutrients, except phosphorus (Callesen et al. 2005). A first generation Scots pine stand was planted in 1964 with a high initial planting density (8 000 trees per ha). The forest type is *Pinetum vacciniosum*, and the soil is classified as haplic arenosol. The increment is relatively low. No long-lasting

Table 3.7. Soil nutrient contents and nutrient balance accounts for Nordmoen, Norway. N.E. not estimated

	DW	N	P	K	Mg	Ca
Soil pool*, total, Mg ha^{-1}		5.8	21	178	123	63
- available**, Mg ha^{-1}			1.048	0.261	0.035	0.221
Weatherability estimate***			medium	medium	medium	medium
Est. of weathering rate, kg ha^{-1} yr^{-1}				1.6	1.2	0.4
Deposition, kg ha^{-1} yr^{-1}		5.7	0.4	1.3	0.2	0.8
Leaching, kg ha^{-1} yr^{-1}		0.7	0.1	1.4	1.8	3.6
CH, export****, kg ha^{-1} yr^{-1}		3.6	0.4	4.0	0.6	3.6
- , balance, kg ha^{-1} yr^{-1}	2900	1.4	-0.1	-2.5	-1.0	-5.0
WTH, export****, kg ha^{-1} yr^{-1}		11.1	1.5	7.5	1.1	8.0
- , balance, kg ha^{-1} yr^{-1}	3900	-6.1	-1.2	-6.0	-1.5	-10.4

*0-100 cm, **0-100 cm, ammonium nitrate, *** Callesen & Raulund-Rasmussen, unpublished, ****Stupak, unpublished.

Table 3.8. Soil nutrient contents and nutrient balance accounts for Ilomantsi, Finland. N.E. not estimated

	DW	N	P	K	Mg	Ca
Soil pool*, total, Mg ha^{-1}		2.1	1.1	0.38	1.1	0.94
- available**, Mg ha^{-1}		0.01	0.02	0.06	0.03	0.14
Weatherability estimate						
Est. of weath. rate***, kg ha^{-1} yr^{-1}					0.4	2.0
Deposition, kg ha^{-1} yr^{-1}		3.1	0.002	1.4	0.2	1.1
Leaching, kg ha^{-1} yr^{-1}		0.2	low	3.4	2.1	0.7
CH, export****, kg ha^{-1} yr^{-1}	1100	0.7	0.07	0.4	0.2	0.9
- , balance, kg ha^{-1} yr^{-1}		2.2	-0.07	-2.4	-1.7	1.5
WTH, export****, kg ha^{-1} yr^{-1}	1400	2.3	0.2	1.1	0.4	1.4
- , balance, kg ha^{-1} yr^{-1}		0.6	-0.2	-3.1	-1.9	1.0

*0-30 cm, **0-30 cm, ammonium acetate, *** Starr et al. (1998), ****Based on one thinning (1/3 of the biomass) at the age of 35 years and final clear-cutting at the age of 100 years experiments with intensive forest harvesting for fuel or fertilisation experiments have been performed in Lithuania. In a recently established experiment on the site including nitrogen and wood ash fertilisation, initial results indicate positive crown growth effects of nitrogen and especially of nitrogen together with wood ash (Ozolincius et al. 2005). This may later lead to positive stem growth as well. The nitrogen balance is positive due to a relatively high deposition. The situation is similar for potassium and calcium, and presumably also for magnesium (deposition not estimated). The weatherability is not high but, taking the sandy texture into account, not very low either (Callesen et al. 2005). In conclusion, this site is relatively robust with respect to conventional harvesting, but presumably sensitive for intensive harvesting. Consequently, it could be reasonable to recycle phosphorus-, potassium-, calcium- and magnesium-containing wood ash together with nitrogen fertilizers when doing very intensive harvesting on such sites.

Case 6: Rääkkylä, Finland (organic soil)

This site is a ditched, ombrotrophic and nutrient poor bog having a 2 to 2.5 m deep Sphagnum/Carex peat layer. A naturally regenerated 85-year-old Scots pine stand is growing on the site (Finér 1992). Tree growth is higher than in average on sites like this. The depth of the groundwater table fluctuates from 18 to 70 cm during the summer months. On such sites, the nutrient balance of most elements will be negative even after conventional harvesting. This also seems to be the case here. Further, we know from fertilisation experiments that growth on most drained peatlands is limited by phosphorus and potassium. On ombrotrophic sites such as this one, nitrogen is also deficient (Finér 1991). This type of site is generally very sensitive and intensive harvesting might cause growth reduction if compensation with all elements is not done. The site is especially sensitive with regard to potassium, boron and phosphorus. Compared to the soil stores, whole-tree harvesting during one rotation (one thinning + final harvesting) removes a large part of soil potassium. Because of the thick peat layer, there are no inputs through weathering. It is strongly recommended to compensate, especially for phosphorus, potassium, boron (e.g. through ash fertilisation), and nitrogen if doing intensive harvesting from such sites.

Table 3.9. Soil nutrient contents and nutrient balance accounts for Kacergine, Lithuania. N.E. = not estimated.

	DW	N	P	K	Mg	Ca
Soil pool[*], total, Mg ha^{-1}		2.4	3.0	7.2	6.7	3.6
- available[**], Mg ha^{-1}			1.4	0.076	0.017	0.063
Weatherability estimate[***]			Medium	Low	Low-med.	Medium
Est. of weathering rate, kg ha^{-1} yr^{-1}						
Deposition, kg ha^{-1} yr^{-1}		12	N.E.	2.4	N.E.	5.3
Leaching, kg ha^{-1} yr^{-1}		N.E.	N.E.	N.E.	N.E.	N.E.
CH, export[****], kg ha^{-1} yr^{-1}	2100	1.8	0.2	0.8	0.4	1.9
- , balance, kg ha^{-1} yr^{-1}		10.2	-0.2	1.6	-0.4	3.4
WTH, export[****], kg ha^{-1} yr^{-1}	2600	5.0	0.6	1.8	0.8	3.1
- , balance, kg ha^{-1} yr^{-1}		7.0	-0.6	0.6	-0.8	2.2

0-100 cm, [**] 0-100 cm, ammonium acetate, [***] Callesen & Raulund-Rasmussen, unpublished, [****] Stupak, unpublished.

Table 3.10. Soil nutrient contents and nutrient balance accounts for Rääkkylä, Finland.

	DW	N	P	K	Mg	Ca
Soil pool, total[*], Mg ha^{-1}		1.90	0.11	0.06	0.07	0.39
- available[**], Mg ha^{-1}		0.01	0.02	0.05	0.05	0.28
Weatherability estimate						
Est. of weathering rate, kg ha^{-1} yr^{-1}						
Deposition[***], kg ha^{-1} yr^{-1}		4.0	0.1	1.0	0.1	0.9
Leaching[****], kg ha^{-1} yr^{-1}		1.7	0.1	1.0	0.4	1.0
CH, export[*****], kg ha^{-1} yr^{-1}		0.6	0.04	0.3	0.1	0.7
- , balance, kg ha^{-1} yr^{-1}		1.7	-0.04	-0.3	-0.4	-0.8
WTH, export[*****], kg ha^{-1} yr^{-1}		2.0	0.2	0.7	0.3	1.3
- , balance, kg ha^{-1} yr^{-1}		0.3	-0.2	-0.7	-0.6	-1.4

[*] 0-20 cm, [**] 0-20 cm, available N and P estimated assuming equivalency to organic layer in Mälkönen (1974), [***] Piirainen (2002), [****] Lehmusvuori (1980), [*****] estimated from Kaunisto and Paavilainen (1988), Finér (1992)

3.5 Synthesis and nutrient compensation recommendations

Many experiments have documented a negative growth effect of intensive biomass harvesting. However, the negative growth effect is not consistent and 'no effects' experiments have also been reported at least in the short term. The negative growth effect might be explained by an induced deficiency of essential nutrients, mostly nitrogen. On sites with high nutrient status, i.e. highly resilient robust sites, no growth depression will appear. Our case studies clearly indicate negative nutrient balance accounts and limited compensation capability from soil mineral weathering or soil organic matter mineralisation. In the case studies, the balances are estimated over a rotation period and therefore the negative balance will be significantly higher in the short term right after the intensive harvesting and when the nutrient demand is high. This has to be considered, especially for nitrogen.

Negative growth effects are not consistent with the principles of sustainable forest management (MCPFE 2002, Wei et al. 2003). Even when intensive harvesting can be practised without a short term negative growth effect it might be questioned whether intensive harvesting can be accepted as sustainable management if it is followed by a permanent decrease in the pool of available nutrients in the system.

It seems obvious to compensate for a negative growth effect or a negative nutrient balance by use of fertilisers or by use of the biomass combustion ash. Use of the wood ash furthermore seems to solve a waste problem and to a certain degree re-establish the nutrient cycling characterising the entire ecosystem. However, during the combustion nitrogen is evaporated and wood ash therefore does not compensate for a nitrogen deficit. Use of wood ash to compensate the negative nutrient effect is the topic of Chapter 4.

Management of nutrient compensation following intensive harvesting includes as a first step consideration of which nutrients to compensate. Here it seems obvious to consider nitrogen and thereafter the elements present in wood ash in relationships fairly comparable to the ratios in the harvested biomass, i.e. calcium, magnesium, phosphorus, potassium and micronutrients. When considering the elements to compensate and the degree of compensation it might be relevant to include the soil status and the natural processes also causing nutrient depletion. As an example Wei et al. (2003) compare the nitrogen loss due to intensive harvesting to nitrogen loss due to natural forest fires. Another example is the Stenholt Vang case showing very high natural leaching rates of calcium (about 100 kg Ca ha^{-1} yr^{-1}) due to a very high calcium soil status, high soil pH and dissolution of carbonic acid.

Nitrogen

Most sites in our region are first of all sensitive because of nitrogen limited growth. This has been shown by long-term intensive harvesting experiments (Jacobson et al. 2000), and specific fertilisation experiments also indicate general nitrogen limited growth, at least in large parts of Fennoscandia (Binkley et al. 1999, Nilsen 2001, Nohrstedt 2001, Saarsalmi & Mälkönen 2001). The nutrient accounts in all 6 case studies show balance or a positive balance following conventional harvesting, whereas whole-tree harvesting causes a negative balance for the productive sites. It seems therefore obvious to recommend a general compensation for nitrogen export when practising very intensive harvesting. However, in Denmark, the southern part of Sweden and limited parts of Norway, nitrogen deposition due to air pollution has caused a high nitrogen status with leaching of nitrate and low C/N ratios in the soil as a consequence (Callesen et al. 1999, Gundersen et al. 2006). On such soils, like the Danish case Stenholt Vang, it might be recommendable to export a part of the nitrogen surplus by intensive biomass extraction (Gundersen et al. 2006). Due to favourable soil, climate and the high nitrogen status in the soil the production rate is also high, and it must be expected even at this site that a negative balance in the very long term will lead to a growth depression following very intensive export. In the short term we recommend full compensation of the nitrogen export on sites where the yearly nitrogen deposition is less than 15 kg ha^{-1} and on sites known to be nitrogen limited. However, we do not have experimental proof that a single nitrogen fertilisation dose compensates in the long term (> 10 years), perhaps with repeated intensive thinnings. Results reviewed by Saarsalmi & Mälkönen (2001) show that nitrogen fertilisation effects last less than 10 years in Scots pine and Norway spruce stands. Thus, repeated doses might be necessary. From a nutritional point of view, the best time to add the fertiliser is when the nutrient demand of the stand is high, i.e. during canopy closure, typically between tree heights of 4 to 8 m.

Phosphorus

All case studies indicate a significant negative balance of phosphorus both for conventional and especially for whole-tree harvesting. The negative balance is caused by export due to leaching and biomass export exceeding the very limited input from deposition. Consequently, all phosphorus must be supplied from weathering of soil minerals. The phosphorus status of the soils in the region range from very poor to very rich (Callesen et al. 2005). In particular, the organic soils and many quartzitic sandy soils are poor whereas mainly mineral soils containing large reserves also occur. The negative phosphorus balance is a natural process leading to phosphorus regulated fertility in the very long-term perspective (Wardle et al. 2004). However, in the Nordic-Baltic region, phosphorus seldom regulates growth rates although fertilisation experiments have shown phosphorus deficiency both in Denmark, Norway and Sweden (Ingerslev et al. 2001). On such soils, and in general on soils with low phosphorus status, it should be recommended to compensate for the negative phosphorus balance. If phosphorus becomes a limiting element it will probably be relatively easy to counteract by fertilisation (Scott & Dean 2006). Furthermore, phosphorus fertilisation is generally believed to have a relatively long lasting effect.

Acidification and base cations

Much research has focused on soil acidification and deficiency of the so-called base cations, i.e. calcium, magnesium and potassium, during the last 25 years. The main reason for this is air pollution and especially acidifying sulphur (and nitrogen) compounds. The acidification effect of intensive biomass harvesting is comparable to the effect of deposition of strong inorganic acid.

Magnesium deficiency is a well-known phenomenon related to acid soils and remoteness to the sea (Katzensteiner et al. 1995).

Potassium deficiency is relatively rare although e.g. Vejre et al. (2001) hypothesised indirect health problems in Denmark caused by lack of potassium. Direct physiological calcium deficiencies have not been reported from our region. However, indirect effects of low calcium status might be seen e.g. as slow turnover rates of organic matter (Vesterdal & Raulund-Rasmussen 1998).

In large parts of the southern region the seepage water is relatively acid, indicating already insufficient ongoing weathering of soil minerals to compensate for ongoing acid production and deposition. On such soils intensification of biomass export would cause an added acid load and direct or indirect effects on growth must be expected; thus, compensation of the exported elements must be recommended.

Contrary to the case for acid soils, soils containing a large amount of mafic minerals, and having high weathering rates and neutral pH, lose large amounts of base cations due to natural processes (dissolution of CO_2 and leaching of bicarbonate) compared to very intensive harvesting. On such soils, compensation of losses due to harvesting would be more or less pointless. The Stenholt Vang case is a good example illustrating the inferior contribution of even whole-tree harvesting to the overall negative calcium account.

Micronutrients

According to a Finnish survey on boron in Norway spruce needles (Saarsalmi & Tamminen 2005, Tamminen & Saarsalmi 2004), boron deficiency was observed especially in stands situated in central and eastern Finland. Needle concentrations lower than the critical value of 5 $\mu g\ g^{-1}$ were observed in 33-70% of the 49 studied plots in that area, and on 30% of a total of 101 studied plots in southern Finland. Critically low boron concentrations are found in parts of Sweden (Möller 1983), and also in Norway in inland areas such as Ottadalen lying in a rain shadow (Brække 1979, Kohmann 1997).

Seawater is the most significant natural boron source in Scandinavia (Wikner 1983) and low concentrations of boron are often related to remoteness from the sea (Möller 1983, Wikner 1983). Low concentrations of boron might also be related to dry sites and high basal area and density of Norway spruce stands (Saarsalmi & Tamminen 2005, Tamminen & Saarsalmi 2004). In a mature Norway spruce and Scots pine stand, most of the boron in trees is in stems, and thereafter in needles. For instance, in a 100-year old Scots pine stand on a poor site type, 50% of boron is in stem wood and 20% in needle biomass. Thus, boron distribution greatly differs from that of e.g. nitrogen, which has the highest concentration in needle biomass.

It can be concluded that harvesting, and especially very intensive harvesting, removes so much boron that it should be recommended to compensate on soils with a critically low content. We cannot give threshold values for critically low soil contents, and local experience is needed.

To our knowledge, deficiency of other micronutrients has not been reported, and we do not recommend general fertilisation with micronutrients. However, combustion ash contains many of the micronutrients (Chapter 4) and compensation by use of ash will be a good assurance on sensitive soils.

Conclusions on compensation recommendations

- Nitrogen removed from the system due to intensive biomass harvesting should be compensated. On sites with high deposition or soils with very high nitrogen status it can be considered not to compensate, at least for a period. Compensation is optimal at a stage of stand development where the need is high, i.e. around canopy closure. Avoid compensation before clear-cut and right after establishment because of increased leaching loss. Compensation can be done by use of conventional fertiliser.
- Phosphorus removed from the system due to intensive biomass harvesting should be compensated on soils with low phosphorus status (sensitive soils). On soils with high phosphorus status it might not be necessary to do so currently. Compensation with phosphorus may be done by use of pre-treated biomass combustion ash (see Chapter 4) or by use of conventional fertiliser.
- Removal of base cations due to intensive biomass harvesting should be compensated on acid soils, i.e. soils with pH lower than roughly 4.7-5.0 at 50 cm depth. Such soils are often sandy soils with poor mineralogy (light minerals). Compensation may be done by use of pre-treated biomass combustion ash (see Chapter 4) or by use of a slowly dissolving limestone and conventional

fertiliser. If the ash is sufficiently hardened or the limestone very slowly reacting, use might be made when appropriate. Micronutrients should only be added when local experience indicates a specific need. In most cases, return of wood ash might prevent development of deficiency.

These recommendations are based on a combination of experiments on intensive harvesting effects, on fertilisation experiments, and on interpretation of nutrient accounts in combination with the precautionary principle and the criteria for sustainable forest management. Like Weetman (1998), we strongly recommend that long-term effects on forest ecosystems are monitored and evaluated by use of permanent plots.

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Chapter 4

WOOD ASH RECYCLING – POSSIBILITIES AND RISKS

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4.1 Introduction

The increased use of forest fuels will result in an intensified export of plant nutrients from the forest. A large part of the forest fuel consists of fractions (branches, tops, needles) that were earlier left to decay in the forest. Although they only amount to a small proportion of the total weight of the tree, these fractions have a much higher nutrient concentration per unit weight than the stemwood. Thus, the increased nutrient export following the increased use of forest fuel is not negligible. Another undesired effect of the nutrient export is enhanced soil acidity. A relevant question is therefore if the withdrawal

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of nutrients from the forest will result in a decrease in the productivity of the forest by impoverishment and acidification of the soil.

Wood ash is the solid residual after incineration of wood. Due to the increased use of forest fuels the production of wood ash is increasing. Much of this ash is today considered as waste and is deposited on landfills at a considerable cost. Wood ash contains all the major mineral plant nutrients except nitrogen and has a liming effect when returned to the soil. Recycling of wood ash to the forest is a possible way to close the nutrient cycle and counteract increased soil acidity.

Two problems that have been aggravated by the increased use of forest fuels can then be solved. The nutrients are returned to the forest and the waste problem is reduced. However, if the ash is going to be recycled to the forest ecosystem it is important to know that there are no negative impacts that might outweigh the positive effects. Also, there are questions to be raised. Why can we not find any positive growth effect on trees when mineral soils are amended with wood ash? Does wood ash application have any detrimental effects on soil microbiological processes that are important for the vitality of the trees? Can biodiversity decrease? Does wood ash affect the quality of berries and mushrooms?

In this chapter, current knowledge of the ecological and environmental consequences of wood ash recycling is summarised. Both possibilities and risks of wood ash recycling are discussed.

4.2 Wood ash properties

4.2.1 Wood ash composition and quality

Except for oxygen, the major components of wood ash are calcium (Ca), potassium (K), magnesium (Mg), silicon (Si), aluminium (Al), iron (Fe) and phosphorus (P) (Nilsson & Timm 1983, Steenari et al. 1999, Holmroos 1993, Eriksson & Börjesson 1991, Kofman 1987).

Infobox 4.1. Combustion and wood ash formation

Forest fuel consists of organic compounds synthesised by the tree from the products of photosynthesis. The major elements in these organic compounds are carbon (C), oxygen (O) and hydrogen (H). Nitrogen (N) and sulphur (S) are also important building blocks of organic molecules but make up a much smaller proportion of the biomass. The purpose of incineration of biomass is to release the chemical energy stored in the chemical bonds of the organic molecules as heat energy. This is achieved by oxidation of the organic compounds. During the oxidation the greater part of the organic compounds are volatilised as CO_2 and H_2O, the same constituents that the tree once used as building blocks during photosynthesis. Since oxygen (O_2) is added during the combustion, the mass of the gases released is approximately twice the mass of the fuel. N and S are also volatilised as nitrogen oxides (NO_x) and sulphur dioxide (SO_2).

Apart from the dominant elements in the organic compounds the forest fuel also contains other elements with a higher volatilisation temperature that are either left in the incineration bed (bottom ash) or volatilised and thereafter quickly re-condensed (fly ash). Around 3% (by weight) of the fuel is left as ash after a complete combustion. The major elements in the ash are Ca, K, Mg, Al, Fe, Na, Mn, P and S. The greater part is in the form of oxides or hydroxides, e.g. CaO or $Ca(OH)_2$, but the mineralogy is complex and a wide range of different minerals can be found. Some elements are found in minerals with a high solubility like K while others have a much lower solubility like P. The ash has an alkaline reaction (liming effect) and when mixed with water the pH of the solution becomes high. Complete combustion of the biomass is rarely achieved and the ash usually contains a fraction of partly oxidised carbon, elemental C, usually in the form of charcoal. The proportion of charcoal varies with different ashes.

Ash is generally very low in nitrogen (N) because it is vaporised during combustion. Trace elements found in ash include arsenic (As), barium (Ba), boron (B), cadmium (Cd), copper (Cu), chromium (Cr), silver (Ag), molybdenum (Mo), mercury (Hg), nickel (Ni), vanadium (V) and zinc (Zn), where B, Cu, Mo and Zn can also be regarded as micronutrients (Booth et al. 1990). The average element contents of wood ash from a number of different ashes from the Baltic region are presented in Table 4.1.

Wood ash reacts easily with water. When the ash gets in contact with water the pH of the solution becomes high as the oxides and hydroxides in the ash dissolve and hydroxide ions are formed. Thus, the ash has a liming effect when added to the soil as an amendment and can be used to neutralise acidity. The chemical constituents that determine the liming effect are essentially the same as for lime. However, ash is a more complex chemical mixture and the liming effect is lower than for lime products when expressed per unit weight. Three tonnes of wood ash has a liming effect equivalent to about one ton of quicklime, CaO. The ash that comes directly from the incineration is not chemically stable in the presence of moisture and the atmosphere. The oxides in the ash react with water and CO_2 and form hydroxides and carbonates. During this process the ash increases in weight.

Wood ash varies considerably in quality. The variation can only to some extent be explained by the composition of the fuel. Even if the concentrations of ash-forming elements in different parts of the tree may vary with as much as an order of magnitude, the relative proportions of the elements vary less. Hence, the amounts of ash

Table 4.1. Elemental composition of the fly ash fraction of wood ash given as mean, median and a 95% confidence interval (n=32-98) (Source:http://woodash.slu.se).

Element	Mean	Median	CI
Macro-elements g kg^{-1}			
Ca	212	203	16
Mg	20.6	21.1	1.5
K	61.0	63.0	6.8
Mn	11.6	9.9	1.7
Al	26.2	23.0	4.2
Fe	25.9	16.0	12
P	13.7	14.0	1.2
S	18.1	19.1	2.5
Micro-elements mg kg^{-1}			
As	31.4	15.0	8.2
Ba	2304	1970	545
B	297	307	59
Cd	24.5	23.0	3.2
Cu	150	139	11
Cr	84.3	66.0	13.9
Mo	10.4	7.30	2.4
Hg	1.4	0.61	1.3
Ni	50.0	43.0	7.2
V	35.2	29.0	4.5
Zn	4820	4160	690

formed vary but the expected variation in concentration of the ash due to different compositions of the fuel should be rather small. Instead, there are other factors that cause variation in the concentrations of elements in the ash. The type of burner and incineration conditions, contamination of the fuel and storage conditions influence the composition and properties of the ash. In particular, the amount of charcoal (elemental C) due to incomplete combustion causes large variation in element concentration expressed per unit weight (Hjalmarsson et al. 1999).

The solubility of different elements in the ash varies considerably. Usually K is found in salts with a high solubility and is rapidly dissolved and released when the ash is leached. However, this is not always the case. Sometimes primary minerals from sand particles in the incineration bed or soil from contaminated fuel contains K e.g. in K-feldspar that is very resistant to weathering (Steenari 1998). Thus, the total concentration of K in the ash cannot always be assumed to become plant available after spreading. Ca and Mg have intermediate solubility while P is less soluble in the ash. The solubility of P can increase after some time when the more soluble components in the ash have been dissolved (Larsson & Westling 1998). Generally the solubility of the macronutrients in the ash decreases in the following order K>Mg>Ca>P (Eriksson 1998b).

Since the origin of the ash is different fractions of the tree, the nutrient content is rather well balanced with the exceptions of N and S that are lost during combustion. Differences in plant availability will occur over time. For example availability of K will increase rapidly just after the distribution of the ash while long-term effects cannot be expected. For P the picture is different. The addition of P will not result in immediate increases of P availability. The P in the ash will become available to the tree stand over a longer period of time.

4.2.2 Contamination risks

Heavy metals in ash originate in most cases from the fuel. All biomass fuel contains heavy metals but in low concentrations. As long as the amounts of heavy metals in the ash are not higher than what is exported through the harvested forest products, recycling of wood ash will not result in an increase of heavy metal levels in the forest if given in doses that correspond to the export of nutrients. However, the availability of the metals might be influenced by the ash treatment itself. When ash reacts with water the pH of the solution becomes high, which normally decreases the solubility of heavy metals and other trace elements. When the ash dissolves in an acid environment like a forest soil the alkalinity of the ash is consumed and the metals are exposed to a pH far lower than in the ash, leading to their increased solubility (Eriksson 1996b). The ash might also have high concentrations of heavy metals because the fuel is contaminated. Wood from demolition and wood preservatives in scrap wood usually contain elevated levels of some heavy metals. As a result of the relatively low volatilisation temperatures for many of the heavy metals, they become enriched in the fly ash (Steenari et al. 1999, Holmroos 1993). Hg is easily volatilised but due to the low amounts of Hg in the biomass only low concentrations are found in the fly ash (Holmroos 1993). In Table 4.1 mean and median concentrations of heavy metals in ashes are presented.

Generally, the amounts of polyaromatic hydrocarbons (PAHs) are low in wood ashes (Ek & Sundqvist 1998), but the concentrations are highly variable (Wallander et al. 2003) and concentrations above the generic guideline for soils set by the Swedish EPA have been found (Johansson & van Bavel 2003). It should be noted that the number of studies done on the content of organic pollutants in wood ash are quite few. As with heavy metals the big problems seem to arise when the fuel is contaminated prior to combustion. Wood debris from construction and scrap wood is often contaminated with wood preservation agents, insecticides, metals and plastic products (Bockelmann et al. 1995). Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) have been identified in wood ash (Pohlandt & Marutzky 1994) and there was a relationship between the level of contamination of the wood and the PCDD and PCDF content of the ash. Combustion of railroad ties treated with creosote led to elevated PAH levels in the ash (Johansson & van Bavel 2003).

Contamination levels in wood ash are determined by the quality of the fuel. Wood ash from power plants that use fuel fractions that are likely to be contaminated (scrap or demolition wood) should be avoided for recycling. It is advisable that incineration plants that deliver ash for recycling certify the ash quality by regularly conducting analyses of the ash.

4.2.3 Pre-conditioning before recycling

Ash properties will change during storage. CO_2 and moisture from the air spontaneously react with the ash and form hydroxides, carbonates, bicarbonates and other minerals like gypsum and ettringite (Etiégni & Campbell 1990, Steenari et al. 1999). The hardened ash is less reactive and the solubility of many elements is reduced. The reactivity of an ash product is also reduced by the formation of larger agglomerate particles and stable dense structures (Steenari et al. 1998). Stabilisation and agglomeration methods used today usually involve the addition of water to the ash and then either pellet formation, granulation or spontaneous stabilisation combined with crushing (Steenari et al. 1998, Åbyhammar et al. 1994). To make granules, the ash is mixed with water and sometimes with cement to make the paste more stable before it is rolled on a rotating plate. Granulation is difficult and expensive because of the heterogeneity of the ash material. In the process of making pellets the ash is mixed with water and, if carbon content is high (>10%), additives with a gluing effect (Åbyhammar et al. 1994). The mixture is then pressed through a strainer forming oblong cylinders. This method is cheaper and not that sensitive for ash heterogeneity. Spontaneous stabilisation after water addition (self-hardening) is the easiest and cheapest method. The ash is crushed after drying, but it is more difficult to get a uniform and adequate size of the ash particles than with granules or pellets (Fig. 4.1). If the carbon content is too high the stabilisation process will not be successful, resulting in porous particles with high solubility in the forest. Also, stabilisation of large quantities is a slow process inside a large pile of ash. An impermeable layer of carbonates on the surface of the pile reduces the rate of CO_2 and water transport into the pile and the stabilisation process is not complete (Steenari & Lindqvist 1997). In order to achieve acceptable results the ash and water have to be mechanically mixed (Lindkvist 2000).

Fig. 4.1. Self-hardened and crushed wood ash. Photo: Anja Lomander.

To avoid short-term negative effects caused by the high reactivity of the ash, some type of aggregation is advisable. The possibilities of applying more advanced ways of preparing the ash, like preparation of granules and pellets, are still limited by the cost for preparation and the low availability of machinery to carry out the work. There are no comparative studies of how different aggregation methods influence the effects of wood ash application in the forests but it is likely that the differences between the different types of aggregated ash will be small.

4.3 Effects of wood ash application on soils

4.3.1 Soil acidity changes

Wood ash neutralises acidity when it is dissolved in water. When applied to a soil it will raise the pH and reduce the total acidity that is associated with the soil. The effect in the upper part of the soil, in forest soils usually the organic horizon (O horizon), is often considerable and dependent on both the type of ash and the dose applied (Bramryd & Fransman 1995, Saarsalmi et al. 2001, Levula et al. 2000, Moilanen & Issakainen 2000, Ozolincius et al. 2005b). In Fig. 4.2 the initial effects of wood ash application on pH in the O horizon (mor layer) and in the upper part of the mineral soil are shown. Raw ash gives the largest and most rapid pH increases while pre-treatment of the ash, like self-hardening or granulation, dampens the effect on pH (Arvidsson & Lundkvist 2003, Eriksson 1998a), and the higher the dose the higher the increase in pH.

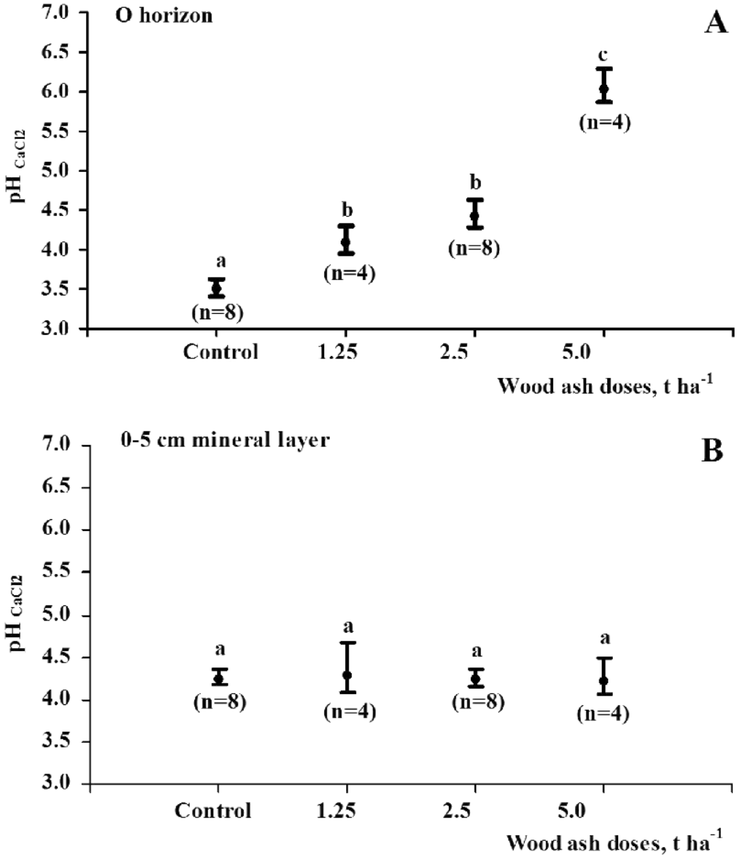

Fig. 4.2. Effects of wood ash treatment on average pH$_{CaCl2}$ of the O horizon and the 0-5 cm layer of the mineral soil 5 months after the treatment in a field experiment in Kačerginė, Lithuania. The error bar indicates the 95% confidence interval. Averages marked with the same letter are not significantly different ($p<0.05$).

The effects of wood ash on the acidity properties of soils seem to last over a long period of time. Ash doses around 5 t ha^{-1} have been shown to cause changes in pH of 1.4 to 2.0 pH units for 10-19 years after their application (Mälkönen 1996, Moilanen & Issakainen 2000, Bramryd & Fransman 1995).

The transport of alkalinity down through the profile is slow and the effects deeper down in the profile are found to be small and usually occurring a considerable time (>10 yrs) after the application of the ash (Bramryd & Fransman 1995, Saarsalmi et al. 2001). Hence, an increase in the pH of the soil solution in mineral soils is not usually found (Ring et al. 1999, Arvidsson 2001, Fransman & Nihlgård 1995) except when very high doses (>10 t ha^{-1}) have been applied (Kahl et al. 1996). In some cases initial depressions of the pH values in the soil solution have been reported (Rumpf et al. 2001, Eriksson et al. 1998). The decrease in pH can be explained by initial leaching of dissolved salts that increase the ionic strength of the soil solution and mobilize hydrogen ions from the exchangeable pool of acidity in the soil.

Some of the elements in the ash are quickly leached with the percolating soil solution. Elevated concentrations of K can be found in the soil solution at deeper levels shortly after the ash application, while the leaching of Ca and Mg is slower (Rumpf et al. 2001, Arvidsson 2001).

Wood ash application results in a fast and lasting increase in pH and a decrease in soil acidity in the humus layer or in the top of the mineral soil if there is no humus layer. The penetration to deeper soil layers will take decades. The magnitude of the effect is dependent on the solubility of the ash and the dose. Pre-treatment of the ash in order to reduce solubility will result in a less drastic response but also a slower penetration of the effect to deeper soil horizons.

4.3.2 Effects on microbiological processes in the soil

Increased or decreased mineralisation of C and N are useful indicators of effects on the degradation of organic matter in the soil. It is well known from liming experiments that lime can increase the degradation rate of soil organic matter. There are rather few studies of wood ash treatment on carbon mineralisation and the results are not conclusive. An increased CO_2 evolution rate in ash amended soils has been found in some studies (Bååth & Arnebrant 1994, Fritze et al. 1994, Bååth et al. 1995). However, in an incubation experiment with field treated soil from Sweden (Skogaby) no treatment effects were found in the CO_2 evolution rate and treatment in the laboratory of material from Flakaliden decreased the CO_2 evolution rate in the wood ash treatment (Rosén et al. 1993).

