



Increased biomass harvesting for bioenergy

– effects on biodiversity, landscape amenities and cultural heritage values

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TemaNord 2009:591

© Nordic Council of Ministers, Copenhagen 2009

ISBN 978-92-893-1962-1

Copies: 0

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Preface

This project was initiated by the Terrestrial Ecosystem Group (TEG), a working group under the Nordic Council of Ministers. The project's overall aim has been to describe and document possible effects of increased harvesting of bioenergy on biodiversity, landscapes, outdoor recreation, and the cultural heritage in Finland, Norway, and Sweden. Erik Framstad of the Norwegian Institute for Nature Research (NINA) has coordinated the project and edited the report. Håkan Berglund (Swedish Agricultural University, SLU) and Raimo Heikkilä (Finnish Environment Institute, SYKE) have been mainly responsible for effects on biodiversity in forests, Martin Weih (SLU) has had main responsibility for effects on biodiversity on agricultural land, Vegard Gundersen (NINA) has been responsible for effects on landscapes and outdoor recreation, whereas Ole Risbøl (Norwegian Institute for Cultural Heritage Research, NIKU) has been responsible for effects on the cultural heritage. Other contributors have been Taru Peltola and Noora Lankinen of SYKE. In addition, Nicholas Clarke (Norwegian Forest and Landscape Institute), Göran Lundh (Swedish Forest Agency), Lars Nesheim (Bioforsk), Svein M. Søgne (Norwegian Forest Owners' Association), and Anne Sverdrup-Thygeson (NINA) have kindly provided information or reviewed various sections of earlier drafts of the report. The main contact for the project at TEG has been Gudrun Schneider (Norwegian Ministry of Environment) up to 1 Sep. 2009, and Jannica Pitkänen-Brunnsberg (Metsähallitus) thereafter. The project has been financed by contributions from the Nordic Council of Ministers (over TEG's budget), the Norwegian Ministry of Environment, the Swedish Environmental Protection Agency, and the participating institutes.

Oslo, November 2009

Erik Framstad
Project leader

Summary

As part of a strategy to combat climate change, the Nordic countries intend to greatly increase the production and use of renewable energy. Bioenergy is one important form of renewable energy where Finland, Norway and Sweden in particular have considerable potential. Greatly increased use of biomass for energy may, however, have wide-reaching consequences for our land management and for associated environmental values. The aim of this review is *to present an overview of current knowledge on the effects of biomass harvesting for the purpose of bioenergy on biodiversity, landscape amenities (especially outdoor recreation), and cultural heritage values in Fennoscandia*. The review is based on existing studies and general knowledge of the production and harvesting systems and their effects.

The current supply of renewable bioenergy in Finland, Norway, and Sweden is equivalent to 83 TWh, 15 TWh, and 104 TWh, respectively, of which more than 90% comes from the forest sector. Assessments for total supplies of bioenergy by 2020 vary but are in the order of 126 TWh, 34 TWh, and 151 TWh for Finland, Norway and Sweden, respectively. Many biomass harvesting options exist but they are not all equally likely in the Nordic countries. Based on various public recommendations and the current debate on the use of biomass, the following options need to be considered from forests, farmland and mires and wetlands.

- Increased harvesting of logging residues, stumps, trees from tending and thinning of young forest, and non-standard wood from current logging areas, especially from forestry districts near roads and facilities for effective use of the biomass resources (e.g., heating plants, industrial facilities).
- Increased intensity of forest cultivation activities, such as building of forest roads, soil preparation, nitrogen fertilization, planting, various thinning regimes, use of high-yield varieties or species, and shorter rotation time, on current logging areas.
- Increased harvesting of woody residues from clearing of power line corridors and along roads where effective transportation to facilities for use of the biomass is possible.
- Increased harvesting from currently non-commercial forest as well as increased afforestation may be relevant under suitable economical constraints, especially in Norway.
- Increased cultivation of energy crops on arable land, such as grains, oilseed crops, and grasses, primarily in Finland and Sweden.

- Increased short rotation forestry with willows and poplars on farmland, primarily in Finland and Sweden.
- Increased harvesting of wood resources from marginal agricultural land, field edges etc, to a limited extent where the biomass can be exploited locally.
- Biomass harvesting from mires and wetlands may primarily be in the form of harvesting of *Sphagnum* and canary reed grass on former peat mining areas and harvesting reed in shallow water bodies, mainly in Finland.

The following biomass harvesting measures will in most cases be acceptable or have only minor negative effects:

- Harvesting of logging residues, including trees from tending of young forest and thinning, seems to be among the more acceptable forms of biomass harvesting. It will probably have only marginally negative or no effects on biodiversity and cultural heritage values and a positive effect for landscape appreciation and outdoor recreation. This requires, however, that the general environmental concerns in forestry are strengthened and that appropriate measures are taken to avoid damage to important resources for biodiversity (e.g., coarse dead wood, old deciduous trees) and cultural heritage remains.
- Harvesting of biomass from power line corridors and along roads will have similar limited effects for biodiversity and cultural heritage values and positive effects for landscape appreciation as removal of logging residues.
- Harvesting of bushes and trees from marginal farmland is likely to have mainly positive effects for biodiversity, landscape appreciation and cultural heritage values as it will reduce the negative effects of succession to woody vegetation. However, particular measures are needed to avoid damage to cultural heritage values and to preserve valuable resources for biodiversity, especially old/large deciduous trees.

The following biomass harvesting measures will have mainly or even serious negative environmental effects:

- Harvesting of stumps will have a negative effect particularly on landscape appreciation and cultural heritage values. The effects on biodiversity are inadequately known.
- Intensification of silviculture will magnify the various negative effects of current forestry activities for biodiversity, landscape appreciation and cultural heritage values through a more schematic and less diverse forest landscape, less un-exploited forest area, shorter rotation time,

more extensive use of non-native species, and more disturbance.

Shorter rotation time will be particularly negative for biodiversity.

- Harvesting of biomass from currently non-commercial forests is likely to have a negative effect on biodiversity, landscape appreciation and outdoor recreation, as well as cultural heritage values, since such forest areas probably have had less human impact in the recent past. However, we need better information about the distribution of biodiversity and cultural heritage values in such areas.
- Natural succession of woody vegetation or planned afforestation on former marginal agricultural land will have a strong negative effect on biodiversity, landscape appreciation and cultural heritage values as open landscapes characterised by extensive traditional farming activities are among the most valuable for biodiversity and landscape appreciation as well as often important locations for cultural heritage remains.
- Increased use of bioenergy crops like reed canary grass and short rotation forestry with willows etc on arable land will in most cases have a negative effect on biodiversity and landscape appreciation through its dense and closed vegetation, and on cultural heritage values both by changing the cultural environment and by risking disturbance of remains in the soil through deep and powerful root systems. The effects of reed canary grass and willows on biodiversity and landscape appreciation may be more positive in landscapes dominated by intensive agriculture.

1. Background and delimitation of the issues

The European Union and its member and associated states have committed themselves to a significant reduction in the emissions of CO₂ and other greenhouse gasses by 2020. As part of the strategy to meet this objective, these countries will greatly increase the use of renewable energy, including bioenergy and biofuels, to reduce the use of fossil energy. The underlying assumption is that the various policies and measures to increase the use of bioenergy will be efficient measures to reduce CO₂ emissions and the associated effect on global warming.

The ambition to use far more bioenergy is generally acknowledged to have wide-reaching consequences for our land management and organisation of the energy sector in general. Hence, there is a potential for conflicts between the bioenergy objectives and other environmental objectives on which the European Union and its member states also place great emphasis, e.g., such as halting the loss of biodiversity by 2010. In particular, it is likely that greatly increased harvesting of biomass for bioenergy purposes will have considerable effects on the landscape and its constituent ecosystems and associated values linked to biodiversity, landscape amenities and cultural heritage values. A coherent policy for the increased use of bioenergy should be aware of such effects and seek to find solutions that may accommodate the various environmental objectives as well as possible.

The overall objective for this review is *to present a coherent overview of current knowledge on the effects of biomass harvesting for the purpose of bioenergy on biodiversity, landscape amenities (especially outdoor recreation), and cultural heritage values in Fennoscandia.*

The review is focused on the effects of biomass harvesting activities for bioenergy purposes that may change land use or management actions in addition to or instead of the land use and management that would occur without increased harvesting of bioenergy. Both negative and positive effects are considered, and important gaps in knowledge are identified. The review does not consider biomass harvesting from marine ecosystems, nor issues of energy efficiency, overall climate effects of the measures, or the technical, economical or social conditions for the implementation of the various bioenergy policy options or measures. We may reasonably assume that only measures that will be effective in reducing the long-term emissions of CO₂ should be considered in a credible bioenergy policy. However, as our mandate does not include an assessment of the real effects of possible bioenergy measures on carbon pathways and stor-

age, we will focus on those measures that have been proposed for bioenergy in the Nordic countries, especially those that influence land management, irrespective of their real contribution to the carbon cycle or their socio-economic realism.

The review is based on a collation of existing knowledge, with an emphasis on the Nordic countries, but it has also drawn on other relevant knowledge. The aim is to provide an improved basis for making decisions on the use of biomass for bioenergy in the Nordic countries, both at local and national levels.

The main focus of the review is on changes in land use and management of forests and farmland that may result from increased harvesting of biomass for bioenergy purposes. Other types of ecosystems may also provide some biomass for bioenergy, e.g., wetlands, margins along transport corridors etc, and these are also briefly considered.

The effects on biodiversity and other environmental values will mainly be mediated through changes in land use, i.e., where one kind of land use is changed to another which is more suitable for biomass production or harvesting, or through changes in land management that will yield a higher harvestable output of biomass. Such changes will affect the structure of the landscape at a range of spatial scales, the functions of ecosystems, and the resources available to plants and animals as well as humans. Effects on biodiversity may manifest themselves through changes in population levels, community structure or ecosystem processes. Landscape changes may also influence the extent and quality of landscape amenities, how the landscape appears and is understandable to humans, and how suitable it is for recreation purposes for different user groups. Such landscape changes may also directly influence cultural heritage remains and monuments and how they function in relation to their local environment and in a landscape setting.

The review is structured according to the main land categories (forests, farmland etc). The consequences for biodiversity and other environmental values are then explored for each of the various measures for biomass harvesting that are most likely for the respective land categories. Only measures that are relevant to at least one of the Nordic countries (Finland, Norway, Sweden in particular) are considered. Similarities and contrasts in measures and their effects among the Nordic countries are explored.

The assignment for this review from the Terrestrial Ecosystem Group of the Nordic Council of Ministers covers Finland, Norway and Sweden. Collectively, these countries should be referred to as Fennoscandia, but for simplicity we have also occasionally referred to them as the Nordic countries (although not all Nordic countries are covered by our assessment).

2. Objectives and potential for bioenergy

2.1 Objectives for climate, biodiversity and other environmental concerns

The Nordic countries as well as the European Union have ambitious objectives for sustainable development, where further social and economic development should be well balanced with the objective of protecting and, where necessary, improving the environment. In tackling the challenges of global climate change, the need to balance the various societal and environmental interests become especially acute. Many measures to reduce the emissions of green house gases or to adapt to the consequences of climate change may conflict with other important environmental concerns, such as preserving biodiversity, landscape amenities or our cultural heritage.

In this report our focus is on measures to increase the production and harvesting of biomass for use as bioenergy, with the policy aim of reducing the consumption of non-sustainable fossil energy, and how this may affect other important environmental values (cf chapter 1). Hence, in this section we will briefly present some of the key policy objectives for renewable energy (bioenergy included) on the one hand and these other environmental concerns on the other.

Objectives for climate and renewable energy

The European Union has adopted ambitious objectives for the energy supply and use of its member states in order to combat global climate change and improve energy security, formulated as the so-called '20-20-20' initiative agreed by the European Council in March 2007 (EC 2008). This specifies that by the year 2020, the EU and its member states shall have achieved:

- Reduced the emission of CO₂ by 20%
- Reduced the total energy consumption by 20%
- Increased the share of renewable energy to 20%
- Increased the share of fuel in the transport sector from renewable sources to at least 10%

In its directive on renewable energy (EC 2009), the European Commission specified how these objectives shall be achieved and set targets for the member states. For Finland and Sweden the targets for renewable

energy as a share of gross final energy consumption are 38% and 49%, respectively, up from 28.5% and 39.8% today (EC 2009, Annex I). As this legislation also applies to Norway under the EEA agreement, similar targets can be expected for Norway (not yet decided by October 2009). A few NGOs in Norway have attempted to estimate what the target may be for Norway, and they conclude that Norway will have to increase its share of renewable energy by 13.5–14.5% (Bellona¹, Point Carbon²). Depending on how the figures are calculated, this could imply a share of renewable energy of more than 60%.

In its Biomass action plan (EC 2005), the Commission stressed the importance of biomass as a source of renewable energy, as well as the realistic possibility of more than doubling the use of biomass for energy by 2010 compared to 2005.

Finland, Norway and Sweden already have an impressive part of their energy supply from renewable sources. All three countries have national objectives to further expand the use of renewable energy. In this strategy, increased use of biomass for energy is a key component.

- In Finland, the goal by 2020 is to increase the proportion of renewable energy sources up to 35–45%. The aim is to reach this target by increasing the use of forest bioenergy and by increasing the area of energy plant cultivation (mainly canary reed grass) ten-fold compared to the present situation. Also energy production from agricultural land is planned to be increased, especially to produce fuel for vehicles (1st generation fuels as a transition to 2nd generation) (Antikainen et al. 2007).
- The Norwegian government has stated that Norway aims to become carbon neutral by 2050 (MD 2007a). As one element in this strategy, the objective is to nearly double the use of bioenergy to about 30 TWh by 2020, with a potential additional increase to 40–50 TWh within a few years later. The government emphasises that this expanded use of biomass shall take place fully in accordance with the principles of sustainable use. The government's policy is that arable land shall not be used for energy crops and that most new biomass for energy shall come from the forest. This may imply that the annual biomass harvest from forests will increase by 50% to about 15 mill. m³.
- Sweden has ambitious environmental objectives covering 16 different areas (Anon. 2004), including "Reduced Climate Impact". The national environmental quality objectives were adopted by the Swedish Parliament, Riksdagen, in 1999. The current target is to decrease the greenhouse gas emissions by 40% by 2020 (in comparison with 1990). This means that emissions must decrease by around 20 million tonnes CO₂ equivalents. Further, Sweden aims to

¹ http://www.bellona.no/nyheter/nyheter_2009/Fornybardirektivet_Er_Eos_Relevant

² <http://www.tu.no/energi/article169142.ece>

become carbon neutral by the middle of this century. Half of Sweden's energy use in 2020 will come from renewable energy sources, for instance, from both agricultural land and forests (Anon. 2008a). The government has announced a more active policy for forest management and increased production of bioenergy from forests (Anon. 2007). Also the Swedish government emphasizes that this expanded use of biomass shall take place fully in accordance with the principles of sustainable use.

Biodiversity

The United Nations' Convention on Biological Diversity (CBD) has as its objectives³ to conserve biodiversity, to use its components sustainably, and to share its benefits fairly and equitably. The CBD presents a framework of requirements and recommendations that the parties to the convention have to adopt and implement. The CBD does not specify any particular species or habitats that should be protected but focuses on the maintenance and protection of the various components of biodiversity. The European Union, its member states and most other European states are parties to the CBD and thereby bound to adhere to its objectives and work to implement its recommendations.

At the World Summit for Sustainable Development in Johannesburg in 2002, as part of the Millennium Development Goals, it was decided to greatly reduce the loss of biodiversity by 2010⁴. At the Environment for Europe conference in Kiev in 2003⁵ the European Union and the European nations further strengthened this goal by deciding to halt the loss of biodiversity by 2010 (UNECE 2003, article 56). This objective has since been a key priority of European biodiversity policy. It has been emphasised that to fulfil such an objective traditional conservation measures will be not be enough. They have to be supplemented by efforts to maintain biodiversity also in non-protected areas.

The European Union's Habitats and Birds Directives represent the major policy instruments for biodiversity conservation in Europe (EC 1979, 1992). In various annexes these directives specify species and habitats of European concern. The directives clearly identify the obligations of the member states to ensure the favourable conservation status of these species and habitats, both within designated Natura 2000 sites and in the general landscape. As EU members Finland and Sweden are bound by the EU nature directives, whereas Norway is not. Most European nations as well as the European Union are parties to the Bern Convention for the protection of the flora and fauna of Europe (CoE 1979). This convention has many of the same requirements as the EU Habitats and Birds Directives (although with a weaker legal status). Both the EU directives and

³ <http://www.cbd.int/convention/convention.shtml>

⁴ <http://www.johannesburgsummit.org/>

⁵ <http://www.environmentforeurope.org/efehistory/kiev2003.html>

the Bern Convention require the member states and parties to manage their natural resources and territory in a way that does not threaten the conservation status of the priority species and habitats.

The Nordic countries have both ambitious objectives for biodiversity at the national level and aim to fulfil the requirements of the EU directives and the Bern Convention. This is reflected in their nature conservation legislation as well as their sectoral policies where sustainable development is a key concept.

- The Finnish ministry of the environment has prepared a biodiversity strategy 2010–2016 (Heikkinen et al. 2008). It states that the biological diversity must be preserved and used sustainably for the benefit of present and future generations. Species habitats and ecosystems and their functions and processes should be safeguarded. Species have to be able to survive in long-term viable populations with sufficient genetic variation.
- In the new Norwegian Nature Management Act (MD 2009) the perspectives on conservation and sustainable management of biodiversity are expanded compared to the previous law on nature conservation. The law provides a comprehensive framework for the protection and sustainable management of Norway's natural diversity. A novel element is the focus on priority species and habitat types of special conservation interest. The favourable conservation status of these species and habitats shall be ensured also outside formally protected areas, with potentially wide-reaching consequences for land management. Until such priority species and habitats have actually been designated, the government recommendation in force is to avoid physical impacts in threatened habitats and to maintain important ecological functions in vulnerable habitats (as defined in MD 2000).
- The Swedish national environmental quality objective "A Rich Diversity of Plant and Animal Life" (Anon. 2004) states that the biological diversity must be preserved and used sustainably for the benefit of present and future generations. Species habitats and ecosystems and their functions and processes should be safeguarded. Species have to be able to survive in long-term viable populations with sufficient genetic variation.

Landscape

The European Landscape Convention (ELC) is the first international treaty to be exclusively concerned with all dimensions of European landscapes (CoE 2000). It defines landscape *as an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors*. Hence, the landscape is defined in a wide sense and comprises a variety of values – cultural, ecological, aesthetic, social and economic. The ELC is process-oriented, promoting the protection,

management and planning of European landscapes, organizing European co-operation on landscape issues, and promoting public involvement in matters concerning the landscape. It does not specify particular landscape qualities to be protected but states that the parties to the ELC are obligated to identify and assess such qualities. The ELC underlines the fact that the landscape is a common good as well as a subject of common responsibility. It covers all landscapes, both outstanding and ordinary, that determine the quality of people's living environment. The ELC proposes legal and financial measures at the national and international levels, aimed at shaping landscape policies and promoting interaction between local and central authorities. The use of natural resources and development of landscapes is often a matter of negotiation. A close co-operation between national and local authorities, private organizations, and the public is necessary to achieve a sustainable development of the landscape (CoE 2000). The European Landscape Convention has been ratified by Norway and Finland, and signed by Sweden. The ELC does not enter into force until a country has ratified it. Implementation of the ELC's objectives and requirements at the national level implies concrete actions to maintain and develop landscape qualities.