Ash amendment might have other effects on the organic matter. In a leaching experiment with columns of litter and mor humus to which wood ash (corresponding to 4 t ha^{-1}) was added, the leaching of dissolved organic carbon (DOC) from the ash treated columns increased by 25% compared to the control columns (Eriksson 1996b). The increased solubility of DOC could therefore result in an increased translocation of organic C to deeper soil horizons; however, it does not seem to affect runoff from catchments (Parkman & Munthe, 1998). Nitrogen mineralisation seems to be unaffected by wood ash treatment

Infobox 4.2. Soil acidification and alkalinity in wood ash

When a tree grows it takes up nutrients in the form of charged ions from the soil solution, such as K^+, Ca^{2+}, Mg^{2+} or HPO_4^{2-}. Most of these ions originate from the weathering of soil minerals. In order to maintain the charge balance in the soil solution, the uptake of positively charged ions has to be balanced by the release of an equal amount, on a charge basis, of positively charged ions from the root. These ions are H^+ ions, which will make the soil solution more acid. If the root takes up a negatively charged ion, it will release e.g. a bicarbonate ion, HCO_3^-, which in turn has the capacity to neutralize acidity. However, most plants take up more positively charged ions than negatively charged ones and, hence, the soil will become more acid when the tree grows. When the tree dies and decays the alkalinity will be returned to the soil. If the tree is cut and removed from the forest the acidity will remain in the soil. The same phenomenon is well known from agriculture. Acidity is there normally counteracted by liming. The acidity in the soil may be neutralised by weathering of soil minerals, but if whole tree harvesting is practised the weathering rate of many soils will be too low to counteract the increased export of nutrients and the soil will become more acid over time. Upon combustion of the tree, most of the nutrients and the alkalinity remain in the ash. That is why wood ash is alkaline. Returning the ash to the soil is therefore not only recycling of nutrients but also a process whereby alkalinity is returned and acidity neutralised.

in some cases (Fritze et al. 1994, Eriksson 1996b, Ring et al. 1999, Arvidsson 2001) but increases have been found in others (Högbom et al. 2000, Martikainen 1984). Inhibition of nitrogen mineralisation by wood ash treatment has also been found (Eriksson 1996a).

In most studies there have been no observations of increased NO_3^- concentrations that would indicate increased nitrification due to wood ash treatment (Arvidsson 2001, Bååth & Arnebrant 1994, Eriksson 1996a, Fransman & Nihlgård 1995, Fritze et al. 1994, Bååth et al. 1995, Ring et al. 1999, Saarsalmi et al. 2005). In some cases indications have been found (Kahl et al. 1996, Martikainen 1984, 1985, Ring 1998, Rosén et al. 1993) and in other cases more evident effects (Högbom et al. 2000, Rumpf et al. 2001). In a wood-ash experiment in Lithuania (Fig. 4.3), a significant increase in the total number of the microorganisms in the O horizon of Arenosols was found 3 months after the application of raw wood ash. The number of nitrifying microorganisms compared to the control increased markedly (Ozolincius et al. 2006).

The differences in results can most probably be explained by different conditions in the soils when wood ash was applied. The nitrogen status (C/N ratio) of the organic matter may determine the risk for nitrification as a consequence of raised pH and neutralisation of acidity with ash or lime. Persson & Wirén (1996) suggested that the risk is higher when the C/N ratio in the O horizon is lower than 28.

One of the most prominent changes caused by ash amendment is the increase in pH and decrease in acidity of the forest floor. Microbial communities respond in many ways to changes in pH and, because of that, ash amendment has a large impact on the microbiology in the upper part of the soil. The type and species distribution will change and microbial processes will be influenced. These effects are one of the main reasons to avoid high doses and to reduce the reactivity of the ash before spreading. Up to now, there are no reports that these impacts have any considerable negative effect on either tree growth in the treated forest stand or water quality in the treated catchments. However, there is reason to be cautious and avoid spreading at sites where N availability is high in combination with reduced N uptake, such as on clear-cuts where there might be risk of nitrification and subsequent nitrate leaching.

4.4 Effects of wood ash application on trees

4.4.1 Mineral soils

Results concerning the effect of wood ash on tree growth in forest stands on mineral soils are fairly conclusive. The addition of wood ash does not result in a significant growth increase or decrease (see Table 4.2). The limiting factor for tree growth in stands on mineral soils is in most cases the availability of N (Tamm 1991). As long as N remains the growth limiting nutrient, the addition of other nutrients will not increase the growth. Nevertheless, even in experiments

Table 4.2. The effect of wood ash application on tree growth in different field experiments on mineral soils.

Location	Stand(s)	Treatment	Findings	Reference
South and central Sweden	Scots pine (1) Norway spruce (1)	Wood ash: 0.3 t ha^{-1} 0.5 t ha^{-1}	No stem growth response 5 yrs after application	(Sikström 1992)
Northern Finland	Scots pine (1)	Wood ash: 3.6 t ha^{-1} 7.2 t ha^{-1}	No stem growth response after 10 yrs	(Moilanen & Issakainen 2000)
Northern Finland	Scots pine (1)	Wood ash + peat ash: 10 t ha^{-1}	Slight decrease in stem growth after 15 yrs	(Moilanen & Issakainen 2000)
Sweden	Scots pine (4) Norway spruce (3)	Wood ash: 1, 3, 6 or 9 t ha^{-1}	Tendencies for increased growth (good site quality) and decreased growth (poor site quality), but no significant effects	(Jacobson 2003)
Finland	Scots pine (4) Norway spruce (1)	Wood ash: 3 t ha^{-1} N: 120 or 150 kg ha^{-1}	No positive growth response of wood ash alone. N treatment gave the same positive response with or without ash	(Saarsalmi et al. 2004)

in which N has been added alone and in combination with wood ash there has been no extra response in the combined treatment that could be attributed to the wood ash addition (Table 4.2). In some cases the combined treatment gave a lower response than N additionalone. This effect was attributed to loss of NH_3 to the atmosphere due to the high pH caused by the wood ash (Pettersson 1990, Jacobson 2003). The possible effects on tree growth of wood ash in combination with N might be more complex than the results presented above indicate. In a study of the effect of simultaneous N (180 kg ha^{-1}) + wood ash (4.5 t ha^{-1}) addition on volume growth in a Scots pine stand in northern Finland, it was found that the ash treatment gave an increase in the volume growth, but only after more than 10 years after fertilisation, i.e. when the fertiliser nitrogen could no longer affect the growth (Moilanen & Issakainen 2000). There is a possibility that application of wood ash will give an increase in tree growth in the long term, but a definite confirmation can only be given by monitoring tree growth in long-term field experiments.

4.4.2 Peat soils

The effect of wood ash addition on tree growth in forest stands on peat soils is entirely different. Experiments established as early as 1918 in Sweden and in the 1930s in Finland have shown that ash increases tree growth and improves the conditions for natural stand regeneration (Huikari 1951, Lukkala 1951, 1955). The positive effects on tree growth are long-lasting (Silfverberg & Huikari 1985, Ferm et al. 1992, Silfverberg 1996, Silfverberg & Issakainen 1996, Moilanen et al. 2002). Peat soils deficient in K and P but with a good N status show the highest increase in tree growth (Silfverberg & Moilanen 2000) while tree growth on peat soils low in N (<1%) remains low (Silfverberg & Issakainen 1987, Silfverberg & Huikari 1985). On wood ash fertilised plots tree growth can exceed its pre-fertilisation growth by as much as ten times and eliminate nutrient induced growth disturbances (Ferm et al. 1992).

4.4.3 Tree physiology, morphology and biochemical status

In the literature there is hardly any information on changes in tree physiology or morphology that would allow us to draw any definite conclusions about effects on the physiological state of trees treated with wood ash. However, some experimental work with alkaline cement dust or various other ashes shows that the treatments can cause various disturbances to plant metabolism (Darley 1966, Oblisami et al. 1978, Mandre, 1988, 1995, Mandre & Klõšeiko 2000, Mandre et al. 2006). Some effects of wood ash on physiological processes seem likely, especially since there are indications of morphological effects. In small-scale sample plot experiments with young Norway spruce, differences in above and below ground biomass were observed between an untreated control and four year old Norway spruce treated with wood ash (2.5 or 5.0 tonnes ha^{-1}). The heights of the treated trees were 7–15% shorter than those of the control (untreated variant), but the biomass of their roots had increased by 3 - 25% more than the control (Mandre, 2001). The dry mass of shoots, needles and stems was estimated to have decreased under the influence of wood ash application by 5.0 tonnes ha^{-1} (Mandre et al. 2004).

An indirect indication of effects on tree physiology is the effect on needle chemistry. There are many studies that show no effect of wood ash on needle N concentrations (Levula 1991, Moilanen & Issakainen 2000, Jacobson 2003, Arvidsson & Lundkvist 2002, Saarsalmi et al. 2004, Saarsalmi et al. 2005), but a decrease of N in needles and an increase in roots and stems has also been reported (Mandre 2001, Mandre et al. 2004). Increased N in needles has been found in stands planted on peat soils (Silfverberg & Hotanen 1989) indicating increased mineralisation of N from the peat. Increases in concentrations of needle K, P and Ca are commonly found after ash applications, especially during the first five years after application (Moilanen & Issakainen 2000, Jacobson 2003, Mandre 2001, Arvidsson & Lundkvist 2002). In studies where sampling has been made 5 years or more after ash application, effects on needle macronutrient concentrations tend to be small or absent (Levula 1991, Sikström 1992, Moilanen & Issakainen 2000, Saarsalmi et al. 2004, 2005). Wood ash has led to increased needle B concentrations in

Fig. 4.3. Spreading wood ash at the Wood-En-Man field experiment in Kačerginė, Lithuania. Photo: Iveta Varnagiryte-Kabasinskiene.

Scots pine and Norway spruce stands in both short-term and long-term studies (Moilanen & Issakainen 2000, Mandre 2001, Jacobson 2003, Saarsalmi et al. 2004, 2005). On drained peatlands, wood ash has proved to be a reasonable source of B (Silfverberg & Huikari 1985, Silfverberg & Hotanen 1989, Silfverberg & Issakainen 1987, Silfverberg 1991).

Wood ash application to sandy soil under seedlings of Norway spruce resulted in an increase of chlorophylls and carotenoids, but not to statistically proven changes in their ratios (Mandre et al. 2004). Stimulation of lignification processes in needles was also found in the upper parts of the *Pinus sylvestris* canopy (Mandre 2004).

4.4.4 Effects on fine root growth, mycorrhiza and vitality

Decreased amounts of fine roots after ash application have been found in a few field studies (Persson & Ahlström 1990, Erland & Söderström 1991) especially in high ash dose treatments. However, the negative effect may not be long lasting. Negative effects found three years after wood ash application in an experiment in south-west

Sweden (Persson & Ahlström 1990) did not remain five years after treatment (Clemensson-Lindell & Persson 1993). In general, ash application seems to cause less negative effects on fine roots than has been reported for e.g. liming (Arnolds 1991). One important difference is that ash contains boron. Boron availability may be an important factor affecting fine root responses to nutrient applications (Lehto 1994b). Other factors that may explain the negative effects of ash on fine roots are the increased ionic strength and increased pH(Lehto 1994a). Wood ash application affects the mycorrhiza-forming fungal community in various ways. The infection rate of mycorrhizal mycelia on fine roots has been shown to decrease for some species in laboratory experiments (Erland & Söderström 1990). However, the fungal activity seems to be little affected by ash application in field experiments (Fritze & Bååth 1993, Frostegård et al. 1993, Bååth & Arnebrant 1993). It has also been found that some mycorrhiza species colonize wood ash granules or patches while other species avoid wood ash (Mahmood et al. 2001, Hagerberg et al. 2003). However, it is not possible to draw any general conclusion on the effect of ash amendment on mycorrhiza function.

In conclusion wood ash has little effect on the growth of trees on mineral soils but a significant positive effect on tree growth on nutrient rich peat soils. Positive effects on tree growth in the long term have been indicated on mineral soils in combination with N fertilisation, but more studies need to be done to confirm these results. Wood ash definitely affects mycorrhizal species composition but no effects on function have been demonstrated. The above-mentioned indications of effects of wood ash on tree physiological processes emphasise the need for more studies.

4.5 Effects of wood ash application on ground and understorey vegetation

4.5.1 Species composition

Wood ash application may cause rapid increases in the concentrations of salts and the pH in the forest floor (Eriksson et al. 1998, Kellner & Weibull 1998). From liming and fertilisation experiments we know that mosses and lichens are the most sensitive to drastic changes in pH and/or ionic strength, and that they often show immediate damage after treatment with raw ash (Mälkönen et al. 1980, Mäkipää 1994). For ash applications, mosses seem to be more susceptible than lichens, although the number of species studied is small. The effects on mosses are usually described as necrosis or discoloration of the leaves, and appear shortly after the application of the ash. The mosses seem to recover within three to five years after application (Kellner & Weibull 1998, Jacobson & Gustafsson 2001, Arvidsson et al. 2002).

Changes in the availability of N have a strong impact on plant species composition. Since wood ash in some cases increases mineralisation of N, the species composition is affected with an increase in nitrophilic plants like wild raspberry (*Rubus ideaus*) (Rühling 1996). The changes are most evident on drained peatland where wood ash has a major effect on the species composition of the ground vegetation and converts the vegetation from mosses into more herb-and grass-rich types (Silfverberg & Huikari 1985, Szlfverberg & Hotanen 1989, Ferm et al. 1992). The changes in both the field and bottom layers in a peatland forest can still be visible even 50 years after ash treatment (Moilanen et al. 2002).

There has been some concern about effects on the quality of berries and mushrooms after wood ash amendment. A potential risk for increased uptake of toxic heavy metals, particularly Cd, has been discussed. The contents of toxic heavy metals in berries and mushrooms have been studied in several different experiments both on mineral soil and on peatlands. The effects of wood ash application on elemental composition in berries (e.g. bilberries, cowberries, cloudberries) are small and usually transient. In particular, increased levels of K have been observed shortly after ash application, but increased levels of Ca, B and P have also been found in some cases (Silfverberg & Issakainen 1991, Moilanen & Issakainen 2000). No investigations have reported increased uptake of Cd and Pb in berries after ash application, neither on peat nor on mineral soil. In some cases the levels of Cd have decreased due to treatment (Moilanen & Issakainen 2000).

Fruit bodies of fungi normally have higher concentrations of heavy metals than berries. There is large interspecies variation in the uptake of elements in the fruit bodies of edible fungi, i.e. wild mushrooms (Lodenius et al. 2002). The average Cd concentration in mushrooms collected from forests (mycorrhizal species) was found to be 4.9 mg kg^{-1} (Kojo & Lodenius 1989), although species like ceps (*Boletus edulis* Fr.) contain concentrations around 12 mg kg^{-1} (Kojo & Lodenius 1989, Rühling 1996). Increased concentrations of Cd in forest mushrooms after wood ash addition have been reported (Lodenius et al. 2002, Rühling 1996), but these observations are only for some (*Russula emetica, Cortinarius palaeceus*) of several studied species. In other studies no elevated concentrations of Cd have been found at all after wood ash addition (Moilanen & Issakainen 2000). The variation in Cd concentrations between different species of edible forest mushrooms within the same plot was often larger than that between the treated and control plots (Rühling 1996).

4.6 History, current use and regulation of ash recycling

The interest in recycling of wood ash is not recent. The good fertilizing effect of wood ash on Scots pine growth on nitrogen-rich peatlands has long been known as the result of Swedish and Finnish experiments established in the beginning of the 20th century (Silfverberg 1996, Nilsson 2001). The first known ash trials on peatlands were established in 1918 on a mire just outside Umeå in northern Sweden and the experiment was expanded in 1926 (Malmström 1953). The first Finnish wood ash experiments were established in 1937 on peatland sites (Lukkala 1951). During the period 1937 - 1997, the Finnish Forest Research Institute established more than 200 experiments using ash as a fertiliser, about 90% of which were on peatland sites (Silfverberg & Moilanen 2000). Early experiments in Sweden revealed, contrary to the results from peatlands, the absence of growth effects on trees when ash was spread on mineral soils (Malmström 1953). In addition to drained peatlands, wood ash fertilisation has been considered to be suitable for a range of special sites such as stands suffering from nutritional disorders, peat cutaway areas and afforested peatlands (Veijalainen 1984, Kaunisto 1987, Ferm et al. 1992, Nilsson 2001).

The interest in wood ash recycling was renewed after the oil crisis in the beginning of the 1970s and the emerging interest in an increased use of biomass for energy (Hakkila 1984). Air pollution and acidifying deposition were also considered to be a threat to the forests and the liming effect of the ash was seen as a possible way to mitigate soil and water acidification. The principle of compensating for the nutrient losses caused by the removal of timber from the forest was another aspect that was recognized in a number of studies (e.g. Mälkönen 1974, Finér 1989, Lundborg 1998).

Despite the good fertilizing effect of wood ash on Scots pine growth on nitrogen-rich peatlands, the use of ash has until today largely remained on an experimental level both in Finland and in Sweden (Nilsson 2001). Most of the ash has thus ended up in landfills and only a small amount is being used in landscaping (Korpilahti et al. 1999). Unrecycled ash, however, poses a considerable and expensive storage problem, and it can be seen as an environmental threat at storage sites and tips. The general prospects for recycling wood ash in the Baltic region are good owing to the high proportion of forest land and the advanced technical level of forestry and the forest industry (Silfverberg 1996, Lundborg 1998).

In the early 1990s, recycling and the desire to minimise landfill waste were encouraged by legislation, landfill directives and waste taxes in Sweden, Denmark and Finland (Moilanen et al. 2002, Ek & Westling 2002). This led to trials with spreading ash on the forest floor. The forest industries, the practical forestry sector and environmentalists have shown growing interest in wood ash fertilisation. Nowadays, the research in this field is focused on pre-treatment and spreading techniques for ash (Fig. 4.4), the effects of ash on site characteristics, and the environmental impacts of ash fertilisation (Korpilahti et al. 1999).

Today the wood and pulp industry and power stations annually produce ca. 100 000 t of wood and bark ash in Finland. About 14% of this material is treated (granulated) and applied in the forests (Piirainen 2001). The area annually fertilised with wood ash is currently about 3000 ha and consists mainly of peatland. Granulated ash is applied either from the air using helicopters or from the ground using forwarders.

The long-term economic effects of ash fertilisation can also be positive (Silfverberg & Moilanen 2000). Profitability calculations applied to four old wood ash fertilisation trials on peat soil produced projections of internal rates of return on investment of between 4% and 9% for assessment periods of between 44 and 56 years (Lauhanen et al. 1997).

Around 18 500 tonnes of DW ash from biofuels were spread on 6 550 ha forest in Sweden in 2006 (von Arnold, 2007 pers. comm.). Approximately 40% of the spread ash were pure wood ash and 60% were mixed ashes where wood was the dominant fuel (>50%). The major part of the ash was deposited on landfills. The amount recycled increases every year.

In Denmark ashes from biofuel burning are divided into wood ash, straw ash, or a mixture of these, and from their origin in the burner, bottom ash, fly ash, or a mixture of these (Serup 1999). Around 50% of the raw ash is ash that can be considered free of contaminants and originating from wood fuel. A resolution restricts the spreading of ash in the forests to protect the environment from contamination with heavy metals and xenobiotic compounds (Miljø- og Energiministeriet 2000).

Fig. 4.4. Spreading of wood ash in the forest with purpose-built spreading equipment. Photo: Anja Lomander.

The cost of spreading the ash varies due to transport, pretreatment cost and mode of distributing the ash. In most cases it is the ash producer who pays for the spreading of the ash and in return they do not have to pay waste taxes and land-fill fees. If the ash producer finds cheaper alternatives to get rid of the ash, other than spreading it to the forest, there might be a shortage of recyclable ash. It may then be difficult to fulfil recommendations on ash recycling.

4.7 Recommended doses and regulations

In Finland, a dose of 2.5-3 t ha^{-1} of wood ash is considered to be an appropriate dose in upland forests, and one of 4-8 t ha^{-1} appropriate on forested peatlands (Mälkönen et al. 2001). The ash dose on drained peatland stands is adjusted to correspond to 45 kg P ha^{-1} (Silfverberg 1996).

The Swedish Board of Forestry (Samuelsson 2001) has made guidelines for ash recycling to the forest:

- The main part of the ash has to originate from forest fuel: stem, bark and branches (and roots).
- The ash has to be stabilized and pre-treated to avoid damage to soil chemistry, flora and fauna.
- The ash dose should be based on the amount of base cations (Ca^{2+}, Mg^{2+}, K^{+}) removed and have a liming effect (CaO).
- During a 10-year period, a maximum of 3 tonnes ash per ha should be spread.
- The total amount of heavy metals spread during a rotation period (approx. 100 years) should not exceed the amounts removed at harvest.
- Choosing a proper method, time and dose for the ash re-circulation should minimize leaching and nutrient loss (i.e. not during wintertime and not 5 years before and after clear-cutting).

Preliminary guidelines for ash recycling to the forests have also been prepared in Lithuania by the Lithuanian Forest Research Institute on request from the Ministry of the Environment. Compensation by wood ash fertilisation is recommended in Scots pine stands growing on sandy soils (mineral soils of normal moisture that are oligotrophic to mesoeutrophic) or peat soils (oligotrophic to mesoeutrophic) in stands after clear-cuts where wood fuel extraction has been performed. Wood ash doses of 1.5-3.5 t ha^{-1} are recommended to be applied twice during the stand rotation. Wood ash should be applied for the first time during stand thinnings and the second time in the middle-aged stands, applying wood ash together with N fertiliser (Ozolincius et al. 2005a).

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Chapter 5

INSECT PESTS AND FOREST BIOMASS FOR ENERGY

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5.1 Introduction

Many insect species are dependent on dead wood for their reproduction. A few of these species can be considered to be forest pests since they degrade the quality of timber and damage or kill living trees. Forest management, including handling of forest fuel, may influence the performance of such species at both the local and regional scales. In conventional stem harvesting, logging residues are left on the clear-cuttings and may serve as breeding material for pest insects. This is also the case in thinnings. In contrast to this, removal of logging residues (for energy purposes), before colonisation by pest species or before the new generation have emerged, diminishes the amount of breeding material and hence the risk of subsequent attacks on living trees. On the other hand, if forest fuel is stored in larger quantities compared with what is left after conventional cuttings, the risk for damage may increase. In the following text, the risks for

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insect damage as a result of handling of forest fuel are discussed. It is important to review existing information about the magnitude of such risks and in what way the risks can be reduced by modifying the methods for handling of forest fuel out in the forest. From this information, national operational guidelines may be improved. There are a few earlier reviews about forest fuel and risks for insect damage (Bejer & Ravn 1984, Egnell et al. 1998, Schroeder & Weslien 2001, Kytö & Korhonen 2001, Ravn & Lisborg 2004), but none of them are in English (two in Danish, two in Swedish and one in Finnish). Furthermore, new studies have been conducted which are not included in the earlier reviews. This review is mainly directed towards the Nordic and Baltic countries, and to insect species causing economically important damage to living trees.

5.2 Pest species

Five insect species that may be influenced by the handling of forest fuel can cause economically important damage to living trees (Table 5.1). The species are common in all Nordic and Baltic countries. Four of them are bark beetles (Coleoptera: Curculionidae): the spruce bark beetle (*Ips typographus* L.), *Pityogenes chalcographus* L., and two species of pine shoot beetles (*Tomicus piniperda* L. and *T. minor* Hart.)

Table 5.1. Main tree species and tree parts utilised as breeding material and type of damage caused by the five species. All five species are primary colonisers and only reproduce in fresh material.

Species	Host tree	Breeding material	Damage
Spruce bark beetle	Spruce	Stem	Mortality of mature trees
P. chalcographus	Spruce	Stem, top, branches	Mortality of young trees
Pine shoot beetles	Pine	Stump, stem	Growth losses of healthy trees and mortality of weakened trees
Pine weevil	Spruce, pine	Stump, roots	Mortality of seedlings

The fifth species is the pine weevil (*Hylobius abietis* L.) (Coleoptera: Curculionidae). Estimates have been made of the magnitude of economic losses caused by some of these species. The spruce bark beetle killed 31 million m^3 of spruce in nine European countries between 1990 and 2001 (Grégoire & Evans 2004). The annual loss caused by the pine weevil in the four Nordic countries is estimated to 23–28 million € (Långström & Day 2004). The biology and the type of damage caused by these species are shortly described in the following text. A more detailed review of bark beetle biology can be found in Sauvard (2004) and of pine weevil biology in Day et al. (2004).

5.2.1 The spruce bark beetle

The spruce bark beetle is one of the most important pests of mature Norway spruce, *Picea abies* L. (Karst.), in Eurasia (Christiansen & Bakke 1988, Wermelinger 2004). In some situations, the spruce bark beetle is able to kill living trees in large numbers. The species reproduces in wind-felled or otherwise damaged spruce trees, and in unbarked spruce logs, but not in stumps. It requires diameters over 10 cm for reproduction. Below this diameter, the bark is too thin for it. The flight period starts when the temperature exceeds 18ºC in the spring. In Latvia and Lithuania the main flight starts in the second half of April or in early May, while in Denmark, Sweden, Norway and Finland it starts somewhat later, in May or early June. The spruce bark beetle has a large dispersal capacity (Forsse & Solbreck 1985). Spatial analyses of the locations of colonised trees in relation to the locations of breeding material from the previous year indicate that a considerable part of the beetles do not disperse further away than to the closest suitable breeding material (Wichmann & Ravn 2001). The males initiate the attack by boring into the bark and releasing an aggregation pheromone, which is an odour that strongly attracts both females and males. Each male is generally joined under the bark by two to three females. Starting from the entrance hole, each female excavates an egg gallery under the bark. Along the walls of the egg galleries the females deposit their eggs. From each egg a larva emerges which feeds on the inner bark. The larvae develop through five larval stages, one pupal stage and finally into a new adult. After having established the egg galleries the parent beetles leave the brood material and may establish a second brood (sister brood) in another tree later in the same summer. In Sweden, Norway and Finland the species generally has one generation per year while in Denmark, Latvia and Lithuania it may have two generations per year. In Denmark, Latvia and Lithuania the first offspring generation starts to emerge in June or early July and the second generation in late August or September. In Sweden, Norway and Finland the new generation of beetles may start to emerge in late July or August. The new generation may also hibernate under the bark of the breeding material and in that case they emerge first in the spring of the next year. Individuals emerging in the autumn hibernate in the ground. The spruce bark beetle is not able to survive the winter as immature.

5.2.2 Pityogenes chalcographus

Pityogenes chalcographus reproduces in wind-felled trees, broken tops, and logging residues such as cut branches and tops of spruce. The broader diameter span used by this species compared with that used by *I. typographus* is a result of the smaller size of *P. chalcographus*. The species may occasionally cause high tree mortality in young stands of Norway spruce (Thomsen 1939, Eidmann 1992) and may also attack and kill older, weakened spruce trees. It is also often found on the upper parts of standing trees colonised by the spruce bark beetle. The flight period lasts from April/May to August. The males of *P. chalcographus* initiate the attack and release an aggregation pheromone (Francke 1977). Each male is joined by several females under the bark, which establish egg galleries in the same way as the spruce bark beetle (see above). In Denmark, Sweden, Norway and Finland *P. chalcographus* generally has one generation per year (Eidmann 1974, Annila 1977, Harding et al. 1986). The species is able to survive the winter both as adult and immature.

5.2.3 The pine shoot beetles

Tomicus piniperda and *T. minor* may cause two kinds of damage to Scots pine trees, *Pinus sylvestris* L.: (1) following heavy defoliation or after other kinds of tree stress, they may attack and reproduce in living trees which are then killed, and (2) at high population levels the feeding of the parent and the new generation beetles in shoots of living pines can result in considerable tree growth reduction. Pine shoot beetles reproduce in stumps, wind-felled and weakened pine trees, and in unbarked pine logs. The two species differ in what parts of the trees they colonise. *T. piniperda* usually attacks the lower parts of the bole with rough thick bark while *T. minor* attacks the upper parts of the trees with thinner bark. The flight periods of the two species are short and occur in March-May in days when the temperature exceeds 12ºC (Bakke 1968, Eidmann 1974). The females initiate the attack and are joined by one male, and then establish one egg gallery. *T. piniperda* does not have an aggregation pheromone, but is strongly attracted by monoterpene odours released from damaged pine trees and from the boring holes of attacking beetles (Byers et al. 1985, Schroeder 1987). *T. minor* utilises a pheromone synergised by host odours (Lanne et al. 1987). The new generation of beetles emerges from the breeding material in July. After emergence both parent and new generation beetles feed on shoots in the crowns of living pine trees. Most of the emerging beetles only fly as far as necessary for finding a living pine tree with suitable shoots. This behaviour results in a declining number of attacked shoots with distance from the breeding material, as has been demonstrated around timber yards. Close to timber yards, growth reductions of up to 70% have been recorded (Långström & Hellqvist 1990, 1991, Borkowski 2001). To result in measurable growth losses, a tree must lose a certain number of shoots. Experimental removal of shoots and release of *T. piniperda* beetles into caged pine trees have demonstrated that a loss of 25 to 50 shoots per tree does not result in any measurable growth reductions, while a removal of 200 shoots per tree resulted in about 30% growth losses (Ericsson et al. 1985, Långström et al. 1990). *T. piniperda* hibernates in the bark at the base of living pine trees while *T. minor* hibernates in the ground. Neither species is able to survive the winter as immature.

5.2.4 The pine weevil

Adults of the pine weevil feed on the thin bark of coniferous seedlings and branches of older trees. High proportions of seedlings planted on fresh, one-year- or two-year-old clear-cuttings may be killed as a result of the feeding damage (von Sydow 1997, Örlander & Nilsson 1999). Thus, the pine weevil is one of the economically most damaging forest insects. The species reproduces in the roots of fresh stumps of pine and spruce. Thus, a silvicultural system based on clear-cuttings provides ideal conditions for the species. The pine weevil is able to fly tens of kilometres (Solbreck 1980). The dispersal flight occurs in the spring when the air temperature exceeds 16°C (Solbreck & Gyldberg 1979). Flying pine weevils are attracted to freshly cut areas by the terpene odours released from fresh coniferous stumps and logging residues. On the ground, the weevils use odours released by the roots to locate roots for egg laying (Nordlander et al. 1986). The eggs are laid in the roots or in the soil adjacent to the roots (Nordenhem & Nordlander 1994; Nordlander et al. 1997) and the larvae feed under the bark of the roots. In southern Scandinavia, the new generation adults emerge in late summer in the year after the egg laying or in the spring of the following year (Bejer Petersen et al. 1962). Further north the developmental time is longer. The new generation adults feed to develop flight muscles before migrating to new areas with suitable host material. Adult weevils hibernate in the soil, and may remain on the same site for several years (Nordenhem 1989).

5.3 Risk for tree mortality in relation to insect density and tree vigour

Two characteristics are especially important for the capability of bark beetles to kill living trees: (1) The mutualistic relationship with certain fungi that play an active part in killing trees. The fungi are carried by the beetles and inoculated into the living tissue of the tree after the bark beetles have bored through the bark. (2) The release of aggregation pheromones from individuals boring into the bark. The pheromone ensures a mass attack by a large number of individuals of the same species, which increases the possibility of the beetles' overcoming tree defences. Bark beetles attacking living coniferous trees have to overcome two major tree defence mechanisms for successful reproduction (Christiansen et al. 1987). At first, they may be repelled or pitched out by large amounts of resin exuded from resin ducts in the phloem and xylem when boring into the bark. Secondly, trees infected by fungi as a result of bark beetle attacks respond by forming a necrotic area around the site of infection. The necrotic area is impregnated with high concentrations of resin, which at high concentrations is toxic to bark beetle eggs, larvae and fungi.

For the spruce bark beetle it has been demonstrated that the number of attacking beetles must exceed a threshold to overcome the defensive system of the trees (Christiansen 1985, Mulock & Christiansen 1986, Christiansen et al. 1987). In accordance with this, the risk of trees being killed by the spruce bark beetle has been demonstrated to increase as regional spruce bark beetle densities rise (Weslien et al. 1989). The actual density of beetles per ha required for successful colonisation of living trees, and at what spatial scale, is unknown. In addition to beetle density, tree vigour also influences the risk for trees being killed. With lower tree vigour, the threshold for number of attacks necessary for overcoming tree defence will also be lower. This may be one factor contributing to the general experience of higher tree mortality caused by the spruce bark beetle in years with drought stress. Thus, both beetle density and host tree vigour influence the risk for trees being killed by the spruce bark beetle (Christiansen et al. 1987).

A relationship between regional population level and the risk of trees being killed has not been demonstrated for *P. chalcographus*. This species is not consistently associated with any aggressive fungi (Krokene & Solheim 1996), in contrast to the spruce bark beetle. This may explain why *P. chalcographus* seems less able to kill healthy spruce trees. The tree killing ability of *P. chalcographus* has been experimentally tested by baiting of healthy young Norway spruce trees with the synthetic aggregation pheromone of *P. chalcographus* (Hedgren 2004). Of 37 baited trees that were attacked by *P. chalcographus* alone, only 8% were killed. Thus, despite high attack densities provoked by the pheromone baiting, the tree mortality was relatively low. In contrast, of the 22 baited trees also attacked by the spruce bark beetle, 64% were killed. However, periods of drought stress seem to increase the risk for tree mortality caused by *P. chalcographus*. Drought was suggested as one of the main causes of the widespread tree mortality in young spruce stands in Sweden in the early 1970s (Lekander 1972, Ehnström et al. 1974). Thus, in this situation there could be a positive relationship between the density of *P. chalcographus* and the risk of young spruce trees being killed (Lekander & Långström, 1976).

Pine shoot beetles are generally not able to kill living trees. But if the trees are stressed by e.g. heavy defoliation or fungal infections, both species may reproduce successfully, which will kill the trees and result in increased population levels (Vaivada 2003). Thus, the risk for trees being killed by pine shoot beetles should increase at higher densities if the trees are under some kind of stress.

The number of pine weevils immigrating to fresh clear-cuttings should increase at higher regional weevil densities. At the scale of individual clear-cuttings the risk for seedling mortality increases with pine weevil density (Nordlander 1987). This relationship is however influenced by the vitality of the seedlings (stresses like drought may interact with feeding damage and increase the risk for seedling mortality) and the amount of alternative food (e.g. shelter trees, which reduce the feeding damage).

5.4 Insect reproduction in forest fuel

It is important to evaluate how the colonisation rates and the reproductive successes of the pest species are influenced by different methods of forest fuel handling. By acting as a focus for attraction (see below) and by affecting at least the local population densities, forest fuel affects the risk of damage to living trees. Removal or chipping of forest fuel directly after thinning or final cutting will prevent colonisation by the insects and thus reduce the amounts of breeding material compared with a situation without retrieval of forest fuel (all branches, tops and small diameter stems left). If whole trees from thinnings are stored in the forest, the amount of breeding material may on the other hand increase. The timing of cutting in relation to the flight periods of the insect species then determines whether or not the material can be colonised. Furthermore, the developmental time of the insects in relation to the storage time decides if a new generation of insects emerges before the forest fuel is chipped or removed from the forest. If pine is cut after the flight period of the pine shoot beetles but before August, the wood cannot be colonised in the same year and will be too desiccated for breeding in the following spring (Lekander & Långström 1976). The degree of desiccation depends on geographic location, diameter and length of the material (smaller diameter and shorter objects desiccate faster), and on exposure to the sun. Trees cut during the autumn or winter are generally suitable as bark beetle breeding material in the following spring and summer. In contrast to pine, spruce may be colonised from late spring to July - August (depending on geographic location) by *P. chalcographus* and the spruce bark beetle. Thus, there is almost no safe cutting period. In Denmark, the safe cutting period for these species is expected to be limited from mid-August to mid-September (Ravn & Lisborg 2004). Tops and branches may be left spread out or piled in small or large piles. Piling may be conducted directly after cutting or later on. There are only a few studies about the effect of piling of forest fuel. The available information indicates that colonisation densities of bark beetles are generally lower in the inner parts of piles than in the outer parts if the material is piled before being colonised. The attack densities of *P. chalcographus* in small (2 m^3) and much larger piles, consisting of green branches, tops and low quality parts of Norway spruce stems, were compared in a study conducted in central Sweden (Persson 1981). Small piles were sampled on two clear-cuttings and larger piles on one clear-cutting. No attacks were found on objects in the inner parts of the large piles. In both small and large piles the attack density was about 70% lower in objects 20 cm below the surface of the piles compared with exposed objects on the surface. Studies conducted in Denmark have demonstrated that at high bark beetle densities even the inner parts of piles put in rows and inside plantations may be attacked (Bejer & Ravn 1984).

Branches and tops are not an important breeding substrate for the pine weevil. It is only able to colonise material that is at least partly covered with soil. There are no studies about the risk for colonisation of such material in piles. In piles of conifer bark the species is able to reproduce (Brammanis 1962). Thus, it is possible that piles of forest fuel may also serve as breeding material. However, as a result of the long developmental time (at least 15 months) it is unlikely that any new generation weevils will be able to emerge before stored forest fuel has been removed from the forest. Removal of stumps from clear-cuttings, before the new generation beetles have emerged, has been estimated as reducing the breeding substrate of the pine weevil with about 80% (Lekander & Lindelöw 1977) and thus should reduce the risk for damage. However, the only evaluation conducted so far did not demonstrate any effect on the attack rate on seedlings (Bejer-Petersen 1954). If the stumps are piled and stored on the clear-cuttings, a few larvae may survive and develop to new adults, but this should have no effect on the risk for seedling mortality.

5.5 Influence on regional population densities

The risk for tree mortality caused by the insects increases at higher population densities, cf. above. Thus, it is important to understand whether the handling of forest fuel affects the regional population densities and in that case, whether the densities are reduced or enhanced. A first step in such an analysis is to evaluate how large a part of the landscape-wide available breeding material that is affected by the handling of forest fuel. At present there are large differences in this respect between countries. In the Baltic countries, almost no forest fuel (as defined in this context) is retrieved and hence the regional population densities are not at present influenced by forest fuel harvesting. In Denmark, Sweden and Finland, considerable quantities of forest fuel are retrieved but the area affected differs much between regions within countries. As an example, in the northern part of Sweden forest fuel was retrieved from only 2% of clear-cuttings in 2003 while the corresponding figure from the southern part was 47% (national average 26%, Anonymous 2004). The figures may be even higher close to power plants. In this situation it is possible that the handling of forest fuel may decrease the regional population densities of species for which logging residues offer a suitable breeding material. Because most forest fuel consists of branches, tops and stems with a diameter under 10 cm, and because spruce is the most important tree species for retrieval of forest fuel, the species most likely to be affected is *P. chalcographus*. Forest fuel may be chipped or removed from the forest directly after cutting (no reproduction of beetles possible), or removed after being attacked but before the parent beetles or the new generation have emerged (thereby acting as trap wood), or stored in piles over summer to dry out (generally lowering production of beetles compared with a situation without piling). Thus, in regions where large amounts of forest fuel are retrieved the population densities of *P. chalcographus* may be somewhat reduced.

5.6 Risk for damage close to forest fuel piles

Piles of forest fuel from final cuttings are in some cases located close to stand edges of living trees. Forest fuel whole trees originating from thinnings are generally piled and stored in rows inside the stands. Both scenarios may induce bark beetle attacks on nearby standing living trees. Both the spruce bark beetle and *P. chalcographus* release aggregation pheromones that may attract high numbers of beetles of the same species to colonised material. Some of these attracted beetles may induce attacks on adjacent living trees. Later on, the new generation beetles emerging from stored forest fuel may attack nearby standing living trees.

The risk of tree mortality as a result of storage of forest fuel close to stand edges on clear-cuttings has been evaluated experimentally for both the spruce bark beetle and *P. chalcographus*. For the spruce bark beetle, large living spruce trees were cut in early spring at mature spruce stand edges bordering fresh clear-cuttings in Sweden (Hedgren et al. 2003a). The treatments were edges with zero, one or five cut trees colonised by *I. typographus*. The cut trees simulated large diameter stem parts of spruce in piles of forest fuel stored close to stand edges. During the two following summers living trees were killed by the spruce bark beetle in about one third of the edges but the number of trees killed did not differ between stand edges with zero, one or five cut trees. Thus, storage of five mature spruce trees, corresponding to more than 50 metres length of large diameter spruce, did not increase the risk for trees being killed at the edges. A field survey conducted in Finland also failed to demonstrate a relationship between number of wind-felled trees colonised by *I. typographus* in stand edges facing clear-cuttings and number of killed trees (Peltonen 1999). One interesting observation in the study by Hedgren et al. (2003a) was that the cut trees colonised by *I. typographus* provided focal points for attacks on living trees, and hence influenced the spatial distribution of killed trees within the stand edges. Within edges with felled trees, the density of killed trees close to the felled trees was higher than at other parts of the edges. In the study by Hedgren et al. (2003a), edges with large numbers of naturally wind-felled trees were also included in the analysis. This analysis demonstrated a threshold level in that year of about 20 spruce trees colonised the previous year (corresponding to more than 300 metres length of colonised large diameter spruce wood) above which the tree mortality caused by the spruce bark beetle in the following year increased with increasing amounts of wind-felled trees. Below the threshold the number of trees killed per edge did not differ between edges with or without wind-felled trees.

For *P. chalcographus,* piles of cut young spruces were established in springtime at edges of young spruce stands in southern Sweden (Hedgren et al. 2003b). Similar stand edges without piles were used as controls. Five times more attacked living trees and 13 times more entrance holes were recorded at edges with piles compared to edges without piles, but of 226 trees attacked by *P. chalcographus* only four were killed. Two of these were also attacked by the spruce bark beetle. In general *P. chalcographus* seems to have a low capacity for killing healthy trees, cf. above. In two studies, one in Denmark and one in Sweden, the risk for attacks on living trees after thinnings in young spruce stands has been evaluated (Bejer & Ravn 1984, Nordanstig unpublished). In both studies, the cut stems were left over summer inside the stands. Attacks by *P. chalcographus* were found on living trees in both studies. However, all attacks were unsuccessful and no trees were killed.

There are no studies of the risk of growth losses caused by pine shoot beetles when piled forest fuel or whole trees of pine are stored close to living pine trees (in thinnings and clear-cuttings). In this case, much less wood is stored compared to timber yards and the wood is only stored for one year at the same locality. Thus, the risk for growth losses should be much smaller. In one study conducted in Sweden (Långström personal communication), the number of shoots attacked around piles of logs was estimated at two sites. In the first year, about 100 pine logs (3 m length) were laid out at each site (in one layer) inside a pine stand. The highest number of fallen shoots per m^2 ground was found at distances under 40 m from the piles. Based on the estimates of number of fallen shoots per tree, it was concluded that only a few trees experienced considerable growth reductions. Most piles of forest fuel should contain less exposed material than the 100 logs in this experiment.

Fresh coniferous branches and tops release odours attractive to the pine weevil. Thus, piling of such material may influence the spatial distribution of adult weevils within clear-cuttings. Removal of branches and tops before the weevil flight period may also reduce the number of immigrating weevils. However, host volatiles are also released from stumps and it is hard to evaluate the relative importance of the two kinds of substrates. The bark of fresh coniferous branches and tops serves as food for adult pine weevils. It has been demonstrated that it is possible to protect seedlings from feeding by supplying fresh branches on a weekly basis on clear-cuttings (Örlander et al. 2001). In accordance with this, removal of fresh branches and tops from clear-cuttings may increase damage to seedlings (Axelsson 1987), although the effect is of relatively short duration. Branches and tops may probably be used as food for only two to three weeks before drying out (Örlander et al. 2001). Thus, the retention of logging residues in regenerations should be of little importance for reducing seedling mortality (Örlander & Nilsson 1999), and the removal of stored logging residues for forest fuel does not seem to increase the risk for seedling mortality caused by the pine weevil.

5.7 Legislation

National legislation regarding the amounts of coniferous wood that may be left or stored in the forest exists in many countries. Since these rules are quite detailed, differ between countries, and are continually modified, they are not given in this review. The rationale behind these rules is to decrease the amount of breeding substrate for pest bark beetle species, and thereby reduce their population densities and the risk for damage to living trees. As discussed above, the risk for damage to living trees increases for some of the species at high population densities. Even though these regulations were generally formulated before management of forest fuel started, they apply to which amounts of logging residues and stems of certain diameters that can be left after cuttings and during which time of the year coniferous wood can be stored in the forest. Thus, when handling forest fuel, it is necessary to be aware of national legislation, guidelines and recommendations.

5.8 Conclusions

The five insect species considered in this review are the spruce bark beetle (*Ips typographus*), *Pityogenes chalcographus*, two species of pine shoot beetles (*Tomicus piniperda* and *T. minor*), and the pine weevil (*Hylobius abietis*) (Coleoptera, Curculionidae). All five species may reproduce in stored forest fuel and are able to kill or damage living trees. The spruce bark beetle may kill mature Norway spruce trees, *P. chalcographus* may kill young spruce trees, pine shoot beetles may cause growth losses to living pines and kill weakened pine trees, and the pine weevil may kill seedlings of both spruce and pine. Both insect density and tree vigour influence the risk for damage, and the insect density is again influenced by the amount of breeding material. At higher densities, the risk for the insects being able to overcome living trees' defences increases and hence so does the risk for tree mortality. If trees are stressed, i.e. have low vigour, the risk for tree mortality may increase even at lower population densities. *P. chalcographus* and the pine shoot beetles are generally not able to kill healthy living trees, but when trees are stressed by drought or defoliation they may cause considerable tree mortality. The way in which forest fuel is generally handled at present should reduce the risk for damage compared with conventional stem harvesting and thinning. Removal of forest fuel from the forest, or chipping directly after logging prevents reproduction. Piling of forest fuel before insect colonisation decreases the amount of wood colonised as a result of lower colonisation of the inner parts compared with the outer parts of piles. In most areas, forest fuel handling is unlikely to affect the regional population densities of the species, because other sources of breeding material are more important on the landscape scale. However, in regions where large amounts of forest fuel are retrieved the regional population densities may be affected. The most likely species to be affected is *P. chalcographus* because it reproduces in tops, branches and small diameter stems of spruce, which constitute the major part of forest fuel. Because most forest fuel that is stored in the forest is piled, a somewhat reduced regional population density, compared with a situation without retrieval, can be expected. Piles of forest fuel from final cuttings are in some cases located close to stand edges of living trees. Forest fuel whole trees from thinnings are generally piled and stored in rows inside the stands. Both scenarios may induce bark beetle attacks on nearby standing living trees. However, studies conducted so far indicate that the risk for this kind of damage is small. Tree mortality caused by the pine shoot beetles and *P. chalcographus* is generally associated with low tree vigour caused by drought or defoliation. To increase the risk for living trees being killed by the spruce bark beetle, or for the pine shoot beetles to cause growth reductions, large quantities of forest fuel must be stored close to living trees. These quantities exceed what is at present generally stored in single piles of forest fuel.

5.9 Management recommendations from an insect pest perspective

- Avoid summer storage of large amounts of spruce with a diameter exceeding 10 cm close to mature living spruces.
- After warm and dry summers avoid storage of spruce in thinned stands.
- Avoid storage of both pine and spruce in defoliated forests.
- Follow national guidelines for handling of forest fuel.

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Chapter 6

THE EFFECTS OF FOREST BIOMASS HARVESTING ON BIODIVERSITY

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6.1 Introduction

Extraction of dead wood as forest fuels will decrease the amounts of dead wood in the landscape. Because dead and decaying wood has been identified as a key factor in explaining why many forest species are threatened (Berg et al. 1994, Esseen et al. 1997), extraction of forest fuels may increase the threat. The wood that is presently in focus for use as forest fuel is mainly logging residues, i.e. twigs, branches and tops, although logging stumps and whole trees might also be used (see below). The logging residues may be defined as belonging to fine woody debris (FWD), in contrast to coarse woody debris (CWD). The limit between fine and coarse wood is here defined at 10 cm diameter. Coarse wood is widely acknowledged as an important habitat for saproxylic (wood living) organisms (Grove 2002), especially for threatened species (Berg et al. 1994), and many studies have therefore been done on saproxylic organisms in coarser

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dimensioned wood. Finer wood has been much less studied. It has generally been retained in forest operations and is therefore abundant in managed forest landscapes. However, comparative studies show that fine wood hosts a large number of species (Harz & Topp 1999, Kappes & Topp 2004, Kruys & Jonsson 1999, Nittérus et al. 2004, Nordén et al. 2004, Schiegg 2001). There might also be organisms that use the fine wood for shelter on open areas (Gunnarsson et al. 2004). Thus, the extraction of fine woody debris from the forest landscape might reduce the habitat for several organisms.

In addition to logging residues, the stumps remaining on a clear-cut have been suggested as a potential energy resource. In Finland, spruce stumps are presently removed as forest fuel on a larger scale. They were also used in Sweden in the 1980s, but costs for transport in addition to the very large effects on the soil put an end to this use. However, with increasing energy prices, it may be considered again. Stumps are coarse woody debris, and constitute a considerable part of the wood that is left to decay in the forest landscape today. Therefore, the effects on the saproxylic organisms may be considerable if stumps are harvested on a large scale.

6.2 Potential problems for biodiversity due to forest biomass harvesting

The threats to biodiversity because of extraction of logging residues may have different causes:

- Most obviously, saproxylic organisms will have less substrate in the forest. This applies both to saproxylic invertebrates and fungi.
- Recently harvested residues that are stored in the forest before transportation to thermal power stations may act as trapping wood for saproxylic insects. Most of them are mobile flyers and actively search for breeding habitats by tracking their odours. A pile of residues may therefore attract large numbers of egg-laying adults. After the insects have reproduced in the stored material, the offspring would be burnt up in thermal power stations.
- Organisms may lose the shelter or the growing substrate that piles of twigs and branches may provide (Åström et al. 2005). This may be both a physical shelter that ground living animals can hide under and a shelter from extreme microclimate, mainly drought or extreme temperatures.

For e.g. mosses the piles could serve as a refuge for survival during the clear-cut phase and when the new forest grows they might bloom again (Åström et al. 2005). Some ground living invertebrates seem affected by the presence or absence of the organic compounds that accumulate under the logging residue piles. The residues may also constitute substrates for lichens to grow on (Caruso & Thor 2007).

- The amount of logging residues that are left to decay may also affect the nutrient levels in the ground. For ground dwelling invertebrates effects have been shown (Section 6.2.2), whereas for vascular plants effects have been harder to show (Åström et al. 2005).

A fifth issue related to the use of bioenergy is the effect that recirculation of the ash from the thermal power stations back to the forest will have on the biodiversity. Some studies of this have been made on mosses (Dynesius 2005, Chapter 4).

A sixth issue that might have relevance is the effect on organisms on higher trophic levels, such as insect feeding birds. As the effect on the base of the trophic chain is vaguely known, it is not possible to even guess about trophic effects, and therefore this question is not treated further in this chapter.

The main emphasis in this review is on the species that may use the logging residues as food or breeding substrate, i.e. saproxylic species, and it has a Fennoscandian perspective. It starts out by defining which and how many species that may be affected by extraction of logging residues. Based on what we know about the present situation in Scandinavian forests compared to the natural situation, I propose which types of logging residues probably host the most sensitive species. One main conclusion from writing this review is that a lot of facts that would be useful for assessing risks for biodiversity are not known.

6.3 Organisms that may be affected by bioenergy use

6.3.1 Wood living organisms

The term ‘saproxylic’ was defined by Speight (1989) as an organism “that is dependent, during some part of its life cycle, upon the dead or dying wood of moribund or dead trees, or upon wood-inhabiting fungi, or upon the presence of other saproxylics”. Many species fall within this definition. A qualified estimate of the total species number for the Finnish flora and fauna ended at a sum of 4000-5000 species, with insects probably being the most diverse group, followed by macrofungi (Siitonen 2001). Finland encompasses almost only boreal regions, so adding the more nemoral parts of Scandinavia increases the species number considerably. An estimate for Sweden ends at 6000-7000 saproxylic species (deJong et al. 2004). This corresponds to 12-16% of the whole insect fauna and 27% of the fungal flora of Sweden (cf. Gärdenfors et al. 2003). Among the insects, three orders encompass >90% of the saproxylic species: Coleoptera (beetles), Diptera (flies and midges) and Hymenoptera (ants, bees, sawflies, and wasps) with about one third of the species number each. However, the estimates for the Dipterans and Hymenopterans are vague because the biology of many of the species is not well known (deJong et al. 2004, Siitonen 2001). In fungi, ascomycetes, particularly pyrenomycetes, dominate together with the basidiomycete groups corticoids, polypores and agarics. Together these constitute 90% of the saproxylic fungi. Pyrenomycetes and corticoids are the two largest groups, each with nearly 600 saproxylic taxa known in Fennoscandia (Dahlberg & Stokland 2004). All these estimates refer to wood of all types. The number of species using fine wood is a fraction of the total because most saproxylic organisms, especially insects, are more or less specialised on some type of wood (see Section 6.3 below).

6.3.2 Organisms dependent on piles of logging residue

The piles of logging residues may also be important for many species that are not saproxylic, for at least two reasons. Firstly, they may be used as shelter by various organisms. These include animal species that need somewhere to hide while not foraging, such as ground-living invertebrates (Gunnarsson et al. 2004) and maybe also mammals. They also include organisms adapted to closed forests that may survive the open clear-cut phase under logging residue piles, such as mosses (Åström et al. 2005). When the new trees grow, they may recolonise the stand from these refuges - they are "life-boated" through time (Vanha-Majamaa & Jalonen 2001). Secondly, the raised levels of nutrients and organic matter in the soil under the piles may be important for soil dwelling invertebrates, such as collembolans, gamasid mites, Enchytridae, Tardigrada, Diptera and Oribatida, and also larger animals such as spiders and carabid beetles (Bengtsson et al. 1997, Persson et al. 2005). Abundances of these organisms are affected for several groups, both in the short term (Bird & Chatarpaul 1986, Persson et al. 2005) and the longer term, at least up to 18 years (Bengtsson et al. 1997, 1998). Although most of these studies have shown only small effects on the species composition, so that the effects on biodiversity seem small, the data on which to draw conclusions are scarce and emanate from samples from only a handful of sites.

6.4 Associations with different types of wood

This section concentrates fully on saproxylic organisms, mainly because other organisms using fuel wood as shelter or growing substrate are rather unspecific in their preferences. Most saproxylic organisms, especially insects, are more or less specialised on some type of wood, which can be defined by the variables tree species, stage of decay, degree of sun exposure, diameter and part of the tree (Jonsell et al. 1998, Palm 1951, 1959).

6.4.1 Tree species

Most saproxylic insects and fungi discriminate between tree species, although there is a range from monophagous species (only found on one tree species) to extremely polyphagous ones (Boddy 2001, Ehnström & Axelsson 2002, Palm 1959). This is also shown in studies explicitly made on logging residues (Jonsell et al. 2007, Nittérus et al. 2004). The largest difference in species composition is between coniferous and deciduous tree species (Dahlberg & Stokland 2004, Jonsell et al. 1998). Among saproxylic fungi, roughly 60% of the species in Fennoscandia only occur on deciduous trees and 30% exclusively on conifers, while the remaining species may grow on both (Dahlberg & Stokland 2004). For the insect fauna there is considerable difference among the deciduous trees between a group of 'boreal' deciduous trees, viz. *Alnus, Betula* and *Populus*, and a group consisting of more southerly deciduous species (*Quercus, Fagus, Ulmus, Tilia* etc.) (Jonsell et al. 1998). For fungi, the patterns seems different, as *Quercus* seems to have the most distinct species composition compared with *Tilia* and *Fagus* (Heilmann-Clausen et al. 2005). However, there are also conspicuous differences in insect fauna between closely related tree species as shown for *Populus* and *Betula* (Wedmo 2004). For organisms that use the wood surface to grow on there are much smaller differences in flora between wood from different tree species, as shown for bryophytes in Denmark (Heilmann-Clausen et al. 2005).

6.4.2 Sun exposure

Because much of the dead wood in natural forest landscapes is created by large disturbances, mainly fires or storms (Lindbladh et al. 2003, Niklasson & Granström 2000, Zackrisson 1977), many organisms have probably adapted to live on wood exposed to the sun (Kouki et al. 2001, Lindhe 2004, Lindhe et al. 2004). For beetles, this has indeed been proven to be true (Ehnström & Axelsson 2002, Harz & Topp 1999, Lindhe et al. 2005, Palm 1959, Ranius & Jansson 2000). However, the association with sun exposure is rarely obligate, as most sun-favoured species also occur less densely on more shaded wood (Jonsell et al. 2004, Lindhe et al. 2005). There are also many beetles that are associated with shade. These kinds of data are scarce for other insect groups. However, there is one conspicuous example of species associated with shaded places, the fungus gnats (Diptera: Mycetophilidae) where almost no species seems to be favoured by exposure to the sun (Økland 1994, Økland et al. 2005). Among fungi few, if any, species are supposed to be associated with sun-exposed material, although they may use it. In Sweden, fine spruce wood on clear-cuts was found to have fewer species than similar wood in old growth or recently thinned forests (Allmér et al. 2005b). Furthermore, few species were found only on the clear-cut (Allmér et al. 2005b). Drying out due to exposure to the sun mainly has the effect that decomposition is delayed, because it is slow in the beginning and accelerates after the wood becomes more humid.

The association of many beetles with sun exposure might be explained by a need for a higher temperature in the breeding substrate. Differences in moisture may also be important, but as temperature and moisture covary it is hard to assess which is more important. The general conclusion from this is that several species, at least of beetles, use sun exposed logging residues, and furthermore, that many of them favour these before more shaded material.

6.4.3 Diameters

In coarse wood the associations of beetles with different diameters have been rather few and not very strong (Heilmann-Clausen & Christensen 2004, Jonsell et al. 2004, 2005, Lindhe et al. 2005). However, below the coarse wood limit (=10 cm) there seem to be stronger associations, as 63% of the species were significantly associated with some diameter class (Jonsell et al. 2007). Other studies of fine wood have shown that many species use this material (Harz & Topp 1999, Kappes & Topp 2004, Kruys & Jonsson 1999, Nittérus et al. 2004, Nordén et al. 2004, Schiegg 2001).

Fine woody debris has generally been regarded as less species rich than coarse wood. Therefore, the results of two studies in temperate broadleaved forests could be regarded as surprising, as they showed higher species numbers of insects (Schiegg 2001) and ascomycete fungi (Nordén et al. 2004) in fine wood than in coarse for similarly large samples (Table 6.1). However, the unit for measuring sample size affects the results and in these cases the unit was species per m^3 of wood. As pedagogically shown by Kruys and Jonsson (1999), comparing the species number per m^2 of mantle area results in greater similarity of numbers between fine and coarse wood (Table 6.1), while an opposite result is obtained if comparing the number of species per log (=unit of wood). All these measurements, counting the number of species per amount of habitat, are called species density (Gotelli & Colwell 2001). Norden et al. (2004) also compared the species richness, which means the number of species in relation to the number of individuals or records encountered. Fine and coarse wood were then found to be similar for the ascomycetes whereas coarse wood had somewhat more species of basidiomycetes (Table 6.1). In samples of logging residues, the thinnest wood (1-4 cm)

Table 6.1. Species numbers in fine and coarse wood as revealed in four comparative studies (see footnotes). Values are in several cases extracted from graphs in the cited publications, and therefore not exact calculations.

Organism group	Number of species		Compared unit
	Fine wood	Coarse wood	
Species density			
Cryptogams	25	18	6.2 m^3 wood[a]
Cryptogams	25	27	384 m^2 wood surface[a]
Cryptogams	24	37	555 logs[a]
Ascomycete fungi	100	25	ca. 34 m^3 wood[b]
Basidiomycete fungi	230	210	ca. 34 m^3 wood[b]
Coleoptera	182	70	1.15 m^3 wood[c]
Diptera	347	167	1.15 m^3 wood[c]
Coleoptera slightly decayed beech wood	9.5	10.0	Species m^{-2} wood surface[d]
Coleoptera moderately decayed beech wood	13	11.5	Species m^{-2} wood surface[d]
Coleoptera moderately decayed oak wood	22	17.5	Species m^{-2} wood surface[d]
Coleoptera highly decayed oak wood	23.5	20.0	Species m^{-2} wood surface[d]
Species richness			
Ascomycete fungi	25	25	35 records[b]
Basidiomycete fungi	165	216	791 records[b]

a) Kruys & Jonsson (1999), boreal Sweden, spruce (*Picea abies*) wood, FWD = 5–9 cm diameter; CWD = ≥ 10 cm.

b) Nordèn et al. (2004), south Sweden, wood in broad-leaved forest, FWD = 1–0 cm; CWD = ≥ 10 cm.

c) Schiegg (2001), Switzerland, beech (*Fagus sylvatica*) wood, FWD = 5–10 cm; CWD = > 20 cm.

d) Kappes & Topp (2004), Germany, beech and oak (*Quercus petraea*) wood, WD = 5–7 cm; CWD = 40–60 cm.

had for deciduous tree species a somewhat lower number of beetle species per sample than wood between 4-15 cm, but 32% of the species were still significantly associated with the thinnest wood (Jonsell et al. 2007).

In conclusion, fine wood harbours many species, but whether more or less than coarse wood depends on how you calculate. Which measure that is correct depends on the question asked. Measured on a large spatial scale, with large amounts of wood, coarse wood most probably hosts more species than fine wood. However, in managed forests of Scandinavia coarse wood is scarce, and the species number supported by the two wood categories in a stand seems for many organism groups to be higher for fine wood than for coarse wood. This could be explained by most stands containing several more units of fine wood than coarse wood, and the more units there are the more different types of wood qualities are encompassed. Although coarse wood probably is more species rich, the diversity in fine wood has probably been underestimated because this fraction has not been much studied.

6.4.4 Decay stages

During the decay of wood there is a succession of species using the wood. There are several systems for defining successional stages, and how they are constructed is much based on the organism group in focus (Siitonen 2001). For insects the phase of primary colonisation only lasts for one or maybe two years (Ehnström & Waldén 1986, Esseen et al. 1997, Siitonen 2001), whereas fungi, bryophytes and lichens have a slower species turn-over in the beginning (Renvall 1995, Söderström 1988). After the initial phase the insect succession slows down, and is probably much driven by the fungal flora (Crowson 1981, Jonsell et al. 2005). However, the relationships are complex as many fungi can be dispersed by insects.

For saproxylic beetles in logging residues, species density is considerably higher in wood that has been decomposed for 3-5 years than in wood that is only one summer old (Jonsell et al. 2007).

6.4.5 Tree part

Whether the wood is standing or lying, and whether it is the stump, the trunk, or wood from twigs affects the species composition as well (Jonsell & Weslien 2003, Jonsell et al. 1998). From the forest fuel perspective stumps are interesting (twigs and branches are treated under section 6.3.3). Stumps belong to the coarse wood, and might as such be a valuable contribution to the total habitat resource for saproxylic species in a managed forest landscape. However, although the insect fauna in logging stumps is not well known, it is different from that in high stumps, especially the upper part (Abrahamsson & Lindbladh 2006, Hedgren 2007). We do not know much about the differences compared to lying logs, but there are probably differences. A reason to believe this is the close contact with the ground that makes the wood comparatively moist. Also, wood in the roots is different compared to ordinary trunk wood. More data about which species that use stump wood would be needed to assess the effect of stump harvest.

6.5 Dispersal of saproxylic organisms

One important property that affects a species' chance of survival is how it disperses between patches. This capacity should relate to how the habitat is distributed in space and time to predict how well a species may survive in a landscape.

Data on dispersal capacity for saproxylic species are scarce, but the data that exist indicate that these species are rather good dispersers. This is also reasonable from an evolutionary point of view as saproxylic species are forced to find new patches when the habitat decays. Ecological theory predicts that the less predictable the habitat is, the better dispersal capacity is required (Southwood 1977), and such patterns have been suggested for saproxylic beetles also (Nilsson & Baranowski 1997). However, the dispersal might take place both in space and time (Solbreck 1978). Either the organism can fly to the next patch when the old decays, or it has to be long lived and wait in the same place for the next substrate patch to arrive.

Among insects, flight by the wings is used and, most probably, most insects use odour orientation to find suitable habitat patches (see below under Section 6.6). Some pest insect species have been shown to be able to disperse tens of kilometres (Forsse & Solbreck 1985, Nilssen 1984, Solbreck 1980). Almost the same distances seem to be covered by some insect species living on bracket fungi (Jonsell et al. 2003, Jonsson 2003). Fungal species that have large spore production can be wind-dispersed large distances by the spores (Högberg et al. 1995, Nordén & Larsson 2000). Wind dispersal is a very chancy strategy, as the flight cannot be directed at all. However, many fungi use insects as vectors and can thus take advantage of the insect's orientating abilities with the spores stuck to the body of the insect. Many beetles have specific structures for storage of spores that are termed mycangia (Crowson 1981, Kullingsjö 1999), and in some cases the fungi and the insects have a truly mutualistic relationship (Beaver 1989). Most research about these relationships has been made on pest species, mainly bark beetles (e.g. Solheim & Långström 1991), and for other groups the field is largely unknown. There are also fungal species using the strategy of moving over time. They have well developed long-lived mycelia strands, mainly growing in the organic layer of the forest floor and utilizing most kinds of cellulose resource that they encounter (Allmér et al. 2005a).

The size of the patches and the distance between them affect the probability for individuals to be successful in colonising new patches (Hanski 1994). A larger patch will, firstly, have a larger probability of being encountered by a migrating individual. A larger patch may also support a larger population, which can produce more migrating offspring. With more offspring there is a larger chance that one of the individuals will successfully reach a new patch to reproduce in. The longer the distance between an occupied patch and an empty patch, the less is the chance that any individual will find its way to the empty patch. In the bioenergy context a large patch is a place where there is a lot of suitable wood for breeding, whether logging residues or other types of wood. Species may differ considerably in which wood patches they recognize as suitable (see Section 6.3).

Patch size may also be important for bad competitors. There is generally a trade off between good dispersal and good competitive ability. It is probably so that many of the species adapted to large unpredictable disturbances are much favoured by finding patches that are devoid of competitors. Such patches are for example large fire areas or clear-cuts with a lot of wood left. Bark beetles may for example have a 10-20-fold reproduction rate when few females colonise at low densities (Anderbrant et al. 1985) compared to situations in which the substrate is scarce. Thus, there might be species that need large amounts of substrate in one place in order to reproduce successfully.

6.6 Risks for species loss

All organisms in the forest have evolved under natural forest conditions, i.e. before man had any drastic effects on the forests. To evaluate which organisms that are potentially under threat from practices in forestry, it may therefore be relevant to compare the situation under different management regimes with the natural situation (Bengtsson et al. 2000, Fries et al. 1997).

The ultimate answer one would like to give is a quantitative estimate of how much that can be harvested without an effect on the biodiversity. However, the diversity of species on a site is determined by processes working on very large scales both in time and space. The dispersal distances mentioned above indicate that insects can move several km during one year. The extinction of a population is a process that works over many years. With this long time scale, the geographical scale for possible dispersal increases. Thus, it is logical that no one has been able to make any quantitative predictions. Qualitative predictions are possible, i.e. to suggest which life history characteristics make a species more prone to extinction compared to others. However, extinction risks for organisms using the logging residue piles as shelter etc. are hard to speculate on.

That there is a relationship between population size and amount of logging residues is obvious for species preferring fine wood. However, for species that are unspecific in their diameter requirements, the fine wood may also constitute a rather large part of the available breeding material, because the coarser wood is often scarce. This effect would be even more accentuated if the stumps too should be harvested. Analyses of how much various types of wood contribute to the populations of different species could be useful for making predictions about the usefulness of various measures for conserving biodiversity in the forest. However, most of these data are lacking (but see Jonsell et al. 2007, Dahlberg et al. 2005).

The positive effects – i.e. the main gain of decreased extinction risks – of care taken during forest operations may differ between regions, even when the structure of the stand and tree species composition etc. are similar. To preserve viable populations of many forest species, it has been suggested that efforts for conservation should be concentrated to areas where the most valuable flora and fauna are found (Hanski 2000, Huxel & Hastings 1999). This may seem obvious: however, the present policy in Scandinavia is that basic care for nature conservation is equally spread over all forest land, and that the most valuable land is incorporated into reserves (Anonymous 2000, Raivio et al. 2001). Concentrating conservation measures during forest fuel extraction requires that these hotspots for biodiversity can be defined. Unfortunately, data for such a categorisation is lacking for large regions. However, in Sweden the south-eastern part of Småland has earlier been identified as an area where forest fuel extraction should be done cautiously (Egnell et al. 2001), mainly because the area has a rich fauna of saproxylic beetles (Nilsson 2001). There are also other areas known for a particularly rich fauna of saproxylic beetles that should be considered. Also, more caution should be taken on a smaller scale, near or within nature reserves with high biological values associated with dead wood.

6.6.1 Processes that create dead wood in natural and managed forests

In a natural forest dead wood is created in at least three different processes (Figure 6.1). These processes work on vastly different scales, both in time and space (Esseen et al. 1997). The largest-scale events are forest fires and very large storms, which are very unpredictable both in time and space. In a natural forest, fires usually cover several km^2 (Niklasson & Granström 2000), with enormous quantities of wood becoming available at just one time. A process working on a smaller scale is wind throw due to more ordinary storms, or gap dynamics. This is a more predictable process that creates smaller openings in the forest, with less dead wood. Dead wood is also created by self-thinning of single trees, and even of single branches on a tree. How important these natural disturbances are depends largely on the forest type. Fires are rarer on wetter grounds. Fires have probably also had more influence in the boreal forests than in the nemoral, where wind throws are supposed to be more important (Bengtsson et al. 2000). Nordén et al. (2004) argue that the amount of self thinned wood, i.e. branches and twigs, retained in the canopy is larger in nemoral broad-leaved forests than in boreal, more coniferous forests.