The holistic understanding of the landscape concept as reflected by the ELC is partly adopted at the national level, e.g., in physical planning at the landscape level where the aim is comprehensive coverage of the various environmental and socio-economic values represented in the landscape. Other sectoral policies, e.g. for biodiversity, outdoor recreation or the cultural heritage, more often focus on particular properties and spatial scales of the landscape that are especially relevant for these policies. In terms of assessing the landscape effects of increased bioenergy production, it may be more useful to focus on such specific landscape properties than to try to capture the effects on the landscape as a holistic entity. The effects on such specific properties may be more easily identified and understood than effects on the landscape as a whole, and they may therefore be linked more explicitly to relevant policies.

Outdoor recreation

By national laws, people have general access to the forest and other nature types in Finland, Norway and Sweden as a result of the traditional Everyman's right of free access to both private and public land. This brings opportunities for recreation and nature tourism for all citizens, and also management strategies that take into account public demands for forest recreation. In Norway for example, there exists an official manual of planning tools for urban nature areas (DN 2003), and also the Living Forest Standard facilitates important aspects of outdoor recreation (Living Forest 1998).

Opportunities for outdoor recreation are crucial for the public's physical and mental health, and are important national goals for sustainable

development in Finland, Norway and Sweden (NCM 2006, MD 2001). There is no specific international convention related to outdoor recreation covering the three countries. However, all three countries have stated that outdoor recreation is important to create respect for and to take care of the natural environment. The importance of focusing on outdoor recreation in political and economical processes have to be seen in connection with both national legislation and international conventions on biodiversity, landscape and environmental issues as a whole. The benefits and uses of intensively managed areas are described elsewhere (e.g., Tyrväinen et al. 2005, 2009).

Political goals for outdoor recreation in Norway are stated in MD (2001). Strategic goals are that all inhabitants should have possibilities to take part in outdoor recreation for the sake of health and well-being, and by performing environmentally friendly activities in urban and more rural nature areas. More specific goals are:

- To protect the right of free access to all public and private land for all citizens.
- Children and youth shall be given possibilities to take part in outdoor recreation.
- To protect natural values and the possibilities to take part in outdoor recreation in areas of special importance for outdoor recreation.
- To protect nature areas close to homes, schools and kindergarten, and connect these areas to a larger green structure.

Cultural heritage values

The obligation to protect the cultural heritage is regulated by international agreements. The European convention on the protection of the archaeological heritage (CoE 1992) and the Convention for the Protection of the Architectural Heritage of Europe (CoE 1985), both initiated by The Council of Europe and ratified by all Nordic countries, are highly relevant in this case. The Convention on the Value of Cultural Heritage for Society (CoE 2005), which is ratified by Norway but not Finland and Sweden, is also important, e.g., with its aim to *promote cultural heritage protection as a central factor in the mutually supporting objectives of sustainable development...* (Article 5e). The European Landscape Convention deals with the entire landscape, including cultural heritage values (CoE 2000).

The legislation in the Fennoscandian countries further clarifies the cultural heritage values and to what extent the governmental authorities emphasize these values. According to the Norwegian Cultural Heritage Act all monuments and sites earlier than AD 1537 are automatically protected (MD 1978). Similarly the Swedish Heritage Conservation Act (Kulturdepartementet 1988) and the Finnish Antiquities Act (Ministry of Education 1963) also state that ancient monuments and remains are pro-

tected by law and shall not be damaged. Monuments and sites are widely defined as *all traces of human activity in our physical environment* in the Norwegian act – a similar definition applies in all three countries. According to the laws one is not allowed *to damage, destroy, excavate, move, change, cover, conceal or in any other way unduly disfigure any monument or site.....or to cause a risk of this happening* (MD 1978 § 3).

According to a national goal of the Norwegian government, the yearly loss of cultural monuments and environments shall be reduced to 0.5 % before 2020 (MD 2005). This goal is set because of alarming reports recording a rise in the loss and destruction of cultural heritage monuments and remains. The national goals of Swedish authorities are specified separately for the forest landscape and the agricultural landscape: *The forest must be utilized in such a way that it does not damage ancient cultural monuments and in a way that damages done to other known and valuable cultural remains are brought to an insignificant level latest at 2010*, and in the agricultural landscape *the number of culture bearing landscape elements taken care of shall increase by 70% by 2010* (Regeringens proposition 2005 – own translation). Similar legislation applies to the cultural monuments and remains in Finland.

Other environmental policy areas

Increased production and use of bioenergy may affect a range of other environmental policy areas, related to pollution, physical planning and sustainable development in general. Given the likely expansion of human use of the landscape in order to produce and harvest the necessary biomass for bioenergy, a particular concern is the amount of territory not affected by human infrastructure like buildings, roads etc. This is precisely the focus of a Norwegian national indicator (INON), of key importance in measuring the human environmental footprint, and it is a national aim to maintain the extent of such areas without human infrastructure (e.g., MD 2007b).

2.2 Current energy supplies and potential for bioenergy in Fennoscandia

Current energy supplies

Like all highly developed countries, the Nordic countries have a high level of energy use per inhabitant. The total energy supply in Finland was about 435 TWh (1567 PJ) in 2006, whereas it was about 303 TWh (1092 PJ) in Norway and 597 TWh (2148 PJ) in Sweden (Table 1). The total amount of fossil energy (coal, oil, natural gas) constituted 58% in Finland, 55% in Norway, and 35% in Sweden (including peat for Finland and Sweden). Hydro power is especially significant in Norway with 39% of the total energy supply, versus 10% in Sweden and less than 3% in

Finland. The latter countries have a considerable energy input from nuclear power (16% in Finland and 34% in Sweden). Finland and Sweden also have a significant supply of bioenergy, with 17–19%. In Finland, peat is also an important bioenergy source (7% of all energy) (Antikainen et al. 2007), although peat should not be considered as renewable energy (Seppälä et al. 2009). There is only a marginal contribution from other renewable energy sources, mainly wind power (<1%).

The data on energy supply from various bioenergy sources are less precise and vary to a considerable extent among the countries in the breakdown of the types of sources (Table 2). In particular, it is difficult to get reliable and comparable data on different types of biomass from forestry and agriculture, as well as accounting for the contribution of organic wastes. Nevertheless, it is clear that biomass from forests comprise the most important share of bioenergy, making up at least 90% in all three countries (Table 2). In Finland and Sweden, forest-based bioenergy comes mainly from by-products of the pulp industry (black liquors, 52% and 44% of forest-based bioenergy, respectively), other by-products from the pulp and sawmill industries (32% and 35%), and wood, stumps and logging residues (16% and 20% of forest bioenergy in the respective countries). In Norway, forest-based bioenergy is divided about equally between forest industry wastes and by-products and the local use of firewood. So far only marginal supplies of bioenergy come from agricultural land, mainly from short rotation forestry (willows) in Sweden and reed canary grass in Finland (Table 2).

Table 1 Energy supply in Fennoscandia in 2006 according to the International Energy Agency (IEA), given as Total Primary Energy Supply (TEPS) (<http://www.iea.org/Textbase/stats/index.asp>).

	Finland			Norway			Sweden		
	TWh	PJ	%	TWh	PJ	%	TWh	PJ	%
Crude oil and oil products	122.9	442.4	28.2	103.2	371.5	34.0	170.0	612.1	28.5
Natural gas, gasworks gas	45.1	162.2	10.4	55.1	198.4	18.2	10.3	36.9	1.7
Coal, coke and peat	85.6	308.1	19.7	8.3	29.9	2.7	31.2	112.4	5.2
Unspecified heat production	0.6	2.3	0.1	0.4	1.5	0.1	3.3	11.9	0.6
Combustible renewables, waste	88.7	319.4	20.4	15.5	55.7	5.1	110.1	396.2	18.4
Hydro	11.5	41.4	2.6	119.4	429.9	39.4	61.7	222.2	10.3
Nuclear	69.4	249.9	15.9	0.0	0.0	0.0	203.0	730.8	34.0
Wind	0.2	0.6	0.0	0.7	2.4	0.2	1.0	3.6	0.2
Tidal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar photo voltaic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar thermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity import/export	11.4	41.0	2.6	0.9	3.1	0.3	6.0	21.7	1.0
Total energy supply	435.4	1567.3	100.0	303.4	1092.3	100.0	596.6	2147.9	100.0

Table 2 Current and potential (assumed for 2020) bioenergy supply (TWh) in Fennoscandia. Forest industry residues etc include black liquor for Norway. Note that the IEA does not consider peat as renewable energy (although it represents energy from biomass); peat has therefore been excluded from this table.

	Finland		Norway		Sweden	
	2007	2020	2006	2020	2005	2020
<i>Forest sector</i>	82.0	110.0	14.0	24.2	99.0	130.0
Black liquor	42.5	40.0			44.0	45.0
Forest industry residues, by-products	26.0	25.0	6.8	8.8	35.0	42.0
Logging residues, thinning, stumps etc		30.0		8.2	7.0	20.0
Domestic wood fuels	13.5	15.0	7.2	7.2	13.0	20.0
<i>Agriculture</i>	0.3	8.0	0.1	4.5	1.0	12.0
Farm by-products, waste			0.1	3.5	0.5	4.0
Grain, oil seed energy crops		6.0		1.0		4.0
Grass crops	0.3	2.0				
Short rotation forestry					0.5	4.0
<i>Municipal and other waste</i>	0.4	8.0	1.3	5.5	4.0	7.0
Construction, industrial waste			0.2	0.7		
Municipal solid waste			1.1	2.5		
Landfill and other biogas	0.4	8.0	0.1	2.3		
Other biofuels						2.0
Total bioenergy supply	82.7	126.0	15.4	34.2	104.0	151.0

Sources: Finland: Statistics Finland 2007, Laitila et al. 2008, Asplund et al. 2005, Lehtomäki 2008; Norway: Berg et al. 2003, NOU 2006, Langerud et al. 2007; Sweden: Anon. 2006a, Fredga et al. 2008, Nilsson 2006

Both Finland and Sweden have a well-developed infrastructure for district heating, as well as heat-based power plants (including combined heat and power, CPH, plants) that can utilise bioenergy. Norway has a less extensive infrastructure for district heating, focused on cities and larger towns to exploit local biomass resources (notably organic waste), although it is being developed to also exploit forest-based bioenergy like wood chips. There are no commercial power plants in Norway able to utilise bioenergy.

Potential production of bioenergy

All the Fennoscandian countries have announced considerable ambitions when it comes to increasing the production of bioenergy and its proportion of all energy used (cf chapt. 2.1). Essentially, the national governments aim to increase the bioenergy production and use by 50–100% over the next decade (cf Table 2). It is challenging to assess a realistic potential and to identify the sources of this bioenergy. Several assessments have been conducted over the last few years in each of the countries, but a comprehensive consensus is still lacking. Assessments differ partly because of inadequate statistics and knowledge. Estimates of future potentials will also be highly dependent on the assumptions and limiting criteria (economical, technical, ecological etc) applied by the investigators. We have tried to balance estimates from several assessments to give a picture of how the bioenergy potential is likely to be realised from the main biomass sources, rather than attempting to give precise indications of the magnitude of future bioenergy production (cf Table 2, Figure 1).

As all bioenergy must at some stage be produced as biomass, the area available for the production of such biomass will be an essential resource and limiting factor. Finland, Norway and Sweden all have rather large territories relative to their population sizes (Table 3), compared to other countries in Europe (without Russia, about 1 ha per person). When it comes to areas for the potential production of biomass, Finland, Norway and Sweden have ample forest area, with 2–4 ha of forest per person, compared to only 0.33 ha in Europe (excluding Russia). The agricultural area is relative less extensive, being about the average of 0.44 ha of agricultural area per person in Europe (excluding Russia) for Finland, a bit less for Sweden (0.35 ha) and considerably less for Norway (0.22 ha). Farmland is still considered relevant for the production of energy crops in Finland and Sweden, but in Norway there is a clear political priority to use arable land for food rather than energy crops (although waste from food production may be used for bioenergy) (OED 2008). Although biomass production from marine ecosystems, algae in particular, is also being investigated internationally, this is not yet considered in the national assessments of the bioenergy production potential in Fennoscandia. Overall, assessments of future bioenergy production in Finland, Norway and Sweden are particularly focused on biomass from forests.

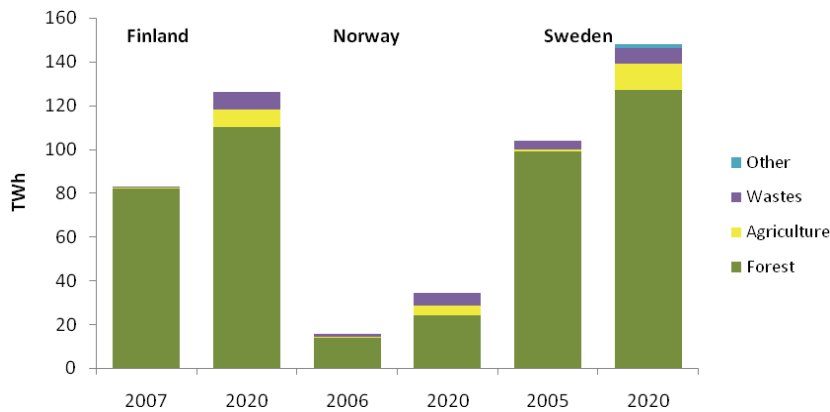


Figure 1 Current (2005-2007) and potential (2020) bioenergy supply (TWh) in Fennoscandia, for the main types of sources. Data from table 2. Note that peat is not included.

Table 3 Distribution of main land classes and population in Fennoscandia.

	Finland		Norway		Sweden	
	1000ha	%	1000ha	%	1000ha	%
Country area	33 842	100	32 380	100	45 029	100
Forest area	22 510	67	9 421	29	27 550	61
Other land	5 604	17	19 974	62	10 347	23
Inland water	3 433	10	1 952	6	3 996	9
Agricultural area	2 295	7	1 033	3	3 136	7
Arable land	2 253	7	854	3	2 643	6
of which fallow land	232	1	2	0	281	1
Permanent meadows and pastures	34	0	174	1	488	1
Population (mill., per 2006)	5.26		4.67		9.08	
Total area (ha) per person	6.43		6.94		4.96	
Forest area (ha) per person	4.28		2.02		3.03	
Agricultural area (ha) per person	0.44		0.22		0.35	

Sources: FAOSTAT, ResourceSTAT, April 2009, <http://faostat.fao.org/site/377/default.aspx#ancor>; PopSTAT, February 2009, <http://faostat.fao.org/site/550/DesktopDefault.aspx?PageID=550#ancor>;

Table 4 Forest resources and possible additional future harvesting of biomass for energy purposes (TWh) by approximately 2020, in Finland, Norway and Sweden. The data on forest resources are derived from FAO (2006) and the data on potential biomass harvesting from Kärhä et al. (2009) (Finland), Langerud et al. 2007, Berg et al. 2003 (Norway) and Anon. 2006b (Sweden). For Norway, the numbers for residues (GROT, long tops) include small trees from thinning.

	Finland	Norway	Sweden
<i>Forest resources</i>			
Forest area (1000ha)	22 500	9 387	27 528
Area of other wooded land (1000ha)	802	2 613	3 257
Forest growing stock (mill. m ³)	2 163	910	3 191
Annual growth (mill. m ³)	81.9	20.0	101.0
Annual cutting (mill. m ³)	64.3	9.2	76.8
Annual change in growing stock 2000-2005 (mill. m ³)	17.6	10.8	24.2
<i>Potential new biomass harvesting</i>			
Residues (GROT), including long tops	10-12	2.0-12.5	8.8-15.8
Stumps	10-13	0.0	5.1
Small trees (from thinnings)	17		3.0
Other clearing residues (power lines, roadsides, field margins)	2	1.5	3.0
Rotten wood	0.5		0.4
Total	39.5-44.5	3.5-14	20.3-27.3

In Finland, trees on 23.3 mill. ha of forest and other woodland comprise 2163 mill. m³ growing stock with an annual production of 82 mill. m³, 78% of which is currently harvested (Table 4). Although Finland already has a substantial bioenergy supply from forests (19% of total energy supply; Table 2), assessments indicate that this will increase by about 50% over the next decade (Antikainen et al. 2007). The emphasis is especially on increasing the use of processed wood chips, from currently just over 3 mill. m³ annually, to 15–16 mill. m³. There is also a technical potential for additional harvesting of logging debris, stumps etc, as currently only 20–30% is harvested (Laitila et al. 2008). Residues from the forest industry (especially black liquor) are unlikely to offer much new potential over current levels. The use of wood is decreasing in the pulp and paper industry, and more wood than currently may be used for energy production.

According to a recent estimate by the Finnish Forest Research Institute the use of industrial roundwood will diminish by one third (23 mill. m³) by 2020 (Hetemäki & Hänninen 2009). Part of this raw material is already used in energy production. A great majority of wood-based fuels are waste liquors that are by-products of the forest industry. The availability of such by-products is likely to decrease due to the restructuring of the forest industry.

In Norway, 12 mill. ha of forest and other woodland support a growing stock of 910 mill. m³ with an annual production of 25 mill. m³, of which only about 44% is currently harvested (Table 4). Although Norway does not have so extensive forest resources as Finland or Sweden, the proportion of currently un-harvested biomass growth is still substantial. Current bioenergy supplies from forests are limited to less than 5% of the total energy supply (Table 2). Some assessments consider the potential for additional harvesting of forest biomass for energy to be around 8.8–18.3 TWh (NOU 2006, Berg et al. 2003), i.e., an increase of 63–131% over the currently used 14 TWh. Gjølshjøl & Hobbelstad (2009) even calculated the potential current forest-based biomass usable for energy to as much as 36.9 TWh, after subtracting the energy equivalent of today's forest harvesting. However, when considering also economic constraints, Langerud et al. (2007) suggested that only an increase of about 3.5 TWh (25%) from forests and other woodlands is realistic. Most of this increase is seen as coming from the exploitation of logging debris and other woody resources currently not used to any extent. In addition, there may be some potential for increased supplies also from the forest industry (1.7–4.3 TWh; Berg et al. 2003, NOU 2006), although Langerud et al. (2007) found this unlikely. Langerud et al. (2007) pointed out that, due both to the size of biomass resources and to economic and operational constraints, about half of the potential new biomass harvest from forests would come from the central lowland forest areas in Eastern Norway, where forestry is already quite intensive. A recent assessment of the potential for forestry development in the coastal counties (from Rogaland to Finnmark) has taken a different perspective (Kystskogbruket 2008, Øyen 2008). They concluded that the coastal counties already represent a large part of Norway's potential for increased forest harvesting, that increased silviculture, improved growing stock and new tree species will greatly increase this potential, and that this will contribute considerably to Norway's capture of CO₂ in forests as well as providing ample resources for both the forest industry and bioenergy. However, the economic and technical conditions to fulfil such a potential have yet to be realised.

In Sweden, the 30.8 mill. ha of forest and other woodland contain a growing stock of 3191 mill. m³ with an annual production of 101 mill. m³, 76% of which is currently harvested (Table 4). Like Finland, Sweden already has a substantial bioenergy supply from forests (16.6% of total energy supply; Table 2). Also in Sweden forests provide the greatest po-

tential for new bioenergy production, with a foreseen increase of about 30% to 130 TWh by 2020 (Table 2). Most of this potential (20 TWh) will probably be realised by a doubling of the exploitation of thinning and logging residues, stumps, and harvesting of wood resources along power lines and roads (Fredga et al. 2008, Anon. 2006a,b). Over a longer time span (to 2050), a substantial increase (27 TWh) may also come from nitrogen fertilisation of up to 5% of the forest area, as well as other measures to increase overall forest production, such as genetic improvement of the growing stock, increased use of exotic tree species etc (Anon 2006a). Industrial by-products will only provide a limited increase (8 TWh) (Anon. 2006a).