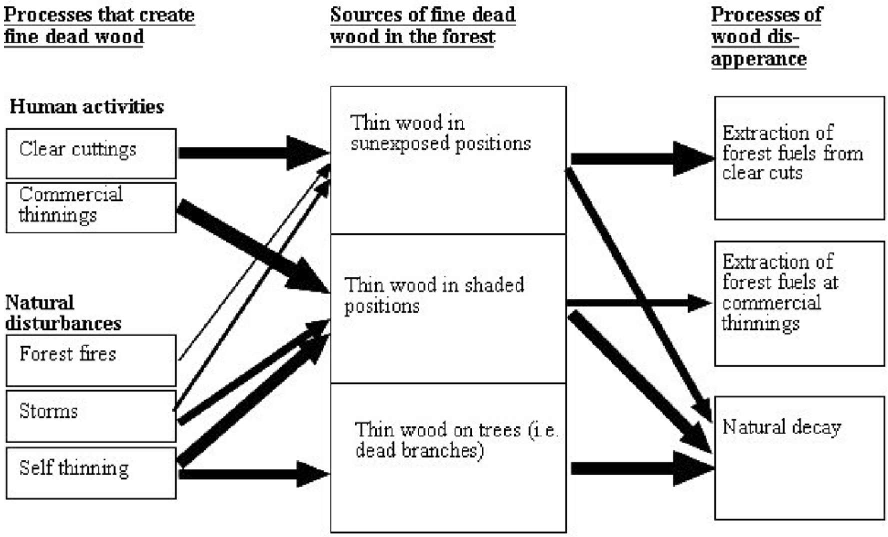

Fig. 6.1. Model of how three categories of fine woody debris are created and disappear in a forest. Arrow thickness represents how large the flows might be in a forest landscape where logging residues are used on a large scale. However, no real data exist for parameterising these arrows. The amount of wood that ends up in the “Natural decay” box equals the amount of habitat available for saproxylic organisms.

The situation in managed compared to natural forests is probably rather similar regarding self-thinning processes. Forestry, however, tries to minimise self-thinning among trees with thinnings in which, traditionally, only the coarse wood is extracted. Wind throws occur commonly in managed forests, but the coarse wood is often extracted, at least after larger events. These processes, self-thinning, gap dynamics and thinning by foresters, create a lot of dead wood of finer dimensions, mainly in shaded positions. In contrast, clear-cuts and forest fires create large openings where the remaining wood is heavily sun exposed. The main differences between clear-cuts and forest fires are that the coarse wood is extracted from clear-cuts, that the area of clear-cuts in a landscape is similar from year to year and that the clear-cuts are usually smaller. Also, the fire itself affects the quality of the wood, which in turn affects which organisms that may use it (Wikars 2002). Thus, in managed forests fine wood in shaded positions is still produced in rather large quantities from natural processes, whereas sun-exposed fine wood is mainly produced at clear-cuts.

6.6.2 Risks of species loss due to degree of sun exposure

It is obvious that the less habitat a species has, the larger is the chance that the species will not survive, i.e. become regionally extinct. Often the risk is expected to increase rapidly below a certain amount of habitat, a so-called threshold (see Angelstam et al. 2002). Thresholds are hard to demonstrate empirically but it is very probable that they exist, as shown in more theoretical models (Fahrig 2001, 2004). For forest landscapes in Sweden, 20% of the original area of various forest types (Angelstam & Andersson 2001) or 20 m^3 wood ha^{-1} (deJong et al. 2004) have been suggested as thresholds over which the diversity of forest and saproxylic species respectively are maintained. These numbers have, however, low empirical support, because studies on relevant scales have rarely been done.

Estimates of how the amounts of habitat are affected by forest fuel extraction – or a parameterisation of the arrows in Figure 1 – would thus be useful for predictions of extinction risks in the context of this chapter. On clear-cuts in spruce forests in hemiboreal Sweden the total amount of logging residues was 15.0 m^3 ha^{-1} (Rudolphi & Gustafsson 2005). Of these, 9.1 m^3 consisted of fine material (diameter <10 cm), and of these 7.3 m^3 (80%) was in piles to be extracted (Rudolphi & Gustafsson 2005). 1.0^{3}m wood ha^{-1}, in the diameter interval 1-5 cm, was retained on average. This corresponds to a mantle surface of 97 m^2 ha^{-1}. The same figure for wood 5-10 cm thick was 0.8 m^3 and 11.7 m^2 ha^{-1}. However, a rather large proportion of this wood is debarked or totally destroyed by forest machines. In eastern Finland, 67.6% of the coarse wood (diameter >10 cm) was estimated to be destroyed, with the largest impact from scarification (Hautala et al. 2004). Assuming a similar impact on fine wood, 10-20% of the wood remains as suitable habitat compared to a clear-cut without any fuel wood removal. All these numbers refers to spruce, and other tree species may differ in extractability. However, no data exists that I am aware of. The calculated percentage, 10-20%, is near the limit suggested by Angelstam & Andersson (2001). It is also near the percentage (2-10%) of coarse wood found in the managed forests of Scandinavia compared to the natural situation (Siitonen 2001), and this amount has been shown to be critical for many species. Thus, a large scale extraction of forest fuel could probably increase the extinction risk for populations that are specialised for sun-exposed fine wood as it, in the absence of fires, is mainly to be found on clear-cuts. This is especially the case if the methods for extracting fuel wood develop and leave less habitat behind on the clear-cuts in the future. Similarly, lack of coarse dead wood because of absence of natural disturbances (=fires) is suggested to be one of the main reasons that several saproxylic beetles have declined (Kouki et al. 2001, Lindhe & Lindelöw 2004), Furthermore, especially in the more nemoral parts of Scandinavia, the forests of today are much denser than they used to be (Nilsson et al. 2001). This is partly an effect of the changed tree species composition, but mainly due to cessation of grazing of cattle in the forests, compared to the situation a century ago (Nilsson et al. 2001). Before human impact, megaherbivores (and fires) probably contributed to a more open landscape (Lindbladh et al. 2003, Svenning 2002).

Extraction of logging residues will affect neither the amount of fine wood formed by self thinning nor the amount of wood in roots and stumps. Consequently, a modelling study of Norway spruce forests in Sweden showed that only 5-6% of the total dead wood will be lost during a rotation period if logging residues are extracted at cuts (Dahlberg et al. 2005). The corresponding figure specifically for wood in branches was 35-45% (Dahlberg et al. 2005).

In conclusion, I suggest that extraction of fine wood for forest fuel will have more effect on species specialised for sun-exposed conditions than on species in shaded conditions. However, the data on which this conclusion is based are vague. To make better predictions we would need to know more about where fine wood is to be found in the forest landscape, how much that is produced by different processes, and how organisms that use fine wood discriminate between wood emanating from these processes. Similar data are needed for logging stumps in order to predict any effect of their extraction.

6.6.3 Risk of species loss due to tree species associations

Species associated with tree species that have generally decreased in abundance should have a higher extinction risk than species associated with tree species that have increased. Forestry has strongly favoured conifers at the cost of deciduous trees, and aspen in particular has been actively eradicated (Esseen et al. 1997, Niemelä 1997). Pollen analyses from south Sweden show that this change has been most drastic during the last 500 years, and lime in particular has decreased (Björse & Bradshaw 1998, Lindbladh et al. 2000) (aspen is not detected in pollen analyses). The same trend is true in north Sweden (Axelsson et al. 2002). In accordance with this, an investigation of logging residues in south Sweden showed several red-listed species from aspen, birch and oak wood, whereas only one species was detected from spruce wood (Jonsell et al. 2007). Thus, species dependent on deciduous trees, and especially aspen and lime, are probably more sensitive to decrease in habitat than most other species, because they have a history of severe habitat decline. On the other hand, spruce associated species have today more habitat than earlier.

6.7 Trapping of insects in piles of logging residues

The ability of insects to direct their flight towards new suitable breeding patches by tracking odours from their breeding substrates (Moeck 1970, Schroeder 1988, Jonsell & Nordlander 1995) make them different from organisms dispersing short distances or by passive flight. Because of this ability they have gained the advantage of being able to find small distinct patches and may therefore be more specialised in the type of wood they use. However, this dispersal efficiency is a risk if the wood they colonise is transported away and burned. The large quantities of wood that are created at logging sites emit a lot of odours and may attract a rather large proportion of the local population. The wood that is burned may thus be considered as trapping wood for saproxylic insects (Egnell et al. 2001).

The effect of trapping wood is hard to assess with present knowledge. However, the distribution of the insects’ habitat must be important. Species that occur in habitats that only constitute small islands in the landscape can probably be very sensitive to trapping. A good example is broad-leaved stands in Sweden. They are often restored by thinnings in the tree layer where the cut wood is often used for bioenergy, and therefore large piles of residues are frequently stored on the sites. If the material is stored during the swarming period a considerable amount of insects, primarily the offspring of the present generation, will be transported away.

For more widely distributed insects the risk with trapping wood is probably lower. Mass trapping has been used in efforts to control pest insect species, e.g. the bark beetle *Ips typographus*. High numbers of insects are usually caught (Weslien & Lindelöw 1989, 1990). However, on a landscape scale, a rather low proportion of the population is caught and the method seems inefficient in suppressing the population unless applied on a very large scale (Weslien & Lindelöw 1989).

The extent to which insects are trapped in the piles can be affected by how the piles are treated. If the wood is cut during the cold season, trapping can be avoided if the wood is transported away or chipped before the insects swarm. The exact timing of this depends on how far north you are and on the weather that particular year. Furthermore, different insects swarm in different periods, so the later in spring and summer the wood is extracted the more insect species are affected.

If the wood is colonised by the insects, one may leave parts of the piles while the main part of the wood is extracted for industry. In large piles (i.e. storage piles at the road which are some metres high) insects have been shown to colonise mainly the uppermost layers (Jonas Hedin personal communication). Thus, leaving part of the surface of the pile gives many insects per amount of wood retained. However, there is a large potential for making studies on various other treatments to find out other ways of taking care of the biodiversity. Such studies could include effects on colonisation of various coverings, from how large an area insects are attracted to a pile, and to what extent retention of smaller amounts of wood in the stand mitigates the negative effect of trapping in the large piles. The Swedish Forestry Board has suggested that wood that has been colonised should be stored an extra year in the forest in order to let the new generation of insects grow to maturity (Egnell et al. 2001). This suggestion may help the primary colonisers, but for the whole fauna it is probably counterproductive, because later in the succession there are more species in the wood, although the numbers of individuals are lower (see Section 6.3.4) (Jonsell et al. 2007).

6.8 Management recommendations

Extraction of logging residues may have negative effects on saproxylic organisms, both because it reduces the amount of available habitats and because saproxylic insects can get trapped in the wood. However, in many types of stands these effects are probably negligible and the benefits of using forest fuels could be considered larger than the negative effects. Spruce is the most common tree species, and fine spruce wood has a rather low diversity of organisms (Jonsell et al. 2007). This is true for many coniferous stands in Scandinavia, especially for ordinary spruce plantations. On the other hand, it is valuable to retain most deciduous trees, and maybe especially aspen, oak and other southern deciduous trees (Jonsell et al. 2007). In areas with a rich fauna or flora associated with dead wood there is most probably good reason to be cautious with forest fuel extraction. A problem is how these areas should be defined, because data are patchy.

6.8.1 Extraction of logging residues

- Retain logging residues of the most valuable (for biodiversity) tree species. Which are the most valuable depends on where you are, but deciduous trees are generally more valuable than conifers. Southern deciduous trees, especially oak and lime and aspen are probably the most valuable tree species, whereas spruce is the least valuable tree species for biodiversity. There may, however, be good reason to also retain spruce wood in hot spot areas.
- The more machines that drive on a logging site, the higher the proportion of the remaining wood that is destroyed. It is important to minimise driving in places where care needs to be taken for biodiversity.
- In Sweden it was found that a considerable fraction of the coarse wood remaining from the original stand was also harvested at logging sites

(Rudolphi & Gustafsson 2005). As coarse wood is generally a resource that many species lack, this should be avoided.
- Stump harvest could probably affect the amounts of dead wood in the forest landscape considerably, and may therefore have large negative effects.
- Measures for biodiversity are most efficient in areas where many species are present (Hanski 2000). It is therefore important to follow the above-mentioned points on sites with high nature conservation values, and less important at sites with low such values. These areas could be particular regions, or cuts near nature reserves.

6.8.2 Storage of logging residues in the forest

The negative effects of trapping may occur mainly on small, mainly deciduous, forest sites. Such sites are often thinned to enhance biological or cultural values, and the wood extracted to become biofuel.

- It is best to cut and transport the wood during the cold part of the year, i.e. before the insects swarm. The exact timing for this depends on how far north you are, and on the weather in the particular year.
- If the wood is colonised, one may retain part of it in the forest. In large piles, the upper layer is the richest both in species number and number of individuals and is therefore the most valuable to retain.

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Chapter 7

REVIEW OF RECOMMENDATIONS FOR FOREST ENERGY HARVESTING AND WOOD ASH RECYCLING

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7.1 Introduction

In other chapters of this book, different economic, environmental and social aspects of forest fuel harvesting and wood ash recycling are treated and recommendations are given. However, national recommendations have already been elaborated by authorities in Sweden, Finland, Denmark and Lithuania (Billeschou & Klitgaard 1985, Danish Forest Agency 1985, Koistinen & Äijälä 2005, National Board of Forestry 2002, Ozolincius et al. 2005), and other recommendations and information materials have been elaborated by different national or international groups with varying degree of stakeholder involvement (Table 7.1). Synthesis information on these issues is also being provided by internet homepages such as www.aboutbioenergy.info by IEA Bioenergy Task 29, and computer models

D. Röser et al. (eds.), Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on the Baltic and Nordic Region, 155–196.

(cf. Chapter 9). The existing recommendations and information materials cover a wide range of topics including economic, ecological, environmental, social, technical and practical aspects for the whole forest fuel chain, ranging from available and potential resources, silviculture and production in the forest, harvesting technology, processing, handling, storage and transport to fuel quality, combustion technology, and emissions from the energy plant. In addition, waste production, wood ash recycling to the forest and institutional and participatory aspects are covered (Stupak et al. 2007).

Within the various topics (Table 7.2), a range of values is usually given if a certain harvesting type and intensity can be considered as sustainable for a certain type of site. The main types of operations related to forest fuel extraction are whole-tree harvesting in cleanings and thinnings, and harvesting of logging residues and possibly stumps before regeneration (cf. Chapter 2). Other related operations are pre-drying of whole-trees or logging residues in the stand, and compensation fertilisation with wood ash or other fertilizers. The harvesting intensity varies with the number of forest fuel extractions during the rotation, and the share and type of biomass removed in the single operations.

Table 7.1. Overview of reviewed recommendations and information materials.

Publication	Reference
A	Danish Forest Agency (1985)
B	Pedersen & Hald (1996)
C	Centre for Biomass Technology (2002)
D	Nurmi & Kokko (2001)
E	Koistinen & Äijälä (2005)
F	Ozolincius et al. (2005)
G	Egnell et al. (1998)
H	Skogsstyrelsen (2001)
I	National Board of Forestry (2002)
J	Energimyndigheten (2006)
K	Egnell et al. (2007)
L	Samuelsson et al. (2007)
M	Nisbeth et al. (1997)
N	British Biogen (1999)
O	Richardson et al. (2002)
P	Emilsson (2006)
Q	Vares (2006)

The answer to the question of what is sustainable forest fuel harvesting depends on the conditions within the specific country or region, and also on the priorities of authorities, the forest owner and other stakeholders. However, existing recommendations can be a starting point for developing new recommendations for other countries, regions, forest estates etc. The present chapter reviews the contents of existing recommendations for sustainable forest fuel harvesting and wood ash recycling, including those provided in the chapters of this book. Finally, other sources have been consulted when there was a need to fill in gaps. Environmental criteria are reviewed mainly on the basis of issued guidelines and recommendations (7.2), as is also the case for social, landscape, and cultural effects (7.6 and 7.7). Silvicultural criteria (7.3) are reviewed, mainly based on Finnish recommendations and research. Technical, logistic, and economic aspects (7.4 and 7.5) focus on implications of ecological constraints, and the description is also mainly based on Finnish experiences. However, the methods which they concern are widely used in Sweden and the Baltic countries too, and the conditions under which they are used are increasingly comparable. Finally, the major tradeoffs between different criteria are outlined (7.8), and concluding remarks are made (7.9).

7.2 Environmental aspects

7.2.1 Soil nutrient fertility

When forest fuel is based on residual biomass, more nutrients are removed from the forest ecosystem compared to conventional stem harvesting. This has led to concern for decreased soil fertility, availability of nutrients in the soil, soil organic matter, and subsequently degraded forest productive functions (cf. Chapter 3). Not much is known about the effect of nutrient removals on long-term soil fertility and nutrient pools, but there is general consensus that an effect should be expected, at least for very intensive utilisation and at least on some site types. In the Nordic countries and the United Kingdom,

Table 7.2. Overview of topics included in recommendations, guidelines and related information material. DK: Denmark, FI: Finland, LT: Lithuania, SE: Sweden, UK: United Kingdom. See Table 7.1 for references.

		DK			FI		LT	SE						UK		International		
Topic:	Reference:	[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]
SFM, certification, C&I, legislation											1					1		
Soil fertility (nutrients, acidific., erosion...)		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Soil organic matter (C-storage, leaching...)		1		1				1	1		1	1		1		1		
Wood production		1			1			1	1		1	1				1		
Biodiversity and wildlife					1	1		1	1	1	1	1	1	1	1	1	1	
Insect pests, fungi		1	1		1	1		1	1	1	1	1	1					
Hydrology, water quality, streams and lakes						1		1	1		1	1		1		1	1	
Landscape, archaeology, culture and leisure					1	1		1			1	1		1				
Nature conservation												1			1			
Silviculture		1	1		1	1						1		1	1	1		
Stump harvesting		1				1			1			1				1		
Production costs, sales and economy			1	1		1									1	1		

recommendations first classify sites and stands according to the sensitivity to forest fuel extraction, and different restrictions are then imposed for the specific site types (Billeschou & Klitgaard 1985, British Biogen 1999, Danish Forest Agency 1985, Koistinen & Äijälä 2005, National Board of Forestry 2002, Nisbet et al. 1997).

The used s*ite and stand classification* uses ecosystem types and classification systems for e.g. soil type, forest type, soil fertility, wood production, soil compaction, slope. Furthermore tree species or the atmospheric deposition of nitrogen is sometimes used to distinguish sites. Five to ten classes can be distinguished in the Swedish, Finnish, and Danish recommendations (Infobox 7.1). In whole-tree harvesting guidelines from the United Kingdom, high risk soils are distinguished from low risk soils, with two-three classes being defined for soil fertility, risk of ground damage, and terrain slope each (Nisbet et al. 1997).

For all countries, forest fuel extraction should be completely avoided for some site or stand types. Otherwise, it can be practiced with different limitations in type, number and intensity of extractions (Infobox 7.2). Six *types of restrictions* can be separated:

- Number of extractions during the rotation
- Types of extractions
- Share of material left in the single harvesting operation
- Spatial distribution of the left residues
- Use of compensation fertilisation
- Time for the nutrient removal and fertiliser addition in relation to the season and stand development stage

It is sometimes recommended to keep a historical record of the extractions made, e.g. in the forest management plan. The contained information may be the extracted tree species, time of extraction, and if needles were removed or left behind (National Board of Forestry 2002). This may serve as documentation to support whether recommendations are being followed, and for planning of possible compensation fertilisation. If extractions should be reported to authorities as in Sweden, these will also hold some documentation.

It is often recommended to limit the *number of extractions* to one or two per rotation if no compensation fertilisation is performed (Infoboxes 7.1 and 7.2).

Infobox 7.1. Details of site and stand type classification for sensitivity to forest fuel harvesting. The numbering was performed by the authors, see Billeschou & Klitgaard (1985), Koistinen & Äijälä (2005), and National Board of Forestry (2002) for exact details.

Site and stand classes

Denmark: Five site classes, the last being divided into two stand classes which are again divided into two subsite classes. The baseline recommendation is to perform stand-wise evaluation and for conifers to leave needles by pre-drying over at least two spring- and summer-months (Recommendations for forest fuel harvesting are given in parentheses):

(1) Stands of special value for flora and fauna, and which are not primarily managed for wood production (only after careful evaluation)
(2) Exposed forest edges (to be avoided)
(3) Nature conservation areas (recommended unless in contradiction with nature conservation purposes)
(4) Inferior forest, especially mountain pine stands (recommended but with limited utilisation of crown material and only after pre-drying)
(5) Other: Conifers: Production class over or under 9 m^3 ha^{-1} yr^{-1} (low production classes only after fertilisation). Broadleaves: Sandy soils and other soils (to be avoided on sandy soils)

Finland: About ten site or stand type classes. Site classes are not exactly the same for whole-trees in thinnings and logging residues/stumps, but they are nevertheless similar. Recommendations are given in parentheses: (whole-trees in thinnings, logging residues, stumps). N.a.=not applicable, i.e. the site class is not used for the particular utilization type.

(1) Mesic upland sites and more fertile soils (n.a., OK, OK)
(2) Sub-xeric and xeric sites (No, Logging residues can be removed only if necessary to perform stump harvesting, OK)
(3) Barren upland sites with lichens (No, No, Recommended if stumps are infected by root rot)
(4) Peatland forest sites with herb and blueberry vegetation, i.e. forests on ditched organic soils which were forested before the ditching and are within fertility class 1-3 (n.a., OK, OK)
(5) Peatland forest sites with cowberry vegetation or poorer, i.e. forests on ditched organic soils which originally were without trees and of different types, and have fertility class 3 or lower (No, No, No)
(6) Stands with much bedrock, rocks and stones (n.a., No, No)
(7) Stands the suffer from disturbances in availability of nutrients (No, OK if fertilisation with wood ash or boron takes place, OK if fertilisation with wood ash or boron takes place)
(8) Water conservation areas (n.a., OK, No)
(9) Managed stands with >75% spruce (No, n.a., n.a.)
(10) Stand where utilisation of logging residues has taken place in the previous regeneration or whole-tree harvesting has been applied in cleanings or thinning of the present rotation (No, n.a., n.a.)

Sweden: About five site classes. The baseline recommendation in Sweden is to leave the needles by pre-drying, evenly spread, and to perform compensation fertilisation (Recommendations for forest fuel harvesting are given in parentheses):

(1) Generally (only after pre-drying and leaving the needles evenly distributed. Needles can be taken out once in clearning or hinning. If more than once per rotation, fertilisation compensation should take place)
(2) Lichen rich sites in northern Sweden (to be avoided if it causes difficulties for regeneration)
(3) Strongly acidified land (compensation fertilisation should always be performed)
(4) Peat land (compensation fertilisation should always be performed)
(5) Land under strong nitrogen impact (needles can be removed if compensation fertilisation takes place).

Concerning *types of extractions*, extraction of whole-trees from thinnings or logging residues is typically to be avoided on poorer sites. In Denmark stump harvesting should generally be avoided, and in Finland it is only recommended on certain site types. In the national recommendations in Sweden, there is no explicit mention of stump harvesting, but a new environmental assessment report on stump harvesting has recently been published (Egnell et al. 2007). Stump harvesting is emerging, especially in Finland, even if the harvested areas are still small and limited to spruce dominated stands.

The *share of nutrients that should be left* in each operation often corresponds more or less to the nutrient contents of the needles (Infobox 7.2). In Sweden and Denmark, it is recommended to perform pre-drying in the stand. In Finland, pre-drying is only recommended for logging residues on nutrient rich mineral soils when the harvesting takes place in spring or summer. Otherwise, different methods for leaving a part of the fresh material during the harvesting operation are suggested, e.g. leaving residues of every fifth tree, leaving a part of the top, or delimbing when more trees are handled together. For stump harvesting, the Finnish recommendations suggest leaving approximately 20 stumps ha^{-1} (diameter >15 cm), evenly distributed in the stand. On clay and silt soils, the recommendation is to leave 50 stumps ha^{-1} (Koistinen & Äijälä 2005). In Sweden, Egnell et al. (2007) recommend that part of the stumps are left in the forest. Burger (2002) furthermore suggests that de-barking can be a measure, e.g. if calcium depletion is accelerated by both intensive utilisation and high levels of acid deposition. Developments in biomass harvesting technology for the control of nutrient losses has been emphasised for example in the Swedish national recommendations (National Board of Forestry 2002) and by Hakkila (2002).

Nordic guidelines recommend that some effort is made to *spread the needles evenly* after pre-drying or that 30% of the residues are left evenly spread over the clear-cut (Infobox 7.2). In the Danish recommendations it is mentioned that forwarding to windrows should be avoided.

Infobox 7.2. Details for reduction of nutrient removals in existing recommendations (Billeschou & Klitgaard 1985, Egnell et al. 2007, Koistinen & Äijälä 2005, National Board of Forestry 2002).

Types and frequency of forest fuel extractions

Denmark: Removal of stumps should be avoided, and removal of logging residues should be limited. Conifers, production class <9 m^3 ha^{-1} yr^{-1}: only first and second thinnings should be used, unless the stand is fertilised.

Finland: Logging residues and stumps after regeneration cutting can be harvested with some limitations. In thinnings: extraction of small-trees can be performed in the first thinnings where cleanings have not been performed, or where nurse trees should be removed are recommended for forest fuel extraction. Removal of small whole-trees should be avoided if logging residues were removed in the previous regeneration, or if whole-trees have been removed in previous cleanings or thinnings during the present rotation.

Sweden: Logging residues and thinnings can be harvested if compensation fertilisation is performed and if needles are left and spread evenly. One single harvest per rotation can however take place without compensation fertilisation if the needles are spread evenly. Stump harvesting is of emerging interest, and a preliminary assessment report for stump harvesting recommends that only spruce and pine stumps are used, whereas stumps from broad-leaves should be left.

Share of material removed in single forest fuel extractions

Denmark: It is generally recommended to leave needles by pre-drying over at least two spring- and summer-months. Conifers, production class <9 m3 ha^{-1} yr^{-1}: logging residues should be pre-dried if removed at all.

Finland: For *thinnings* it is recommended to reduce nutrient removals by (1) leaving the upper most part of the tree crown, about 1-1.5 m, and stems that are less than 4 cm in diameter at ground level, (2) debranching of stems in the bundle when more trees are handled together, (3) leaving cut deciduous trees should to dry for the foliage to be shed. In *regeneration*, it is recommended to leave 30% of the nutrients in logging residues. The recommended method depends on season and site type: (1) during summertime, the logging residues should be left in piles on the clear-cut to dry, (2) except for the cool period, every fifth tree should be delimbed so that its crown residues are left outside actual piles of logging residues, and furthermore leaving about 10% of the logging residues on the clear-cut, (3) during wintertime, the amount of logging residues that cannot be retrieved technically should be left. *Stump harvesting*: The recommendation is to leave approximately 20 stumps ha^{-1} diameter >15 cm) evenly distributed in the stand. On clay and silt soils, the recommendation is to leave 50 stumps ha^{-1}.

Sweden: It is generally recommended to leave needles or a similar amount of nutrients. However, needles can be removed once per rotation in connection with light thinning or clearing if compensation fertilisation is performed. Furthermore, nutrient removals should be limited to an amount that can be compensated with 3 tonnes of wood ash ha^{-1}. It is recommended to leave part of the stumps <20 cm & >60 cm.

Spatial distribution of the left residues

Denmark: When pre-drying of whole-trees in thinnings in the stand the clustering of the needle biomass is not significant.

Finland: Logging residues should be left evenly spread on the whole clear-cut.

Sweden: Effort should be made to spread the needles out evenly after pre-drying.

Infobox 7.3. Recommendations on where to perform compensation fertilisation (Billeschou & Klitgaard 1985, Koistinen & Äijälä 2005, National Board of Forestry 2002).

Compensation fertilisation

Denmark: Fertilisation is recommended if forest fuels are extracted on sites where production class <9 m^3 ha^{-1} yr^{-1}.

Finland: Wood ash fertilisation is recommended on peat land after forest fuel extraction in thinnings, or if logging residues or stumps are extracted from sites that suffer from nutrient disturbances.

Sweden: Compensation fertilisation is generally recommended when forest fuels are extracted. Exception is made for one extraction per rotation unless soils are highly acidified or on peat land.

Compensation fertilisation is a general requirement in Sweden, unless only one extraction per rotation is performed (Infobox 7.3). In Denmark, fertilisation is suggested on less productive soils in coniferous stands. In Finland, wood ash compensation is recommended on peat land, and on soils with nutrient disturbances which are often seen in areas where slash and burn has been practiced (Saarsalmi & Tamminen 2005).

The principles used for recommendations in Chapter 3 are essentially the same as those that have been applied at more aggregated levels in the existing recommendations. The main advantage of the approach taken in Chapter 3 is the possibility to make an evaluation at stand level. The basic principle is that the total nutrient removals during one rotation should simply be compensated by fertilisation, unless the input by soil mineral weathering or atmospheric deposition is large. The actual possibilities of adding compensatory amounts of fertiliser might, however, be limited by maximum allowable amounts in existing legislation, by general fertilisation recommendations from national forestry agencies, or by the economy of the forest owner.

Six site categories are suggested in Chapter 3 with the separation being based on the combination of two soil categories, sensitive and robust soils, and three nitrogen deposition regimes: 2-5, 5-15, and >15 kg ha^{-1} yr^{-1}. The removal of nitrogen should be compensated 1:1, unless atmospheric nitrogen deposition exceeds 15 kg ha^{-1} yr^{-1}. Removal of phosphorus, potassium, calcium, and magnesium should be compensated 1:1 on sensitive soils, while no compensation is recommended on robust soils. Different climate and soil variables are used to distinguish robust soils from sensitive soils (Figure 3.8). The major disadvantage of the system is that these variables are not always readily understood by forest managers, or available from forest management plans. As such, extra costs will usually be needed to obtain such information.

7.2.2 Soil organic matter and carbon storage

The concern for site fertility also includes effects of the additional organic matter removal. In existing recommendations and information materials, a decrease in input of organic matter to the soil is recognized as potentially important e.g. for the soil structure, temperature, water balance, biological composition and activity, nutrient availability, and wood production (Burger 2002, Centre for Biomass Technology 2002, Danish Forest Agency 1985, Egnell et al. 1998, Skogsstyrelsen, 2001, Splechtna & Glatzel 2005), but not much is known about the effects on long-term soil fertility (Egnell et al. 1998, Energimyndigheten 2006).

In general, soil organic matter should be maintained as removals cannot be easily compensated. Burger (2002) suggests that soil organic matter contents can be preserved by maintaining or even increasing forest productivity (e.g. by fertilisation), and by minimizing disturbance during site preparation. Higher productivity increases organic matter inputs to soils, particularly through root turn-over. It is also recommended that herbicides, when safe and acceptable, are used to replace fire and mechanical weed control as it will reduce residue removal and physical disturbance, which both accelerate organic matter decomposition.

Soil organic matter is also an important question in relation to forest carbon balances and climate change. There are indications that the soil carbon stores are not significantly affected by forest fuel extraction or by wood ash fertilisation if the ash is hardened, but experimental evidence is scarce and difficult to obtain (Egnell et al. 1998, Energimyndigheten 2006). Wood ash may on the one hand potentially increase the decomposition and on the other hand increase growth and thereby the organic matter input to the soil. Taking the replaced fossil fuels into account, the overall carbon balance should however show reduced emissions to the atmosphere (Energimyndigheten 2006).

7.2.3 Wood ash recycling and other nutrient compensation

Wood ash recycling is commonly suggested as a measure to sustain soil nutrient fertility after increased nutrient removals, or to counteract soil acidification due to atmospheric pollution and harvesting of biomass. Also, it has been used to increase forest productivity, especially on peatland, and to correct nutrient deficiencies (Emilsson 2006). As such, wood ash recycling is not necessarily interlinked with forest fuel extraction, and conversely, commercial fertilisers could also be used for nutrient compensation fertilisation after forest fuel extraction. In some countries, the use of wood ash for agricultural and forestry, gardening and landscaping purposes is regulated by specific legislation. In Denmark, the use of ash from biomass combustion is regulated under the Environmental Protection Law (Anonymous 2000), and in Finland, the Fertilizer Act which is now the Fertilizer Product Act 539/2006 was revised lately to remove barriers for using wood, peat or agrobiomass ash as a by-product or as an inorganic fertiliser (Anonymous 2007). In other Nordic and Baltic countries, there is no specific legislation for wood ash recycling, but in Sweden and Lithuania, detailed recommendations have been elaborated (National Board of Forestry 2002, Ozolincius et al. 2005). Based on Swedish and Finnish experiences, a general handbook for practical wood ash recycling was also published (Emilsson 2006). The Danish regulation and Swedish recommendations are currently undergoing revisions (Danish Environmental Protection Agency 2007, Samuelsson et al. 2007). The information found in existing legislation, recommendations and guidelines largely falls within the following categories:

- Purpose of the wood ash fertilisation
- Suitable sites for application, including requirements for soil quality
- Requirements for wood ash quality and hardening
- Methods to document the wood ash quality: sampling and chemical analysis
- Methods for hardening of the ash
- Dosage and rate of application
- Work method, and time of application in relation to stand development stage and season
- Need for additional compensation with nitrogen fertiliser

As with forest fuel extraction, it is recommended (in Finland obligatory) to keep a historical record of performed wood ash applications as many years may pass between the forest fuel extraction and wood ash compensation. In Sweden and Lithuania, the forest management plan is suggested for registration of details such as time of application, amount, and chemical composition (National Board of Forestry 2002, Ozolincius et al. 2005), and in Finland, the forest owners' associations keep records on the fertilized sites where the operation is contracted by the association. If ash is applied to improve the forest health and a state subsidy is received, the operation is furthermore documented by the regional Forestry Centres. In a preliminary revised version of the Swedish recommendations it is also suggested that authorities should be notified and informed of wood ash spreading to keep track of the situation using GIS systems (Samuelsson et al. 2007). According to the Danish regulation for wood ash (Anonymous 2000), the municipal council should be informed about the applied amounts and a map of the fertilized areas should be attached if more than 5 tonnes of wood ash is applied per year.

As mentioned above, fertilisation with wood ash is driven by different *motives*. In Finland, the use of wood ash is mainly performed to increase wood production (Emilsson 2006, Koistinen & Äijälä 2005) whereas compensation of base cations and nutrients is most often the purpose in Sweden, Lithuania and Denmark. According to the Swedish forest policy, the total area being treated with ash should, by 2010, be at least as large as the area from which harvesting residues are collected in connection with final fellings (Swedish Forest Agency 2005). In Lithuania, the application of wood ash is not inherently connected to forest fuel extraction, but it should first of all take place in such stands (Ozolincius et al. 2005). According to the Danish legislation, forest fertilisation with wood ash can in principle be for any planned purpose (Anonymous 2000), whereas compensation for nutrient removals with biomass is the underlying principle in the Danish recommendations and the fertilisation guidelines for State forests (Billeschou & Klitgaard 1985, Danish Forest and Nature Agency, 1998).