Finland is already exploiting peat resources for energy on a large scale (7% of total energy supply) and plans to increase this up to 10% (Antikainen et al. 2007). In Sweden the government is positive to using peat (Anon. 2008a) and a doubling of peat extraction for bioenergy to 8 TWh by 2020 may be possible (Anon. 2006b). There are no plans to extract peat for bioenergy on any scale in Norway.

The agricultural area of Finland and Sweden is quite substantial, with 2.3 mill. ha and 3.1 mill. ha, respectively (Table 3). They both have about 10% of arable land currently laying fallow and, hence, potentially available for energy crops (Table 3). Energy crops already supply some bioenergy in these countries (0.3 TWh and 1 TWh, respectively, Table 2), mainly short rotation woody crops (willows) in Sweden and reed canary grass in Finland, as well as some energy from agricultural wastes. Both Finland and Sweden plan to increase the area of energy crops based on grass and willows, respectively, as well as biofuel production based on grain and oil seed crops. In Finland, various assessments indicate that up to 0.5 mill. ha of agricultural land may be used for energy crops over the next decade, with 0.1 mill. ha for energy grass and the rest for grain and oil seed crops (Antikainen et al. 2007). This may increase the bioenergy supply from agriculture from 0.3 TWh to 8 TWh or more (Table 2). In Sweden, assessments consider a potential for bioenergy from agriculture of 10–12 TWh from the current 1–2 TWh (Table 2; Fredga et al. 2008). This will be somewhat evenly divided between more efficient use of wastes and residues from food production, woody crops and grain and oil seed crops (Table 2). About half of this production is likely to come from currently fallow arable land and abandoned farmland, the rest from existing arable land (Anon. 2006a).

The actively managed agricultural area of Norway is limited, with about 1 mill. ha or 3% of the territory (Table 3), and much of it is marginal from a modern farming perspective. Currently, bioenergy from agriculture is limited to a marginal supply of straw and other residues from grain harvesting (Table 2). The Norwegian policy of not using agricultural land for energy crops implies that most bioenergy from agriculture will continue to be based on various wastes and residues from ordinary

food production. This potential is loosely estimated to around 3.5 TWh (Table 2). However, some assessments also include a potential for bioenergy crops (e.g., 3.1 TWh by NOU 2006).

In summary, the political objectives of substantially increasing the supply of bioenergy will have to be satisfied as follows for Finland, Norway and Sweden:

- Most (54–63%) of the new bioenergy supply will come from forest biomass, mainly by using more of the logging debris, stumps, long tops, small trees from thinning and clearance along power lines and roads.
- Additional forest biomass may also be harvested by application of nitrogen fertilisation and more intensive silviculture in currently managed forests, including more extensive planting, management of young forests, use of exotic tree species and introduction of genetically improved trees.
- To some extent, it may also be possible to increase harvesting of biomass from forests currently not exploited for economic or technical reasons. Technical and economic constraints will be particularly important in deciding whether the biomass potential of marginal forests will be realised.
- Finland and Sweden will probably expand their exploitation of peat resources. This is unlikely to be the case for Norway.
- Agricultural land will contribute an important part (17–23%) of the foreseen increase in the bioenergy supply. A considerable part of this bioenergy from agriculture will be based on the use of wastes and residues from agricultural production, but in Finland and Sweden extensive agricultural areas will also be used for energy crops (grain, oil seeds, energy grasses, short rotation woody crops).
- All countries will make more effective use of the energy potential in various organic wastes from households and industry.

Glossary*

Renewable energy is energy from renewable non-fossil sources such as wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;

Biomass^α is organic material that has been through little or no chemical or biological conversion.

Bioenergy is energy produced from biomass. Bioenergy may have gone through chemical or biological transformation or processing, and the raw materials may have been used previously for some other purpose. Bioenergy can be subdivided into five main types based on their origin.

- *Forest energy* is based on woody raw materials that have not been through any chemical processing; this includes logging residues, branches and twigs, bark, chips and sawdust, wood pellets and briquettes.
- *Black liquor* is a byproduct of paper manufacturing formed when wood chips are converted to pulp.
- *Peat energy* is made from peat, a partially decomposed biological material formed in bogs and fens. Peat is a carbon storage which is not taking part in the carbon circulation of nature and should in general not be considered as a renewable form of energy.
- *Energy crops* are agricultural crops (grains, oil seeds, grass etc) grown for energy purposes or woody crops (fast-growing willows or poplars) grown on agricultural land and managed like a perennial crop.
- *Bioenergy* from sorted waste is usually burned in special incineration plants; combustible gases from digestion of sludge in wastewater treatment plants and landfills also belong to this category.

Biofuels are liquid or gaseous fuels for transport produced from biomass;

Bioliquids are liquid fuels for energy purposes produced from biomass;

Energy units:

- TWh, tera watt hours (10^{12} watt hours)
- PJ, peta joule (10^{15} Joule), 1TWH = 3.6PJ.

* Adapted from Fredga et al. (2008) and EC (2009)

^α The EC Directive on renewable energy (EC 2009) has a somewhat wider definition of biomass: the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste.

3. Environmental consequences of biomass production and harvesting

As we have seen in chapter 2.2, a substantial part (78–89%) of the foreseen new supply of bioenergy in Finland, Norway and Sweden will come in the form of biomass from forests and farmland. The different types of biomass harvesting are likely to affect forests, agricultural landscapes and their ecosystems in varied and complex ways. In chapters 4–6 we will discuss such consequences in considerable detail. Here we will first identify the types of environmental values that are likely to be affected by the changes in forest and agricultural landscapes as a consequence of increased harvesting of biomass for energy. The mandate of our assessment specifies that the environmental values of concern here include biodiversity, the landscape, outdoor recreation, and cultural heritage values. Each of these themes will be discussed in turn.

3.1 Biodiversity

The United Nations' Convention on Biological diversity (CBD) defines biodiversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. Biodiversity is the foundation of all human existence, and it is essential to preserve the ability of biodiversity to maintain the ecosystem services on which humans depend for their well-being. As we have seen in chapter 2.1, the Nordic countries, as well as the European Union, are committed to halting the loss of biodiversity by 2010. Hence, the exploitation of biomass for energy should be conducted in a sustainable manner with appropriate maintenance of the components of biodiversity and their functions. This requires that we are able to identify the various biodiversity components of interest and how these may be affected by the different forms of bioenergy extraction.

Biodiversity is a complex and diverse concept that may be difficult to cover adequately in research or management. Noss (1990) categorised biodiversity according to composition, structure, and function, at a range of organisational scales. In practical conservation and resource management, the focus will usually be on species, habitats or biotopes, and eco-

system functions. Recently, there has also been a focus on the ecosystem services provided by biodiversity (Alcamo et al. 2003, Ranganathan et al. 2008). Here we will especially focus on:

- *Species*: Much of the emphasis in this report will be placed on the effects of increased bioenergy extraction on species, especially threatened species and species of conservation interest, and the habitat structures they need to persist.
- *Habitats, biotopes, and nature types* are biodiversity components in their own right, that are covered by various nature conservation instruments (e.g., the EU Habitats Directive (EC 1992) and the new Norwegian Nature Management Act (MD 2009)). Here we will be concerned with such ecosystems or nature types that are of conservation interest or that have particular ecological qualities.
- *Ecosystem functions* represent an important aspect of biodiversity through a variety of basic processes: primary production, secondary production, fluxes of energy or materials in food webs, and the decomposition of materials. Ecosystem functions are essential for the delivery of ecosystem services. Increased biomass harvesting is particularly likely to affect (i) the primary production of the plant community (vegetation), (ii) the soil processes linked to the soil organism community (mycorrhiza, decomposition, mineralization, etc) and (iii) water quality. It may also affect species interactions and food web structure.

The distribution and viability of native species and the distribution and functions of natural ecosystems will primarily be determined by local site factors (topography, geology, climate etc) and species interactions. These biodiversity components will be further modified and shaped by various natural disturbances such as wind, fire, water, and the impact of various organisms (insects, large herbivores). Landscapes are often diverse assemblages of habitats and ecosystems with very different disturbance processes because of dissimilarities in climate, hydrology, topography and soil properties. Disturbances are followed by succession, a reorganization phase when species which have survived disturbances recover and others (re-)colonize the disturbed area. Hence, natural disturbances generate heterogeneity and new niches and thereby maintain landscape mosaics and high species diversity (at least at moderate disturbance levels).

However, current landscape structure and dynamics are largely controlled by human-induced disturbance factors such as forestry and modern agricultural systems. It reduces differences in biodiversity between different sites. Many natural habitats and disturbance processes have already been severely altered or lost, and many native species have therefore become increasingly rare, shifted their distributional range or become locally extinct. In contrast, species that are capable of surviving

also in intensively managed habitats have become much more common and successively spread to new areas.

These changes correspond to a homogenization of overall biodiversity across managed landscapes. Preserving natural-like habitats and mimicking natural disturbance processes are therefore especially important. For instance, many forest species depend on particular perturbations, habitat structures or successional stages (such as fires, sun-exposed dead wood or old-growth forests). In farmlands, preservation of habitats and restoration of semi-natural meadows and pastures by grazing and mowing is important to restore and maintain the biodiversity confined to mosaics of open semi-natural grasslands and wooded pastures.

Threatened and priority species

The total number of (multicellular) species recorded in the respective countries is estimated to about 40,000–48,000 (Rassi et al. 2001, Gärdenfors 2005, Kålås et al. 2006). A large, but unknown, proportion of these species live in forests and a considerable, but probably somewhat smaller, proportion are associated with agricultural land. The species richness increases from north to south, following the general trend in biological productivity. However, the use of land has been more intensive for a longer time in the south, the proportion of protected land is lower there, and the information on biodiversity is better. Many European species also tend to have their northern limits, with marginal distributions in southern Fennoscandia. The number of species that has been identified as declining, or “red-listed species”, is therefore higher in the southern regions. Species classified as “threatened” on the national Red Lists are considered to be at risk of regional extinction (Rassi et al. 2001, Gärdenfors 2005, Kålås et al. 2006). The extinction threat is assessed based on objective criteria linked to population trend, size and structure and geographical range according to the international standard of the World Conservation Union (IUCN 2008).

The national Red Lists reflect the well-described fact that intensive forestry and agricultural production systems are the main threat factors to biodiversity in Fennoscandia. About 40–50% of the red-listed species may be classified as forest-living species, whereas 28–48% of the species may be associated with habitats on agricultural land (Table 5). Many of the red-listed species are insects (mainly beetles), vascular plants and cryptogams (mosses, lichens and macrofungi; Table 6).

As much as 85% of the red-listed species in Norway is considered to be threatened by various forms of habitat loss and degradation (Kålås et al. 2006). Approximately 1470 species are classified as negatively affected by various forms of forestry, whereas 750 species are threatened by activities in agriculture and 950 species by dense, re-growing vegetation, mainly caused by abandonment of traditional farming activities or by afforestation. In contrast, pollution and climate change threaten a rela-

tively small proportion of the red-listed species (6%). The dominance of habitat loss and degradation as the main threat to red-listed species is similar in Finland and Sweden (Rassi et al. 2001, Gärdenfors 2005).

In forests, the main reasons for species decline are the great reduction of the area of natural forest and the structural simplification of managed forests. The great reduction of coarse dead wood (or coarse woody debris; CWD) and large trees are important factors. For instance, about 20–30% of all forest-dwelling species are depending on dead wood for their survival and reproduction (Siitonen 2001, Gärdenfors 2005). Wood-living

Table 5 The number of all species recorded, red-listed species, and the proportion of red-listed species that are found in forests and farmland, respectively, in Finland, Norway and Sweden. For Norway and Sweden all species on the national red lists are included. For Finland only species in the red-list categories CR, EN, VU are included (not NT), and they are allocated to forest or farmland as primary habitat. For Norway, red-listed species on Svalbard are not included. (Rassi et al. 2001, Gärdenfors 2005, Kålås et al. 2006)

Country	Red-list year	Total number of species	Total number of species assessed for red-listing	Red-listed species	Proportion (%) in	
					forest	farmland
Finland	2001	43 000	19 000	1 505	38	28
Norway	2006	40 000	18 500	3 799	48	35
Sweden	2005	48 000	19 875	3 771	51	48

Table 6 Large numbers of red-list species are found among insects (mainly beetles), vascular plants and cryptogams (mosses, lichens and macrofungi). The proportions of red-listed species that utilize forests and agricultural land are shown for each species groups. Note that a species may occur in both types of habitats. For Norway, numbers cover the mainland, not Svalbard. For Finland only species in the red-list categories CR, EN, VU are included (not NT), and they are allocated to forest or farmland as primary habitat. (Rassi et al. 2001, Gärdenfors 2005, Kålås et al. 2006)

Species groups	Finland			Norway			Sweden		
	No. of red-listed species	Proportion (%) in		No. of red-listed species	Proportion (%) in		No. of red-listed species	Proportion (%) in	
		forests	farmland		forests	farmland		forests	farmland
Mammals	7	57	14	25	44	40	19	68	37
Birds	32	25	13	78	42	32	91	41	38
Amphibians, reptiles	3	33	0	5	100	80	9	44	67
Insects	731	-	-	1792	46	39	1683	40	44
Beetles	347	48	30	801	48	37	848	56	60
Moths, butterflies	241	16	57	428	32	62	379	37	66
Spiders	12	25	8	93	37	47	71	54	31
Vascular plants	180	19	28	384	25	48	485	17	68
Bryophytes	91	15	0	215	30	28	220	39	27
Lichens	99	31	10	230	61	36	254	83	47
Macrofungi	265	80	13	744	82	29	632	89	31

(saproxylic) species therefore comprise about 30–50% of the red-listed forest species in the respective countries (Rassi et al. 2001, Gärdenfors 2005). Another reason is that forestry has largely decoupled forest habitats from their natural disturbance processes. Many forest species depending on fire, sun-exposed dead wood and the early phases of natural successions are therefore characterized by declining and threatened populations.

General biological productivity and tree species composition are also important for forest species, and may thus overlap with the forests with the highest biomass production. Stokland (1997) found that the species richness of birds and beetles, including red-listed species, was far higher in forest dominated by deciduous trees than by coniferous trees. Productive broad-leaved deciduous forests tend to have the highest species richness, and 30% of red-listed species in forests occur primarily in such forest types (database for the Norwegian red-list, Kålås et al. 2006). However, also forest of low productivity has been shown to host unique parts of the red-listed species; 2% of Swedish red-listed species are mainly associated with unproductive forests (impediment) (Cederberg et al. 1997).

Some habitats comprise unique environmental settings (e.g. sites on calcareous soils) and may therefore be biodiversity 'hot spots' and host many exclusive and naturally rare species. Furthermore, where fragments of natural-like habitats still remain, they often comprise the richest and most threatened reservoirs of species diversity. For example, 25% of all red-listed macrofungi in Norway occurs in broadleaved forests which constitute only about 1% of the total forest area (Svedrup-Thygeson et al. 2007). Another example is old-growth swamp forests which comprise some of the most species-rich forest habitats in Fennoscandia. Mapping of such biodiversity 'hot spots' and remaining natural-like habitats have therefore been a priority in sustainable forest management during the last 10–20 years (e.g., so called key-habitat inventories; Nitare & Norén 1992). Such habitats are not always formally set aside from management but should routinely be protected from biomass production.

On agricultural land, the large-scale changes during the 20th century have decreased the amount of managed meadows and pastures, i.e., areas that were mowed or grazed. The more economically productive of these habitats have been taken over by intensive agricultural production systems, whereas marginal agricultural land has been abandoned to spontaneous regrowth with scrub and trees or converted to forest by afforestation. Agricultural land close to towns and cities has also been taken over for housing, transport or industry. The overall effect is a homogenization of habitats, removal of natural biotopes, and reduction of small-scale heterogeneity, with negative impacts on several species associated with agricultural landscapes. The rapid loss of open, unimproved permanent grasslands is a particular threat to many species of the old agricultural landscape, as well as to characteristic biotopes of this landscape (cf section 3.1.2).

The Bern Convention (CoE 1979) and the EU Habitats Directive and Bird Directive (EC 1979, 1992) specify species of European conservation interest, and the Nordic countries are committed to preserve these species and their habitats (cf chapter 2.1). The individual countries have also identified species of national conservation concern and have given some of these species legal protection. Habitats hosting such designated species should be protected from negative impacts of bioenergy production. The

following habitats for red-listed species may be particularly sensitive with respect to increased biomass harvesting:

- Broad-leaved deciduous forests of various types
- Species-rich forest types: calcareous forests, rich swamp forest, rich boreal deciduous forests
- Remaining old-growth forest and forest structured by natural ecosystem dynamics
- Traditionally managed agricultural landscapes, with permanent, unimproved grasslands, wooded meadows, and parks with old/large deciduous trees
- Remnant biotopes, farm ponds, streams, field islets, etc in intensively managed agricultural landscapes

Threatened and priority habitats and biotopes

Conservation interest of many habitat types is motivated by their function as important core areas and resources for threatened or other priority species. Ecosystems, biotopes or nature types may also have conservation value in their own right, by representing unique assemblages of natural features and characteristic species communities. The Bern Convention (with its Emerald Network; CoE 1979) and the EU Habitats Directive (EC 1992) specify a number of different habitat or biotope types that should be protected against threats to their favourable conservation status. As EU members and/or Bern Convention parties Finland, Norway and Sweden are formally obliged to ensure the favourable conservation status of these specified habitats (cf Sohlman (2008) for the status of the Habitats Directive priority habitats in Sweden). Hence, these types of habitats or biotopes should not be used for increased bioenergy production.

The individual countries are also in the process of identifying habitat or biotope types of national conservation interest (e.g., Norway's new Nature Management Act (MD 2009)). Threatened vegetation types in Norway were identified by Fremstad & Moen (2001) and included thermophilous spring forest, rich wooded fens, rich swamp forest, alder sea-shore forest, various other rich forest types, various grassland formations, and coastal heathland. The individual countries will also have a responsibility to preserve certain characteristic habitat or biotope types that may otherwise be rare in Europe. In Norway, this includes the 'boreal rainforest' of central Norway and other oceanic forest types, coastal heathlands, stream canyons, and grasslands characterised by long-term traditional management. Although coastal heathlands and grasslands have been formed and maintained by long-term management, they have little economic value today. Hence, such biotopes have often been the target of afforestation efforts, in spite of their obvious biodiversity values. It seems reasonable to assume that all habitats or biotopes in Fennoscandia that are considered as areas of high conservation value will not be used for in-

creased bioenergy production. This assumes, however, that the locations of such biotopes and their biodiversity values have been identified and that adequate regulatory instruments exist to ensure the maintenance of their conservation value. Nevertheless, we will not assess such biotopes or habitats of designated conservation value any further in the context of biomass harvesting.

The capacity of landscapes to sustain biodiversity will not only depend on what is done in protected areas or especially valuable habitat types, but also on the management of areas used for commercial biomass production. For instance, in order to improve the prospects of forest biodiversity, ‘new forestry’ has been widely implemented since the 1990s (Larsson & Danell 2001). It involves using the disturbance processes of natural forests as a model to guide the design of the managed forest. Small-scale biotopes are protected and structural elements such as large and old trees and dead wood are retained at harvesting sites. This is also referred to as “general environmental considerations for managed forests”. Such environmental considerations are part of the requirements for the various forest certification schemes (e.g., Anon. 2003, Living Forest 2006). Likewise, various subsidy schemes for the management and restoration of semi-natural meadows and pastures, as well as other support schemes to improve conditions for agricultural biodiversity and landscape quality, have been applied in Finland, Norway, and Sweden to increase biological values in agricultural landscapes (Anon. 2008b).