The sites recommended for wood ash fertilisation are closely interlinked with the motives for fertilisation. In the Finnish recommendations wood ash recycling is recommended on peatlands, where positive effects on growth are significant and long-lasting (Koistinen & Äijälä 2005). In Sweden compensation fertilisation, preferably with ash is, with some exceptions, recommended, where forest fuels are extracted (National Board of Forestry 2002). In Lithuania, application of wood ash is recommended in the exploitable forest stands growing on mineral soils of normal moisture, some drained or self-drained peatland soils, on poor agricultural lands before afforestation, re-cultivated pits, and on sandy soils degraded by wind (Ozolincius et al. 2005). According to the Danish legislation, wood ash can be applied in all forested areas where there is a fertilisation need, and the concentrations of heavy metals in the soil are below certain limits (Table 7.3). The Danish guidelines consider that fertilisation is required if forest fuels are extracted from sites of poor growth (Billeschou & Klitgaard 1985).

In Sweden, the *quality of the ash* is decisive rather than the type, and fertilisation with mixed ash from different fuel types is allowed if quality requirements are met. In Lithuania only forest fuel ash is recommended for use in forests, while in Denmark wood ash and mixed wood and straw ash are allowed in forested areas. In Finland ash from combustion of peat and agrobiomass may also be applied in forests as long as the maximum values for e.g. heavy metals are not exceeded. Threshold values for chemical contents of wood ash are summarised in Table 7.3. In Sweden, Finland and Lithuania, but not in Denmark, the concentrations of some nutrients in the ash should be above certain minimum thresholds. The concentration of heavy metals and PAHs should generally be below certain maximum thresholds. In Sweden, there is furthermore an upper threshold value for caesium, and target values for electrical conductivity, which decreases with increasing dosage. The latter is assumed to reflect the reactivity of the ash, and thereby the potential damaging effect on the ecosystem. Recommendations are given, that the reactivity of the ash should be diminished by *hardening* (Emilsson 2006, National Board of Forestry 2002, Samuelsson et al. 2007, Väätäinen et al. 2000, Vesterinen 2003). Granulation or pelletizing of ash in particular slows its dissolution in the forest, but is more expensive than e.g. self-hardening (Emilsson 2006). In the new requirements currently being elaborated in Denmark, new tests will probably be introduced to determine the degree of hardening of the ash. There is some documentation that these tests reflect the potential damage of the ash to the ecosystem (Morten Ingerslev, pers. comm.). In Sweden, higher values for electrical conductivity will probably be allowed (Samuelsson et al. 2007). Finally, hardening also eases the handling and spreading of the ash. In Sweden, Finland and Denmark, national, Nordic, or American standards are currently

Table 7.3. Threshold values for soil and wood ash quality for wood ash use in forestry. Denmark (DK): Anonymous (2000), Finland (FI): Anonymous (2007), Lithuania (LT): Ozolincius et al. (2005), Sweden (SE): National Board of Forestry (2002) and Samuelsson et al. (2007).

Element/ Comp.	Soil quality	Wood ash quality			
	DK	DK	FI	LT	SE
			g kg^{-1}		
Ca			>60	>125	>125
Mg				>20	>20(15)[a]
K				>30	>30
P		<90 kg ha^{-1} 3 $years^{-1}$	>10 (P + K)	>10	>10(7)[a]
Cl			>20		
			mg kg^{-1}		
B				<500	<500(800)[a]
Cu	<40		<700[b]	<400	<400[c]
Zn	<100		<4500[b]	<7000	(500)[a]1000-7000 [c]
As			<30[b]	<30	<30[c]
Pb	<40	<120	<150[b]	<300	<300[c]
Cd	<0.5	< 0.5-15[d]	<17.5[b]	<30	<30[c]
Cr	<30	<100	<300[b]	<100	<100[c]
Hg	<0.5	<0.8	<1[b]	<3	<3[c]
Ni	<15	<30(60)	<150[b]	<70	<70[c]
V				<70	<70[c]
ΣPAH		<3[e]		<2[e]	<2[e]
Cs					<10 kBq kg^{-1} (0.5)[f]
Conductivity					Target value: 10-14 mS cm^{-1}
Impurities fx stones			<0.2-0.5%		

[a]Figures in parantheses are according to the preliminary revised version of the Swedish recommendations (Samuelsson et al. 2007). [b] The maximum value is for utilisation in forestry only. [c] The maximum amounts of the element that can be added per hectare differs depending on the forest type (pine or spuce) and location (Southern, Central, Northern Sweden), with maximum limits being highest in spruce, and increasing towards the south, [d] The maximum amount that can be added depends the Cd concentration, [e] Sum of several PAHs, the specific PAH differing between countries, in Sweden EPA 16, in Lithuania only bensopyren, [f] in areas with some extent of reindeer husbandry.

recommended or prescribed for *sampling procedures and methods of chemical analysis* (Anonymous 2000, Emilsson 2006, National Board of Forestry 2002). Sampling errors are believed to be the major source of uncertainty when wood ash is sampled to determine its quality, and a common standard method and use of accredited laboratories would therefore be preferable to avoid incorrect and incomparable analytical results. In Finland, the use of accredited laboratories is mandatory (Annex I of decree 12/07). Emilsson (2006) suggests that a new European standard for sampling of solid fuels (CEN/TS 14778-1) can be used for wood ash too. Such standards, in addition to ongoing revisions of acts, regulations and recommendations in e.g. Sweden, Denmark and Finland, will possibly lead to a higher degree of harmonisation in the future (Emilsson 2006).

Current practise in Finland suggests a *dosage* of 3-5 tonnes of wood ash ha^{-1} when ash is applied on peat soils, and 1-3 tonnes more for mixed peat and wood ash (Emilsson 2006). In Sweden, the recommended dosages are presently based on the nutrient balance method with differences according to species and utilisation intensity, and a maximum of 3 tonnes of ash ha^{-1} 10 yrs^{-1}. The maximum will probably be 3 tonnes $rotation^{-1}$ after revision of the recommendations (Samuelsson et al. 2007). In Lithuania, 1.5-3.5 tonnes ha^{-1} are recommended twice per rotation on the site types mentioned above. The dose depends on the forest type according to a national classification. In Denmark, the maximum allowable amount of wood ash that can be applied over 10 years ranges from 0.5 to 7.5 tonnes ha^{-1}, decreasing with increasing cadmium concentrations. A maximum of 7.5 tonnes ha^{-1} $rotation^{-1}$ is presently allowed.

In Sweden, the national recommendations request that spreading of the wood ash takes place with a *working method* and at a *time* where nitrogen leaching and loss of input nutrients can be avoided (National Board of Forestry, 2002). As such, compensation must not take place during periods of snow cover (see also Ozolincius et al. 2005), ground frost or severe run-off, if there is a risk that nutrients will subsequently end up in the water courses. For the same reason, compensation fertilisation should not take place five years before or after regeneration felling. The fertiliser should furthermore be spread evenly in the stand, and mechanical damage to soil and trees should be limited. Ozolincius et al. (2005) recommend that the first ash application takes place at the time of thinnings, and that the second application takes place in the middle-aged stand. For ecological reasons, it would be beneficial to add the ash when the need for nutrients is highest in the single stand, i.e. when growth is at a maximum. However, to minimise costs, it might be more beneficial to map the stands planned to receive wood ash, and add the ash to a larger number of closely situated stands at the same time (Samuelsson et al. 2007). Finland and Denmark do not have national recommendations on method and time for wood spreading, but in Finland ash is spread with helicopters or forwarders and usually in connection with the first thinning on peaty soils. More details are given by Emilsson (2006).

Nitrogen is almost absent in wood ash as it vaporises during combustion. In some areas, it is assumed that nitrogen removals can be compensated by high atmospheric deposition, whereas in other areas the only option for compensation is to add nitrogen as commercial fertiliser or possibly sludge. In the Swedish recommendations (National Board of Forestry, 2002), it is recognised that in certain cases, nitrogen fertilisation might be needed where deposition is low, e.g. in northern Sweden. According to the Lithuanian recommendations (Ozolincius et al. 2005), nitrogen should be added during the second of two recommended wood ash applications during the rotation. Fertilisation with nitrogen is not mentioned in the Finnish recommendations (Koistinen & Äijälä 2005), possibly because the purpose of fertilisation in Finland is rather related to increased wood production than to ideas of nutrient compensation. In Denmark, atmospheric deposition is believed largely to compensate nitrogen removals as forest fuel extraction is practiced today (Pedersen & Hald 1996), but the Danish Forest and Nature Agency (1998) suggest that fertilisation with nitrogen, preferably with recirculated fertiliser types such as sludge, could be needed in stands with strongly intensified removal of biomass for energy purposes. In Chapter 3 it is generally recommended that compensation with nitrogen takes place in areas with an atmospheric deposition less than 15 kg ha^{-1} yr^{-1}. (Emilsson 2006) suggests a limit of about 5 kg ha^{-1} yr^{-1} on sites of modest quality, and a somewhat higher and lower limit for sites of low and high quality, respectively.

7.2.4 Hydrology and water

The acidifying effect on leaching water and subsequently streams and lakes has been a serious adverse effect of atmospheric deposition in northern Europe, and biomass removals may contribute to this acidification. This is the main reason that compensation fertilisation with wood ash is recommended in Sweden (Energimyndigheten 2006). On the other hand, removal of logging residues might diminish the leaching of nitrogen and loss of base cations to streamwaters in areas with high nitrogen deposition (Egnell et al. 1998, Energimyndigheten 2006, National Board of Forestry 2002, Nisbeth et al. 1997, Samuelsson et al. 2007, Skogsstyrelsen 2001).

To avoid streams and waters being polluted with particles and nutrients, it is generally recommended to remove residues and avoid harvesting of stumps and storage of material near ditches, streams and waters (Egnell et al. 2007, Koistinen & Äijälä 2005, Nisbeth et al. 1997, Samuelsson et al. 2007). For stump harvesting Koistinen & Äijälä (2005) propose protective zones of 2-3 m for ditches, 3-5 m for small streams and springs, and 7-10 m or more for larger waters. Egnell et al. (2007) propose a protective zone of 15 m where harvesting of stumps should be avoided.

On steep slopes with a risk of soil erosion stump harvesting should be avoided or performed perpendicular to the slope (Koistinen & Äijälä 2005). The risk of erosion is largest on sandy soils. Care should furthermore be taken for forests lying on bedrock with a thin soil layer (< 0.5 m), craggy and rocky (Koistinen & Äijälä 2005).

7.2.5 Biodiversity

Harvesting residues can act as shelter, or feeding and breeding substrate, for a number of organisms. If removed, they may act as trap wood for rare organisms colonising the wood (cf. Chapter 6). Angelstamm et al. (2002) provide generic recommendations for preservation of biodiversity in connection with forest fuel extraction, while national recommendations are more specific (Billeschou & Klitgaard 1985, British Biogen, 1999, Danish Forest Agency 1985, Egnell et al. 1998, Koistinen & Äijälä 2005, National Board of Forestry 2002, Nisbet et al. 1997, Skogsstyrelsen 2001). Generally, it is recommended that elements of known importance for biodiversity at various hierarchical levels are spared. These may comprise:

- Nature conservation areas and valuable nature types
- Rare tree species, and species especially valuable for biodiversity
- Other trees and bushes left for nature conservation purposes, e.g. old trees
- Standing or lying dead wood and decaying wood in different stages of decomposition
- Harvesting residues
- Other natural objects such as bird nests, anthills, fox earths etc.

Such valuable objects may be defined by legislation, but otherwise the identification must be done by the forest owner, possibly with consultation of national or local authorities (British Biogen 1999). Angelstamm et al. (2002) furthermore mention the possibility of considering biodiversity when afforestation or forest restoration takes place to enhance the use of wood for energy.

Koistinen & Äijälä (2005) encourage considering the qualities of *valuable natural objects* when extracting forest fuels. Valuable natural objects are defined e.g. as forest types protected by the Finnish Nature Conservation Law §29, habitats mentioned under §10 of the Finnish Forestry Law, and Criterion 10 under the Finnish Forest Certification Standard (FFCS 1002-1). In Sweden, National Board of Forestry (2002) exempts wet forest land or other forests with high natural values from forest fuel extraction, if their natural values are affected negatively. In Denmark, Billeschou & Klitgaard (1985) recommend that stands of special value for flora and fauna, and which are not primarily managed for wood production, should be carefully evaluated before wood chipping is performed. For the United Kingdom, British Biogen (1999) advises that particular care should be taken on certain sites of conservation importance. Reference is made to relevant national and local authorities for identification of such sites.

In Finland and Sweden, it is recommended to leave *tree species* that are less common in the stand or in the landscape. These are often broadleaves (Koistinen & Äijälä 2005, National Board of Forestry 2002). The National Board of Forestry (2002) also stresses the importance of not damaging trees and bushes that have previously been left untouched in consideration of their natural and cultural values. Furthermore, Angelstamm et al. (2002) and the Forestry Commission (2004) mention that old trees in particular are very important elements for biodiversity.

Fresh and decaying dead wood at different stages of decomposition are also recognized as important for biodiversity, both as standing and fallen trees, and as stumps and high stumps. Larger dimensions of wood in later decay stages are especially important, and deciduous wood is generally considered more important than coniferous wood. The importance of leaving coarser dead wood in brooks to create new substrate for water-living animals and algae is also mentioned (Skogsstyrelsen 2001), as is general planning for future nature conservation trees (Forestry Commission 2004, Skogsstyrelsen 2001). Samuelsson et al. (2007) recommend that one fifth of the logging residues are left for biodiversity, preferably in sun exposed places. Recommendations occasionally suggest measures against temporarily stored wood that might act as *trap wood*. If deciduous residues are removed as forest fuel, these should be covered with fine residues of conifers during storage in the forest (Skogsstyrelsen 2001).

Koistinen and Äijälä (2005) recommend leaving *other objects* such as bird nests, anthills, and fox earths, and Egnell et al. (2007) recommend that all stumps near larger stones, ant hills, or trees of nature conservation value are left. The recommendations given in Chapter 6 are in accordance with the existing guidelines. It is stressed that measures for biodiversity are most efficient in areas where many species are present. This suggests a need for mapping of these so-called hot spots (see e.g. Swedish Forest Agency 2004). The importance of deciduous species is confirmed, while the importance of stumps for biodiversity is still considered to be uncertain. In existing guidelines it is recommended to leave dead wood from the previous stands. Investigations have shown, however, that a considerable fraction of this dead wood is extracted together with the logging residues, and there is a risk of dead wood habitats being destroyed by vehicles (Chapter 6). As such, education and information provided to machine operators should be in focus, and extraction technologies and methods have to be considered.

7.2.6 Insect pests and fungal diseases

Extensive damage to living trees caused by insects is relatively rare, but there has nevertheless been concern over whether temporary stores of wood fuel in the forest may be colonised by pest insects that might subsequently attack adjacent stands (Chapter 5). When forest fuels are extracted, the amount of breeding material decreases compared to conventional stem harvesting, and the risk of pest insects is therefore normally reduced. However, forwarding of logging residues to large piles or windrows, or pre-drying of whole-trees in thinnings might pose an increased risk. Types of protective measures mentioned in existing guidelines and legislation are:

- Recognising exceptional weather conditions
- Controlling the amount and type of material that can be left in the forest
- Controlling location of stored material in relation to living trees
- Controlling storage time and season in relation to swarming periods
- Separate handling of material with different risk potentials
- Covering of the stored material

The recommendations given in Chapter 5 are in line with the existing recommendations and refer to both these and legislation. In Sweden, Finland, Norway, Estonia, Latvia, and Lithuania storage of wood in the forest is regulated by legislation (Stupak et al. 2007). Focus is on storage of timber, which should usually be removed from the forest before a certain date (sometimes depending on species and region within the country), or should be made unsuitable as breeding material for insect pests e.g. by safe location of the material, debarking, chemical treatment, storage in water, sprinkling with water, or covering e.g. with plastic, finer fractions, or debarked wood. Wood of finer dimensions is also sometimes addressed, and the methods recommended to avoid colonisation of pest insects are similar to those for timber (Infobox 7.4). In Latvia and Estonia logging residues should be piled, removed or destroyed. In Sweden there are limitations to the amount and coarseness of material that can be stored. In Finland and Norway, legislation makes possible the issuing of regulations if needed.

Infobox 7.4. Details of Nordic and Baltic national legislation and storage in the forest recommendations.

Sweden: It is generally not allowed to leave more than 250 m of coniferous wood with diameter over bark >7 cm, and of these, not more than 50 m must be coarser than 15 cm in diameter (Skogsstyrelsen 1998). For spruce and pine there are exceptions related to specific regions and specific times of harvesting during the period May-September. In the Swedish recommendations, reference is made to the legislation for separate handling of larger amounts of coarser and finer material (Egnell et al. 1998, National Board of Forestry 2002, Skogsstyrelsen 2001). Otherwise, the coarser wood residues should, if possible, be covered with finer fractions. It is recommended that stacks of slash are positioned at least 50 m from the forest edge.

Finland: The ministry can make regulations for wood of smaller dimensions compared to timber (Anonymous 1991).

Norway: The forest owner is responsible that logging residues are treated in way so that risk of damages by insects does not arise. If the forest owner is warned about risks of swarming by pest insect, he should removed all coarse wood, including tops, from the forests, or otherwise make the material unsuitable for breeding by pest insects (Anonymous 2006).

Latvia: There are detailed regulations for storage of harvesting residues in stacks (Anonymous 2004a): 1) minimum height × width should be 3 × 4 m, 2) coarse residues >15 cm should be covered with at least a 0.5 m thick layer of smaller dimension residues, 3) if more than 30% of the stand is spruce and the cutting is done from 15 April-15 June, the stacking must be start no later than 2 weeks after cutting, 4) heaps should be removed from the forest no later than one year after cutting, 5) heaps should not be placed closer than 30 m from coniferous stands, except if there is a road between the heap and the stand, and 6) if more than 30% of the harvesting residues are spruce, heaps can't be placed closer than 50 m from spruce stands older than 50 years.

Estonia: It is generally not allowed to leave logging residues spread in the forest (Anonymous 1999). If not used for strengthening of skidding roads, they should be forwarded to piles or windrows for decomposition, burned, chopped and spread, or removed. Burning is restricted to mineral soils after heavy rain or during periods where the forests are otherwise inflammable. On certain nutrient poor site types, the residues must not be removed. In general, piles and windrow must be designed to cover less than 20% of the areas left for reforestation. Undried and unbarked coniferious wood is not allowed in the forest, unless: a) topdiameter <8 cm and length <2 m., b) the wood is covered with plastic film, or c) the trees are trap trees.

Denmark: There is no legislation on forest protection against insects. However, Billeschou (1983) and Billeschou & Klitgaard (1985) recommend paying special attention to coniferous stands in dry years, where storage periods should be as short as possible. Otherwise advice on the timing of felling and forest fuel extraction in relation to swarming times is given (Pedersen & Hald 1996, Ravn & Lisborg 2004).

Lithuania: Instructions on forest sanitary protection do not consider storage of logging residues or finer fractions (Anonymous 2004b).

7.2.7 Harvesting damages

In relation to forest fuel extraction, the number of operations involving machine traffic is increased compared to stem harvesting, especially if wood ash spreading is also performed. Machine traffic in the forest may generally cause damage to the soil (including soil erosion), living trees, brooks, paths, dead wood and other valuable habitats. The influence of forest fuel harvesting and wood ash recycling on fungal diseases has not been debated much, but in Finland in particular, stump harvesting is recommended as a measure against future root rot infection (Koistinen & Äijälä 2005).

Normally, the residues after regeneration are used as support for the forest machinery to diminish soil physical changes, as increased soil compaction has a negative influence on the soil water, air, and heat balance, the extent and duration of root growth is reduced, and processes controlled by soil fauna and flora are affected (Burger 2002). Damage to living trees occurs if machines or loaded material hit the stems of standing trees or compress their roots (Koistinen & Äijälä 2005, National Board of Forestry 2002). Formation of driving tracks or worn trails can cause eroded material to be led into water courses, especially in high rainfall areas (British Biogen 1999, Skogsstyrelsen 2001), and paths, dead wood, standing or lying conservation trees can be damaged simply by driving over or removing them with the forest fuel (Skogsstyrelsen 2001). Suggested measures to avoid damage, especially to soil, tree roots, water courses, and paths, comprise:

- Consider site constraints at an early stage
- Choice of best possible technology
- Confining operations to periods when the carrying capacity of the soil is highest
- Leaving a part of the residues to increase soil carrying capacity
- Restrictions on movements in the landscape, terrain, and stand
- Use of specialized equipment

As an overall measure, it is suggested that negative environmental effects of machine operations can be minimized by *considering the site constraints* on harvesting at an early stage (British Biogen 1999), and especially for prevention of soil erosion, Burger (2002) suggests the development of codes of practice for specific sites and regions.

The Swedish national recommendations state that the *technique* used for forest fuel extraction and compensation fertilisation should be chosen to minimize negative effects on soil and trees (National Board of Forestry, 2002). Planning of forwarding trails is emphasized to avoid damage, and Koistinen & Äijälä (2005) mention that the stand should be left in a good silvicultural condition with an even spatial distribution of trees. It is furthermore mentioned by British Biogen (1999) that in wet conditions, wide-tyred or tracked vehicles may be used in conjunction with brash mats. Otherwise, specifications for best possible technology and harvesting methods are scarce. In general, the same base machines are used for the extraction of forest energy as are used for roundwood, and often the choice is determined by availability and economy.

Recommendations generally stress the *timing* of the operation and *use of brash mats* to increase soil carrying capacity. Especially for soft soils with low carrying capacity, it is important that operations take place during frosty periods in the winter or when the soils are dry in the summer (Burger 2002, Koistinen & Äijälä 2005, National Board of Forestry 2002, Skogsstyrelsen 2001). If operations take place when the soil is soft, the use of residues as brash mats becomes increasingly important, but it should also be considered to completely avoid the removal of residues in terrain parts with low soil carrying capacity (Koistinen & Äijälä 2005). Reinforcements should anyhow be removed again if they have a negative effect on ditches or water protection (Koistinen & Äijälä 2005).

Skogsstyrelsen (2001) recommend that *driving near water courses* should be avoided, and the *driving direction* should follow the height curves of the terrain to avoid downward transportation of water and eroded material. Brooks and paths should be passed at a right angle, and, if possible, bridges and other protection should be constructed for passage. To avoid *damage to living edge trees* beside the main track, Koistinen & Äijälä (2005) recommend that loading is performed carefully with no larger branch or stem pieces sticking out. Finally Skogsstyrelsen (2001) warn against driving over lying or standing dead wood, high stumps, living trees and bushes that have been left for nature or culture conservation purposes.

7.3 Silvicultural aspects

Various silvicultural aspects of forest fuel harvesting are mentioned in existing recommendations and guidelines. The topics are for example selection of stands for forest fuel harvesting, integration with traditional forest management, and various indirect effects on other silvicultural measures (Anderson et al. 2002, Asikainen et al. 2002, Egnell et al. 2007, Koistinen & Äijälä 2005, Röser et al. 2006). Below, the silvicultural implications when extracting whole-trees in early thinnings, logging residues at clear-cuts, or stumps are considered together with storage of the material.

7.3.1 Woodfuel from early thinnings

Thinnings are important silvicultural actions during the whole forest rotation. Woodfuel harvesting from young forest is usually a thinning operation which can be carried out as separate woodfuel harvesting or as combined woodfuel and roundwood (pulp- and logwood) harvesting, depending on the available wood markets. The aim of the woodfuel harvesting, as well as thinnings in general, is to steer future growth of the trees which have the best quality and growth potential (Fredriksson 2004).

If the stand's early development phases are neglected, i.e. plantations are not cleaned, the growing stock is too dense or the accumulation of commercial roundwood is insignificant, a woodfuel harvesting can be carried out before the first commercial harvesting. Consequently, the first roundwood harvesting could be done later when the accumulation of wood is higher. Woodfuel harvesting can increase the economic profit from young forests. A well managed stand can produce up to a 10% better economical profit compared to a stand which has been unmanaged before the first commercial thinning due the increased accumulation of roundwood for sawlogs (Hynynen & Ahtikoski 2004).

Woodfuel harvesting from the young forest can be done either motor-manually or mechanically. In order to make the harvester-based logging economically profitable, the stem size has to be large enough. The mean size of the stems should be between 20-30 dm^3 and the dominant height of the stand should be more than 10 m.

From an ecological point of view, practically all forest stands managed for commercial purposes are suitable for woodfuel thinning, if it is carried out as delimbed stems, and branches and stem tops are left in the stand. However, if whole-tree harvesting is applied, it is usually recommended to avoid certain site types or stands due to concern for site fertility and nutrients (Infobox 7.1). Finally, the increased logging damage risk for the remaining trees has to be considered and should be minimized (cf. Chapter 7.2.7)

7.3.2 Logging residues from forest regeneration

Logging residues which can be collected from regenerated stands are another important source of energy wood. Logging residues are a by-product of the normal harvesting operation for roundwood, and should be already piled in the stand by the harvester when it is delimbing stems. A forwarder then collects the loose residues to the roadside storage for chipping and transportation. Another option is to bundle the logging residues in the stand using a bundling machine. The bundles can then be transported to the roadside storage using conventional forwarders.

The collection of logging residues from the regenerated site has multiple effects on various silvicultural operations. The most positive effect can be seen in the cost and quality of forest regeneration. The collection of logging residues improves the quality of soil preparation for all work methods applied. However, productivity is increased the most when excavator based soil preparation is used. The increase of productivity can be about 15-20%. The costs of manual and machine based planting are also decreased (Saksa et al. 2002). The speed of spot mounding with an excavator is also improved when logging residues are removed from the site. Other associated benefits are that planting of the regenerated site is easier and the survival rate of seedlings is improved (Harstela 2004). When planting birch and spruce the quality of the saplings benefit from logging residue removal. Finally, nutrient leaching from the stand after regeneration is decreased.

Adverse effects due to the increased removal of nutrients, particularly in spruce, have to be taken into consideration, especially when the residues are removed right after the felling operation. In addition, the thickness of the humus layer is also decreased (cf. Chapter 7.2.) As a result, the growth of the stand can be reduced. However, the total economic effect of logging residue collection is estimated to be positive despite the growth reduction (Harstela 2004).

7.3.3 Stump harvesting

Stump removal can be applied at sites where logging residues have been collected. After lifting the stumps from the ground they should be left in the stand in order to dry and to wash away impurities such as stones or soil material. After the drying period stumps will be forwarded and transported for crushing to a terminal or the heating facility.

The removal of stumps also has an effect on silvicultural operations. The cost of soil preparation and planting are reduced when stumps are removed from the site. Nonetheless, when stumps are removed natural regeneration increases which also increases the need for plantation cleaning later on (Egnell & Dahlberg 2007, Koistinen & Äijälä 2005).

The prevention of the spread of root rot (*Heterobasidium annosum*) is seen as one of the most positive effects of stump harvesting (Egnell & Dahlberg 2007, Lipponen 2002). Damage caused by the pine weevil (*Hylobius abietis)* may also decrease (Chapter 5, Egnell & Dahlberg 2007). As with removal of biomass from thinnings and logging residues, stump harvesting decreases the amount of nutrients and organic soil from the forest site, and may lead to increased mineralisation and leaching (Högbom et al. 2007). As with logging residues the total economic effect of stump removal is, however, estimated to be positive (Harstela 2004).

When harvesting stumps, unnecessary exposure of soil should be avoided. The soil raised when stumps are lifted should be shaken off the stump and holes of more than 30 cm (from the bottom of the humus layer) should be prevented due to silvicultural and mainly environmental reasons. If a soil preparation is carried out, the necessary quantity of planting spots should also be placed in areas from where stumps have been removed (Koistinen & Äijälä 2005).

7.3.4 Storage

Proper storage of woodfuel will benefit both the chipping and transportation of the material. The storage place should be flat and well bearing terrain. Furthermore, the storage place should be in a windy location and free from rocks, stumps and trees, and away from electricity and phone lines. There has to be sufficient space for chipping and loading of the transport trucks in the storage area. The woodfuel piles should be high in order to keep the area exposed to rain as little as possible, and, in addition, the pile should be covered (Figure 7.1, Fredriksson 2004). If the pile contains a substantial amount of large diameter softwood, it has to be removed in time to avoid damage caused by bark beetles, cf. 7.2.6.

Figure 7.1. Picture of paper covered pile in Eastern Finland. Photo: D. Röser.

7.4 Costs, technical, and logistic aspects

The analysis of technical and logistic solutions in forest fuel harvesting, and the effects on productivity and related costs, is essential for profitability. It can be used to evaluate the economic impacts of recommendations that are based on ensuring the ecologically sustainable production of biomass. For example, the costs of replacing the removed nutrients by ash or other fertilizers can be compared with the costs of minimizing the nutrient removal at the harvesting stage. With special focus on the impacts of ecological constraints on harvesting costs, the factors influencing costs related to forest fuel harvesting are briefly reviewed.

7.4.1 Existing recommendations and guidelines

Information on costs, technical and logistic aspects in harvesting and wood ash recycling is scarce in existing recommendations and guidelines (Table 7.2). The given information most often relates to harvesting damage, cf. 7.2.7. The need for careful planning is emphasised, and a wish is expressed for technological improvement of productivity and lowering of costs in both harvesting and compensation fertilisation, and for minimisation of adverse environmental effects (Burger 2002, Hakkila 2002, National Board of Forestry 2002). Suggestions for limiting adverse environmental effects include controlling loss of nutrients and minimizing ground compaction. Selective harvesting of biomass components might also be desirable depending on the customer's raw material requirements. For instance, in small boilers only the stem can be used as raw material for chips, whereas big fluidised bed boilers can use also branches, needles and even stumps and coarse roots. The general technical and logistic aspects of forest fuel harvesting and implications for productivity and costs have been more comprehensively reviewed by Asikainen et al. (2002) and Anderson et al. (2002).

7.4.2 Harvesting of forest fuel - overview of cost factors

Estimation of the impacts of different forest energy harvesting options on costs of operations has to be done at all stages of the supply chain. Finally, the costs at each stage are summarized and the total impact on the cost of chips or energy content delivered to the user can be estimated. The main factors determining the cost level comprise:

- Accessibility of the stand
- Density and amount of the harvestable fuel in piles on the single site and in the local area (incl. influence of pre-drying)
- Forwarding distances to the landing, and distance to the nearest plant
- The quality of the fuel
- Storage of harvested material to buffer demand, and
- Harvesting methods and technology

Many of these factors are inherently interlinked.

7.4.3 Accessibility

Preconditions for energy harvesting are the accessibility of the stand and also suitable terrain conditions within the stand. The soil bearing capacity must allow the use of harvesting machinery. In some cases in final fellings, residues must be placed on the trails to enable the moving of machinery on soft soils (Wood et al. 2003). In such cases their recovery for energy can not be performed, because the residuals become contaminated by soil (sand, stones etc.). In general, consideration of ecological constraints does not affect the accessibility of stands. It may, however, leave part of the stands outside the harvesting operations.

7.4.4 Density, amount of harvestable fuel, and forwarding distance

All biomass components of a tree can in principle be utilised as a fuel. In practice, the finer root system can not be harvested, but all other parts of a tree have been used for energy production. Selective harvesting of biomass components is technically possible, and may have either positive or negative impacts on the productivity and costs of harvesting. Nutrient losses can be reduced by leaving the most nutrient rich parts of trees on the site. This can be done either by seasoning the trees or by cutting part of the crown or branches and leaving them outside harvesting.

From the operational and economic point of view, optimal stands for forest fuel harvesting have a high density (m^3 ha^{-1}) of harvestable biomass and are located near forest roads. In addition, the total volume that can be harvested from the site should exceed 50 solid m^3.

Practical guidelines for stand selection suggest that a suitable final felling stand is spruce dominated and the volume of the harvested roundwood has to exceed 250 m^3, which corresponds to 120-180 m^3 (loose) of logging residue chips. Also, the forwarding distance should be less than 500 m and the distance to the nearest plant should not exceed 100 km. In addition, a chip truck must have enough room for turning at the landing. In young stands the stem volume should be at least 20-30 dm^3 $stem^{-1}$ and the dominant height of the trees should be over 10 m. In addition, the under-story should not prevent mechanised cutting (Fredriksson 2004).

Seasoning of spruce logging residues reduces the productivity of a slash bundler and chipper significantly (Asikainen et al. 2001). In young pine stands, leaving the top of the crown in the forest diminishes the productivity of a feller buncher by 30-50%. Also, delimbing of trees diminishes the productivity in felling by about 25% (Heikkilä et al 2005). The total amount of wood fuel to be recovered per site affects the need to move machinery from site to site. It has been estimated that the moving costs of a machine are 0.8-1 € m^{-3} for roundwood (Väätäinen et al. 2006). The less material is harvested on each site, the higher are the moving costs per m^3. On the other hand, seasoning of the material improves the heating value of biomass and the total effect on the costs/energy unit can be positive.

In a case study of tree sections, the value of the wood material increased by 12% during storage. This could be greater, but storage can also cause considerable losses of raw material (Brunberg et al. 1998). For instance, storage of spruce material can lead to 20-30% losses due to defoliation (Thörnqvist, 1984). As a result, the recovery rate diminishes. Thus, the radius of the procurement area increases, raising the cost of trucking. In addition, the loading time for forwarders or off-road chippers may increase due to the lower density per area unit of the material (Kärhä 1994).

7.4.5 Quality of chips

The higher the quality of the chips, the higher is usually also the harvesting cost. Moisture content and particle size distribution are the most important variables describing the quality of chips. The quality is higher with lower moisture content and more even size distribution. In addition, the amount of sand, metal and other contamination, as reflected in the ash contents, should be minimized. Ash contents are also affected by the amount of minerals in the biomass. The moisture content can be reduced by seasoning the material. Seasoning also contributes to reducing the nutrient losses and ash contents. In general, the production of high quality chips diminishes the flow of nutrients out of the stand. Chips made of delimbed trees have the lowest moisture content, even particle size distribution, a low level of contamination, and the nutrient removals are lowest. The logging cost of delimbed trees is higher than that of whole trees (Heikkilä et al. 2005). On the other hand, chips made of delimbed trees can be used by small district heating plants which usually pay a higher price for the chips.

The quality of chips made of logging residues can be improved by stacking and seasoning them at site prior to harvesting. Stacking the material before forwarding reduces the risk of mixing of soil in the residues when they are loaded by a forwarder. The negative environmental effect is the possible rut formation on softer soils as residues are not on the trails where machines are driving, cf. 7.2.7.

7.4.6 Storage of harvested material to buffer demand

A problem in the forest energy chain is that supply and demand of raw material varies over time (Andersson et al 2002). In Nordic and Baltic conditions, forest biomass must be stored for several months, because it is mainly used in the winter, when energy is needed in space heating. There must be enough room for storage of the material at the roadside. This can be a problem in the case of small private forest holdings, especially when both roundwood and slashes are forwarded simultaneously to the roadside. If the storage area is very small, systems based on compaction of forest residues into bales or in-woods-chipping can be used to reduce the volume of stored material. Minimizing of insect pest risks would, however, suggest the removal of the material from the vicinity of living forest as soon as possible, or at least before the insects reproduce in the pile. This would mean increased storage at the plants. The cost effects of changing of storage place have not been studied, but often there is not enough storage space at the plants to enable large scale storage.

7.4.7 Harvesting methods

Different harvesting methods react differently to work-site factors. For instance, off-road transport of unchipped residues with a forwarder is less sensitive to terrain conditions than chipping and transport of chips using a chip harvester. The mobility of vehicles must be considered when machinery is selected for a specific site. Rut formation in the forest soil can be avoided by timing the harvesting to seasons when the bearability of soil is high, e.g. in winter and in dry periods in the summer.

Harvesting of forest energy has been found to be challenging, especially in the young, dense stands. Harvesting damage to the remaining trees can be minimized by training of the operators and careful planning of the harvesting. Working in daylight in the most difficult stands improves the visibility and reduces the amount of harvesting damage. Planning of work beforehand and use of suitable technology minimises the damage, and ensures the high quality of fuel delivered to customers.

7.5 Economic aspects

Many economic aspects of forest fuel harvesting apply more to political and aggregate levels than to the forest owner level, e.g. competitiveness, green taxes and subsidies, and transactions costs (cf. Chapter 8). However, the profitability of forest fuel harvesting is decisive for the forest owner, and the economic value of the production depends on the balance between production costs, income, savings, and expected future income (see also Chapter 9).

The value of forest fuels for the forest owner can be estimated e.g. from production costs, extraction cost, future income or loss of income, avoidance of future costs, market prices, and subsidies. The growing costs have been, up to now, considered to be non-existent as all costs are assigned to roundwood and the energy fraction is considered as a by product of conventional forestry. For estimation of harvesting and delivery costs, hourly cost estimation of the machines must be based on actual costs of all cost elements. The costs of labour, machine investment, fuel, oils and machine maintenance have all to be included. The cost of each step in the supply chain must be estimated separately based on the actual output of the machine (tonnes hour^{-1}, m^3 hour^{-1} or MWh hour^{-1}). Finally, the unit costs of biomass can be estimated by dividing the output by costs of machine hours at each step of the supply chain.

The most important economic constraints for the bioenergy value chain are set by the prices of products (heat, electricity and liquid fuels) on the energy market produced from other sources of energy. Furthermore, bioenergy production has to compete with other uses of biomass. Small diameter trees can be partly used for pulp or particle board production and their pricing when used for energy purposes approaches the market prices of pulpwood. In the case of logging residues and stumps, no other uses for the material are available at present. CO_2 emission trading has increased the competitiveness of woody biomass. The forest and energy industries have started to pay stumpage price for all energy assortments and as the price of energy on world markets has been increasing, the prices of forest fuels have been rising, too (Asikainen 2007).

Governmental subsidies increase the profitability of forest energy harvesting. For example, in Finland subsidies are given to encourage cleaning and early thinnings, and furthermore to produce energy from the extracted wood. However, the purpose of this subsidy is rather to secure the future growth of the logwood than to encourage harvesting of energy wood.

7.6 Social and health aspects

As for many economic aspects, many social aspects apply more to political and aggregate levels rather than to the forest owner level, e.g. employment impacts, security of supplies, and public health (cf. Chapter 8). However, when pre-dried trees or residues are chipped, or when wood chips are stored for longer periods and thereafter moved, it might cause working environment problems (Anderson et al. 2002, Centre for Biomass Technology 2002, Poulsen et al. 2006). Depending on moisture conditions, chemical composition, particle size distribution, stacking height and compression, microorganisms such as bacteria and fungi can develop quickly in stored material. When chipped or moved, dust and microorganisms are whirled up into the air. Depending on the exposure time and concentrations, inhalation might cause health hazards such as irritation of the respiratory system, head-aches and general tiredness, allergy, asthma, or lung diseases. Measures to prevent health problems include filter systems in cabins of chipping machinery, or in the case of short-term exposure, air purifying respirators. Generally, there are less mould fungi in the winter and therefore less risk of exposure during chipping, loading, or unloading.

7.7 Landscape, archaeology, culture, non-wood goods

Harvesting of forest fuel can have an impact on landscape values. Nisbet et al. (1997) write that “whole-tree harvesting can provide both positive and negative effects on the landscape compared to conventional harvesting. The cleaner site and faster rate of revegetation reduce the visual impact of the felled site, but worn extraction routes and roadside brash stores can be very unsightly”. Investigations also show that impressions after removal of logging residues are usually positive while impressions after removal of stumps are negative (Egnell 2007).

It might be reasonable to abandon forest fuel extraction completely because of aesthetics. As such, British Biogen (1999) encourage consideration or protection of “landscapes designated as requiring special consideration, including National Parks, Areas of

Outstanding Natural Beauty (AONBs) and various county-level designations". This applies also to sites of archaeological interest that have "survived in a variety of forms, including earthworks, ruined structures and historic landscapes". For example stump harvesting should be avoided near valuable natural and cultural places (Egnell 2007).

Investigations also show that removal of logging residues and stumps may reduce the production of berries on clear-cuts considerably (Egnell & Dahlberg 2007). Reasons for these issues having only received little attention in existing recommendations and guidelines might be unawareness, or that such sites are already adequately protected, that precautions to be taken are common for all forest management operations, or that it is of minor concern for authorities, business, NGOs, the general public, and the local population.

7.8 Benefit and drawback trade-offs

Several trade-offs usually occur between different ecological, economic, and social criteria for sustainable forest fuel harvesting and wood ash recycling at different levels, and balancing them against each other is performed by the market or by different state governance means such as legislation, or forest certification, or by the forest owner. For example, compensation fertilisation, pre-drying, and storage should be performed in agreement with legislation and forest certification standards if relevant.

From the forest owner's point of view, some issues that might need prioritizing are shown in Table 7.4. The major trade-offs are balancing the economic efficiency of the operation, silvicultural and forest sanitary aspects against the wish to leave part of the material behind for the benefit of site fertility, future yield, biodiversity, and strengthening of skid roads against soil compaction and rut formation. The forest owner ideally resolves the balancing of advantages and disadvantages in a qualified decision making process, where the trade-offs are weighed against each other by their economic importance or according to other forest owner preferences (see also Chapter 9).

Table 7.4. Some of the possible forest owners' trade-offs in sustainable forest fuel harvesting.

Operation	Pro's	Con's
Forest energy harvesting as whole-trees from thinnings	- Income from otherwise non-commercial operation - Increased quality and income of future logwood	- Low profitability of the operation - Increased nutrient and organic matter removals - Less dead wood for dead-wood-living organisms
Harvesting of logging residues	- Income from otherwise unutilised raw material - Savings in soil preparation - Savings in planting - Reduced leaching - Aesthetics - Reduced breeding material for insect pests	- Increased nutrient and organic matter removals - Less dead wood for dead-wood-living organisms - Less berries on the clear-cut
Stump harvesting	- Income from otherwise unutilised raw material - Control of root rot - Reduced risk of pine weevil attacks - Savings in soil preparation - Savings in planting	- Increased nutrient and organic matter removals - Less dead wood for dead-wood-living organisms - Increased decomposition and leaching - Aesthetics - Less berries on the clear-cut
Pre-drying or leaving part of the harvestable material behind	- Reduction of nutrient removals - Protection against soil damages as compaction and rut formation - Improved wood chip quality and possibly higher income - The drying material might act as trap tree for pest insects	- Higher costs per harvested m^3 - The drying material might act as trap tree for rare species - The drying material might act as breeding substrate for pest insects
Limiting harvesting to certain seasons	- Protection of soil due to low carrying capacity - Avoiding adverse effects for dead-wood living organisms or of pest insects	- Reduced return of harvesting machinery investments
Road side storage to buffer demands	- The drying material might act as trap tree for pest insects	- The drying material might act as trap tree for rare species - The drying material might act as breeding substrate for pest insects
Wood ash recycling	- Nutrient removals are to some extent compensated - Counteracting acidification of soil and adjacent waters	- Increased costs with no short-term effects on income - Adverse impact on the ecosystem if the ash is not hardened
Hardening of wood ash	- Slower release of nutrients - Lower impact on the ecosystem	- Increased costs

7.9 Conclusions

A large amount of research literature exists, especially on ecological consequences of forest fuel harvesting and wood ash recycling. Economic, technical, social, institutional, and participatory aspects have also been treated. Such information constitutes the backbone of recommendations and guidelines elaborated by different parties. Synthesis information on the issue is also being provided by internet homepages and emerging computer models. However, the amount of available information varies greatly among countries, as does the progress of subsequent dissemination activities. The extent to which forest fuels are harvested also vary, and proposed systems or services for wood ash recycling have not yet been established in any country.

The topics treated and criteria given for sustainable forest fuel extraction and wood ash recycling reflect the values of the authors or authorities that issued them. Those not already part of the framework setting (e.g. legislation) is left for decision making by forest owners. Tools have not yet been designed to support the balancing of values and trade-offs in forest fuel harvesting and wood ash cycling, but if the present development in use of forest fuels continues, the work to ensure national and international consensus with regard to what can be considered sustainable forest biomass extraction and wood ash recycling must also continue at all levels.

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Chapter 8

POLICY AND ECONOMIC ASPECTS OF FOREST ENERGY UTILISATION

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8.1 Introduction

Bioenergy projects must be economically viable for the different actors in the value chain. Forest biomass used for energy purposes must be able to compete with other uses of the biomass, and at the same time the energy produced from biomass must be as cheap as or cheaper than energy produced from competing energy systems. The costs in these calculations are changing all the time; in particular the cost of fossil fuels shows large variations. As the risk is high and the economic margins in many cases are low, there is a tendency that investors are reluctant to invest in bioenergy projects. On the other hand, prices of wood based fuels have been rising modestly compared with e.g. oil and gas, which reduces the economic risk when investing in a

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bioenergy project (Metla 2006, Kåberger 1997). In addition, there are many socioeconomic benefits to bioenergy projects that in many cases are not accounted for in the market prices, which is a strong argument for economic support of bionenergy projects.

Bioenergy projects contribute to many important elements of national and regional economic development: economic growth through production and business expansion (earnings), employment, import substitution (direct and indirect on the trade balance), security and diversificaton of energy supply (distributed energy) (see e.g. Hillring 2002). Other benefits include strengthening of traditional industries and rural communities (Borsboom et al. 2002).

The forest-based industry provides a very effective platform for the generation of energy in combination with the production of fibres and 'green' chemicals. There is, as part of this, an emerging bio-refinery concept, which foresees a new balance in the use of wood for lumber, pulp, green chemicals, liquid biofuels, and green energy. In this context, the sector has the potential to deliver increased amounts of energy as a by-product of industrial processing, and for wider use than just as a source of local heat. Therefore the forest-based sector will play an even more prominent role in supplying much-needed renewable energy to Europe, especially important in view of the EU's ambitious targets for promoting green energy resources in the region.

Economic studies can contribute to the understanding of many of the above mentioned aspects. Modelling and understanding of how markets for forest energy work will lead to insights about possible increased use of biomass for energy purposes. The supply, both at individual and aggregate level, depends on factors like operational costs and transport costs, prices of biomass for industrial purposes and public policy. The demand depends on the income level, quality differences between the energy systems and prices of competing energy systems. Utilisation of biomass for energy purposes has environmental consequenses and to study how these effects can be internalized is an important task. Impacts on regional income and employment and on socioeconomic variables such as energy security and balance of payments will vary in importance from country to country. The last point to be mentioned is the role of institutional factors in market development.

Chosen policies and their applicatons have direct and indirect impacts on the competitiveness of forest energy compared with other sources. It is important to increase the knowledge about the design of different tax and support regimes to get the desired effect. The development within the EU and the practical implementation of the relevant directives will have a decisive influence on the knowledge of how to stimulate the increased use of renewable energy in the best way. It is a challenge to evaluate how different regulations and incentives work and contribute to updated knowledge in this field.

8.2 Sustainability from an economic point of view

Sustainability is a broad topic, expressed in many different ways. In the last 15 years the concept of sustainability has become more popular and wider. The term 'sustainability' is in the title of many institutes, departments, commissions, companies, centres, movements etc. Today it is very modern to speak about sustainable projects, development and education. EU and national energy, industry and forest policies stress the sustainable use of natural resources over over time.

In the forest sector the first understanding of sustainability came in the 18th and 19th centuries in terms of sustained yield and the model of the normal forest. The World Commission on Sustainable Development report in 1987 and the United Nations Conference on Environment and Development in 1992 created the basis for the current understanding of sustainability. In many countries many political activities have been carried out to implement ideas from the above mentioned events. Several political processes have encouraged and inspired many individuals and organizations to produce their own interpretations and applications of the sustainability concept.

The classical concepts of sustainability in forestry and also those used by the Brundtland Commission define sustainability in physical terms. According to an international handbook on environmental accounting this is classified as a measure of strong sustainability

(United Nations et al. 2003). A central concept in this thinking is critical load and that there are certain critical levels for both individual species and ecosystems. Economists have been preoccupied with the possibility of substitution of natural capital with man-made capital and typically define sustainability in relation to the total stock of capital (Solow 1974, Hartwick 1977). Translated to the forest sector this means that if a forest is harvested and there is some damage to the forest which reduces the forest capital, the action can still be sustainable if this leads to an increase in other forms of capital and the sum of the change is positive. Such a definition can be called a weak definition of sustainability. If such a concept shall work, all the effects have to be valued in monetary terms. Even if environmental economics has made large progress in valuation, much still remains to be done and there are often large uncertainties in the monetary estimates. Navrud (2002) has made a review of the different definitions and controversies, and shows how bridges can be built between the natural science concept of critical load and the substitution view in economics. One way is to define lower boundariess and allow for substitution above those boundaries.

Socio-economic impact studies are commonly used to evaluate the local, regional and/or national implications of implementing particular development decisions. Typically, these implications are measured in terms of economic indices, such as employment and monetary gains, but in effect the analyses relate to a number of aspects, which include social, cultural and environmental issues. A complication lies in the fact that these latter elements are not always tractable to quantitative analysis and, therefore, have been precluded from the majority of impact assessments in the past, even though at the local level they may be very significant. Several aspects of the production and use of woody biomass must be considered in the context of sustainability (Table 8.1).

8.2.1 Sustainable production of woody biomass

Forests and woody crops are a source of energy through the conversion of woody biomass into convenient solid, liquid or gaseous fuels to provide energy for industrial, commercial or domestic use. Sustainable sources of woody biomass are those harvested from managed natural forests (stems and residues) together with by-products and wood waste from forest industry. Dedicated energy crops are another source of woody biomass for energy. Short-rotation (3-15 years) techniques for growing poplar (*Populus*) and willow (*Salix*) have been developed over the past 2-3 decades. Sustainability of natural resources combines economic, environmental, and social/cultural considerations.

Table 8.1. Socio-economic drivers in implementing bioenergy projects (IEA Bioenergy Task 29 2005).

Category	Impact	Quantitative indicators
Basic needs	Improved access to basic services	Number of families with access to energy services (cooking fuel, pumped water, electric lighting, milling etc.), quality, reliability, accessibility, cost
Income generating opportunities	Creation or displacement of jobs, livelihoods	Volume of industry and small-scale enterprise promoted, jobs/EUR invested, jobs ha^{-1} used, salaries, seasonality, accessibility to local labourers, local recycling, of revenue (through wages, local expenditures, taxes), development of markets for local farm and non-farm products
Gender	Impacts on labour, power, access to resources	Relative access to outputs of bioenergy project. Decision making responsibility both within and outside of bioenergy project. Changes to former division of labour. Access to resources relating to bioenergy activities.
Land use competition and land tenure	Changing patterns of land ownership. Altered access to common land resources. Emerging local and macro-economic competition with other land uses.	Recent ownership patterns and trends (e.g. consolidation or distribution of landholdings, privatisation, common enclosures, transferral of land rights/free rights). Price effects on alternative products. Simultaneous land use (e.g. multipurpose crop production of other outputs such as biofuel, fodder, food, animal products.

Sustainability - in relation to the use of the forest -involves ensuring that forest management and the benefits from forests derived by present generations do not compromise the opportunities for future generations to benefit in a similar fashion. Woody biomass can be a sustainable source of energy, a valuable renewable alternative to finite fossil fuels. The focus on bioenergy initiatives is to ensure the use of land for bioenergy is economically, environmentally and socially sustainable. There are environmental impacts arising from the production of biomass, having also an influence on the economic implications (Börjesson 2000). Three of the more important ones relate to site productivity, biodiversity, and greenhouse gas balances.

Site productivity

A commonly expressed environmental concern about harvesting biomass for energy is that soil nutrients, organic matter and moisture-holding capacity may be depleted by intensive harvesting methods (see also Chapter 3). Impacts on the inherent fertility of sites are a function of harvest intensity and the short rotation periods.

Nitrogen and other elements are abundant in twigs and foliage so that harvesting all above-ground biomass could theoretically remove a large portion of nutrients. In practice this does not occur since harvesting practices remove only a small portion of the branches and tops and leave sufficient biomass to conserve organic matter and nutrients. Furthermore, if nutrients are returned to the forest through ash from combustion of the residues, this ash fertilisation normally alleviates nutrient losses, possibly in combination with nitrogen fertilisation.

Production of soil relies also on careful harvesting practices to reduce physical soil disturbance and compaction or removal of organic matter layers on the soil surface. These problems can be minimized by operating when soils are dry or frozen and by avoiding repeated passes of heavy equipment.

Biodiversity

Biodiversity (see also Chapter 5) concerns arise at the species and landscape levels. Biodiversity conservation is a central issue in forest management and is a significant public policy issue. Management of natural forests emphasizes conservation of extant biodiversity, by protecting unique ecosystems and critical habitats, and balancing the vegetation structure, growth stages and forest ecosystem types over time.

It is encouraging that experience indicates that normal utilization of residues after forest operations has little negative impact on biodiversity. When energy crops are planted on agricultural land, species diversity may increase since diversity is low where single agricultural crops are grown. It is expected that concerns over the compatibility of bioenergy and biodiversity can be met by keeping biodiversity as a key factor in the forefront of production planning and management.

Greenhouse gas balance

Bioenergy systems offer significant possibilities for reducing greenhouse gas emissions when bioenergy replaces fossil fuel in energy production. The greenhouse gas balance of producing bioenergy is positive, so replacement of fossil fuel derived energy with bioenergy reduces emissions. Potentially, bioenergy systems can also enhance carbon sequestration since short-rotation forests established on former agricultural land act as carbon sinks by accumulating carbon in the vegetation and soil. Afforestation alone is a temporary carbonsink, whereas bioenergy provides long-term benefits.

The Kyoto Protocol, which came into force on 16 February 2005, is stimulating policies directed towards the limitation of green house gas emissions, particularly carbon dioxide. Bioenergy presents many opportunities for society to reduce greenhouse gas emissions through fossil fuel substitution and reversal of deforestation by afforestation.

8.2.2 Sustainable use of woody biomass

The growing diversity of uses and public expectations related to forests has led to the concept of sustainable forest management as a central purpose of adopted forest policies. Sustainable forest management is yet to be defined; however, governments and other organizations have developed *Criteria* and *Indicators* so that the range of forest activities can be assessed and their management adapted accordingly. These Criteria (values) and Indicators (measurements of values) are designed to be implemented on regional, national and international scales. *Environmental* criteria evaluate the health, productivity capacity, biodiversity, soil, and water, nutrient and carbon budgets. *Economic* criteria consider levels of employment, price of wood and other forest products, and *social* criteria include for example public participation in forest management decisions, security and health of workers and the use of forests for their spiritual and aesthetic characteristics. Since biomass for energy is a product from forests it can be monitored using Criteria and Indicators to ensure sustainability.

The development of bioenergy markets can have many positive economic benefits including:

- Creating markets for biomass wastes,
- Improving the economic viability of thinning and harvesting operations,
- Promoting new crops for farmers, especially on marginal or unused agricultural land,
- Creating employment in biomass production, harvesting, transport and conversion to useful energy, and
- Providing a saleable energy product.

The essence of *social sustainability* is how biomass production is perceived and how different societies benefit from it. In the discussion about bioenergy the benefits of rural employment and local use of energy (*distributed energy*) are often mentioned. Active regional policy with concepts such as ‘living rural areas’ is part of the discussion about land use policy. Distributed energy resources can be distinguished from centralized energy resources in several respects. Distributed energy resources are small, modular, and come in sizes that range in capacity from kilowatts to megawatts. They comprise a portfolio of technologies, both supply- and demand-side, that can be located on-site or near to the location where the energy is used. This provides the opportunity for less transport, greater local control and more efficient waste heat utilization to boost efficiency and lower emissions.

Most residue harvesting operations are conducted by contractors who might supply biomass for a small district heating plant, or who collectively supply larger plants. However, as the efficiencies of scale increase, or as integrated harvesting systems are used, fewer people tend to be employed per volume of biomass harvested.

Urban attitudes to biomass production are related to conventional forestry systems generally, and to broader concerns for the environment. Better communication needs to be encouraged to promote an awareness and understanding of biomass production and use. The examples of bioenergy applications in Helsinki, Stockholm, Vilnius and some other European cities also illustrate that bioenergy is not just about local, rural communities – it is important for cities too.

8.3 Constraints and measures of bioenergy utilisation

Over the past decade, the importance of wood as an energy source has increased considerably. The EU's target in the White Paper on Renewable Energy Sources is to increase the share of renewable energy sources in total energy production to 12%. Wood is an important part in that effort, based on the large amount of resources available in most European countries (see also chapter 2). Despite the growth of forest fuel utilization, the development has been slower than originally anticipated. The reasons for the development being slower than anticipated development are multifold, but apparently there are some basic bottlenecks that hamper further growth of wood fuel utilization.

The barriers and drivers behind successful bioenergy market growth have previously been analysed by Roos et al. (1999) and the critical factors were narrowed down to 6 issues:

1. Integration with other industries
2. Scale effects
3. Competitive market
4. Competition with other fuels/energy types
5. National policy
6. Local policy and local opinion

From an economic point of view there are three main groups of actors in the bioenergy market: households, firms and public authorities. There are different goals and different drivers behind the decisions taken by the three groups and this needs to be understood to be able to make a well functioning bioenergy policy. Incomplete information is one main reason behind market failure in the bioenergy sector. As the market matures, actors will be better informed. Another important factor is uncertainty about fuel quality; as the fuel standards improve this factor can be removed.

At present, low profits in the wood fuel sector and the resulting competitive disadvantage compared to fossil fuels are key restraints. The business is only at the beginning of development and has not yet succeeded in finding its right form in most countries. Nevertheless, there are large differences among the different countries. To further improve the situation, investments in both heat and power plants and biomass supply chains are needed, particularly in the Baltic countries. In the infant phase of the industry, subsidies are needed. If we take Austria as an example, there have been investment subsidies of up to 40% of the total investments in bioenergy systems in the last two decades (Voegel 2007). Similar data, but with lower subsidy percentages, can be found for the Nordic countries. It is evident that the forest fuel sector will offer abundant development opportunities in the future in the Nordic and Baltic region (Hansen et al. 2006). Also, a higher degree of cooperation between the forest industry and energy companies could decrease production costs and increase profits.

The supply of forest fuels is still associated with high harvesting and transportation costs, particularly in the case of whole tree harvesting in first thinnings (Laitila et al. 2004). Today, the fuel chips from first thinnings are not competitive without subsidies. Shortage of skilled entrepreneurs and a lack of harvesters suitable for harvesting of small sized trees cause low profit margins for the operations, and these problems remain major challenges for the future.

In the case of logging residues from final fellings, the situation is more favourable if no excess amounts of industrial residues are available on the market. However, the low density of the raw material remains one of the biggest challenges, and limits transport of forest fuel to a radius of about 80-100 km surrounding the end-use facility. Nevertheless, new innovative technologies, particularly for the transport of forest residues, have been developed and today there are examples of profitable harvesting and transport systems. The Baltic countries would also benefit from increased use of modern technology, since the share of mechanization in fellings is comparatively low. Due to the low labour costs prevailing in Baltic countries manual harvesting in first thinnings might also be an economically viable alternative. Nevertheless, a prerequisite for more profitable harvesting and utilization of logging residues is the mechanization of harvesting operations using modern harvesting and transport equipment. This would allow the piling of residues and forwarding would be more effective with improved quality of the material.

Forest fuels have a long history of utilization, and are commonly used in the form of chopped firewood, particularly in rural areas. Nevertheless, the large scale utilization of logging residues in the form of chips is a rather new development and there is a general lack of knowledge among forest owners, decision-makers and the general public. Misconceptions have to be overcome, and the advantages, particularly in regard to CO_2 emissions, highlighted. In addition, forest owners and forest owners' associations lack knowledge about the economic possibilities linked to the harvesting of logging residues and heat entrepreneurship.

The high degree of utilization of industrial process residues in the Nordic countries results in limited opportunities to increase energy production from industrial residues (Röser et al. 2003). Larger sawmills consume their residues very effectively and even in smaller sawmills less than 5% of the residues are not utilized. The primary focus must be on forest residues from conventional forestry and energy crops from plantations. The situation in the Baltic countries is different, where large amounts of industrial residues have no use and would be available for energy production.

A significant bottleneck in Norway is the lack of district heating networks. Norway's heating systems for private homes are largely based on electricity and wood as a fuel source and limited to small installations. In the Baltic countries almost all equipment in district heating plants was supplied from factories in the former Soviet Union, designed to operate on heavy fuel oil and natural gas, which resulted in a lack of sufficient plants to utilize wood fuels and the urgent need to modernize the current equipment. This has offered a new opportunity for the large scale introduction of forest fuels in district heating and there are already successful cases in both the industrial and district heat sectors.

Finland, in particular, has invested large sums in extensive research and development programs, where more enhanced and efficient machine technology, logistics and organizational aspects of forest fuel supply have been developed. These programs have been important tools to widen existing bottlenecks. Today there is a clear need for the delivery and extension of research results to the operational level and political reforms to support the use of wood as an energy source.

A theoretical explanation for the above mentioned differences between the countries can be found by using the concept of transaction costs from institutional economics (Bohlin 2001). Transaction costs have something to do with uncertainty/complexity, bounded rationality, few actors, opportunism and lack of trust (Williamson 1986).

Transaction costs are typically large when a new market develops and decrease as the market gets more mature. When the market develops there will be more competition in all parts of the value chain, standards are developed to secure deliverance quality and there are small risks connected with each individual transaction. Bohlin (2001) uses this theory to illustrate the growth of the Swedish biomass industry from 1980 to 2000. Figure 8.1 illustrates the main points.

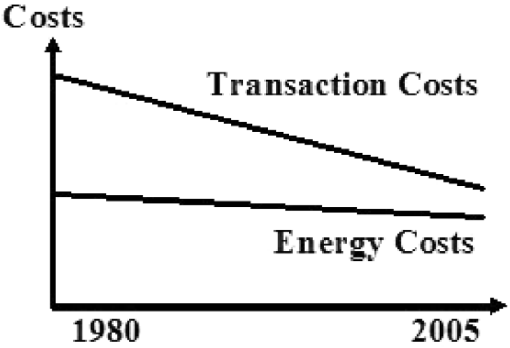

Fig. 8.1. Development of energy and transaction costs in biomass based energy production in Sweden (adapted from Bohlin 2001).

The decision-makers are not only faced with the production costs typically calculated in project appraisals. They take the total cost, including transaction costs, into consideration. This explains the fact that even if bioenergy is cheaper than fossil energyin the introductory phase, it might not be chosen because of much higher transaction costs.

The political implications of the findings are that reduction of transaction costs should be focused much more to the introductory phase of bioenergy. Development of standards will reduce uncertainty and quality differences between bioenergy and fossil fuels. Competition and professional actors, including qualified consultants, in all parts of the value chain will reduce uncertainty for the large investment needed in equipment in all parts of the chain. Investment in research and development also contributes to cost reduction and increased competitiveness. This might also lead to industrial development and export possibilities for the industry.

8.4 Supply of wood-based biomass for energy

There is a rich literature describing factors influencing the supply of timber at the individual forest owner level (Bolkesjø 2004). Price, expected price, operational cost, standing volume and size of the property are among the factors found to be significant (Kuuluvainen et al. 1996, Lönnstedt 1997, Bolkesjø 2004). For large holdings the supply does not change very much over time, but for small holdings there might be significant changes.

Socioeconomic factors other than price also matter, cf. Karppinen (2000). Much focus is given to changes in the goals of the forest owners (Hyberg & Holthausen 1989). As the economic importance of timber income decreases, a new group of forest owners increases; forest owners who focus more on environmental goals, hunting and tourism. This group of forest owners is found to have a much lower logging intensity than forest owners who live on the income from the property.

Changes in the supply of timber have in many cases a direct influence on the supply of forest fuels because many assortments of forest fuels can be considered as by-products. The amount of logging for energy purposes is for instance a direct function of logging of commercial timber. In this case the forest owner must find that the revenue from the sale of residues and reduction of silvicultural costs is larger than the environmental costs involved in the removal of the residues (Miranda & Hale 1998).

Bohlin and Roos (2002) found in a survey of forest owners in four communities in central Sweden that wood fuels had been sold from 60% of the estates. The price paid had little influence on the decision to sell; the primary reason was that the harvesting operation cleared the ground of debris. Some owners did not sell forest fuels because of fear of soil fertility losses. The findings indicated that large-scale suppliers of forest fuel have to make direct contact with forest owners and inform them about ecological and silvicultural effects to be able to increase the supply. They also found that offering ash recycling might be more effective in enhancing the supply than marginal price increases.

Energy wood has up to now been a byproduct from logging; the fiber which has no use as industrial wood is processed and sold as energy wood. In the last years there has been a development where energy wood is competing with pulpwood. In Norway there is at present (2007) no industry that uses hardwood pulpwood – almost all pulpwood of, for instance, birch is used as woodfuel, mainly firewood. The same tendency is seen for pine pulpwood in those districts with high transport costs. This development is both an opportunity and a threat for the traditional actors in the forest sector.

The bioenergy sector is currently growing rapidly at the national level in most countries. The forest industry is subject to powerful pressures to adapt. Competition is steadily increasing both within and outside the region from countries with lower raw material and production costs. Changes in the energy market have also led to substantial increases in energy costs in the industry; moreover, interest in using forest-based biomass as a source of energy is steadily increasing. The forest industry in the region faces major challenges. The way forward requires products with a higher added value such as liquid fuels from biorefineries, and the industry must play an active role within the energy sector.

A balance will have to be found between the increasing demand for forest biomass for energy production and an increasing demand for forest-based products. In this context, it should be taken into account that forest-based products can also be used to generate energy after their primary use.

The transition to large scale production and use of energy wood will demand new equipment, new logistic solutions and new buyers. For self-employed forest owners, modification of existing equipment for processing of energy wood is a natural solution. Large scale harvesting, production of bundles, pellets etc. will demand special equipment which only contractors will be able to invest in.

Similar arguments can be used for storage, marketing, sale, and distribution etc. of processed energy wood. This opens for organizations that work vertically in the value chain; there are several examples of cooperation and alliances between partners that normally do not cooperate (forest owners' cooperatives, farmers' cooperatives, district heating companies, public utilities, municipalities etc.). There are many examples in the Nordic countries in which forest owners manage and control the whole value chain from the forest to the consumption of the energy (farm entrepreneurship, 'farm energy', mostly for small and medium sized heating systems in rural communities).

Case: Privatisation of forests in the Baltic States: influence on forest fuel supply

The Baltic States form a special case as the privatisation of the forests in the last decade has led to small average sizes of the forest properties. In the Soviet time, forest management in the Baltic States was centralized and planned at the ministry level. Supply of and demand for wood based products was not based on market conditions. Restoration of independence changed not only the political but also the economic situation in Baltic States – from centralized planning to free trade. After the declarations of independence in the Baltic countries in 1990 some new phenomena emerged in Baltic forestry: the formation of a free timber market, increase of timber export, development of new modes of ownership (private forests) and enterprise (private logging companies), and the privatisation of the forest industry. The number of participants in market activities has increased very rapidly due to the privatisation process.

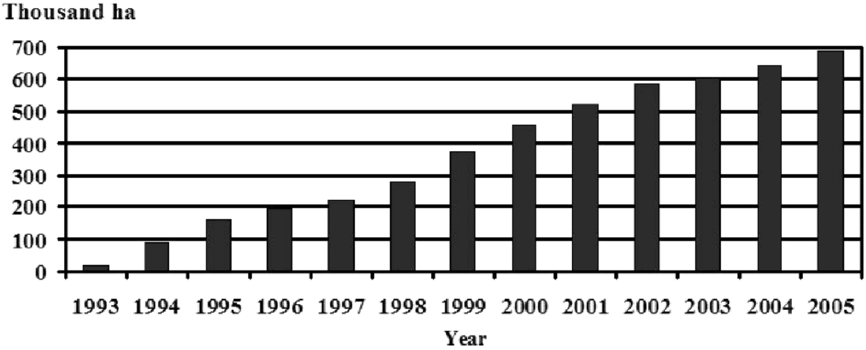

Fig. 8.2. Forest restitution in Lithuania (1993-2005) (Mizaraite 2005).

The privatization process in the Baltic States has led to fragmentation of forest properties. According to data of the Latvia State Land Service there were 148 925 private forest owners and 163 029 forest properties in May 2004. In Lithuania, the private forest sector constitutes 231 900 private forest owners and 684 451 ha of private forest (Figure 8.2).

Small-sized private forest properties have been formed in the Baltic States. The average area of a private forest holding is 4-11 ha (10.5 ha in Estonia, 7.5 ha in Latvia, 4.5 ha in Lithuania). For instance, estates with an area of up to 5 ha accounted for 74.7% of the total number of private forest holdings in Lithuania (Fig. 8.3). In Latvia 30% of all private forest properties are less than 2 ha, 47% are from 2 to 10 ha, 15% are from 10 to 20 ha, and only 8% of properties are bigger than 20 ha (Fig. 8.4). In Estonia more than 40% of

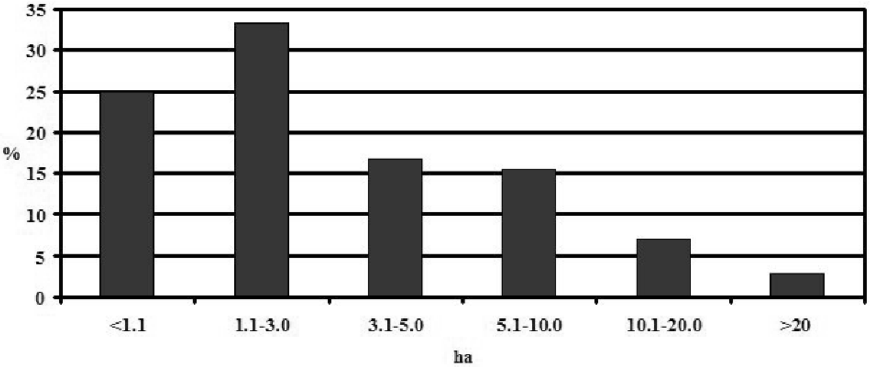

Fig. 8.3. Distribution of forest estates by size in Lithuania (January 2004) (Mizaraite 2005).