Thus, when increasing bioenergy production valuable habitats or biotopes should be avoided and general environmental considerations for managed forests should be secured or reinforced. Likewise, remnant farmland biotopes and unimproved meadows and pastures need to be protected and restored.

Ecosystem processes and functional organism groups

The number, relative abundance, identity and interactions of species all affect ecosystem processes. Ecosystem processes can be considered in functional terms, for example, as primary production, secondary production, fluxes of energy or materials in food webs, and the rate of decomposition of materials. Processes working through species interactions may also affect the way ecosystems are regulated, their trophic dynamics, and key mutualistic functions such as pollination. Such ecosystem functions may be distorted if the diversity of species changes due to management, e.g., through increased biomass extraction.

Species in an ecosystem that are functionally equivalent, meaning that they do much the same thing, are usually grouped together as functional types (e.g. plants, herbivores, carnivores, decomposers). Particularly plants (vegetation) are fundamental components of any ecosystem. In terrestrial and some aquatic ecosystems they act as physical habitat structures for other organisms. They are also ‘primary producers’ and affect

the efficiency with which resources are sequestered and processed, as the foundation of the consumer food chains. Changes in plant species diversity, or merely the reduction of overall plant biomass, may therefore affect the 'secondary production' in the food chain. Another group of key importance in terrestrial systems is that of various soil organisms. They are vital for the many aspects of soil functions. Mycorrhizal fungi help tree and plant roots to absorb nutrients. Soil animals, bacteria and saprophytic fungi facilitate decomposition and nutrient cycling. Through changes in biomass production, storage and extraction from ecosystems, increased bioenergy production may have profound effects on such functional aspects of ecosystems.

3.2 Landscape and outdoor recreation

The Nordic region

Pröbstl et al. (2009) outline a Nordic region of outdoor recreation and nature tourism, including Finland, Norway and Sweden, as one of five regions in Europe. The regions were primarily derived from a combination of socio-economic and natural conditions. For much the same reason Bell et al. (2005) define a northern European landscape culture (incl. the Baltic States). The Nordic region has certain similarities – the forest dominates the landscape (except for the most south-western region of Sweden, with only 18% forest cover), the cities have expanded into the forests, the forestry sector is important for the national economy, and people are using the forest landscape frequently for outdoor recreation (Bell et al. 2005).

The landscape history has similarities in the three countries (for open farmland see chapt. 3.3). In early days, forests in the proximity of cities served the need for commodities like firewood, pasture and construction timber. Since the late 1800s, leisure and recreation gradually gained importance as a motivation for developing urban woodlands. Many of these early plantings were established for a multitude of purposes, before the concept of multiple uses was coined (Bondo-Andersen et al. 1974, Hytönen 1995). The southernmost part of Sweden and the outer coastline of Norway represent an open landscape, with small and fragmented forest areas surrounded by agricultural land. In contrast, the boreal forest zone typically comprises forest-dominated landscapes, in which managed forests are often defined as semi-natural (e.g. Peterken 1996).

During the first half of the 19th century forests in large parts of Fennoscandia were in a degraded state due to exploitation. Here, dimension cuttings were replaced by natural regeneration cuttings from the beginning of the 20th century, again largely replaced by clearcutting and planting from the middle of the 20th century (Fritzboeger & Søndergaard 1995). This period of simplification of the structure and pattern of forests in the

sole interest of efficient timber production was succeeded from the 1970s onwards by an emerging focus on aesthetic and visual aspects of forest ecosystems (Frivold 1991, Hellström & Reunala 1995, Hytönen 1995). Three simultaneous phases of development were noticeable: the intensification of forestry operations, the increase in recreational needs, and the development of the environmental movement (Hellström & Reunala 1995). To reduce conflicts, several administrators of urban woodland began to make changes in silvicultural practices (Hellström 1996, 2001) and recreational values were implemented in forestry policy, forest planning and forest management (Kardell 1978, Hytönen 1995, Gundersen 2005, Karjalainen 2006). These adaptations significantly reduced the conflict level (Hellström 2001). It is important that increased bioenergy production and extraction take the diverse public benefits and demands on forests into consideration.

Multitude of landscape values

Definitions of the landscape are variable and have various expressions in the Nordic region. The landscape as a physical phenomenon is defined in connection with nature and the cultural environment, but refers also to the landscape in terms of visual aspects and topography. The definition of landscape also varies within different cultures and societies, and even within the same society; at least 40 different definitions of the concept 'landscape' exist in Finland (Holldorsson et al. 2008). This clearly demonstrates the role of the landscape for social well-being and stresses the importance of public involvement in the creation and implementation of landscape policies (cf the European Landscape Convention, chapt. 2.1). The term landscape, even in the physical sense, implies the visual interpretation of the land and its various biophysical structures, since this is primarily how a landscape is perceived. A landscape comprises several principal categories in terms of elements: landforms, vegetation, water bodies, human-built structural elements, and depth and breadth in terms of view, but also a long list of other elements like biodiversity, human presence, direction of light and weather forms. Landscapes are diverse and can be repositories of history, rituals, cultural and spiritual meanings, social and personal identities, and emotional memories. Hence, the exploitation of biomass for energy, as all other human use of the landscape, may affect the various components that constitute the landscape, the landscape as a coherent whole, and our perceptions of the landscape (irrespective of any discernible physical changes in the landscape). Bioenergy production and extraction should allow for the stewardship of this wide spectrum of landscape features, including aspects of how people use and associate identities to special places in the landscape. To do this managers and practitioners in the landscape need both general scientific knowledge and principles for landscape planning and management, as well as local contextual knowledge about landscape values and how people use

the particular landscape where different forms of bioenergy extraction will occur.

Values connected to outdoor recreation and landscapes are a complex matter. Outdoor recreational activities have certain similarities connected to the frequency of use, most common activities and most intensively used areas, but also provide a wide spectrum of different use and preferences among the users (Jensen 1995). Outdoor recreation in Finland, Norway and Sweden is an activity most people participate in, and forests are one of the most common types of nature where people live. The accessibility as well as the quality of the areas is of importance for the intensity of use, and forest within or near urban settlements are especially important (Rydberg 1998). In terms of intensity of use, and to evaluate consequences of bioenergy extractions for outdoor recreation, it is especially important to focus on urban areas, as well as nature tourism destinations or landscapes important for scenery. Landscape is a crucial term for evaluation of the environment (Zube et al. 1982), and people's landscape preferences have shown that forest management has a large impact on landscape values (Gundersen & Frivold 2008). Many of the about 60 preference studies that have been carried out in Finland, Norway and Sweden produced relevant and important knowledge to evaluate effects of bioenergy production and extraction on outdoor recreation and landscape aesthetics.

A great diversity of landscapes exists in the Nordic region. For example in Norway, Puschmann (2005) has derived altogether 45 main landscape regions (and 444 sub-types) at the national level. Landscape regions of interest for bioenergy production and extraction exist in practically all nature types below the timberline. Forest areas are, however, considered as the most used areas for outdoor recreation in the Nordic region (Jensen 1995, Rydberg 1998, Gundersen 2005), and bioenergy extraction from forests and woodlands may influence outdoor recreation in different ways. Increased bioenergy harvesting in forests may have effects on both the physical and mental accessibility. Bioenergy harvesting will also influence the aesthetic values at stand and landscape level, as well as possibilities to participate in different kinds of recreational activities. On the other hand, outdoor recreation in open farmland is strongly dependent on the amount and condition of supply roads and designated paths, and also the amount and design of physical barriers like fences and ditches. However, open farmland represents one of the most important scenic landscapes for recreation and tourism, and bioenergy production on farmland may affect this. Increased afforestation may in most cases have significant effects on the landscape, both on landscape values that are important attractions for the users as well as more visual effects at landscape level (Bell 2004). It is important to note that there exists no common conceptual basis for indicators for visual aspects of landscapes like that for landscape ecological indicators (Fry et al. 2009).

Thus, assessments of the consequences of increasing bioenergy extraction on visual aspects of landscapes have mainly to be based on general considerations for landscape use and appreciation.

Urban woodlands and nature tourism destinations

The level of intensity of use is an important factor when considering consequences of bioenergy production and extraction. There has been a shift of focus in forest functions since the 1970s and recreation is an important factor for all natural land. Outdoor recreation has become increasingly important in the three countries, especially around urban areas (Lindhagen 1996, NCM 1996, Hörnsten & Fredman 2000). The majority of the population in Finland, Norway and Sweden lives in towns and villages, and the urban population in 2005 comprised 82%, 76% and 84% in the respective countries (Gundersen et al. 2005). Together, Finland, Norway, and Sweden have 59% cover of forest and other woodland (75%, 40% og 54% respectively; cf Table 4), with an average 3.5 ha per inhabitant, far more than other European regions. It is, however, the quality of limited areas that is of particular importance to urban dwellers for everyday recreation, and the distance from home to the forest is the most important factor to explain the frequency of use (Lindhagen 1996, NCM 1996, Hörnsten & Fredman 2000). Those who live close to a forest site actually visit the site more frequently than those living further away. If we define urban woodlands as forests located in or close to urban agglomerations, with a multiple forest function approach, urban woodlands have been estimated to include 1–4% of the total forest area in Finland, Norway and Sweden (Gustavsson et al. 1999). Visits to urban woodlands have also been estimated to comprise more than half of all forest visits in Norway and Sweden (Rydberg 1998, Gundersen 2004) and probably the same figure can be found in Finland. Hence, it is especially important to evaluate effects of changes in biomass production, storage and extraction within or close to urban areas (cities and villages) or other intensively visited areas like nature tourism destinations and areas with leisure cabins.

Factors important for aesthetics

Various disciplines have taken different approaches to derive knowledge about landscape aesthetic values. Lothian (1999) proposed that landscape quality assessment may be based on two contrasting approaches, one which regards quality as inherent in the physical landscape (objective) and the other which regards quality as a product of the mind (subjective). These approaches underlie the surveys of the physical landscape and studies of observer's preferences, and Lothian (1999) concluded that the subjectivist model should be used in research of landscape quality.

The field of behavioural psychology is central in exploring human preferences for and perceptions of landscape, and evolutionary biology complements this cognitive tradition by focusing on how humans,

through evolutionary history, have developed both positive and negative feelings for nature. The stimulus-response based approach has been an important basis even for landscape planning and forest design, and an essential contribution to the understanding of human perception of the environment (e.g. Kaplan et al. 1998). Thus, several disciplines like environmental psychology, landscape architecture, forest research and cultural geography have focused on measuring scenic beauty, preferences among the public and socially acceptable management practice (Zube et al. 1982). Scenic aesthetics can be used as an umbrella term for theories using quantitative studies of like-dislike, visual or scenic quality, natural scenic beauty or preferences among the public or more specific groups of people. A large part of the research is about recreational people's appreciation for forest landscapes, but it is important to note that studies of scenic landscape appreciation have also involved perceiving landscapes through windows, from home or working space, as well as from different moving vehicles. Increased bioenergy production and extraction will leave signs in the landscape that will affect the scenery in both a positive and a negative manner.

The public experiences landscapes from both close at hand and as a scenic background. Public perceptions of forest amenities have been investigated in several preference studies in the Nordic countries (for reviews see Aasetre 1992, Axelsson Lindgren 1995, Jensen 1995, Gundersen & Frivold 2008). A common pattern in the results is that people's preferences for a forest stand increase with increasing tree size and advancing stage of stand development. Some surveys indicated that the public tended to give high scores to irregular stands with a mixture of trees of different sizes, but on the other hand, a feeling of accessibility and provision of a view was also very important. Obvious traces from forest operations were little appreciated. Trained foresters were more positive to intensive forestry operations than the general population. People prefer well-managed forest stands and a few studies that included unmanaged stands found low scores for these forest structures. Preferences appeared to be fairly stable over time. In general, changes in biomass production, storage and extraction from ecosystems will have consequences for landscape appreciation in different ways, depending on the landscape features present as well as the character and intensity of the methods used. Logging residue is considered as disruptive for landscape experience of the natural state of the forest and for accessibility (running, trekking, picking berries/mushrooms), as well as being a disturbing factor in both forests and clearcuts. Hence, removal of logging debris is considered to improve recreational use of forests. Harvesting of small-diameter trees is also regarded positively as it increases the spaciousness and makes it easier to move in the forest. The preferences mentioned above tend to remain rather stable over time (Ribe 1989, Axelsson Lindgren 1990, Kardell 1990, Jensen 1995, Lindhagen & Hörnsten 2000).

Factors important for accessibility and for the spectrum of use

Outdoor recreation is considered to be important on all natural land in the Nordic region, and this region provides the greatest legal accessibility to natural land of all European regions (Pröbstl et al. 2009). Citizens have the right to free access to all public and private forests in Finland, Norway and Sweden, but this kind of activity should not cause any damage or disturbance to nature. Annually, more than 95% of the population takes part in recreation, including all kinds of non-commercial outdoor activities, e.g., hiking, skiing, bird watching and hunting (Pouta & Sievänen 2001, Sievänen 2001, Hörnsten 2000, Odden 2008). The citizens' access rights also include harvesting of non-wood products like forest berries, mushrooms, wild herbs and other products. It is also said that the Nordic tradition of outdoor recreation is characterised by simplicity and popularity, emphasising its differences from the more commercialised and specialised outdoor activities in North America and continental Europe (e.g. Hytönen 1995, Odden 2008). The dominant leisure activities among the public are linked with nature, are simple and low energy cost activities like walks, bicycle trips, picking berries, hunting, fishing, and other recreational activities (Hörnsten 2000). Farmland has on the other hand limited access for the public, and the possibility for outdoor recreation depends strongly on the amount and quality of walking roads and designated paths.

Outdoor recreation is deeply rooted in the history of using the landscape for different purposes in Finland, Norway and Sweden, and is today an important part of public health and well-being. Many studies have found a relationship between nature experience and positive effects on our social, mental and physical health (e.g. Hartig 2004). Most often, people seem to respond more positively to natural environments than to developed areas, and different theories may explain these findings (e.g. Ulrich 1993, Kaplan & Kaplan 1989). Both the possibilities for participating in outdoor recreation and the appreciation for landscapes would be affected by bioenergy harvesting. Some key factors are important to evaluate effects of bioenergy harvesting: where people use the forest, for what kind of activity, and which trends in activity are important today.

Outdoor recreation grew during the past 150 years to become one of the most common leisure activities among the populations in Finland, Norway and Sweden (Jensen 1995). For Swedish forests about 373 million visits a year are reported (EC 2003) and for Norwegian forests about 200 millions visits a year by people between 18 and 74 years (Gundersen 2005). Traditional activities like walking and cross country skiing are the most dominant part of the recreational activities in these countries. Over the last 30 years, however, there seem to have been some major changes in the recreational use of forests and other land (Hörnsten 2000, Sievänen 2001, Odden 2008):

- Outdoor activity is becoming more varied and specialized.
- Recruitment is failing in certain traditional activities (cross-country skiing, rambling, picking berries and mushrooms, freshwater fishing, rowing).
- There is strong growth in young people's participation in new forms of outdoor recreation (mountain biking, kiting, kayaking and different kinds of extreme sports activities).

Reasons for visiting forest areas can be as diverse as the visitors themselves (Hytönen 1995, Odden 2008). The issue of outdoor recreation includes basic questions about human perception of the environment, the role of place and landscape for identity, and the evolution of a modern, or post-modern commercialized society. Important traditions in research on outdoor recreation are, however, largely based on empirical surveys of behaviour, attitudes, and expectations of forest visitors and stakeholders in a context of spatial conflict resolution and land management (e.g. Patterson et al., 1998). Today it is a trend that people want well-managed forests including quality infrastructure and facilities. Urban areas tend to have most facilities, whereas remote areas have the fewest. This is closely related to the wilderness experience (Hallikainen 1998). The management for bioenergy extraction will also have to consider the possible effects increased harvesting activity could have on people's experiences in more remote wilderness areas. An expanding forest road network to increase the rational harvesting of forest biomass in remote areas would lead to a reduction in the remaining wilderness areas, e.g., such as represented by the Norwegian INON indicator for areas without roads and other technical infrastructure.

Accessibility, both mental and physical, is extremely important for the possibilities of participating in different kinds of recreational activities. Visual penetration, defined as the length of a viewer's unobstructed line of sight in the forest stand, is one of the most important factors for people's appreciation of forest stands as well as mental accessibility to nature. It depends on a number of factors: tree density from planting or natural regeneration, tree species composition, season of the year (leaves off or on), topography, and land features (lakes, clearings, power line clearings, roads, etc). Bioenergy harvesting from established forests may in most cases improve the visual penetration at stand and landscape level, whereas management activities like short rotation forestry and afforestation will give a more obstructed view of the landscape.

3.3 Cultural heritage values

Humans have used and exploited the forest landscape since the forest regenerated after the last ice age some 11–12 000 years ago. The human utilization of the forest is versatile and is historically tied to the forest as

biomass and the forest as land use area. Trees were cleared, areas in the forest settled and cultivated. Moreover, the trees constituted an important resource used for many purposes: timber, charcoal and tar production etc. In some forest areas dwelling sites, grave mounds and cairns etc show an extensive settlement combined with a versatile exploitation of resources back to the stone age. Hunting and fishing have been important activities during all time, as well as agriculture with grazing and cultivation from the Neolithic. In addition, production of commodities like iron, tar, charcoal and so on has left innumerable traces in the forests (Jacobsen & Follum 1997). These traces can be managed like single objects or be defined as cultural environments in those cases where they form entireties. An iron production site for instance is a part of a larger production system that includes a range of adjacent charcoal pits, nearby bogs where iron ore was taken, trees used for charcoal etc (Risbøl 2005). Thus the effects of increased biomass harvesting will have consequences not only for objects but also for larger environment and landscape entities constituted of cultural and natural elements in the landscape.

As opposed to farmland, influenced by thousands of years of agricultural activity, the forest and outfield areas have undergone less dramatic topographical changes. Due to the space-consuming character of agriculture, arable land has been transformed in a much more extensive way than in the case of forests. Because they have been less affected, the forests offer good opportunities to find and explore less degraded cultural remains and monuments still visible in the landscape.

Before the introduction of farming some 6000 years ago the whole landscape (except the mountain areas) was covered with forest where hunters and gatherers lived. Slowly, a more open agricultural landscape was formed by people clearing the forest in order to cultivate the land. Generations of hunters and farmers have marked the landscape and left innumerable traces which today are found as cultural monuments and remains in the landscape (Jacobsen & Follum 2008). Many of these are visible, like grave mounds and hill forts, whereas the main part is hidden structures and cultural layers not visible on the surface.

Even though arable land has been cultivated for generations remnants of constructions or cultural layers are often present below the plough layer. Postholes from prehistoric houses, cooking-pits, graves etc are often found in the underground together with cultural layers consisting of an accumulation of waste and debris left by people living at the location when it was settled centuries ago. These structures and layers are especially vulnerable to increased ploughing depth that will damage or destroy them (Wallin 1994).

Values connected to the cultural heritage are quite a complex matter as this includes cultural remains, buildings and other monuments as well as cultural environments where sites and monuments form larger enti-

es⁶. Also cultural layers which are not visible above the ground are ascribed with cultural heritage values. A large part of all cultural remains and monuments are protected by law. Some are automatically protected, whereas others are protected by law due to specific resolutions. All these levels contribute to the creation of overall landscapes whose development is based on the action and interaction of cultural and natural factors.

These landscapes are not static but undergo a process of continuous change. Increasing biomass harvesting will inevitably contribute to further landscape changes. In this context though, our review will mainly focus on the effects on cultural remains and monuments (except buildings⁷) as well as consequences to cultural environments (inclusive of buildings).

The effects of different actions on cultural heritage values are also complex and it is not possible to elucidate all consequences in detail within the frame of this review. This is partly owing to the limited extent of this review and partly due to a lack of research-based knowledge. More research is required to create a knowledge-based foundation for more of the decisions that will be made in the future concerning effects on the cultural heritage of increasing biomass production and harvesting.

The present management of cultural heritage values is mainly based upon information from national registers and databases where many remains, monuments and sites are listed. It is important to underline that these registers are imperfect and only cover a minor part of what is desirable. This is mainly due to insufficient survey coverage (Harby 2003). We do have a fairly good overview of visible monuments and remains (but not cultural layers) in settled farmland areas. This is far from the case in forest and other outfield areas where only a very small part has been surveyed and mapped (Risbøl 2006). In Sweden it is calculated that 80% of the forest areas have not been surveyed for cultural heritage values (Gustafsson et al. 2009). This fact is a great challenge in relation to all tasks carried out with a potential to threaten cultural heritage values, especially in forests.

⁶ The term *Cultural environment* is defined as *any area where a monument or site forms part of a larger entity or context*. (Ministry of Environment 1978 § 2).

⁷ It is anticipated that buildings as cultural objects not will be directly exposed to the effects of increased biomass harvesting in the same degree as other monuments and that buildings for that reason are not given the same attention in this case.

4. Forests

4.1 Increased harvesting of biomass from forests

If more biomass from forests shall be used for bioenergy, certain measures must be implemented to produce and harvest this additional biomass. Here we will briefly describe relevant measures that may be used to get more wood-based biomass out of the forests. These measures may address

- biomass that is already available in today's managed forests, but that for various reasons has not yet been harvested for bioenergy or other purposes
- ways to increase the production of harvestable biomass from today's managed forests
- how additional biomass may be harvested from forest areas that are currently not harvested, or how additional woody biomass may be produced and harvested from other, non-agricultural land

The purpose of this description is not to give any quantitative prediction of the extent to which these measures will be implemented. Rather, we will give an indication of how they will operate within the forest ecosystem as a background for the assessment of the possible consequences of such measures for biodiversity, landscape appearance, outdoor recreation, and cultural heritage values.

4.1.1 Additional biomass harvesting from managed forests and woodlands

Logging-residue harvesting

Residues for harvesting mainly comprise branches and treetops ('GROT' in Scandinavian short-hand). Residues are primarily harvested from clearcuts and to a lesser extent from thinned stands. Forest stands selected for residue harvesting are mainly located on mesic grounds with high productivity. They are usually dominated by Norway spruce (*Picea abies*), thereby generating large amounts of harvestable residues. About 65–75% of the residues produced at final cutting are extracted during residue harvesting (Eriksson 1994, Rudolphi & Gustafsson 2005).

Residue harvesting is currently widely applied in Finland and Sweden, but the intensity varies considerably between regions. For instance, about 20–25% of the annual clearcut area is used for residue harvesting in Finland and Sweden, but as much as 50% of clearcuts are harvested in the

coastal area of southern Finland and in southern Sweden, compared to only 2–5% in northern regions (Berglund 2006, Kuusinen & Ilvesniemi, 2008; Figure 2). In Norway, there is still only very limited harvesting of logging residues (<1% of timber volumes; S.M. Sjøgnen, pers. com.).

During clearcutting forest residues are put in small piles along the strip roads. The piles are left on the clearcut for some time to shed some of the needles and thereby return some of the nutrients (nitrogen and minerals) to the soil. A roundwood forwarder is then used to transport the residues to a roadside landing where they are left some additional time, usually covered with paper to reduce uptake of moisture. The residues are usually chipped at the roadside but may occasionally be chipped in a forest chip terminal or at the power plant which uses wood fuel.

Alternatively, the residue piles may be chipped directly on the clearcut and thereafter transported to the thermal power plant. Fresh residue piles may also be turned into ‘energy bundles’ by a forwarder equipped with special machinery, a bundler. The bundles are forwarded to the roadside and subsequently transported to the place of use, where they are chipped or crushed.

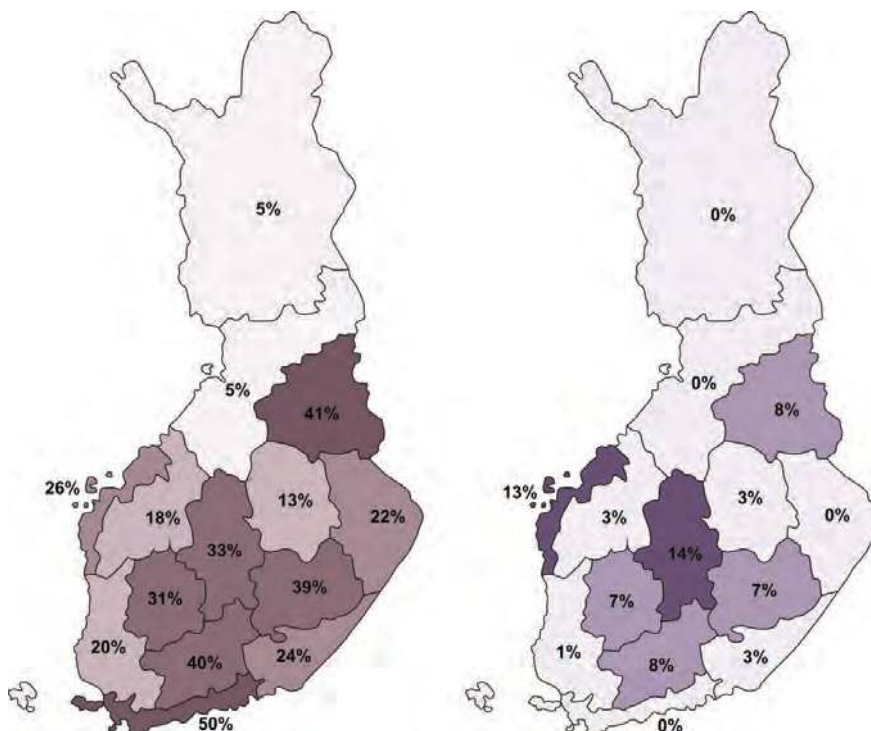


Figure 2 The proportion of crown biomass harvested sites (left) and stump harvested sites (right) of clearcuts in 2006–2007 (Private forests) in Finland.

Source: Metsätalastollinen vuosikirja, (2008a). Original Source: Metsäkeskusten luonnonhoidon laadun seuranta 2006–2007

Stump harvesting

Stumps have been harvested in Finland since 2001, and about 5% of the clearcut area is harvested annually. More than 0.4 million m³ of stump-wood fuel was harvested in 2005, which is a threefold increase of the production in 2004 (references in Egnell et al. 2007). The interest in stump harvesting has recently increased also in Sweden (Egnell et al. 2007), but the issue is not considered in current plans for biomass harvesting from Norwegian forests (although Langerud et al. (2007) have calculated the biomass potential of stump harvesting). The description of stump harvesting below is based on the practice in Finland.

Stumps are currently only harvested on clearcuts, usually within a year after clearcutting, and with almost no exception after first extracting the residues. Hence, residue and stump harvesting along with round-wood harvesting comprise so called 'whole-tree harvesting'. As for residues, mainly spruce-dominated stands near densely populated areas and consumers (thermal power plants) are targeted for stump harvesting (Egnell et al. 2007). Moreover, stumps are not harvested in stony places and steep slopes because of the heavy machinery used.



Figure 3 Current stump-harvesting technique; an excavator with a stump-lifting head is used to lift the stumps and cut them into pieces. Photo: Pär Aronsson.

An excavator (23 tons or heavier) with a special ('Pallari') stump-lifting head is usually used for stump harvesting. After lifting the stump, it is split into 2–4 smaller wood pieces by squashing it between the main teeth of the head and the opposite knife (von Hoffsten 2006; Figure 3). The stumps are shaken with the excavator to remove as much of as possible of the stones and soil that are attached to the roots. The stumps are put in small piles along the strip roads on the clearcut and then a roundwood forwarder with extended loading space transports the stumps to a roadside landing. About 75% of all stumps on clearcuts are usually extracted during stump harvesting (Antikainen et al. 2007). The stumps are stored at roadside for several months to dry by sun and wind, and to get soil and stones washed away by rain. Finally, the stumps are transported to a terminal or a thermal power plant, or to a road-side mobile crusher, where they are crushed.

Non-standard woody resources, sub-standard trees from stand tending and thinning

Non-standard woody resources include round wood that is harvested at clearcutting but without economical value, e.g., wood of deciduous trees or wood types that are normally left on the cutting site such as snags, damaged trees, bolts (lower, rotten parts of trunks), small trees, etc. The current objectives for environmental concerns in forestry generally recommend that such trees and other wood remains be left as biodiversity resources (cf the environmental standards for forest certification (Anon. 2003, Living Forest 2006)).

Tending or thinning of forest stands is conducted to provide the remaining, most productive trees with more light and nutrients. The main purpose is to produce higher quality wood (i.e., for the ordinary forest industry) and a better economic result. It is unlikely to produce more overall forest biomass per unit time and area. Harvesting of excess trees in forest stands may occur at two main stages of the management cycle, as part of the tending of young forest stands by removing excess trees of little future value, and as part of the thinning of older stands to give remaining trees an opportunity for extra growth before logging. In the first case, the removed trees are too small to have any ordinary commercial value, but they could be used for biomass for energy (like logging residues). When thinning of older stands, the harvested trees have usually been supplied to the ordinary forest industry, but could also be used for bioenergy (especially the resulting logging debris). Harvesting of biomass at either of these stages implies additional management effort and disturbance of the forest stand, as well as removal of biomass otherwise left in the stand, compared to management with only final clearcutting. Cultivation efforts of young forest stands as well as thinning of production forests are currently considered to be below optimal levels by authorities and forestry organisations in Norway.

Bioenergy from non-standard wood resources on clearcuts or sub-standard trees cut during thinning does not seem to be used on any large scale today. However, whenever it will become profitable to extract more of such wood for bioenergy, these non-standard woody resources will come into focus.

Resources under power lines and along roads

Trees and bushes under and near power lines are routinely cut to avoid that trees are knocked down over power lines during stormy or snowy weather. There are several hundred thousand kilometres of power lines in Fennoscandia, of which almost 39 000 km of high voltage lines (>100 kV) are owned by the national transmission system operators (<http://www.entsoe.eu/resources/publications/nordic/annualstatistics/>). It is mainly the high-voltage (>50 kV) lines of the national and regional electricity grids that have wide enough transects (9–40 m) to represent a potential biomass resource. For instance, in Finland there are 50 000 ha of power line corridors at least 20 m wide. The frequency of cutting depends on the annual length increment of trees, which may vary from 0–2 m, but on average cutting is done every 6–10 years. The resulting woody resources are now mainly left on the ground (Kuussaari et al. 2003), but may be harvested as biomass for energy. Presently, part of the forest area under power lines in Finland is used for Christmas tree cultivation (Joulukuusi kasvaa kivikkopellollakin 2004), but short-rotation forestry, such as willow cultivation, under power lines has been suggested as a method to increase bioenergy production (Lahtela 2008). Harvesting of energy wood requires co-operation between the land owner and the electricity company (Koistinen & Äijälä 2005), particularly on the use of the potential biomass resources.

The road network also consists of thousands of kilometres of roads where there is a need to clear the roadsides of bushes and trees to reduce traffic hazards. Recently there have also been complaints (in Norway) about the “green tunnels” of trees that prevent travellers from enjoying a view of the landscape. Whereas clearing along roads to reduce traffic hazards may only affect the nearest couple of metres on either side of the road, more extensive clearing may be needed to open up the view. The frequency of clearing may be about the same as for power lines. Although the “productive area” for biomass may be limited, the roads represent a very accessible infrastructure for harvesting of this biomass. Fragmented ownership along roads may present a problem for rational harvesting.

4.1.2 Increasing production of harvestable biomass

In addition to harvesting more of the existing biomass from currently managed forests and woodlands, several measures may be implemented to increase the forests’ capacity for production of harvestable biomass.

This covers various silviculture management measures to speed up forest growth, cut the turnover time, and/or increase the forest biomass per unit area, and thus produce more harvestable biomass per unit of time and space. It will also include improvements in the growing stock and improvement of site productivity by fertilization.

Forest management to increase biomass production capacity

Variation in age structure and species composition will generally be positive for forest biodiversity and landscape appearance, but may not give the highest biomass production. Various measures may streamline the biomass production capacity:

- *Soil preparation* such as patch scarification, mounding or ground ploughing may help seeds or seedlings of forest trees to grow without being hindered by a dense humus layer or competition from other vegetation. This is likely to speed up the establishment of new forest after clearcutting. Surface scarification is used to some extent in Norway, and will normally have only a marginal effect on the forest humus layer. Deeper scarification or ground ploughing is rather extensively used in Finland and Sweden, where it will turn over the surface layers down to 0.5 m depth. In Finland, soil preparation is applied to about 1% of the productive forest area annually (Asikainen 2004), and in Sweden the equivalent figure was about 0.8% in 2006 (Grönvall 2008). In Norway soil preparation is less common (and only involves patch scarification), affecting about 0.06% of the productive forest area in 2008 (SSB 2009a).
- *Planting of new forest trees* is standard procedure in most cases for Norway spruce, somewhat less for Scots pine where natural recruitment from seeds (or seeding of collected seeds) may be sufficiently effective. Planting will quickly re-establish the forest and may be the only option where the humus layer or other vegetation is dense. In Finland and Sweden, planting or seeding is the rule after clearcutting, but this is less so the case in Norway where professional foresters and forest authorities have expressed worries about inadequate planting efforts during the last decade (on average 40% less than the previous decade), and 40% of the forest regeneration area is judged to have sub-optimal planting density (LMD 2009). Hence, there may be a potential for increased biomass production by increasing planting efforts where this is currently below recommended levels. By further improving the growth properties of the seed stocks used for new plants of Norway spruce, additional biomass production may be achieved.
- *Increased cultivation and thinning efforts* of young forest and old production forests (cf section on biomass from thinning above) may lead to improved growth and accumulation of more harvestable

biomass in the remaining trees. The economic results from thinning activities are generally poor and this measure may be used less than optimal biomass production should warrant.

- *Reduced rotation time* and quicker harvest of over-mature forest stands should allow a greater amount of harvestable biomass to be produced over the life cycle of the forest stand. Much of current forest in Norway is older than optimal harvesting models indicate; the proportion of mature forest area has increased from 22% around 1960 to 32% in 2005 and only about 45% of the annual forest growth is harvested (Landsskogtakseringen 2009; Table 4). This may be less relevant in Finland and Sweden where forest operations tend to be more effective over most of the productive forest area.

Introduction of high-yield non-native tree species or GMOs

Native forest trees will through evolutionary time have become well adapted to local site conditions and the biotic communities where they live. Nevertheless, there may be exotic species or exotic varieties of native species that may grow better and produce more biomass over a normal harvest cycle. There is a long history of trying new species and varieties in forestry to improve timber production and forest economy. Non-native Norway spruce has been planted extensively in locations without native spruce, especially in Western and Northern Norway and in Southern Sweden. Lodgepole pine (*Pinus contorta*) is the most wide-spread non-native tree species in Fennoscandia, being planted on approximately 600 000 ha, mainly in upland forests of Northern Sweden (550 000 ha), much less in Finland (40 000 ha) and Norway (6000–8000 ha) (Øyen 2009). With its relatively good production on poor soils it is an important biomass resource. Several other exotic tree species have been introduced, but few have taken hold in forestry. Exceptions are sitka spruce (*Picea sitchensis*) and its hybrid (*Picea x lutzii*) with white spruce (*P. glauca*). Both the pure sitka spruce and the lutz hybrid are rather widely planted in coastal areas of Western and Northern Norway, with a combined area of about 55 000 ha (Stabbetorp 2009). Both varieties are well adapted to the oceanic and sub-oceanic climate of the coastal region and have a considerable potential as timber trees and biomass producers.

Modern gene technology may provide opportunities for developing varieties of forest trees with considerably increased biomass growth properties. Worldwide, genetically modified poplars, pines and eucalyptus have been the most frequently released GMO trees (www.gmo-safty.eu/en/wood). In Europe, poplars dominate. Field trials have been conducted for poplars in both Norway and Sweden and for birch, spruce and pine in Finland. Traits of commercial significance include modification of wood composition (lignin content), herbicide tolerance and heavy metals absorption capacity. However, we are not aware of any foreseen Nordic initiative to develop and release genetically modified trees in na-

ture, for bioenergy or other production purposes. The use of GMO trees in forestry would also not be acceptable according to the environmental standards of Levende Skog, required for forest certification in Norway (Living Forest 2006), as well as in the standards of the Forest Stewardship Council (FSC 2002).

Increased nitrogen fertilization

Nitrogen supply generally limits plant growth in boreal forest ecosystems, and trees of poor forests like the *Vaccinium* type will respond with increased volume growth when nitrogen fertilizer is applied late in the production phase (Røsberg et al. 1998, LMD 2009). Such poor forest types are common in Fennoscandia, and increased biomass growth due to nitrogen fertilization may therefore be of significance, provided that nitrogen saturation of the ecosystems is avoided. Currently, nitrogen fertilization is applied to 35 000 ha in Finland (Metsätalustollinen vuosikirja 2008b), 33 400 ha in Sweden (Grönvall 2008), but only 782 ha in Norway (SSB 2009b). In areas less affected by nitrogen deposition from local or remote sources, there will be a particular need to replenish the nitrogen supply when most of the biomass in forest trees is removed, e.g., by whole tree harvesting (Larsson 1998).

Increased wood-ash recycling (mineral fertilization)

All harvesting of biomass from forests will affect soil nutrient stores, but at moderate levels of such harvesting these stores are replenished from natural weathering processes and deposition of minerals through air and precipitation. With more extensive harvesting of biomass for bioenergy, these sources of mineral (base cation) supplies will not be adequate for most boreal forest areas, and mineral fertilization will be required to maintain soil nutrient stores (Helmisaari et al. 2008). One possibility to compensate for the loss of minerals from forest soils is to recycle the ash generated in the energy plants and forest industry by returning it to forest (Saarsalmi et al. 2004, Nieminen et al. 2005, Kansallinen metsäohjelma 2015, 2008).

Wood ash contains mineral nutrients such as phosphorus (P), potassium (K) and boron (B) that are growth limiting nutrients in forests on peaty soils. Ash does not, in contrast, contain nitrogen (N) which is the main nutrient limiting growth on mineral soils. Wood ash fertilization is particularly needed to compensate for nutrient loss from nutrient-poor peaty soils. To result in increased tree growth on mineral soils, wood ash fertilization usually needs to be supplemented with nitrogen fertilization (Røsberg et al. 1998, Helmisaari et al. 2008).

The fertilization effect of ash can last more than 40 years (Merisaari 1981) whereas nitrogen is known to increase tree growth for nearly 10 years (Saarsalmi et al. 2006). However, combined ash and nitrogen fer-

tilization may improve tree growth an additional 10 years compared to nitrogen fertilization only (Saarsalmi et al. 2006).

The annual production of wood ash in Finland and Sweden is about 150 000 and 300 000 tons, respectively. Of the wood ash, about 18% and 5% is utilized in forest fertilization in Finland and Sweden, respectively (Stupak et al. 2007). In Finnish private forests, the annual ash fertilization area is about 300 ha, while the corresponding area in forest industry and state forests (Metsähallitus) is 1400 ha (Makkonen 2008). There is currently no significant wood ash fertilization of forests in Norway (S.M. Søgne pers. com.).