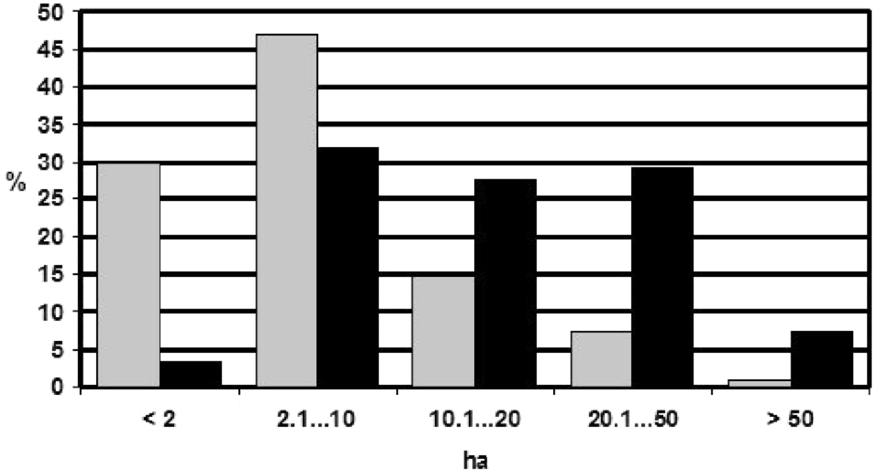

Fig. 8.4. Distribution of forest estates by size in Latvia (June 2004) (Vilkriste 2006).

owners have less than 5 ha of forest. Analysis of the data base of forest owners and properties in Latvia furthermore shows that 75% of the total number of forest owners have only one property (67% of the private forest area), 18% of owners have several forest estates (23% of the area) and 7% of owners belong to owner and estate groups (10% of the private forest area).

The supply of forest products depends not only on the characteristics of the forest property, but also on owner characteristics. During the last decade changes of private forest ownership have been influenced by changes in the demograpy (gender, age, vocation etc.) of private forest owners. According to the results of a study of private forest owners in Lithuania (Mizaraite 2005), 53% of the respondents were men and 47% women. The mean age of the respondents was 53 years. 58% of respondents lived in cities and 43% in rural areas. The average distance from respondents' place of residence to their forest estate was 39 km. Most forest owners lived 5-30 km from their forest estates. Most of the respondents had university and college level education. The largest vocational groups in the study were wage earners and pensioners. 40% of the respondents have owned forest estates for longer than 5 years, and more than 70% of the respondents own estates alone. The majority of these estates are family forest estates, while about 30% of estates are owned with co-owners.

The percentage distribution of female to male owners in Latvia is 44 to 56% with 62% of forest area belonging to male and 38% to female forest owners. The average age of forest owners in Latvia is 54 years. The information obtained during surveys testified that the overall private forest owner education level was higher than the average education level in Latvia, which is also indicated by the results from Lithuania. In Latvia approximately 70% of owners live in the region where the property is situated. The distance from place of residence to forest holding does not exceed 5 km for more than 60% of private forest owners (private forests make up 45% and other forests make up 4.3% of total forest area). The survey data testified that the socio-economic conditions for private forest owners had changed during the last years. The percentage of private forest owners families receiving income from paid employment increased from 39 to 51% (2001-2003), while the percentage of forest holdings dominated by self-subsistence economy decreased from 64 to 46%. These tendencies are partly related to an increase in overall private forest owner welfare; however, in some cases the observed differences were caused by changes in the ownership structure.

During recent years, roundwood supplies from private forests have consistently increased in the Baltic countries. For instance, the felling volume of Lithuania's private forests was over 2 million m^3 meters in 2002 and 2.7 million m^3 in 2003. This is 42% of the total roundwood supply in Lithuania. In Latvia the volume felled in non-state forests was 6.7 million m^3 meters in 2001 and 7.4 million m^3 in 2002. In Estonia the rapid increase of felling volumes in the 1990s took place mainly in the private forests where it increased from 0.6 million m^3 in 1995 to 8.3 million m^3 in 2004.

In spite of increasing activities in the private forest sector, the supply of roundwood and especially woody biomass for energy can increase due to several reasons. Firstly, some areas are still not under forest management. In Lithuania during the last decade part of the forest area was reserved for restitution with utilization of these forests having been suspended. These unused forest resources have a big potential for the market in the future. In Latvia, not all estates are registered in the land book and this also means restrictions on activities.

Secondly, in Latvia only about 75% of forest owners carried out some forest related activities, and in Lithuania the survey of private forest owners' forest-related activities showed that the corresponding figure was only 68%. Thirdly, the situation for potential supply of biofuel changed a lot after the storm in 2005. In Latvia the storm damaged 7.3 million m^3 of wood and in Lithuania 0.8 million m^3. This led to disturbances in the timber market.

Logging residues also have a considerable unused potential. The Latvian State Forest Service evaluated the use of harvesting residues in 2002. According to this expert-opinion-based survey, 74% of the residues stayed in the forest, 7% were collected as firewood and 19% were burned in the forest. Today the demand for wood chips and woodfuel is increasing, but still the demand is well below the potential supply.

At the moment the supply of woodfuel from the private forest sector is very low. One of the explanations is that the properties are too small and in this situation costs will exceed income. The only way to improve the situation is to increase cooperation among forest owners. This has to some extent taken place in Lithuania. The consolidation and cooperation of private forest owners is increasing year by year. For instance, the Forest Owners Association of Lithuania (FOAL) supports the development of networks of forest owners' cooperatives and other private forestry-related companies. FOAL group companies became the biggest supplier in the private forest sector and one of the biggest in the roundwood market in Lithuania. During 2003, FOAL group companies' roundwood sales reached 0.25 million m^3 (10% of the roundwood supply from private forests). This comprised 30% softwood logs, 25% hardwood logs, 30% pulpwood and 15% woodfuel. In 2004 the roundwood sales of the FOAL group companies was over 1 million m^3 or 15-20% of the total roundwood supply to the market. These consolidation and cooperation processes will have a crucial impact on roundwood supply from the private forest sector and the roundwood market, and create an advantageous situation for biofuel market development.

Household consumption has very close links to factors which have an effect on the supply of biofuel. In the Baltic countries the woodfuel market of the household sector decreased because due to the privatization process a lot of owners have the possibility to collect firewood from their own estate. For example, in Latvia survey results show 78% of private forest owners collected firewood in the last years, on average 26 m^3 yr^{-1} (Vilkriste 2003). Only 12% of the private forest owners mentioned that they get income from firewood selling. The average amount collected was 58 m^3 yr^{-1} for this group. Data from the Latvian Statistical Bureau (2001) shows that on average firewood was used in 328 272 dwellings and approximately 1 million m^3 of this fuelwood were prepared by households.

According to the data of Statistics Lithuania the production of firewood and wood waste reached 3.4 m^3 in 2003. Home consumption was about 2.3 m^3. In state forest enterprises firewood production was 0.5 m^3 in 2003. Official statistics of firewood production in the private forestry sector are not available. However, the survey of private forest owners' ownership objectives in Lithuania

Table 8.2. Lithuanian ownership objectives by importance (Mizaraite 2005).

	Percentage of answers					
Question	1	2	3	4	5	
"How important are each of the following forest ownership objectives for you?"	Absolutely not important	Not important	Neither/nor	Important	Very important	Not marked
Income generation from wood and non-wood products sales	17.28	5.86	10.19	6.94	38.12	21.61
Roundwood production for home consumption	17.75	5.56	10.03	8.95	35.03	22.68
Firewood production for home consumption	15.74	4.78	8.95	8.33	45.53	16.67
Recreational use	43.98	6.02	6.33	2.62	8.33	32.72
Forest holding use for hunting purposes	50.00	3.55	5.25	2.47	5.70	33.03
Non-wood products use for home consumption	25.00	7.10	10.65	8.95	23.61	24.69
Protection of wildlife habitat	19.45	7.10	9.88	8.33	27.62	27.62

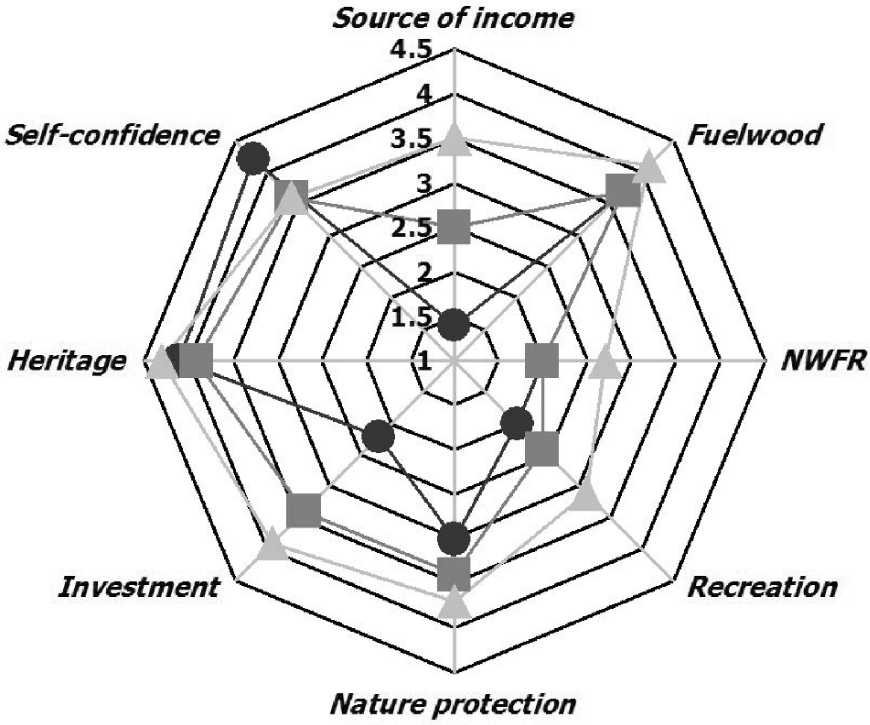

Fig. 8.5. Evaluation of aspects of forest utilization using a 5-point scale. Circles represent private forest owners in 2001, squares represent private forest owners in 2003 and triangles active private forest owners in 2003 (Vilkriste 2006).

showed that the most important objectives for forest ownership were to provide themselves with timber (firewood and roundwood) for their own purposes and for income generation from wood and non-wood products sales. In the survey all ownership objectives were marked using a five-level scale, where 1 corresponds to “absolutely not important”, 2 to “not important”, 3 to “neither/nor”, 4 to “important” and 5 to “very important”. The distribution of answers of 648 respondent private forest owners is shown in Table 8.2.

In Latvia private forest owners’ objectives are relatively similar with the importance of fuel in comparison with other forest benefits is stable and relatively high (Fig. 8.5). Every fifth private forest owner mentioned the possibility to get fuelwood as one of the reasons for obtaining property.

Generally, private forest owners are legally independent with regard to forest management planning. Research results (see e.g. Karppinen 2000) demonstrate that private forest owners have multipurpose targets for forest management, but in the Baltic countries one of the most important activities is firewood collection. Forecasts and calculations of the potential supply of wood-based biomass for energy from the private forest sector are conceivable, but data on potential use are still lacking. Furthermore, information on household consumption and supply of firewood and wood based biomass from private forest properties from different information sources are sometimes very discrepant. The importance of private forest owners as stakeholders also in the bionergy market is increasing and more information and research on the private forest sector is needed for planning and developing processes to improve the use of forests as a source of energy.

8.5 The market for wood for energy

The forest-based sector in the Nordic and Baltic countries is highly export oriented and is going through a process of transformation. Global competition is increasing all the time in many segments of the present range of products. The forest as a versatile resource is attracting more and more attention. The way forward for the forest-based sector in the region lies in developing products with a higher added value, having a strong customer focus and including socio-economic elements.

The forest's role as a supplier of biomass for energy is growing in importance. The forest-based sector is particularly well placed to contribute to sustainable development. Through major technological improvements in bio-energy conversion to heat, biofuels and power, it would be possible to (1) accelerate the decrease in the share of fossil fuels used in the forest-based industrial sector, (2) significantly increase the electricity-generation efficiencies of large-scale combined heat and power (CHP) plants fired by forest-derived fuels and (3) considerably increase the amount of heat and power produced from forest biomass in small-scale industrial, communal and household plants. Accordingly, it will be crucial to secure a high-quality raw-material supply. Improved wood-supply systems and forest management models are therefore needed and links between forest owners and the industrial users of wood need to be strengthened.

The volume of biomass used for energy purposes does not only depend on how much can be supplied at different costs. Equally important is how much the consumers are willing to buy at certain prices. The demand certainly depends on the alternatives that consumers have, which in turn depend on national energy policy, basic energy infrastructure and local availability of alternative energy sources. One example is that there is now a common Nordic market for electricity. Still, there are considerable differences in the prices consumers pay for electricity. A Danish household typically pays 0.15 € kWh^{-1} whereas a Norwegian household typically pays 0.08 € kWh^{-1} for electricity. The difference is mainly due to energy taxes and historical prices. The result of this difference in policy is that in Norway electricity is the main alternative to bioenergy whereas in Denmark electricity is hardly used for heating at all due to the high price. Traditionally, biomass fuels have been used in the same geographical region in which they are produced. In more recent years, this pattern has changed in northern Europe due to large-scale use of biomass for district heating and a vast supply of recycled wood and forest residues. Sea shipments allow for bulk transports of biomass over long distances at low cost and the bioenergy trade has increased rapidly during the past ten years. This trade includes many types of wood materials and other substances, not only solid wood residues and waste. The most significant volumes of biomass are traded from the Baltic countries (Estonia, Latvia, and Lithuania) to the Nordic countries (especially to Sweden and Denmark, but also to Finland). Some pellets are also traded from Finland to other Nordic countries. The traded biomass is most often refined wood fuels (pellets and briquettes) and industrial by-products (sawdust, chips), in central Europe also wood waste. The total volumes in the international biomass trade are not known, but have been estimated to be at least 50 PJ yr^{-1}.

A model study of future pellet demand in the Nordic and Baltic countries showed strong dependency on the market price of fossil fuels. Current market prices for pellets and oil (2005 prices) did not allow for substantial increase in production due to limited availability of the cheap raw material supply (sawdust from sawmilling). Increased future pellet price will allow for substantial expansion (more than 5 times) for production in the Baltic Sea area (Moiseyev et al. 2005).

In Denmark, ambitious targets have been set up regarding the use of renewables. Biomass now accounts for nearly 10% of the total energy production. The market for wood chips and pellets is well developed and with free setting of prices. The price differences between countries make it attractive to import wood fuels from e.g. Poland, Estonia, Latvia and Lithuania (10-15% of the woody biomass used for energy is imported). The importance of chips as an energy resource has continued to increase and chip production equipment has been improved considerably in recent years, which has contributed to keeping the fuel prices at a reasonable level. Emission trading will be required for Denmark to reach the reduction targets in the Kyoto protocol and likely partners will probably be Estonia, Latvia, Lithuania, Poland and Russia. A framework for trading will be needed The future market for biomass will develop, leading to much more integration between the energy sector and the agricultural/-forestry sector.

The annual use of bioenergy in Sweden has increased from 40 TWh to 100 TWh in less than 30 years. Today bioenergy covers 25% of the total energy supply. The main users are the pulp and forestry industry, the district heating plants, detached houses and electricity production plants. The main drivers for this positive development have been the early implementation of CO_2 taxes, the increased use of black liquors in the pulp industry and the building of district heating in almost all cities. Today, more than 50% of the district heating supply is covered by biomass and the use of wood fuels has more than quadrupled since 1990.

Sweden is now a world leader in the utilisation and handling of biomass as well as in combustion equipment for small and medium sized plants. Sweden is also in the lead in refining forest residues, wood waste and by-products. The development of the pellets market is rapid. During the past few years, production has doubled. Today, there are about 40 production plants in operation and additional ones are being planned. The Swedish bioenergy market will most probably continue to increase. The use of wood pellets in the domestic and residential sector is foreseen to increase as well as the use of bioenergy for small-scale district heating systems in towns and villages. However, the prices of wood pellets and by-products from the sawmill industry will rise due to increased competitiveness from other industry branches. This may have a moderating effect on the market development.

In Norway, bioenergy is used primarily for heating purposes. Power production and biofuels for transport are so far of insignificant volumes. Norway has had access to inexpensive hydroelectric power in abundance, but the increasing need can no longer be covered by domestic production.

The use of district heating systems has been limited to areas in the larger cities. Limiting factors are a widely distributed population and the rocky landscape, which makes the building of distribution infrastructure expensive. Industrial use of heat is secured by local electrical or oil fired boilers. District heating is, however, expected to increase significantly. District heating plants are planned in many Norwegian cities and in most cases the plants will be based on energy from biofuels and waste. Central heating of apartment buildings, public buildings, institutions etc. is also becoming more and more common and will give bioenergy sources the chance to compete with electric heating.

In Finland, the Action Plan updated in 2002 has the vision of doubling utilisation of renewable energy sources by 2025, as compared to the situation in 2001, when the share was 23% of the total energy consumption. By 2010, the use of renewable energy sources should be 30% higher than in 2001. Approximatley, 90% of this increase is expected to consist of bioenergy. The main barrier to an increased use of bioenergy in Finland is the price competitiveness in relation to fossil energy sources. The main provider of wood based energy is the forest industry, which gets the wood fuels at a competitive price in connection with raw material procurement or as a by-product of wood processing. Pulp waste liquors are the largest single source of bioenergy in the country (approximately 45% of the total). The amounts of available industrial by-products are highly dependent on the production amounts in the forest industry.

A reasonable share of the forest residue resources is currently utilized, but the rate is expected to grow in step with the planned CHP plants in industry and municipalities. The use of pellets, which are particularly suited to buildings with a boiler rating from 20 to 1000 kW, is increasing. About 90% of the refined wood fuels (pellets) are exported, mainly to Denmark and Sweden. The use of non-wood crops like agricultural wastes is only beginning. The expected increase in the use of biofuels to 2010 is divided between industry's wood-based fuels (50%), fuels obtained from forests (30%), and recovered fuels (20%). In the future, Finland will attempt to make full use of the opportunities to increase the CHP production. It has been estimated that about an additional 25 small-scale CHP plants could be built in Finland (5-10 MWe). The Action Plan aims at increasing the wood based power generation capacity by 1000 MWe as compared to 1995 values.

In Estonia, the volumes of biomass available for energy production have already been taken into use. In terms of the need for new biomass for energy production projects, the supply of wood fuel has become a major problem. According to the Development Plan for Forestry the resources of wood fuel are almost used to an optimal level. The use of low quality wood is, however, fairly stable and considerable quantities of residues are left unused to the benefit of forest growth.

The Estonian production of wood pellets was estimated to be around 150000 tonnes in 2002, but this production is not expected to be extended significantly in the near future due to lack of raw material. More than 90% of the production is being exported. Due to ongoing conversions of boilers to firing of wood pellets instead of oil, an increase in the domestic use of pellets can be expected in the future. The competitiveness of pellets needs to be considered with regard to the development of the Scandinavian market.

In Latvia, the market for wood chips and pellets is well developed, with free price development. The difference between prices in the Baltic Sea Region makes it attractive to export wood fuels from Latvia. The export volumes of wood chips have increased very much during the past years and are now about 600 000 tonnes yr^{-1}. The technological development in Latvia is primarily concerned with small-scale combustion plants using locally produced biomass.

In Lithuania, an increase in the use of renewables by more than 50% is forecasted in the period 2000–2015. In Vilnius a 60 MW retrofit biomass CHP plant started in 2006 and other projects are under planning. Many questions remain, especially with regard to the development of district heating systems. Many of these systems are in need of modernisation, the infrastructure may be inefficient and the administration costs are too high. The prices for domestic renewable fuels have been rising and in some cases, and consumers tend to use natural gas for heating purposes. Grants and subsidies for using biofuels is one way of increasing the use of bioenergy; another way is to introduce carbon taxes and implement the Polluter Pays Principle.

There is presently an overcapacity in electric power production due to the operation of the Ignalina Nuclear Power Plant. The decommissioning of this plant will, however, lead to an increase in the interest for CHP plants based on biofuels. At present the market for wood chips is not yet developed, but the infrastructure is now being built up. Wood pellets are presently too expensive to be of interest on the domestic market.

Differences in taxation can explain part of the different development paths of bioenergy in the Nordic countries. Figure 8.6 shows the differences in taxation of mineral oil for stationary purposes in Norway, Denmark and Sweden in 2005. The taxes were substantially higher in Sweden and Denmark than in Norway and this has been the situation in the last 20 years.

Another example is the Lithuanian energy system where 50-60% of all consumers get subsidized energy from the government. For social reasons there is a maximum limit to how much of their budget a family can use for energy, and if a family uses more than 15% of their income for heating and 5% for hot water, the excess energy consumption is paid for by the government. Consumers who are in the position of using more energy than the limits of 15% and 5% have no incentives to economize with the energy, because the price in that case is zero. This leads to a too high consumption of energy and no incentives for consumers to introduce renewable energy sources like wood stoves or pellet stoves in their apartements.

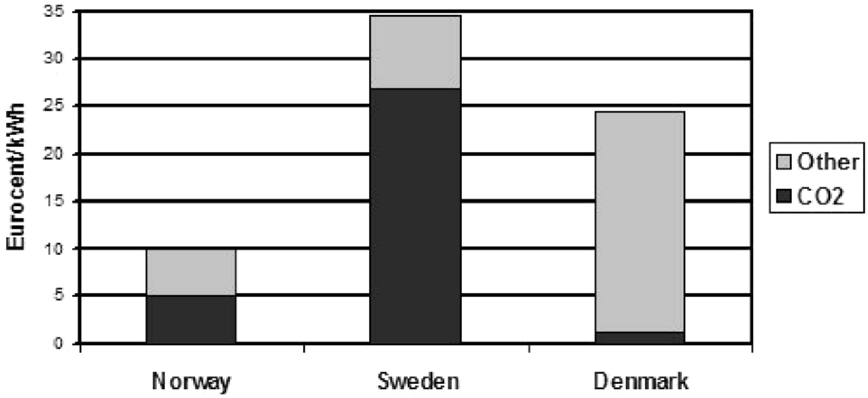

Fig. 8.6. Taxation of mineral oil for stationary use in Norway, Sweden and Denmark excluding VAT (Hohle 2005).

Having summarised the national and regional bioenergy market, barriers and experience, the following conclusions are reached:

- Bioenergy projects in general still need financial support to be viable as they have relatively high investment costs. A successful implementation of more bioenergy projects in the region will depend on the availability of funds. It seems evident that strengthening the priority of bioenergy projects with funds and bilateral support programmes could provide more focus and interest in the field of bioenergy.
- The Joint Implementation Mechanism is expected to become one of the prime tools over the next decade in providing a regionally based demand for bioenergy projects. Given the fact that almost all countries in the region are breaking new ground when adapting public authorities, establishing capacity building and gaining new experience both as buyers and sellers of CO_2 emissions, it would be only natural that some common platform for co-ordination and securing stable and fair trade is established.
- To increase the competitiveness of bioenergy on a regional level it should be considered to initiate harmonisation of energy and environmental taxes in order to create a more levelled playing field for competition in the bioenergy businesses (fuel suppliers, technology suppliers, private service providers etc.) in the region and thereby stimulate the technical advancement of technologies and the general capacity building.
- The EU market for biomass shows all the signs of increasing in the near future, and there will be a significant requirement for new accessible

and easy-to-handle bioenergy fuels, as well as areas in which to grow them. The EU is making efforts to find new opportunities for rural areas, and bioenergy is one of them.

- There is a substantial potential for growing energy crops in the region. This could at the same time be a solution, which could provide the suffering agricultural sector in these countries with a value-added tradable product. If energy crops are to become a commercial success in the near future, product development and exchange of experience must be on the agenda in a regional co-operation in developing a market for bioenergy.
- Coordination with development options and strategies for associated sectors such as the environmental, agricultural and forestry sectors is very important to exploit yet unused resources. Minimising costs of fuel procurement and exploitation of unused resources would require sustainable forestry and agriculture with emphasis on the entire ecosystem and biological diversity as well as a sustainable energy economy.

8.6 Regional co-operation and impacts

To obtain commitment towards a regional co-operation, the countries should consider a *common strategy* defining the broad principles for the regional co-operation regarding bioenergy. The strategy should support the future utilisation of bioenergy resources in the Baltic and Nordic countries taking into account international requirements and national strategies and circumstances. In this connection it would be important that the experiences from strategy development and implementation in the EU countries are transferred efficiently to the non-member countries in the region (Ready et al. 2004).

A dynamic and operational regional action plan and working programme should be developed, which could define the ways to meet the strategy in relation to current possibilities and conditions. A regional programme simplifies the identification of cooperative actions between countries and the challenges are more easily adopted by the actors. This again makes it easier to operationalize the plans.

Cooperation on collection of statistics in the bioenergy field would enable the countries to monitor and evaluate each other's progress on a uniform data and information basis, and to agree on common standards and definitions. These statistics could be presented in annual reports, describing the progress in relation to the Action Plan. Beyond describing the general regional progress, these reports could present the progress in each country in the recent years, including both successes and failures.

In the regional context, the bioenergy market could, as already described, be stimulated by tax harmonisation to open competition. The ongoing standardisation work for biomass fuels will create a better basis for their increasing export/import across country borders and stimulate the bioenergy business in general. Following this standardisation, the Baltic Sea region could establish a common information system on biomass products based on an electronic market place (e-trade) where customers could find suppliers for classified biomass products. The countries could agree on common performance and quality requirements for bioenergy conversion technologies and on this basis establish a common certification system. Information on suppliers and their products could be available in a database system accessible to customers from the internet. The Baltic Sea Region Energy Co-operation (BASREC) and the Nordic Council of Ministers (NCM) have initiated and financed such a database (BAREC/NCM 2002-2005 www.nedatabase.info/bioenergy). The purpose of the network is to promote and make more effective the contacts between bioenergy actors in the Baltic Sea region, with the overall goal of increased regional production and use of bioenergy.

Furthermore, there is a wide scope for common R&D projects. The co-operation network should prioritise projects in relation to opportunities to include private businesses. The exchange of information regarding research and development on bioenergy can also be arranged through seminars, workshops, study visits, training etc. Moreover the cooperation could be stimulated by a common information system to coordinate the research and development activities within various areas.

More regional business partnerships should be established to enhance the Baltic Sea region’s economic and business opportunities within the bioenergy field. Beyond cooperation between businesses, this could function as an overall strategic interest organisation in relation to the political regional cooperation.

The goals and activities of such business partnerships could include:

- Support for further development of technological development and regulatory systems.
- Enhancement of the region's climate for business development by addressing business problems and possibilities in the regional context to politicians and decision-makers.
- Coordination of and support for the use of 'Kyoto Mechanisms' in businesses.
- Common measures for regional business retention and expansion. This could for example include common export promotion campaigns.
- Coordination of international trade opportunities.
- Collaboration with the public and private sectors to foster new development projects.
- Support and advice to individual business clients on regional and international matters (joint ventures, export, markets, legislation etc.).

The local impacts in form of increased employment and income will vary from country to country and from project to project. Boorsbom et al. (2002) present a good review of studies of employment effects of bioenergy projects in European countries. The direct employment effects depend to a large degree on the technology used. In a Swedish study in 1992 the 1992 technology data was used to make a prognosis for future employment effects (Danielsson and Hektor 1992). It later turned out that the technological development was quite fast, so they made a considerable overestimation of the employment effects. This effect is likely to increase with relative increases in salaries, which is expected to be the case in the Baltic States in the coming years.

A factor which is not mentioned by Boorsbom et al. (2002) review is that estimated employment effects are not net effects; at the same time there will be loss of employment in other sectors, particularly in the forestry industry if the biomass might have been used for industrial purposes. Estimations of employment and income effects using input-output models will give upper limits of the effects, because they assume linearity and available resources free of charge. Still, such estimates can be useful and give valuable insights about the local economy. To make more realistic estimates of regional effects a general or partial equilibrium approach is needed.

8.7 External effects – economic and regulatory aspects

All countries in the region have policy documents indicating that increased use of renewable bioenergy is to everyone's advantage. This common understanding is based on the desire for a more reliable and flexible energy balance, greater independence of fossil fuels, environmental benefits (GHG and other emissions), job creation in rural areas and new markets for agricultural and forest biomass. One also recognizes that it may be necessary to protect the production and use of bioenergy in a start-up phase, e.g. through market regulation.

Expert reports show that *taxes* already exist in various countries, but should in some countries be raised to levels that would give more significant influence. Part of the taxes on imported fossil fuels should be used to stimulate and promote clean energy production, introduce energy saving measures, and stimulate the use of local, renewable energy resources.

Most countries have developed support programmes to promote the use of bioenergy. The rapid development in the bioenergy sector over the past two decades has put the Nordic countries in a leading position regarding R&D and utilisation of commercially available technologies. To continue and enhance the development of a bioenergy market, this activity will require substantial funds, and will have to involve both national and regional authorities.

8.7.1 Investment programmes

Bioenergy projects in general still need financial support to be viable as they have relatively high capital costs. Thus, the market development has in all of the countries depended on subsidies, favourable loans and fiscal measures to reward the environmental benefits of bioenergy compared with energy from fossil fuel resources. A sucessful implementation of more bioenergy projects in Russia will also depend on the availability of funds.

When considering the present level of bioenergy related projects funded by e.g. NEFCO/Nordic Environment Fund, the result is a bit discouraging. Less than 10% of the projects are related to utilisation of renewable energy sources or bioenergy. It seems evident that strengthening the priority of bioenergy projects with the Nordic financial instruments and bi-lateral support programmes could provide more focus and interest in the field of bioenergy. It could be considered to establish a more direct communication with the financial level aiming at:

- Providing development assistance for Nordic tailor-made investment programmes aimed directly at bioenergy projects, which could be aimed at better utilisation of the NIB/NEFCO facility, and bi-lateral support programmes, also including EU support programmes.
- Earmark a certain percentage of the energy/environmentally related investment pipeline in e.g. NIB/NEFCO for bioenergy projects.

8.7.2 Joint implementation

Joint implementation (JI) was adopted as an instrument for global emission control under the UN Framework Convention on Climate Change in Kyoto in 1997. The idea with the flexible mechanism for JI is to identify projects and areas that generate the highest CO_2 reduction at the lowest price. In practice, this means that a developed country (Annex B country in the Kyoto Protocol definitions) can implement and finance a project in another Annex B country and get the CO_2 reduction credited in the national register. In May 2002, BASREC presented a first version of a “Regional Handbook on Procedures for JI in the Baltic Sea Region”.

All countries in the Baltic Sea region have either ratified or are in the process of ratifying the Kyoto Protocol and have therefore, in principle, agreed to this type of emission trade. The magnitude of the demand side of the CO_2 trade market is roughly estimated to be worth at least 240 million EUR year^{-1} during the period 2008-2012, and could go as high as 650 million EUR year^{-1}. The price for the project design, validation and monitoring of a JI project is estimated at 30 000-115 000 EUR depending on conditions, but more or less regardless of the size of the project (whether 1 or 100 MW). There is still no developed market for CO_2, but the World Bank has estimated that the value of one tonne of CO_2 will be between 3-9 EUR.

It is obvious that the effects of the CO_2 trade component will influence the financial viability of a bioenergy project. However, all the necessary mechanisms and framework conditions in terms of national/bilateral agreements, appointment and staffing of national administrative units to handle the JI question, access to demand/supply information etc., are still not in place.

The Joint Implementation Mechanism is expected to become one of the prime tools over the next decade in providing a regionally based demand for bioenergy projects. Given the fact that almost all of the countries are breaking new ground when adapting public authorities, establishing capacity building and gaining new experience both as buyers and sellers of CO_2 emissions, it would only be natural that some common platform for co-ordination and securing a stable and fair trade is established. After 2012, new and improved measures for global emission control are expected to come. Most probably this will lead to new opportunities for the bioenergy sector.

8.7.3 Green electricity - Green Certificates

The recent EU directive on promotion of green electricity (electricity production from RES) supports the regional regulatory wishes to promote bioenergy and utilisation of RES. The targets stated in the directive include:

- Increasing the share of green electricity from 14% to 22% of gross electricity production by 2010.
- Doubling the share of RES from 6% to 12% of gross energy consumption by 2010.
- Complying with the commitments made by the EU under the Kyoto protocol on reducing GHG emissions.

This directive defines promotion of electricity from RES through:

- Quantified indicative national targets.
- National support schemes. This is currently implemented and in use in all the Baltic and EU countries.
- Guaranteed access to transmission and distribution of electricity from RES, including objective, transparent and non-discriminatory rules on costs for connection and strengthening of the grid, is also more or less fully implemented in all Baltic and EU countries.
- Green Electricity Certificates. The Green Certificate process has been initiated in some of the EU countries, but remains to be fully implemented and tested as a means to protect and enhance the competitiveness of the bioenergy based electricity market.

8.7.4 Bioenergy-based thermal production

In order to increase the competitive strength of biomass for heating purposes, introduction of CO_2 taxes or emission trading of GHG emissions for biomass-based heat production should be considered as a means to enhance the competitiveness of the bioenergy market – including the synergy effects when combined with Green Electricity Certificates for bioenergy based CHP production.

8.7.5 Promotion and use of biofuel for transport

The European Commission has adopted plans to foster the use of alternative fuels for transport, starting with a minimum level of biofuels as a proportion of fuels sold from 2005, starting with 2% and reaching 5.75% of fuels sold in 2010. According to the Commission's adopted action plan, renewable energy technologies have the greatest potential to contribute to the biofuel supply in the short to medium term. The EC's action plan outlines a strategy to achieve a 20% substitution of diesel and gasoline fuels by alternative fuels in the road transport sector by 2020. It concludes that the adoption of three options would in each case have the potential to contribute by more than 5% to the total transport fuel consumption over the next 20 years. These options are biofuels, which are already available, natural gas in the medium term, and hydrogen and fuel cells in the long term.

8.8 Conclusions

In order to create a close co-operation for the development of an increased and sustainable use of bioenergy and in order to promote the establishment of a more integrated market for different kinds of biofuels in the Baltic Sea region, the following measures are needed:

- All players on the bioenergy market need to find ways to cooperate effectively. Efforts to take into account the interests of the forestry, agricultural and environmental sectors to secure a sustainable basis for the future use of bioenergy resources in the region. Thereby, the requirements of the UNFCCC and the Kyoto Protocol will be met.

- The need for strengthening capacity building as regards bioenergy should be recognised at all levels in the bioenergy chain. The aim is to increase knowledge about the production and use of bioenergy among all players contributing to, or affected by, bioenergy in the Baltic Sea region, as well as improving communication between them.
- The development of standards is essential to achieve market harmonisation and create a basis for increased trade of products and systems in the bioenergy field between countries in the Baltic Sea region. A close co-operation between concerned authorities needs to be established in order to promote the introduction of such international standards, which are now under development within the CEN and other international organisations. Development of standards will reduce uncertainty and transaction costs and make the sector more competitive.
- Bioenergy projects will constitute an important contribution to the work on establishing a testing ground for joint implementation in the Baltic Sea region. The JI handbook will be an important tool for elaborating such projects, which can then serve as suitable reference cases for JI.
- A need is recognised for strengthening co-operation as regards research, development, demonstration and innovation projects in the bioenergy sector between the countries in the Baltic Sea region. Other areas with considerable learning potentials are diffusion of technologies (Madlener 2007) and evaluation of policies. To that end it is important to establish close co-operation and networks with already initiated and on-going activities in the EU, IEA and other international organisations.
- The recommended actions should be implemented through workshops, seminars, training courses, elaboration of handbooks and information material, and, where appropriate, by establishing ad hoc working groups of experts to reach the set goals.