Increased transportation and disturbance

The various potential measures to increase the production and harvesting of biomass from forests will need to be supported by additional infrastructure in the form of roads and machinery, as well as increased activity in the forest, both on logging roads and in the field. There may be a need to go through the individual forest stands more often and/or with different equipment and operations. Increased volumes of biomass will also result in a need for higher capacities for transport and handling outside the forests.

Some data from Finland may illustrate some of the changes that will follow also outside forest areas from the foreseen increase in biomass harvesting:

- The required number of wood-fuel harvest and transport machinery is estimated to increase more than fivefold from 2002 to 2025 (Asikainen 2004)
- Increased maintenance of the road network is required (Lauhanen & Laurila 2008).
- Increase of load sizes by extending the load space is expected (Ranta & Rinne 2006).
- Due to mismatches between harvest potential and use of forest chips on a regional level, forest chips will have to be transported over longer distances (Laitila et al. 2008).

4.1.3 Biomass production and harvesting from non-commercial forests or non-forest areas

In addition to biomass harvesting from managed forests and woodlands there may be opportunities for biomass harvesting from forest areas that are currently not managed or used as a resource for woody biomass. There may also be other non-forest land that could yield such biomass resources in the future after establishment of forest (afforestation). The land available for any of these options is likely to vary considerably among the countries.

Harvesting from current non-commercial forests

All three countries currently harvest less than the annual growth of the tree volume (Table 4). In Finland and Sweden this proportion of unharvested growth is 20–25% and may be at a level which should not be much reduced in order to safeguard the growing stock. In Norway, however, it is well over 50%, and Norwegian forest authorities have developed strategies to increase timber harvesting and associated revenue generation (Vennesland et al. 2006, LMD 2009). Elements of this strategy include increased cutting in less productive forests and in forests with difficult terrain, more building of forest roads in certain areas, and increased cutting of pine and deciduous trees relative to spruce. Overall, one would expect that an emphasis on increased harvesting of forest biomass for energy will motivate various support measures that will reinforce the strategy for increased timber harvesting.

Some of the unharvested forest growth is probably located within managed forest areas, as smaller areas consciously set aside (e.g., as valuable areas for biodiversity) or where harvesting is temporarily suspended for various reasons. However, a substantial part of the unharvested growth in Norwegian forests is located in forest areas that are currently considered uneconomical to harvest ('null areas'), due to low forest productivity, high harvesting costs or technical difficulties such as steep terrain, lack of roads etc. The extent of such non-commercial forests is difficult to estimate due to its dependence on variable economic constraints (market prices, operating costs, government support). However, Bollandås et al. (2004a,b) suggested that this area could cover 5–20% of Norway's productive forest area. Most of this is located in Western and Northern Norway. Although part of these non-commercial forest areas have low productivity, often at higher elevation, some areas (especially in Western and Northern Norway) also include more productive, lowland forests where biodiversity values may be significant (Framstad et al. 2002). These non-commercial forest areas also tend to be dominated by deciduous forest and to be located in steeper terrain than current commercial forests (Framstad et al. 2002), and they tend to have a higher proportion of old forest (Vennesland et al. 2006). To some extent, such uneconomical forest areas also exist in Finland and Sweden.

In Finland it has been estimated that in the near future over 0.5 mill. ha of unproductive forest drainage areas will be left outside ordinary production forestry (Keltikangas et al. 1986). An estimate from the forest industry is even 1.5–2.0 mill. ha (Tuormaa 2006). These former wetland areas could be restored by blocking the ditches and removing the tree growing stock (Rassi et al. 2003). Trees of unproductive drainage areas, such as downy birches (*Betula pubescens*) or low-quality pines, could be harvested as whole tree energy wood (Koistinen & Äijälä 2005).

Increased afforestation

During the approximately 200 years up to the end of the 1800s, exploitation of forest and mountain areas for grazing and fodder collection for farm animals became increasingly intense (Gjerdåker 2002). With the introduction of industrial fertilizers and improved soil management at the end of the 1800s, fodder production for farm animals was gradually shifted to arable fields and improved grasslands. Over the last 100 years this change in agricultural technology and management has fundamentally changed the exploitation of biomass resources in forests and mountains, with a drastic reduction in the use of these resources for agricultural purposes. Since around 1950, most of the grazed forest land and much of the marginal agricultural fields have either been converted to forest by afforestation or have spontaneously re-grown with bushes and trees. The increased forest growth on these areas has obviously contributed to a substantial accumulation of harvestable biomass. To the extent that further afforestation is possible on such open areas or areas with sub-optimal growing stock, additional biomass production would be possible.

In Norway for instance, new forest has been planted on about 0.26 mill. ha of potentially 0.5 mill. ha of open land in Western and Northern Norway since the mid 1950s until the end of the century (LMD 2009). A recent report has proposed the establishment of new forest on another 0.5 mill. ha in this region (Kystskogbruket 2008), but the forest authorities have concluded that 0.22 mill. ha is a more realistic figure. In Finland, the state has been supporting afforestation of farmland since the 1960s, as a measure to reduce excess agricultural production. However, since the mid 1990s, new field clearance has increased and there has been a significant reduction in afforestation, which is now below 10 000 ha annually (Figure 4).

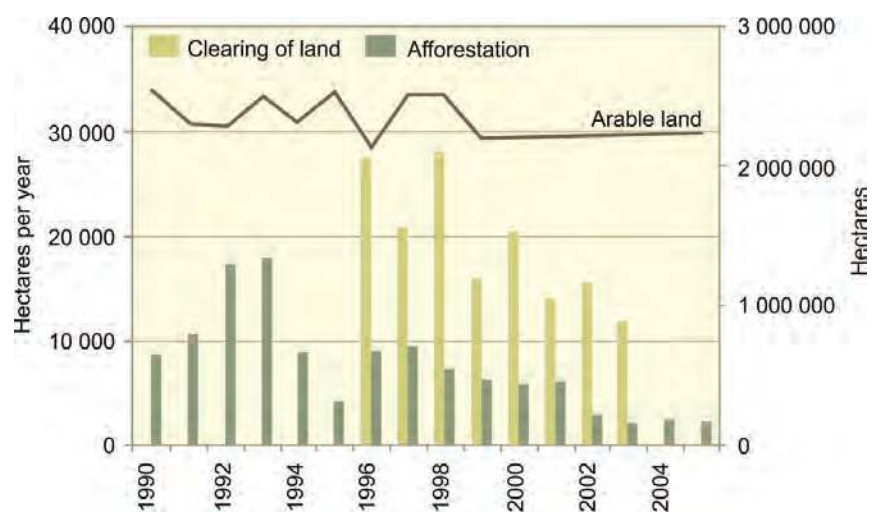


Figure 4 Field clearance and afforestation in Finland.

Source: <http://www.biodiversity.fi/en/indicators/farmlands/fa5-field-clearance-and-afforestation> (21.4.2009). Original source: Ministry of Agriculture and Forestry.

It is difficult to quantify how much agricultural land that has been used for afforestation in Sweden. The Swedish Board of Agriculture (Anon. 2008c) recently estimated that 600–700 000 ha of agricultural land have been abandoned in Sweden. Roughly 100 000 ha have been transformed into forests. The future potential for afforestation is hard to predict. However, if about 400 000 ha of the abandoned agricultural land is used for growth of spruce and hybrid aspen, it may increase the overall forest production by about 5% after 50 years (Anon. 2008d).

4.1.4 Biomass harvesting versus old-growth forest carbon sinks

Forests are important reservoirs of carbon, in the form of biomass in the above-ground parts of trees and other plants but even more so in roots and other organic matter in the soil. In boreal forests about 7 kg C/m² may be found in above-ground plants, whereas perhaps 5 times as much may be found in the soil (Royal Society 2001). The below-ground carbon stores in mires and wetlands are even greater per unit area (about 65 kg C/m²), or approximately 15 times the amount of carbon in the above-ground vegetation (Royal Society 2001).

As the forest grows carbon will accumulate both in the trees and in the soil. The rate of carbon accumulation is highest as long as the forest is actively growing and slows as the forest matures, and Norwegian studies indicate that maximum carbon accumulation may be achieved when the forest is cut 30–50 years later than current forestry models recommend (Nilsen et al. 2008). However, recent studies have shown that even old-growth mature forests may continue to accumulate carbon (Luyssaert et al. 2008). Forests tend to accumulate biomass for centuries, reaching a possible maximum upper limit of 500–700 tons C/ha in forests of the American Pacific Northwest. Disturbances of old-growth forests will lead to release of CO₂ through decomposition of dead organic matter, but this is likely to be exceeded by new primary production as long as the disturbance is small scale and not stand-replacing. In other words, it appears that mature forests with an intact multi-layered canopy structure may keep accumulating carbon for centuries.

Harvesting of mature forests by stand-replacement (i.e. clearcutting) will release substantial (but quite variable) amounts of carbon, both from the harvested biomass that is removed (or the logging waste left to decompose), as well as from decomposition of organic components in the soil, both roots and other organic carbon (Magnani et al. 2007, Nilsen et al. 2008). This loss from the forest carbon stores is rebuilt as the young forest is growing and also rebuilding the soil carbon stores. Various studies indicate net accumulation of carbon already in 10–30 year old forest (Magnani et al. 2007, Nilsen et al. 2008). Nevertheless, Luyssaert et al. (2008) have indicated that young forests are often carbon sources, due to prolonged effects of the disturbance related to the establishment of new

forest and the associated decomposition of coarse woody debris, litter and soil organic matter.

There is still considerable controversy about how boreal forests should be managed to provide the best possible contribution to build the forest carbon stores and reduce atmospheric CO₂ levels. However, it seems obvious that forest management should strive to protect the vast below-ground carbon stores of forests and mires (Royal Society 2001). It is beyond the scope of this review to explore the consequences of various forest management models for the carbon cycle. Studies like that of Luysaert et al. (2008) indicate that maintenance of old-growth forests (e.g. in forest reserves) is likely to provide a positive contribution to the forest carbon stores. Whether other forest management models may provide even higher long-term net carbon accumulation does not yet seem to be entirely clear, and there is an obvious need for more research to clarify this. However, it is clear that the high value of old-growth forests for biodiversity (cf chapt. 3.1 and the section on shorter rotation time in chapt. 4.2.3) may well coincide with a positive contribution of old-growth forests to the forest carbon stores.

4.2 Effects on biodiversity

4.2.1 Nordic forests – past, present and future

Forestry in Fennoscandia is one of the most intensive and technically developed in the world. In most regions 95–99% of the productive forest land is already under intensive management and has been heavily exploited for a long time. Hence, it is evident that increased bioenergy production in forests will constitute an additional link in a chain of different treatments. It will intensify management in forest landscapes that already have been intensively managed for a long time.

The history of forest use in Fennoscandia can roughly be separated into three phases; (1) the natural phase dominated by low intensity agrarian local forest use and large areas of natural forests, (2) the early-forestry phase (gradually intensified mainly during the 16th-19th centuries) characterized by forest exploitation and selective logging of old-growth timber trees across extensive areas, and (3) the modern-forestry phase (introduced at large scale mainly after World War II) including modern silvicultural management: clearcutting, scarification and planting of conifer seedlings. Southern Scandinavia has clearly even a longer history of intensive forest use; some areas were deforested even before the era of forestry. However, also the intensity and extent of industrial forest use varies considerably between different areas. For instance, forest resources have been heavily exploited in southern-middle boreal regions since the 17th century, especially for charcoal production for mining and melting

(Linder & Östlund 1992). In contrast, forests close to the mountain range and northern parts were at first only modestly affected. Many of the most remote areas were until the 20th century only used for low-intensity agricultural purposes.

The industrial forest use has transformed forest landscapes and their biodiversity. While the overall growth and standing volume of forests has successively increased over time, intensive management has also consistently removed biologically important structures from the forest. A clear example is the dramatic reduction (about 90%) of coarse dead wood, or coarse woody debris (CWD; ≥ 10 cm in diameter), an ecologically crucial component of natural forests (Figure 5). Also the quality of CWD has changed; cut stumps currently comprise the bulk (about 60–80%) of CWD in managed forests (Egnell et al. 2007; Figure 6).

In contrast, fine woody debris (FWD; < 10 cm in diameter) occurs abundantly due to increasing litter production of living trees and residue production by forestry. In Finland and Sweden, the volume of living trees has increased by about 50–60% since the 1920s (Egnell et al. 2006, Liski et al. 2006), and in Norway it is more than doubled in 80 years (<http://www.ssb.no/skog/>, LMD 2009). It has probably also doubled in some other regions, for instance in the Götaland region in southwestern Sweden. The increasing standing stock has resulted in increasing annual production of FWD (about 45–80%) in Finland and Sweden (Egnell et al. 2006, Liski et al. 2006). The main source of FWD is the natural input of residues and litter from the standing stock (70–80%), although the production of harvest residues is also important (about 20–30%; Figure 6).

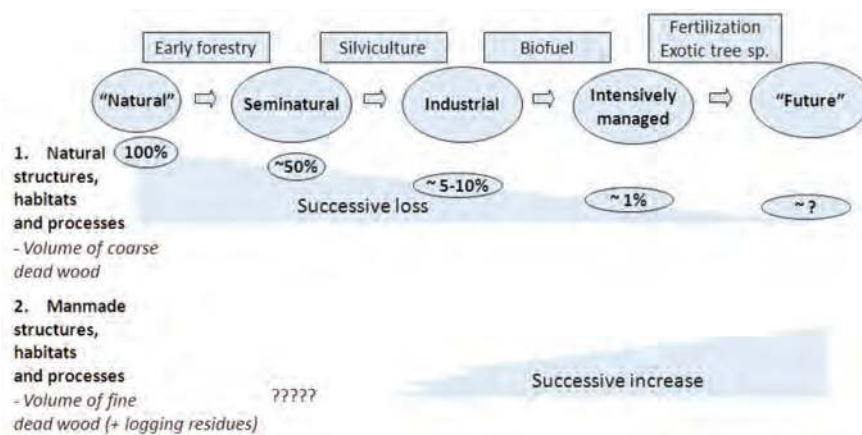


Figure 5 Tentative illustration of the loss of natural structures, habitats and processes during different phases of forest use while manmade structures, habitats and processes have become increasingly important. The relative amount and quality of dead wood is used as example.

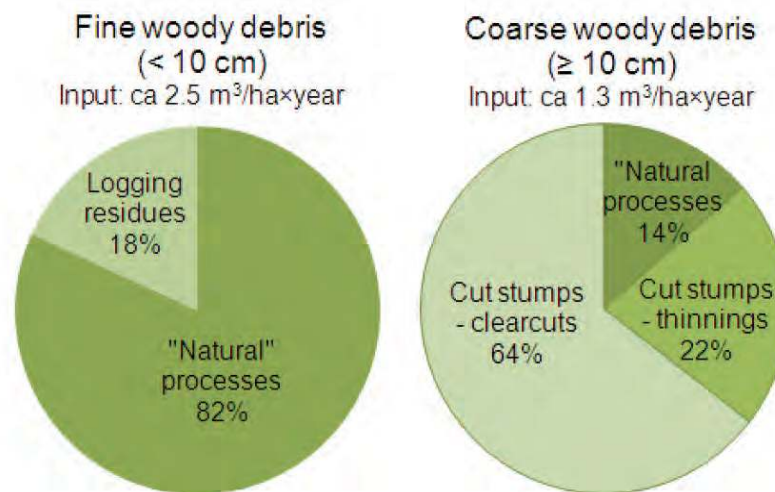


Figure 6 The main sources of fine (FWD) and coarse (CWD) woody debris in the current managed forest landscapes. Roughly 55 million m^3 of FWD are produced in Sweden every year (on average about $2.5 m^3/ha$; Egnell et al. 2006) whereas the production of CWD (including cut stumps) is estimated to about 29 million m^3 (on average about $1.3 m^3/ha$; a rough estimate based on data in Fridman & Walheim 2000 and Egnell et al. 2007). The main source of FWD is the natural input from the steadily increasing growing stock whereas the main source of CWD is stumps produced by clearcutting.

New forestry, including the retention of trees and creation of dead wood at cutting sites, may increase the amount of dead wood in managed forests. On the other hand, increased wood-fuel harvesting will decrease it. For example, while the current level of tree retention in the managed forests of Finland is about 0.5 million m^3 per year, the planned energy-wood harvesting will be about 5 million m^3 per year (Hetemäki et al. 2006).

The depletion of coarse woody debris formed by natural processes has resulted in population declines of several wood-living (saproxylic) species among various organism groups. Saproxylic species therefore comprise a large proportion (35–60%) of the red-listed forest species (Gärdenfors 2005, Gjerde et al. 2009, Jonsell et al. 1998, Tikkanen et al. 2006). Modern forestry has also promoted denser forests with only a few tree species (conifers) in contrast to landscapes influenced by natural disturbances. Hence, species dependent on recently disturbed openings and sun-exposed trees and dead wood have also declined. Retained trees, dead wood and logging residues (e.g. stumps) on clearcuts comprise the bulk of sun-exposed substrates that currently are available for these species in managed landscapes. Although the overall amount of deciduous trees has increased in Fennoscandian forests since national forest inventories began (Berggren 2008), the density and spatial distribution of deciduous trees such as aspen and broadleaved tree species (e.g. oak, linden, elm, ash) have changed because of forestry, browsing by deer and moose, the expansion of spruce, and the absence of forest fires (Edenius & Ericsson 2007, Kouki et al. 2004, Latva-Karjanmaa et al. 2007, Linder et al. 1997). Hence, many species confined to trees and dead wood of these tree

species have declined and are currently at risk of regional extinction. This pattern is evident especially in southern Scandinavia, i.e. in the boreonemoral and nemoral regions of Fennoscandia.

The existing geographical gradients in forest structure partly reflect the historical development of the forest industry (and the forest ownership structure). For instance, the proportion of old forests (>120 years old) and the average volume of coarse woody debris is usually highest in the most remote areas (such as northwestern Sweden) and on more marginal, low-productive land (Anon. 2008e). A similar pattern emerges for the Fennoscandian countries as a whole, where especially extreme north-eastern Finland has a very high proportion of such old forest, whereas only small remnants of such old forest exists in Norway (Stokland et al. 2003).

These fundamental changes to the forest landscape and its habitat structures have caused dramatic shifts in the diversity of species. Whereas specialist species confined to natural-like habitats and structures have become increasingly rare and threatened, species with broad habitat requirements (including pathogenic species) have increased their occurrences in regions with a long history of intensive forest use.

Bioenergy production will most likely reinforce the existing geographical gradients in management intensity and biodiversity. It will be concentrated to specific stand types (mainly spruce forests) and to areas (mainly southern and coastal areas) within close distance to densely populated areas (that have been exploited for wood for several centuries; section 4.1.1). Bioenergy production may thereby increase the contrasts between intensively managed forests and remaining natural-like forests. Hence, the effects of increased bioenergy production need to be assessed in relation to previous and ongoing management treatments, but also in relation to those biodiversity conservation efforts that are currently made. An elementary question is to what extent increased bioenergy production will add to the impacts on forest biodiversity caused by early exploitation and current management measures. Another important question is whether bioenergy production will counteract the effects of current biodiversity conservation actions.

4.2.2 Additional harvesting from currently managed forests

Effects of logging residue and stump harvesting:

- Negative effects of harvesting logging residues from spruce (conifers) seem small. The lack of coarse woody debris (CWD) will remain the main threat to red-listed species irrespective of harvesting of logging residues.
- Harvesting of residues of aspen and broadleaved tree species (e.g. oak, linden, elm, ash) can pose a significant threat to red-listed species.
- Residue harvesting tends to weaken the general environmental considerations for sustainable forestry; CWD tends to be extracted or destroyed, along with the harvesting of residues.
- Residue harvesting will decrease the input of nutrients (nitrogen, minerals) to the soil and may decrease tree growth.
- Stumps comprise the bulk (60-80%) of CWD in managed forests, but the information on their importance for biodiversity is incomplete. More data is required for a thorough assessment of the effects of stump harvesting.
- Stump harvesting is predicted to strengthen most of the threats to species and habitat structures that are induced by residue harvesting (see above).
- Effects of residue and stump harvesting on plant community composition (vegetation) and soil functions (mycorrhiza, decomposition and mineralization) seem to be tolerable and overshadowed by the effects of clearcutting.

Effects of harvesting non-standard woody resources:

- Increased harvesting of non-standard woody resources may result in additional reduction of CWD and valuable host trees.
- Increased harvesting under power lines and along roads will have similar effects as removal of logging residues on cleared areas, but may also expose larger trees along forest edges, thereby benefiting certain species demanding light and heat.

Logging-residue harvesting

Effects on species and habitat structure – Several comparative studies show that fine woody debris (FWD), including residues, is utilized by a large number of species among mosses, lichens, fungi and insects (Kruys & Jonsson 1999, Nitterus et al. 2004, Nordén et al. 2004, Åström et al. 2005, Junninen et al. 2006, Jonsell et al. 2007, Caruso et al. 2008, Hedin et al. 2008). Hence, the harvesting of FWD and residues from the forest landscape may reduce the amount of substrate and habitat for various organisms. For instance, because saproxylic species are clearly confined to dead wood, it is obvious that their populations are likely to decline if the amount of dead wood is reduced. Still, it is generally hard to say that the reduced amounts of FWD, including residues, will put the diversity of saproxylics at greater risk. At least spruce residues seem rarely to be utilized by threatened or red-listed species. These species usually require coarse woody debris (CWD) or other types of uncommon woody substrates for survival and reproduction. In fact, mainly generalist species with broader substrate and habitat requirements seem to utilize spruce residues (Allmér et al. 2005, Junninen et al. 2006, Jonsell et al. 2007,

Caruso & Rudolphi 2009). In addition, fresh FWD is abundant in today's forest landscapes (Liski et al. 2006, Egnell et al. 2006; see discussion above). Thus, its extraction is unlikely to pose a threat to saproxylic species (Egnell et al. 2006, Berglund 2006), with the possible exception for certain broadleaved tree species such as oak. The lack of CWD will remain the main threat to most red-listed species also when logging residues are harvested.

Furthermore, the overall habitat heterogeneity is reduced when residues are harvested on clearcuts. Species that use residues, or piles of residues, as nesting-sites (possibly birds and small mammals; Ecke et al. 2002), hideouts (ground-living invertebrate; Gunnarsson et al. 2004, Nitterus & Gunnarsson 2006, Nitterus et al. 2007) or sheltered microhabitats (drought-sensitive bryophytes; Åström et al. 2005) may therefore be negatively affected. For instance, Åström et al. (2005) showed that residues on clearcuts reduced the local extinction risk of bryophytes by providing shelter and growing substrates. The negative effects of residue harvesting on drought-sensitive bryophytes are thereby added to the stress imposed by clearcutting. Because surviving bryophyte populations facilitate re-colonization, residue-harvested clearcuts may probably recover slower than conventionally harvested clearcuts. But the position on clearcuts seems important for the magnitude of change; the bryophyte vegetation in shadier and less windy places, for example, close to forest edges, is hardly affected by residue harvesting (Dynesius et al. 2008). Many of these bryophyte species seem rather unspecific in their preferences; i.e., most of them can use other substrates and habitats to survive locally on clearcuts. Hence, other stress factors than residue harvesting seem more important for the persistence of these species.

Yet, three important threats induced by residue harvesting need to be highlighted:

- The reduction of uncommon woody substrates, such as residues of regionally rare tree species or sun-exposed dead wood, may increase the threats against red-listed saproxylic species. For example, residues of aspen and broadleaved tree species are frequently used as substrates by several red-listed insects and fungal species (Nordén et al. 2004, Jonsell et al. 2007, Hedin et al. 2008). It is therefore recommended that all or most of such residues are retained in managed forests (Egnell et al. 2006). Furthermore, many insects, especially beetles, seem to prefer the sun-exposed residues of clearcuts rather than the shaded wood materials that are produced inside forests, possibly because they need a higher temperature in the breeding substrate (Sverdrup-Thygeson & Ims 2002, Jonsell 2007, Sahlin & Ranius 2009, Maňák & Jonsell, in prep.). These insects are most likely using residues (and stumps; see below) on today's clearcuts as substitutes for the natural woody substrates that once were available in fire areas.

A large number of beetle species, including several red-listed species, are restricted to sun-exposed wood for their reproduction (Jonsell et al. 1998). Thus, residues of regionally rare tree species or sun-exposed dead wood may serve as ‘stepping stones’ even for threatened species by helping them to disperse between suitable habitats. Such species may thereby be negatively affected by residue harvesting although their regional persistence most probably also depends on the availability of suitable coarse woody debris in the landscape (see discussion about stumps below).

- Piles of residues can act as ecological ‘death traps’ for red-listed saproxylic insects. This problem is obvious when residues of broadleaved trees are harvested, but it is probably also relevant when using residues of aspen. Egg-laying adults of red-listed beetles with a 1–2 year-long larval development are attracted to the residue piles and reproduce in the stored material. The eggs and larvae of the beetles are subsequently lost if the residues are chipped and burned before the beetles have emerged (Hedin et al. 2008). Hence, the use of stored piles of such residues may significantly decrease the local populations of already regionally rare and declining species. If residues of broadleaved trees and aspen are to be removed at all, it is important to harvest the residues in an appropriate way to avoid this trapping effect (Hedin et al. 2008).
- Residue harvesting not only affects the amount of fine woody debris (FWD) and residues; it also decreases the amounts of coarse woody debris (CWD) and increases the deterioration of small biotopes on clearcuts. Thus, this reduction of overall habitat complexity, especially the loss of CWD, is a clear threat to the prospects for biodiversity, particularly the persistence of red-listed saproxylic species. The amount of logs and standing dead trees decreases significantly due to residue harvesting. Rudolphi & Gustafsson (2005) showed in a study of 23 clearcuts in central Sweden that 4 of 10 logs were extracted along with the residues. Furthermore, the quantity of coarse logs on residue-harvested clearcuts is usually 24–27% lower than on unharvested clearcuts (Gustafsson 2004, Andersson 2005). Also the quantity of dead standing trees, high stumps and retention trees are reduced in association with the harvesting of residues (relative decrease: 3–42%) although the absolute changes are usually not statistically significant (Gustafsson 2004, Rudolphi & Gustafsson 2005). Also, residue harvesting significantly increases the damages to the ground and to small biotopes influenced by water (small-scale aquatic habitats; Gustafsson 2004).

Effects on priority habitats and biotopes – All or most of the special habitats and biotopes of conservation interest should be protected from ordinary logging through formal legislation or as key biotopes set aside as part of the environmental standards for forest certification. Hence, no

logging residue harvesting should affect such biotopes. However, as we have seen above (last bullet point), it seems that environmental standards are broken to some degree during logging residue harvesting (cf removal of CDW, retention trees etc). It will therefore be necessary with special safeguards for key biotopes and biodiversity hotspots in production forests during residue harvesting.

Effects on ecosystem function – The effects of residue harvesting on soil nutrient storages and mineralization are probably site and soil specific. Nevertheless, residue harvesting will decrease the input of organic carbon and nutrients to the soil because a large fraction of the tree branches and needles is removed instead of being decomposed. For instance, about 60–70% of the nitrogen content of trees is stored in the residues, only 30–40% in the trunk (Egnell et al. 1998, 2006). Thus, 60–130 kg of nitrogen – the key limiting factor for forest productivity – can be lost per hectare due to residue harvesting after thinning (Jacobson et al. 2000). The loss due to residue harvesting after final cutting is larger; some 200–400 kg of nitrogen can potentially be lost from the system together with the residues if the needles are included (Egnell et al. 1998, 2006). Removal of residues may also alter the physical conditions, like moisture and temperature, important for soil microbial processes. This in turn may decrease the mineralization of nitrogen, making the element less accessible (Olsson et al. 1996, Smolander et al. 2008). Residue harvesting may therefore decrease tree growth (Jacobson et al. 2000) and, hence, perhaps also the biodiversity. When nitrogen losses are not compensated by input of nitrogen via atmospheric deposition or nitrogen fixation, nitrogen fertilization may become necessary. However, in many regions, e.g. the southernmost regions of Sweden and south-western Norway, the depletion of nitrogen is generally compensated by the atmospheric deposition.

However, the harvesting of residues have been shown to induce only small changes to the vegetation on clearcuts (the effects of clearcutting is much more dramatic). The species composition of vascular plants and ground-living bryophytes and lichens is fairly similar on residue-harvested clearcuts and un-harvested clearcuts. Nitrophilous species (*Epilobium angustifolium* and *Avenella flexuosa*) may decrease in abundance due to the loss of the nutrient-rich residues (Olsson & Staaf 1995, Bråkenhielm & Liu 1998, Åström et al. 2005). Drought-intolerant, but still common bryophyte species may decline while pioneer species preferring exposed habitats are promoted (Åström et al. 2005). Yet, as no reasonably common species seems to disappear or become very abundant, residue harvesting does not seem to cause significant changes to ecosystem functions provided by the vegetation community on clearcuts.

Similarly, results suggest that residue harvesting does not cause significant shifts in major soil functions such as mycorrhiza, decomposition and mineralization on clearcuts. The impact of clearcutting is once again much more important. The abundances of soil organisms usually decline

substantially following clearcutting, e.g., mycorrhizal fungal species decrease in abundance because their host trees are removed. However, subsequent harvesting of residues does not appear to affect the species composition among mycorrhizal fungi or litter-decaying fungi on the clearcuts (Mahmood et al. 1999, Allmér 2005). Likewise, the communities of soil-dwelling invertebrates (e.g. collembola, mites, nematodes, Enchytridae, Tardigrada and different insect groups) do not display any major changes in species composition (Bengtsson et al. 1998, Persson et al. 2005). It is possible that many decomposers (species among soil animals, fungi) are redundant, meaning that several species perform the same functions within the ecosystem. Thus, losing or reducing the abundance of some but far from all species performing a certain function probably does not alter ecosystem function in the short run. Small changes may, however, accumulate over longer time spans and may result in more significant changes in the long run.

Organisms at higher levels of the food chain in forests might be indirectly affected by the residue harvesting. For instance, harvesting of residues on clearcuts may reduce the insect production and thereby decrease potential food supplies of insect-feeding bird species. However, as the relative importance of residues for organisms at lower trophic levels is largely unknown, it is impossible to assess potential effects on food webs.

It should also be noted that the effects of residue harvesting on aquatic ecosystems and their biodiversity is inadequately studied. Clearcutting as such has been shown to result in increased runoff, sedimentation, nitrogen mobilization, acidification effects, and leakage of aluminium and heavy metals (e.g. mercury) (Kreutzweiser et al. 2008). The increased harvesting activity and biomass removal may increase most of these effects in the short run, although the long-term leakage of nitrates may be reduced as more biomass is removed.

Stump harvesting

Effects on species and habitat structure – The basic problems associated with stump harvesting are presumably much the same as those addressed in relation to residue harvesting (see above). Stumps left after cuttings are most likely used by numerous species among various organism groups. As previously concluded for residues, stumps may provide shelter, microhabitat heterogeneity and growing substrates for many species that are not saproxylic. Ground-dwelling invertebrates (insects, spiders, etc) and probably also mammals may use stumps to hide or as nesting sites. Stumps can also serve as refuges for drought-sensitive bryophytes during the clearcut phase and may allow bryophytes and lichens to escape the competition from the plants that dominate the ground vegetation on clearcuts. Furthermore, a species-rich flora of lichens is found on stumps (Caruso et al. 2008, Caruso & Rudolphi 2009). Yet, other stress factors than stump harvesting will probably be more important for the persis-

tence of these species; most of them may survive locally on stump-harvested clearcuts because they are also capable of using other types of substrates and microhabitats.

One important aspect is that stumps comprise the bulk (80%) of coarse woody debris (CWD) in managed forests (see above) and, thus, the harvesting of stumps at large scale may pose a threat to the persistence of saproxylic species. At least high stumps created for conservation purposes on clearcuts are known to sustain many saproxylic species, including red-listed species (Lindhe & Lindelöw 2004, Lindhe et al. 2004, Siitonen & Ollikainen 2006, Fossetøl & Sverdrup-Thygeson in press). However, the relative importance of ordinary stumps, and whether they can compensate for the lack of other types of CWD in the landscape, remains largely unknown. Two studies of saproxylic insects indicate that ordinary spruce stumps on clearcuts serve as important resources for the reproduction of many widespread insect species. About 60–70% of all species recorded in ordinary stumps and high stumps, respectively, was found in the ordinary stumps (Abrahamsson & Lindbladh 2006, Hedgren 2007). Furthermore, many species were more abundant in the ordinary stumps than in the high stumps, and some species only occurred in the ordinary stumps (Abrahamsson & Lindbladh 2006). Preliminary results from two ongoing studies in Sweden confirm these results and, thus, suggest that stump harvesting may have negative effects on the diversity of saproxylic insects (Hjältén 2008, Jonsell 2009). Especially coarse stumps (>30 cm in diameter), and stumps of deciduous tree species (e.g. aspen), seem to host high numbers of saproxylic beetles, including red-listed species (Jonsell 2009).

Strictly saproxylic species, or red-listed species, among bryophytes are rarely found on cut stumps (Caruso et al. 2008, Caruso & Rudolphi 2009). Exposed stumps on clearcuts may host light-preferring lichens, but stumps seem not to be important substrates for red-listed lichens (Caruso 2008). Likewise, stumps seem to host mainly common wood-inhabiting fungal species (including pathogenic root-rot species), which have the capacity to utilize both fine and coarse woody debris, different types of wood (logs, treetops, stumps) and wood of different tree species (Menkis et al. 2004, Allmér 2005).

Whereas the lack of ecological data makes it difficult to assess the effects of stump harvesting, some aspects of stumps can be pointed out:

- In particular the harvesting of stumps of aspen and broadleaved tree species might pose a threat to red-listed species. Insects confined to sun-exposed coarse woody debris are probably those forest-dwelling organisms that may be most negatively affected by stump harvesting (Egnell et al. 2007, Anon. 2009).
- The overall effects of stump harvesting on the habitat structure and the general environmental considerations on clearcuts are likely to be at

least as negative as those detected for residue harvesting (see section above). Only one study in Fennoscandia has quantified the relative loss of dead wood; Rabinowitsch-Jokinen (2007) monitored 110 permanently marked logs to compare losses between clearcuts subjected to both stump harvesting and mounding with clearcuts subjected to mounding only. She found that the effects were comparable between treatments and that about 11–13% of the volume of logs was lost. Also soil preparation (scarification) has been shown to be destructive to the initial coarse woody debris on clearcuts; about 68% of the volume is lost (Hautala et al. 2004).

Effects on priority habitats and biotopes – As for logging residue harvesting, we assume that all or most of the special habitats and biotopes of conservation interest will be protected from logging and therefore will not be affected by the harvesting of stumps.

Effects on ecosystem function – It is difficult to assess the effects of stump harvesting on key ecosystem functions because of the general lack of ecological data also on these aspects of biodiversity. Especially potential long-term effects remain unknown. However, if no fine roots (<3 cm in diameter) are extracted, the loss of vital nutrients (e.g. nitrogen) will probably be insignificant (Egnell et al. 2007). Thus, stump harvesting will most likely not jeopardize the productivity of forests. The most significant effect of stump harvesting is likely to be the physical disturbance of the ground. This may provide plants and other organisms with somewhat different habitats (e.g., more exposed mineral soil) than on clearcuts without stump harvesting. In fact, data indicate that the effects of stump harvesting on the vegetation (vascular plants and ground-living mosses and lichens) are generally trivial. The species composition may differ to some extent between stump-harvested and un-harvested clearcuts (Kardell 2008). Some plants (e.g. *Empetrum nigrum*, *Calluna vulgaris*, *Polytrichum* spp.) may become more abundant while others (e.g. *Vaccinium myrtillus*, *Rubus idaeus*, *Epilobium angustifolium*) may decrease, but no species seems to disappear or become exceptionally dominant. Thus, stump harvesting will most likely not alter the vegetation structure (Egnell et al. 2007) or affect the various functions provided by the plant community on clearcuts.

Stump harvesting will probably not alter vital soil functions such as mycorrhiza, decomposition and mineralization. It will rarely worsen the situation for mycorrhizal fungi. Their local survival and subsequent recolonization will probably depend on to what extent living host trees (or groups of trees) are retained on the clearcut. As with residue harvesting, the harvesting of stumps will reduce the amount of dead organic matter and may thus reduce the abundances of important decomposers, fungi and animals in the soil food web (Jurkkala 2007). However, many species among these functional groups are likely to survive locally in pockets of

undisturbed ground (e.g. in the vicinity of retained trees) and may recolonize the surroundings once the forest re-grows.

As for residues, the relative importance of stumps for organisms at the lowest trophic levels is largely unknown. It is therefore impossible to assess potential effects on food webs. Further, there are no data on the effects of stump harvesting on aquatic ecosystems and their biodiversity. However, if stump harvesting increases the damages to the ground as compared to residue harvesting and mounding, it may also increase the sedimentation and leakage of nutrients and heavy metals.



Pile of harvested stumps. Photo: Raimo Heikkilä

Non-standard woody resources, trees from tending and thinning

The extraction of non-standard woody resources may put the general environmental considerations for nature at risk (cf the environmental requirements for forest certification etc). For instance, it is likely that trees and coarse woody debris (CWD) retained for biodiversity will be extracted or destroyed. Thus, the microhabitat variation on clearcuts including the sheltering function of small trees or groups of trees may decrease. Any additional reduction in the amounts of CWD, in particular wood of regionally rare tree species and sun-exposed CWD, will be negative for the biodiversity of managed forests. Importantly, the reduction of such uncommon woody substrates may increase the threats against red-listed saproxylic species. The effects on ecosystem function may be similar to those addressed in relation to residue and stump harvesting (see above).

Sub-standard trees that are cut during tending of young forests are currently left where they are cut. Should they be removed for bioenergy purposes, the effects are likely to have similar effects as the removal of other

logging residues. This is also the case for trees that are cut during the thinning of older production forests. The logs of commercial value are removed today but the logging residues are left in the forest. In addition, there will be some effect of the additional disturbance to the ground and remaining trees from the thinning operations. Again, these disturbance effects are likely to be similar to the effects of the removal of other logging residues.

Resources under power lines and along roads

The harvesting of trees and bushes under and near power lines is likely to have limited negative effects on biodiversity because it will affect relatively small parts of the forest area. Effects listed for removal of logging residues in previous sections might be expected. For instance, this type of harvesting may reduce the amount of key structural elements such as coarse woody debris and living deciduous trees, which are important for biodiversity.

On the other hand, clearing of woody vegetation under power lines and along roads may benefit species of the neighbouring forests preferring exposed edge habitats. Sun-exposed deciduous trees in particular are important habitats for many red-listed species (cf above).

The open area under power lines can also be considered as important habitats for meadow plants and butterflies that have decreased due to a serious decline in the number of traditionally managed open grasslands (Kuussaari et al. 2003). The large volumes of clearance waste that is usually not removed have a negative effect on the diversity of both butterfly and plant species of meadows. Harvesting of clearance residue – as well as the clearance itself (Pöyry 2009) – is therefore likely to have a positive effect on meadow species diversity. Depending on the vegetation types affected, a higher frequency of clearance (e.g., semi-annually) may increase the quality of power line areas for meadow species (Heliölä & Pöyry 2008). Short-rotation forestry under power lines, in contrast, would lead to closed landscapes and, as a result, probably to decreased diversity in meadow species.