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Chapter 9

ENERTREE – DECISION SUPPORT TOOL TO ANALYSE FOREST BIOMASS EXTRACTION SCENARIOS

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9.1 Introduction

Traditional use of forests and forest management planning have concentrated on the production of saw logs and pulpwood as raw material for forest industries. During the last twenty years, non-commercial values like recreation and biodiversity have also been taken into consideration in forest management planning (Kangas & Niemeläinen 1996). Together with such changes in values, information technology has developed very fast, thereby enabling the creation of solutions and tools to support multicriteria forest management planning processes. Besides wood production for forest industries, small diameter wood from plantation cleanings and thinnings as well as residues from logging operations have been used for firewood in households for centuries. The commercial production of

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forest energy has been fairly modest, mainly due to its weak competitiveness: production has been economically profitable only at a large scale and has required subsidies to cover the costs of procurement. Therefore, present forest management planning applications, as well as decision support tools, concentrate on sawlog and pulpwood production, while the use of branches, needles and stem tops has not been taken into consideration. During the last ten years, forest energy utilisation has been actively promoted due to regional and national energy policies aiming at decreasing carbon dioxide emissions from energy production. Information about forest fuel harvesting, wood ash recycling and their consequences has mainly been provided by research. Investigations on a number of issues have been carried out, and reviews of such results have been performed to reach more general conclusions about the effects of forest fuel harvesting, storage, and wood ash spreading.

Computer programs with limited focus have been developed to support decision making. In Sweden, a program, SNURRAN, was developed to calculate biomass and nutrient removals together with amounts of wood ash needed to compensate for the acidification effect of the removals (Jacobson & Mattsson 1998). A similar program, ESBEN, was developed in Denmark (Møller 2001). However, the focus of these tools has been on the ecological consequences. In Sweden, the PRODMOD program allows for simulation of stand development for different species and production potentials, and also calculates biomass and nutrient contents of removals and the remaining stand (Ekö & Ogemark 2005).

Despite research efforts and active promotion, there is a lack of information about forest energy utilisation, especially among the non-industrial private forest owners, and no comprehensive decision support tools dealing also with economic and silvicultural aspects of forest biomass utilisation for energy have been developed for forest owners, forestry consultants, and professionals. The current forest management planning applications are not utilising the research information or models concerning woodfuel harvesting. However, in order to meet the goals of energy and environmental policies, the use of forest biomass for energy has to be planned together with other silvicultural activities, as part of general forest management.

This chapter introduces the principles of decision making at private forest ownership level and presents a decision support tool, EnerTree, for simple analysis of benefits and limitations of different forest residue recovery alternatives in Norway spruce and Scots pine monocultures. EnerTree is a forest stand level application which combines the available ecological and economic information on the topic to estimate economic, ecological and silvicultural data related to different residue extraction alternatives, both for residue recovery in connection with regeneration logging, different woodfuel harvesting scenarios for young forest stands, and harvesting of stumps from the regeneration site. It has been the ambition that the model should be valid in the Nordic and Baltic countries.

The target groups for the model are private forest owners, researchers, lecturers, students and professionals. Below, the structure, main components, and calculation principles of the EnerTree program are presented in the decision making context, and an example of its use is given.

9.2 Decision making on forest energy by forest owners

The overall problem to be solved by forest owners utilising their forest to produce forest fuel is how to weigh economic, environmental and social criteria and balance the trade-offs against each other. The decision making process is often an iterative process which starts from the definition of the problem and ends with the selection of the best alternative. However, the process has several elements which have effects on the final result; the decision maker has to be aware of the current values of society and its priorities concerning the use of natural resources in a sustainable way. Moreover, the decision making environment, such as the economic, ecological and regulatory and judicial framework, has to be taken into consideration (cf. Chapter 8).

The decision making process in forest energy harvesting has the following steps (see e.g. Dale & English, 1999):

1. Definition of the problem; collecting the relevant information about the use of forest energy.

2. Clarifying of the decision maker's preferences and values within the decision making framework.
3. Decision on the feasible alternatives based on the available technology and common practises.
4. Estimation of the consequences (outcomes) of the alternatives.
5. Comparison of the alternatives in relation to the preferences.
6. Selection and implementation of the best alternative.

A neglected phase of the decision making, also in the field of forest energy utilisation, is the post-decision assessments; long-term experiments are relatively rare, but by following the implementations and their outcomes, valuable information could be produced for future decision making. However, the history of intensified biomass extraction for energy on a large scale is short, and information on the outcome of different actions has seldom been collected.

The decision concerning forest residue utilisation is a multicriteria decision making problem. The forest owner is faced with numerous effects of forest biomass extraction and different ecological and economic information that can be seen as criteria for clarifying preferences and making decisions. However, the effects are not necessarily very well known and the criteria are different compared to traditional forest management planning. For instance, the nutrient balance and its effects on site fertility and forest production on different soil types is a difficult criterion to understand and evaluate without a deeper knowledge of soil types and their properties. Its significance as a decision variable is incontestable, but it should to the extent possible be described through other criteria such as increment and its effect on forest owners' economic outcomes.

Economic criteria have traditionally been the most important ones in forest management planning, but nowadays forest owners' preferences have become more versatile and thus the decision making has become more complex. The complete Decision Support System (DSS) consists of tools for calculation (models), planning (optimisation) and decision support (methods) (Pukkala 1994). For decision support, a wide range of multicriteria decision making (MCDM) methods have been developed to support diversified values and preferences in decision making, including in forestry (see e.g. Keeney & Raiffa 1993).

In practice, forest energy related decision making faces several problems which limit the decision options. For instance, forest energy harvesting technology is still developing fast and there are differences between geographical areas with regard to the kind of technology used and the type of woodfuel harvested. Within a certain economic and practical framework and depending on market conditions, the procurement company utilises the best available technology and the most suitable raw material for its purposes. The forest owner may therefore be in the situation where the decision making is limited to whether to harvest woodfuel or not, instead of evaluating different recovery scenarios. Due to the lack of common practices in the forest energy business, the decision making is sensitive to false assumptions on the economic or ecological sustainability of harvesting operations; the decision making process has to be designed carefully for individual cases.

9.3 EnerTree

The EnerTree decision support tool is a PC application which has been made to support stand level decision making concerning the use of forest biomass for energy production. User-friendliness has been an important issue in the development process: needed data inputs should be easily available, and the quality of the information provided by the program should be good enough to assist forest owners in the decision-making process. A forest management plan, or a similar document, is a common tool in forest administration in the Nordic and Baltic countries, and its data content is normally a sufficient basis for forest stand level calculations and estimations. Therefore, it was the goal that the EnerTree input data should be available from a typical forest management plan, with additional data inputs being delivered by EnerTree.

Below, the EnerTree decision support tool is presented as an example of how decision support can be introduced in forest energy harvesting. Also, the description serves as a brief documentation for the programme.

9.3.1 Model structure

EnerTree consists of four main components (Fig. 9.1): data input sheets, presentation of the stand's present condition, simulations and decision criteria. In addition to input data, the user has the option of changing the calculation parameters in order to fine-tune the calculations for different situations.

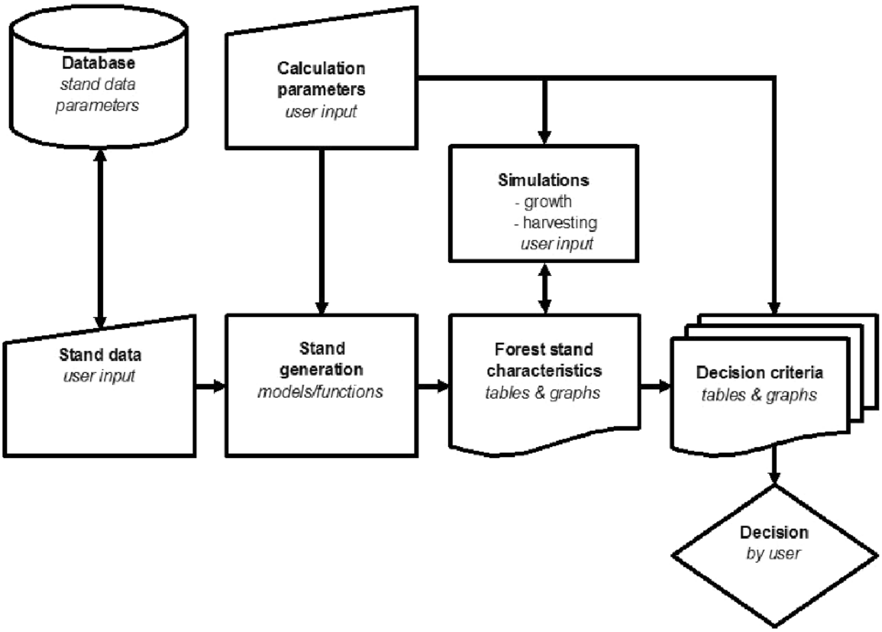


Fig. 9.1. The structure of EnerTree.

9.3.2 Decision environment

Decisions are made within a decision environment, which can be defined as the collection of information, alternatives, values, and preferences. In EnerTree, the decision environment includes six groups of information types (Table 9.1) and seven alternatives (Table 9.2). The information types comprise both ecological and economic knowledge related to forest residue extraction, and they differ when

Table 9.1. Overview of information types for decision support in EnerTree.

Information type	Criteria
Volume, biomass, and energy	Total mass and volumes of a forest stand's biomass compartments
	Logwood, pulpwood and woodfuel logging accruals
	Energy potential of a forest stand
Economics	Revenue from sales of stemwood and residues
	Savings/costs in silviculture due to woodfuel harvesting
	Subsidies for silviculture and woodfuel harvesting
Nutrient balance	Nutrient contents and balance
	Removal of nutrients
	Need for compensation fertilisation, recommendations
Biodiversity	Effects of woodfuel harvesting on biodiversity relative to conventional stem harvesting
	Recommendations
Insect pests	Effects of woodfuel harvesting on insect pests relative to conventional stem harvesting
	Recommendations
Carbon	Carbon contents of harvested biomass and fluxes to other pools
	Fossil fuel savings by harvested woodfuel

it comes to the accuracy and quality of information provided. Some of the information criteria are quantitative estimates based on scientific models (volumes of residues for instance), while others are more qualitative descriptions based on expert opinions (such as effects on biodiversity and insect pests).

In theory, there are numerous alternatives for forest residue recovery, based on different technologies and procurement chains, the intensity of the utilisation, the recovery rate, and the timing of the extraction. As mentioned above, the options might in practice be more limited due to for example market demands and technological choices made by the procurement company. Based on the practice of conventional harvesting, present and emerging practices of forest energy harvesting within the Nordic-Baltic region, and the extreme of removal of all above- and below-ground material, EnerTree includes seven utilisation alternatives or scenarios for regeneration operations, with six of them applying for thinning operations as well (Table 9.2).

Table 9.2. Overview of decision alternatives in EnerTree, ordered according to increasing amount of woodfuel.

	Harvested for industrial use	Harvested for energy	Left in the forest
STEMS	Stems for log & pulpwood	–	Harvesting residues (tops and crowns) and stump-root systems
BROWN	Stems for log & pulpwood	Pre-dried residues (tops and crowns)	Needles and fine material shed during pre-drying and stump-root systems
GREEN1	Stems for log & pulpwood.	Fresh residues (tops and crowns)	Stump-root systems
GREEN2	Stems for logwood.	Fresh residues (long tops and crowns)	Stump-root systems
WTH BR	–	Pre-dried whole-trees	Needles and fine material shed during pre-drying and stump-root systems
WTH GR	–	Fresh whole-trees	Stump-root systems
STUMPS	Stems for log & pulpwood	Fresh residues and stump-root systems	–

The scenarios can be applied together with or without compensation fertilisation to avoid future increment losses due to increased nutrient removal, or with or without future increment losses if extrapolation of stand development is performed. Since the technology of the extraction has a direct effect on the effectiveness of the residue collection, the user can change the recovery rate to fine-tune the scenarios. An increased recovery rate, for instance, will have an effect on the forest owner's economy due to the increased revenue from sales, decreased regeneration costs due to easier soil preparation and planting and increased compensation fertilisation costs. It will also be possible to fine-tune the scenario to a situation with a certain share of low quality logwood actually being harvested as woodfuel. Such aspects can be taken into consideration in EnerTree through calculation parameters and the results are summarised with other economic decision criteria.

Compared to the complete DSS, EnerTree does not have a MCDM method for decision analyses and it does not recommend the best alternative based on the forest owner's preferences. However, decision making does not always require analytical methods. If the calculation system includes the systematic and complete description of the decision environment, information criteria as well as the alternatives, and gives reliable calculation results, decision making can be based on holistic evaluation. EnerTree focuses on the presentation of relevant data for residue extraction and the important relationships between different criteria and alternatives.

9.3.3 Input variables

The input data and calculation parameters required by EnerTree are summarised in Table 9.3, with the first step in running EnerTree being input of stand and site data. The current version of the program deals with monocultures of Scots pine *(Pinus sylvestris)* and Norway spruce *(Picea abies)*, but in the future Sitka spruce *(Picea sitchensis)* and Lodgepole pine (*Pinus contorta*) will also be options. EnerTree contains additional explanations and tools such as maps, graphs and flow charts, which can assist the user in choosing the correct input data for variables which can not be found from forest management plans, such as soil sensitivity or nitrogen deposition.

When inputs have been given, EnerTree generates the diameter distribution of the stand. The diameter distribution is estimated with the 3-parameter Weibull function (Kilkki & Päivinen 1986). Finnish parameter estimation models (Siipilehto 1999) were used to create default parameters of the Weibull function. However, the

Table 9.3. Data requirements for EnerTree. Some data are needed directly from the user, others should be provided with support from EnerTree, and yet others are given as defaults that can be changed by the user.

Stand data from forest management plan	Stand data from the user, assisted by EnerTree	Examples of changeable calculation parameters
Area	Soil sensitivity	Prices of wood and residues
Tree species	Nitrogen deposition	Costs of silviculture
Basal area	Temperature sum	Biomass density properties
Number of stems		Biomass moisture content
Mean height (basal area weighted)		Recovery rate of residues
Mean diameter (basal area weighted)		Diameter requirements for different wood assortments
Mean age		Ash and N fertiliser costs
		Fertiliser nutrient contents
		Subsidies

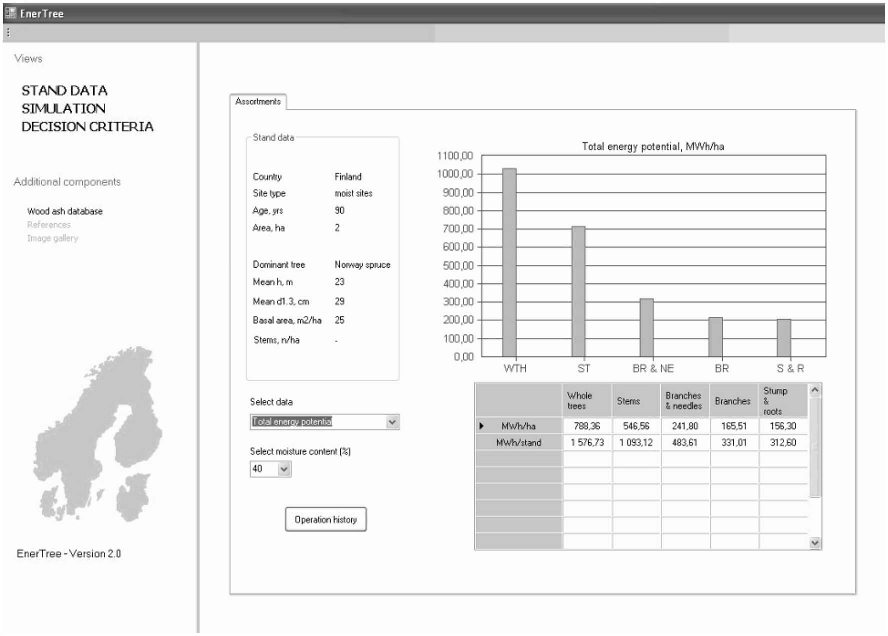
distribution can be changed by the user. The adjustment of parameters requires detailed information about the forest stand structure, and thus is intended mainly for research and education purposes. The diameter distribution is the basis for calculation of all stand characteristics with single tree level models. EnerTree was intended to be valid for the Nordic and Baltic countries. However, compromises had to be made because of missing suitable models. For instance, the estimation of tree height for the same diameter class uses a Finnish model in Finland, northern Sweden, Norway, and Estonia, whereas in Denmark, southern Sweden, Latvia and Lithuania, a Danish model is used. Table 9.4 summarises the references used for estimation of stand conditions as well as the simulation of stand development. Three different combinations of the models and functions are applied to three different geographical areas. The models for stand generation are described in more detail in Röser et al. (2006).

Table 9.4. Models used in EnerTree for the different geographical regions.

Model type	Finland, Norway, north. Sweden	Estonia, Latvia, Lithuania	Denmark, south. Sweden
Diameter distribution & its parameters	Kilkki & Päivinen 1986 Siipilehto 1999		
Single tree height	Näslund 1937	Johannsen 2005	Johannsen 2005
Single tree volume	Laasasenaho 1982	Kuliesis 1993	Madsen & Heuserr 1993
Single tree growth & stand development	Nyyssönen & Mielikäinen 1978, Hynynen et al. 2002	Johannsen 2005	
Thinning	Tapio 2006		
Biomass	Marklund 1988		
Nutrient Concentrations	Chapter 3		
Compensation Fertilisation	Chapter 3		

9.3.4 Stand characteristics

Under “Stand characteristics” (Figures 9.1 & 9.2), the stemwood share of sawlogs, pulpwood and woodfuel is shown. Other figures given are total volume, biomass, and nutrient and potential energy contents of different tree compartments, i.e. stem wood, living branches, needles, dead branches and stumps. The calculation of the energy potential is based on the moisture content of the biomass, which can be changed by the user. Also, other parameters (Table 9.3) can be changed by the user.



Country	Finland
Site type	moist sites
Age, yrs	90
Area, ha	2
Dominant tree	Norway spruce
Mean h, m	23
Mean d1.3, cm	29
Basal area, m2/ha	25
Stems, n/ha	-

Select data: Total energy potential

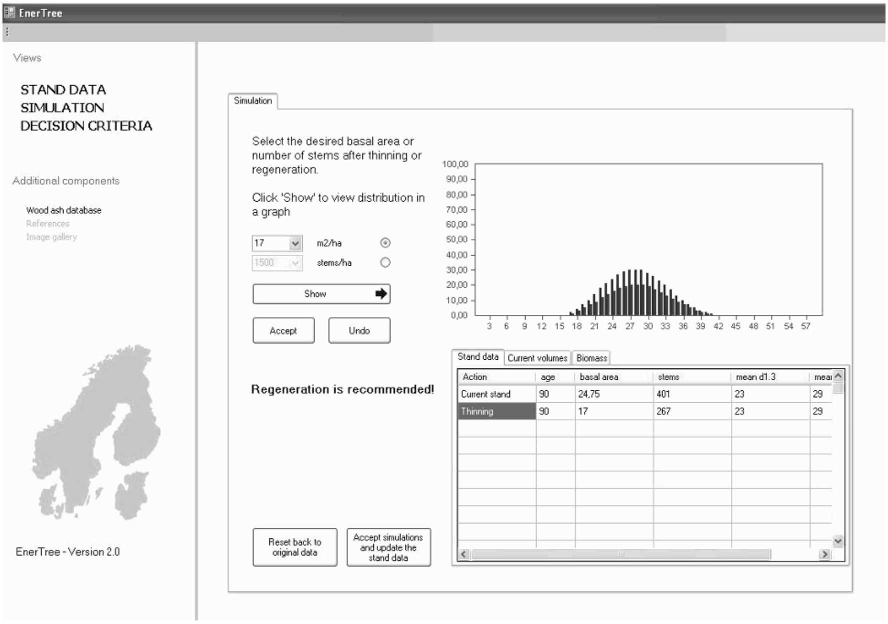
Select moisture content (%): 40

	Whole trees	Stems	Branches & needles	Branches	Stump & roots
MWh/ha	788,36	546,56	241,80	165,51	156,30
MWh/stand	1 576,73	1 093,12	483,61	331,01	312,60

Fig. 9.2. Stand data. The current stand contents are presented to the user in tables and graphs.

9.3.5 Growth and harvesting simulations

The user can update the original stand data by ‘growing’ the stand and performing harvesting operations in the “Simulations and operations” module. Based on the input data, EnerTree suggests a thinning or regeneration when the stand density in relation to the tree



Select the desired basal area or number of stems after thinning or regeneration.

Click 'Show' to view distribution in a graph

17 m2/ha ●
1500 stems/ha ○

Regeneration is recommended!

Action	age	basal area	stems	mean d1.3	mea
Current stand	90	24,75	401	23	29
Thinning	90	17	267	23	29

Fig. 9.3. Growth and harvesting simulations in the EnerTree program.

dimensions is over a certain limit. These suggestions are only advisory and the user can freely select the course of action.

The data updates can be used in different ways. For instance, the user may have an outdated forest management plan, which needs an update of the stand data to obtain a proper basis for making decisions about utilisation of forest energy. Another possibility is to use growth and thinning calculations for the young forest stand to estimate the future development of the stand until the regeneration phase. The most suitable use of the module is a single thinning or regeneration operation for which outcomes can be evaluated under "Decision criteria".

9.3.6 Decision criteria and alternative scenarios

Under the "Decision criteria", different types of outcome information for different utilisation alternatives are shown. If more operations have been simulated, the user can select the operation which he wants to have information for.

EnerTree presents six types of decision criteria: “Volume, biomass, and energy”, “Economics”, “Nutrient balance”, “Biodiversity”, “Insect pests”, and “Carbon”. The quantitative criteria can be adjusted for different situations, but defaults are given. For instance, the recovery rate of residue extraction is about two thirds of the total potential (Hakkila et.al. 1998), and 65% is therefore used as a default value in calculations. However, the practical recovery rate can vary considerably depending on the total quantity of logging residues per hectare and how well they have been piled. Other calculation parameters, such as woodfuel prices, can also have a significant effect on the economic criteria, and the default values can be changed by the user.

The “Volume, biomass, and energy” criterion presents the quantity of recovered wood in solid cubic metres, dry biomass in tonnes, and potential energy content in different energy units assuming a certain moisture content, which can be changed. A cubic metre is a more familiar measurement unit in forestry, while energy units might be more relevant for the energy sector. Thus, it is important to present the relationship between these basic units. From a practical point of view, it is also important to see how much residues can be collected from the stand. This has a direct effect on the economic profitability of residue extraction, both for the forest owner and the procurement company, and may affect decisions related to the planning of work and transport.

The “Economics” criterion summarises the revenues from stem wood and residue sales, the costs of regeneration due to the improved efficiency in soil preparation and planting work, and the costs of possible compensation fertilisation. If subsidies are paid for silvicultural operations or specially for woodfuel harvesting, they can be taken into consideration. One of the interesting aspects from the forest owner’s point of view is the effect of residue extraction on forest regeneration costs. For instance, the research of Saksa et al. (2002) showed that the average speed gain of mounding (spot mounding) in residue extraction areas was 15% higher compared to areas where residues were not extracted. Also, the speed of manual planting was slightly improved (5%) due to the shorter walking distance. The results were based on selected technologies and more research has to be done before far-reaching conclusions can be made.

However, the above-mentioned gain in soil preparation and planting performance can be taken into consideration in EnerTree as reduced costs. The level of savings can be adjusted by the user.

The "Nutrient balance" criterion presents the removals of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) of the selected operation. The removals set the basis of the dosage of compensation fertilisation if fertilisation is recommended. The fertilisation recommendation is a rule-based model where the need for nitrogen and ash fertilisation is evaluated based on soil sensitivity classification and atmospheric nitrogen deposition (Chapter 3, Table 9.5). Soils are divided into two sensitivity classes, sensitive and robust, classified by mean annual temperature, soil type, depth, pH and mineral colour. This simple classification is assisted with maps, graphs and explanations. However, the definition of soil sensitivity is relatively complex and usually requires experience and knowledge about soil properties. To avoid misunderstandings, the default value for soil sensitivity in EnerTree is "sensitive", and this should be changed only if relevant information on soil properties is available.

The recommended dosage of nitrogen fertiliser depends on the total nitrogen removal with the harvesting operation and the properties of the fertiliser. Additionally, nitrogen deposition is taken into account: in low-deposition areas it is recommended to replace the removed nitrogen totally, and in medium deposition areas it is recommended that the total nitrogen compensation should be reduced with 10 years' deposition. In high deposition areas, compensation with nitrogen is not recommended. The dosage of ash fertiliser is based on the removal of cations (acidification effect) or nutrients as chosen by the user. In EnerTree, the dosage is by default based on compensation of the cation removal, but the user can also select phosphorus, potassium, calcium or magnesium. As is the case

Table 9.5. Rule based model for compensation fertilisation recommendations.

Nitrogen deposition	Sensitive soil	Robust soil
Low [0-5 kg ha^{-1} yr^{-1}]	Nitrogen + wood ash	Nitrogen
Medium [5-15 kg ha^{-1} yr^{-1}]	Nitrogen + wood ash	Nitrogen
High [>15 kg ha^{-1} yr^{-1}]	Wood ash	–

for the nitrogen fertiliser, the user can adjust the chemical properties of the wood ash to match the wood ash available.

Forest logging operations always have at least short term effects on forest stand biodiversity. Regeneration felling in particular will change the dynamics of the site's environmental conditions: at stand level some species will disappear, and new species will appear instead. However, as for other decision criteria, EnerTree evaluates the effect of woodfuel harvesting on biodiversity and the risk for insect pests relative to the common practice of harvesting commercial stem wood, denoted as "STEMS" in EnerTree. The evaluation is based on the recommendations in Chapter 5, and is given as a qualitative description for each scenario under the "Biodiversity" and "Insect pests" criteria. The general conclusion from Chapters 5 and 6 is, however, that in most cases extraction of logging residues will not have serious effects on biodiversity and risk of insect pests compared to the baseline scenario ("STEMS"), as the extraction seldom affects the factors of most importance to biodiversity: the size and quality of the habitat (mainly the existence of large-diameter trees and decayed wood), the number and total area of habitats at landscape level and the distance between them. Outbreaks of insect pests causing damage to living trees are related to the amount of breeding material. This amount is decreased for the "GREEN1", "GREEN2", "WTH GR", and "STUMPS" scenarios. In the "BROWN" scenario, the risk equals the risk in the "STEMS" scenario, while "WTH BR" might pose an increased risk in conditions with a high background population of pest species and/or older and maybe even weakened stands in the vicinity. As such, the extraction of logging residues is not expected to affect biodiversity or the risk of insect pest outbreaks critically in most cases. However, precautions should be taken under a few special or aggravating conditions, which are also mentioned in EnerTree.

The carbon criterion gives the biomass and carbon distribution of the harvested wood to other pools: logwood, pulpwood, woodfuel, and residues left in the forest. Furthermore, it is calculated how much oil can be replaced by the harvested woodfuel. The carbon criterion is most relevant for users with interest in the use of wood for energy in relation to climate change, but in relation to soil organic matter and its importance for soil fertility, it might also be of interest to see how large is the proportion of wood left in the forest for a certain alternative.

The calculation inputs, parameters, and information outputs as presented above can be extracted from EnerTree in summary sheets.

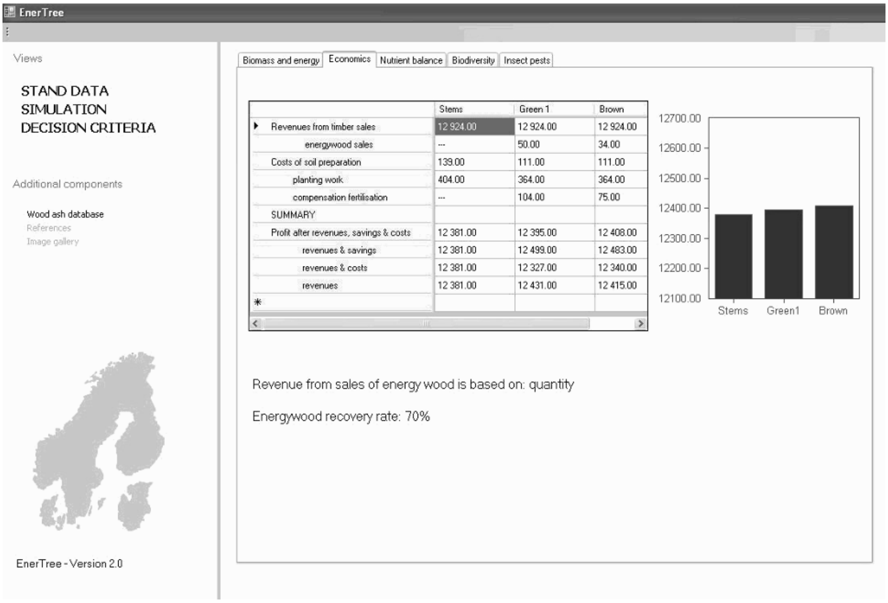
9.4 EnerTree example calculation

This subchapter gives a short example of how EnerTree can assist the forest owner who is considering utilising his forest residues. The hypothetical case chosen is for a forest owner in southern Finland. He is interested in whether logging residues should be collected and sold for energy production or not in mature Norway spruce stands which have been logged for timber and pulpwood. He is interested in the economic consequences of extraction, but also in the ecological consequences, with biodiversity being especially important.

The stand grows on a sensitive soil (cf. Chapter 3) on a site with low atmospheric deposition of nitrogen. On this type of site, it is recommended to compensate the increased nutrient removals due to logging residue extraction to avoid future increment losses. Wood ash is used to compensate for nutrient removals and acidification effects. The compensation amount of wood ash is based on the removals of cations, whereas traditional nitrogen fertiliser is used to compensate for nitrogen removals. It is assumed that removal of residues from the forest stand will decrease the regeneration costs, so that the forest owner saves 20% in soil preparation and 10% of planting costs. The revenues from the sales of logging residues are paid based on the quantity of residues with the revenue paid being 0.5 € m^{-3} (corresponding to about 1 € MWh^{-1}). The total accumulation of forest residues with 70% recovery is 100 m^3 of fresh material or, if the residues are dried on the clear-cut during summer, 67 m^3 (i.e. needles are excluded in the calculation of removals). The most important revenue for the forest owner comes from the sales of roundwood. The total volume of stemwood is 313 m^3 and with the default log and pulpwood prices for Finland, the value of tsales is 12 924 €.

The economics of the three EnerTree extraction scenarios shows that, for example, the “BROWN” scenario (seasoned residues) gives a profit of 27 € ha^{-1} (Figure 9.4.). However, the user should remember that the calculations of savings in particular, i.e. reduced regeneration costs, are essentially based on assumptions, and more information, e.g. from the user's own experience or from machine entrepreneurs, should be available for the calculations to be reliable.

If the forest owner does not want to rely on the calculations of regeneration savings, EnerTree also summarises the economics with different calculation contents, for instance with revenues and compensation fertilisation costs only. If the calculation contents are changed, the economic profitability of the scenarios and their order will change also. Now the profits are highest for the "STEMS" scenario, as the revenues from residue sales do not cover the higher cost of compensation fertilisation. The most positive calculation from an economic point of view is achieved if only revenues and savings are summarised. In that case the "GREEN1" scenario, where the accumulation of residues is highest, is the most profitable. If it is known from other information sources that compensation fertilisation is not



	Stems	Green 1	Brown
Revenues from timber sales	12 924.00	12 924.00	12 924.00
energywood sales	---	50.00	34.00
Costs of soil preparation	139.00	111.00	111.00
planting work	404.00	364.00	364.00
compensation fertilisation	---	104.00	75.00
SUMMARY			
Profit after revenues, savings & costs	12 381.00	12 395.00	12 408.00
revenues & savings	12 381.00	12 499.00	12 483.00
revenues & costs	12 381.00	12 327.00	12 340.00
revenues	12 381.00	12 431.00	12 415.00

Revenue from sales of energy wood is based on: quantity

Energywood recovery rate: 70%

Fig. 9.4. Economic comparison of three selected extraction scenarios.

needed, or if the owner is willing to risk future increment losses, it may be justified to include only revenues and savings.

Because the forest owner considers biodiversity to be especially important, he must consider if his forest is subjected to any aggravating conditions, e.g. if his forest is situated near a forest where biodiversity is known to be high. If there are broadleaves in the stand, he should be particularly careful not to remove dead wood from these species. Also, driving in the stand should be minimised so as not to destroy dead wood habitats (Chapter 6).

9.5 Evaluation and future developments

EnerTree is a new type of decision support tool that combines the present knowledge about forest energy utilisation into one comprehensive program to support decision makers in making better decisions on forest energy issues. However, it is important to be aware of the model's strengths and limitations when using and interpreting the results from EnerTree. EnerTree and its calculation principles are based on several models and functions that have been made for different geographical areas and with different methods and data. These models are combined into one large model chain, as other forest stand simulators also do. All the models and functions have errors and uncertainties originating from different sources, for example there are measuring errors, and sometimes models are used outside their valid range, e.g. geographical range. When statistical models are used and model chains generated, many uncertainties and errors are present and might even accumulate, but their resultant size is difficult to quantify.

To avoid large-scale errors and to ensure logical behaviour of the model, the user must make sure that the input data are within the acceptable ranges as well as logical and consistent. Acceptable ranges are given by EnerTree based on the valid ranges for the single models. Moreover, it is important to remember that the results from EnerTree are estimates, not real measurements from the forest. Many existing forest simulators are highly advanced and are probably much more accurate for predictions (e.g. MOTTI, reference). On the other hand, EnerTree uses relatively simple models, but focuses more on the outcome differences of different alternatives relative to a baseline scenario ("STEMS").

The main scope of the current EnerTree version is in the single operation in connection with thinning or final felling. However, the development of EnerTree is ongoing and new features, such as growth influence modelling and improved full rotation economic calculations, are under construction. Also, its user-friendliness will be developed further.

One of the possible developments in the future is the inclusion of a MCDM method. The evaluations of the alternatives are made in a holistic manner, comparing alternatives in relation to one criterion at a time, which can make decision-making difficult. However, the program does not provide any clear suggestion as to which of the alternatives is the best for the user's multiple preferences. The problem with the traditional MCDM methods is that they require quite accurate information about the decision maker's preferences and are difficult to use without a consultant, whereas the aim for EnerTree is that it should be simple to use and still provide high quality information for decision making. New and more suitable MCDM methods for such aims have been developed, e.g. multicriteria approval (Fraser & Hauge 1998) and multicriteria acceptability voting (MAV) (Pasanen et. al 2005), which are based on voting methods.

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