4.2.3 Increasing production of harvestable biomass

Forest management to increase biomass production

- Increased intensity of forest management will lead to a heavier exploitation of coarse woody debris (CWD), deciduous trees and other key resources for priority species; it will also lead to a more homogeneous forest at both forest stand and landscape scale.
- Soil preparation in the form of patch scarification will have marginal effects on biodiversity; more drastic ground ploughing will affect soil properties (structure, hydrology) and organisms and will increase decomposition of organic material.
- Planting of new trees and increased cultivation efforts will speed up the re-establishment of new forest and reduce the diversity of tree species, age classes, ground vegetation and amount of fine and coarse woody debris, leading to lower species diversity in general and of saproxylic species in particular.
- Reduced rotation time will reduce the amount of old forest stands and old/large trees in the forest landscape and have a negative effect on species (often red-listed) that depend on long-term wood resources and forest stand stability.

Introduction of high-yield non-native trees or GMOs

- Planting of non-native Norway spruce and sitka spruce will lead to increased soil acidification and, for most of the production cycle, a denser tree layer and more shaded ground layer with fewer possibilities for light-demanding species.
- Planting of lodgepole pines seems mainly to result in a somewhat more intensive forest management compared to managed forest stands of native Scots pine.
- Introduction of GMO trees in biomass production raises a host of problem issues, mainly related to the risk of spreading transgenic properties to non-target organisms; this risk is accentuated by the long life span, wide pollen and seed dispersal, frequent hybridization and unstable genetic structure of most forest trees.

Nitrogen fertilization

- Especially in regions where nitrogen critical loads are already exceeded, fertilization may lead to leaching of nitrate to water systems, resulting in acidification and eutrophication.
- Fertilization will benefit nitrophilous plant species, leading to changes in the ground vegetation that may persist for decades.
- Shifts in the carbon-nitrogen balance will affect the biotic community and ecological processes in the soil.

Wood-ash recycling (mineral fertilization)

- Untreated wood ash will damage the ground vegetation and soil functions but these negative effects can be reduced by using stabilized (granulated) ashes of moderate doses (<3 Mg/ha).
- The effects on aquatic biodiversity are highly uncertain and more research is needed.

Increased transportation and disturbance

- At the regional and national level, increased road building will reduce the remaining area without roads and other human infrastructure, thus reducing the value of the Norwegian national indicator for the extent of such areas.
- At the landscape level, increased road building will fragment remaining forest patches and reduce habitat quality for interior forest species.
- Increased traffic may increase mortality rates for small animals.
- Increased disturbance and pollution risk during harvesting operations and transport will reduce habitat quality and damage important habitat elements like coarse woody debris, retention trees, mires etc.

Forest management to increase biomass production capacity

A number of silvicultural measures may be employed to increase the production of harvestable biomass from forests (cf chapter 4.1.2). Collectively, these measures may be summarized as increasing the intensity of forest cultivation and management, resulting in a more homogeneous forest landscape where more of the production capacity is used for human purposes. This will undoubtedly have negative effects for red-listed species, priority habitats and biotopes, as well as the robust function of the forest ecosystems. The further humans exploit natural ecosystems the less resources and space there will be for those components of biodiversity that do not have a role in the production of biomass for human consumption (e.g., Imhoff et al. 2004, Haberl et al. 2007).

Nevertheless, we will briefly go through the likely effects of the most relevant measures to increase biomass production from the current production forest:

- *Soil preparation* is a set of measures to facilitate the rapid re-growth of forest after cutting. The gentlest version of this is surface patch scarification which essentially opens up the litter and vegetation layer to expose the mineral soil below. This activity will disturb the established vegetation, but as this management practice will mainly be employed in common forest types without particularly valuable habitats or biotopes, it is unlikely that an increased frequency of patch scarification will have much negative impact on biodiversity components. More radical forms of soil preparation like mounding and ground ploughing will turn over deeper layers of the soil and expose more mineral soil, resulting in much more extensive changes to the ground surface and soil structure. This will lead to drastic changes in the local soil ecosystem structure and processes, with faster decomposition rates and turnover of nutrients. It will also change the local surface hydrology. Soil preparation has also been shown to result in a loss of coarse woody debris (Hautala et al. 2004). All types of soil preparation will shorten the length of time before new forest is established and, hence, the period of the open early succession phase.

This is not likely to be a problem in the modern forest landscape where the management process of clearcutting has resulted in a much higher frequency of early succession areas than would be found in forests under natural dynamics.

- *Planting of new forest trees* to speed up the regeneration of new forest after cutting or to provide more optimal growing stock is standard practice in much of Nordic forestry, especially for spruce forest after clearcutting. However, not all managed forests are yet under this management regime. Should this practice be extended to all relevant forest areas, it will most likely lead to a more homogeneous and more densely stocked forest. It will reduce the spatial variation in tree species and age structure, as well as in the ground vegetation, at both the forest stand and landscape levels. Large-scale planting of plants bred for specific traits favourable for timber or biomass production will result in less genetic variation in the forest trees. The long-term consequences of this may be a reduced capacity to adapt to future changes in climate, pests and other environmental factors.
- *Increased cultivation efforts*, such as tending of young forests and thinning of older production forest, will improve the development of the remaining trees as timber resources. However, it is not obvious that this will increase the total amount of harvestable biomass from a particular area. Intense cultivation efforts with harvesting of excess biomass will also remove much of the potential for fine and coarse woody debris (FWD, CWD) from the forest stand. FWD and CWD are important resources for many saproxylic species, as well as for species benefiting from the spatial heterogeneity maintained by such debris on the forest floor (cf the discussion in chapter 4.2.2).
- *Reduced rotation time* may be a way to increase the production and harvesting of biomass over the growth cycle of the forest stand, particularly for the remaining over-mature forests. It is well known that old (and large) trees have a particular value for many species (Uliczka & Angelstam 1999, Berg et al. 2002, Thunes et al. 2003, Pykala 2004), both for epiphytic species needing a long-term substrate and species exploiting the large size as such (e.g. hole-nesting birds). Old forest stands are also considered as one of the key resources for many species dependent on long-term stability of their local habitat (e.g., forest interior species, species with poor dispersal ability, mycorrhizal fungi etc) (Berg et al. 1994, Økland 1996, Ohlson et al. 1997, Dettki & Esseen 1998, Martikainen et al. 2000, Rolstad et al. 2002). Old forest is in particularly short supply in the modern forest landscape, especially in the more productive lowland areas (Stokland et al. 2003). Many red-listed species are therefore dependent on such old forest stands as habitat (Rassi et al. 2001, Gärdenfors 2005, Kålås et al. 2006). Hence, reduced rotation time and quicker harvest of forest stands will be especially negative for important components of

biodiversity. It may also be argued that short rotation time may lead to a reduction in the carbon stores in forest biomass and soils (cf chapt. 4.1.4; de Wit & Kvindesland 1999, Royal Society 2001).

Introduction of high-yield non-native tree species or GMOs

Here we focus on the replacement of native forest by high-yielding non-native tree species or genetically modified varieties of native species. Possible effects of such high-yielding species and varieties in new afforestation areas are treated below.

The main non-native tree species used in forestry in Fennoscandia today are Norway spruce outside its native range and sitka spruce (*Picea sitchensis*), mainly in western and northern Norway, and lodgepole pine (*Pinus contorta*) in upland northern Sweden (cf chapter 4.1.2). Norway spruce and sitka spruce tend to be planted in either non-forest areas (cf chapter 4.2.4) or in native birch or Scots pine forest, and lodgepole pine tends to be planted instead of Scots pine. The environmental effects of planting Norway spruce and sitka spruce are rather similar. Where they replace birch or Scots pine they generally make up a denser tree layer, shading out the ground vegetation during much of the growth cycle. The litter of dead needles is more acidic than the litter of deciduous trees, resulting in a higher tendency for soil acidification. The higher production and removal of biomass from planted spruce forests will also increase the acidification process and the depletion of nutrients from the soil (Kreutzweiser et al. 2008). During much of the production cycle, the result is a very impoverished ground flora and clear effects in the soil fauna (Fjellberg et al. 2007). It is likely that these changes in the species communities will also affect important ecosystem processes, but apart from the acidification effects this has not been studied. Should these forest stands be allowed to develop into over-mature old forest, the long-term effects on the ground flora and soil fauna and fungal communities may be different, as the shading effect will probably be reduced, but this has not been studied. Red-listed and other priority species in the regions where these spruces are planted tend to be linked to old trees, coarse woody debris and especially a moist micro climate (Berg et al. 1994, Jonsell et al. 1995, Blom et al. 2004, Bendiksen et al. 2008). Although the long-term effects of the planting of non-native Norway spruce and sitka spruce may be less negative than the short term effects indicate, it is likely that in an intensive management regime where the purpose of the planting is to optimise the production of biomass for energy and other forest products, the short-term negative effects would dominate. Should such planting of non-native trees become widespread in the relevant regions, it is likely that quite serious ecological consequences will result.

Lodgepole pine has rather similar ecosystem effects as Scots pine in managed forest stands. Planting of lodgepole pine is therefore not ex-

pected to have any special ecological consequences as such (Andersson et al. 1999). In Fennoscandia, lodgepole pines appear to have a limited ability for natural regeneration and therefore represent little risk of unwanted dispersal outside plantings (Øyen 2009). However, the greater intensity of management, the need to reduce damages from insects and ungulates, and the shorter rotation time applied to stands of lodgepole pine may have similar effects as a general increase in intensity of production and exploitation of woody resources from the forest (cf above). In addition, extensive planting of lodgepole pines may lead to a reduction of plant species richness at the landscape scale (Nilsson et al. 2008).

The use of genetically modified organisms (GMOs) in nature is a controversial topic. As yet this is not accepted as practical policy in Fennoscandia, but research on the establishment and growth potential of mainly hybrid poplars has been conducted in Fennoscandia to a limited extent (cf chapter 4.1.2). However, there has been no research targeting the particular environmental effects of GMO trees. Any theoretical assessment of such possible effects must be based on the general concerns about GMO plants (EFSA 2009) and the particular properties of forest trees. One of the main concerns about the release of GMO plants relate to the spread of transgenic properties, such as resistance to herbicide or pest organisms, to non-target organisms, thereby potentially threatening key ecological processes and ecosystem structure. GMO trees may also disperse beyond the target area and may become competitively dominant due to advantages related to the transgenic properties. This may also have consequences for important aspects of ecosystem structure and function. Finally, the management of GMO organisms may diverge from the management of the same non-GMO species in order to make best possible use of the transgenic properties, leading to unforeseen environmental consequences. GMO trees present some additional challenges due to the particular characteristics of trees: long life span, high capacity for long-distance pollen and seed dispersal, often vegetative reproduction, high tendency to hybridize with congeners, and very frequent symbiosis with mycorrhizal fungi. All these properties may facilitate the dispersal of transgenes beyond the target organism and generally make any assessment of environmental consequences highly uncertain (www.gmo-safety.eu/en/wood).

Increased nitrogen fertilization

Much of Nordic forests grow on soils of medium or low productivity where nitrogen is the most important limiting factor for biomass growth. Whether to increase biomass growth overall or to compensate for the loss of harvested biomass (e.g., in places with whole tree harvesting), nitrogen fertilization may be seen as a relevant management measure. In southern Sweden and south-western Norway atmospheric deposition of nitrogen is already substantial and may compensate for much of the loss through biomass re-

moval. In more productive forest types, where atmospheric deposition of nitrogen is already substantial, or when excess nitrogen is supplied, there is a clear risk of nitrate leakage to aquatic ecosystems (Rosén et al. 1992). This may have both an acidification and a eutrophication effect (van Dobben et al. 1999). In nitrogen-starved ecosystems, even moderate nitrogen fertilization is likely to lead to species shifts in the ground vegetation, with increased dominance of nitrophilous species of vascular plants (e.g. *Avenella flexuosa*) and reduction for many lichens and dwarf shrubs (e.g. *Vaccinium myrtillus*) (Nordin et al. 1998, Strengbom et al. 2001, 2003). These effects are not just simple responses of plants to additional nitrogen but may involve complex interactions with pathogens and herbivores (e.g. Strengbom et al. 2002). Such effects may last for several decades after the input of nitrogen has ended (Strengbom et al. 2001, Strengbom & Nordin 2008). Adding nitrogen fertilizer may also affect the carbon to nitrogen ratio (C/N) of the soil, with potentially important, if poorly understood, consequences for soil ecosystem processes.

Increased wood-ash recycling (mineral fertilization)

Wood ash recycling or mineral fertilization is considered to be necessary with extensive harvesting of biomass, and removal of nutrients, from forests. It has been suggested that the effects of wood-ash recycling are fairly similar to those of liming (treatment with calcium carbonate). Ash has a strong alkaline ability (raises pH) and can thus be used to neutralize acidified soil and surface water. However, its effect on site productivity is redundant when compared to nitrogen; tree stem growth does not seem to increase in response to wood-ash treatment alone (Jacobson 2003).

With respect to biodiversity, the great majority of studies have focused on the short-term effects (0–5 years) on the ground vegetation (vascular plants, mosses and lichens; Kellner & Weibull 1998, Jacobson & Gustafsson 2001, Arvidsson et al. 2002, Olsson & Kellner 2002, Dynesius 2005). In addition, a small set of studies have monitored the long-term effects (0–20 years) on soil organisms (bacteria, fungi and invertebrates; Perkiömäki & Fritze 2002, Taylor & Finlay 2003, Persson 2005). Wood-ash recycling can also affect the biodiversity of streams and lakes by influencing the water quality, but this aspect seems poorly understood and investigated (Aronsson & Ekelund 2004).

The short-term wood-ash effects on the ground vegetation seem to depend on the physical form of the ash. Loose ash can have harmful effects on the ground vegetation, particularly on the cover and species of bryophyte communities, because it is more reactive to the environment due to its large contact area and high solubility (Kellner & Weibull 1998). However, nowadays ash is hardened into so called ‘crushed’ or ‘granulated’ ash. These coarser types of ash are less reactive to the environment (Larsson & Westling 1998) and potential shock effects of high pH may be avoided (Steenari et al. 1999). Yet, crushed ash has clear biological short-

term effects because it is more soluble than ash granules (pellets) and thereby causes an instant increase in pH. Treatment with crushed ash may therefore be harmful to ground-living plants and bryophytes (Dynesius 2005). Replacement of crushed ash with granules will therefore strongly reduce the short-term effects of ash recycling on the species abundances or biodiversity within the field or bottom layer of forest vegetation (Arvidsson et al. 2002, Dynesius 2005). Note, however, that wood-ash treatment of drained mires may have radical and long-lasting effects on the vegetation. The treated mires may become dominated by grasses and herbs typical for upland forests whereas bryophytes and dwarf shrubs remain dominant on untreated mires (Moilanen et al. 2002).

With respect to soil functions, wood-ash seems to have insignificant effects on the mycorrhizal fungal community, with only small changes recorded in the abundance of a small number of species (Taylor & Finlay 2003). However, wood-ash treated sites may have a different bacterial community structure than untreated sites (Fritze et al. 2000, Mahmood et al. 2003). In fact, the liming effect of wood-ash may induce higher bacterial growth and activity. This in turn may accelerate decomposition and increase organic nitrogen mineralization and nitrogen availability. Also long-lasting effects of wood-ash recycling on the activity of soil decomposers as well as their community structure have been detected (Perkiömäki & Fritze 2002). However, wood-ash treatment seems to have small effects upon the soil fauna (e.g. Enchytraeids, microarthropods), with only minor changes detected in the abundance of a limited number of species. Thus, the soil fauna seems to be rather resistant to the alterations in soil chemistry induced by wood-ash recycling (Haimi et al. 2000, Liiri et al. 2002).

The short-term effects of wood-ash recycling on nitrogen and phosphorous leaching are considered to be insignificant (Pirainen & Domisch 2004). Phosphorous and heavy metals in ash are highly insoluble (Nieminen et al. 2005). Nevertheless, infertile sphagnum peat soils and mires with sparse tree cover are not suitable for wood-ash recycling, as the vegetation is not able to use the increase in nutrients due to its low productivity (Pirainen & Domisch 2004).

Since wood-ash contains cadmium over allowed limits for agricultural use, its recycling has aroused discussion. The cadmium content of ash is not harmful to humus microflora (Fritze et al. 2000) or the soil fungal community (Fritze et al. 2001). Ash could even be used in contaminated or acid sites to neutralize the soil conditions (Perkiömäki et al. 2003; Saarsalmi et al. 2004).

Increased transportation and disturbance

Increased biomass harvesting may result in a need for a denser road network and it will lead to an increase in the amount of transport and traffic

on roads as well as in harvested forest stands. The direct effects of this activity on biodiversity can generally be divided into:

- loss and fragmentation of habitats as a result of more extensive road construction in the forest
- loss of habitat elements due to transport damage to dead wood, retention trees, mires etc in the harvested forest stands, as well as increased pollution risk from machinery
- increased mortality of species as a result of increased traffic density and road casualties
- disturbance of species caused by increased transportation and activity on roads and in forest stands

Although the existing forest road network is already dense in many parts of Finland, south-eastern Norway and much of Sweden, there are still large areas, especially in western and northern Norway and in the mountain areas, where the road network (or other transport facilities) is judged to be inadequate for economical harvesting of the biomass resources. New roads in these areas will occupy some potential habitat. More significantly, this will result in a fragmentation of remaining forest areas and make these areas more vulnerable to storm damage, climate exposure, invasion of generalist predators, weeds etc, as well as incidental human disturbance (more roads provide easier access also for non-logging purposes). At the larger regional scale, an expanding forest road network is likely to reduce the remaining area without roads or other human infrastructure, thereby reducing the value of the Norwegian national indicator for such areas (INON, cf chapt. 2.1)

More extensive use of harvesting and handling machinery will lead to more damage to important habitat elements for biodiversity. Sverdrup-Thygeson et al. (2005) documented that about 30% of investigated clear-cuts had crushed logs of coarse woody debris (CWD) and it appeared that the frequency of damage increased with the intensity of forest operations. Such damages also seem to be more extensive for older logs and logs of deciduous trees (Hautala et al. 2004). Crushed logs will decompose faster and may deprive certain saproxylic species of their habitat. Energy wood harvesting machinery will also contribute to the compaction of the soil, resulting in unfavourable substrate properties (Helmisaari et al. 2008). The use of heavy machinery on mires and other unstable ground may also result in deep tracks and ruts that may lead to erosion and added pollution of watercourses (Morgan 2005). This may be a particular challenge in the steep forests with high precipitation of Western Norway.

Increased traffic intensity and higher frequency of vehicles generally leads to higher casualty among small animals (Grenfors & Nummi 2007). Due to their precarious population status, this may be most serious for rare species (Väre & Niemi 2007).

Energy wood harvesting and transport will cause additional disturbance of bird nesting. Generally one tries to minimize the disturbance of reproducing animals by timber harvesting by directing the logging operations in time and space to avoid bird nesting areas and mammal denning sites. Logging should be avoided especially in forests dominated by deciduous trees, hard wood swamps and in coastline forests (Korjuun suunnittelu ja toteutus 2005). During energy wood harvesting, damage to nests, anthills etc should be avoided (Koistinen & Äijälä 2005).

Chipping at the forest stand instead of transportation of untreated material, will reduce traffic and the number of operating days in the forest (Karjalainen & Sievänen 2008). On the other hand, road-side chipping may cause a delay in the timber transportation as the chipper-shredder blocks the road (Asikainen 2004), resulting in increased disturbance.

4.2.4 Biomass production and harvesting from non-commercial forests and non-forest areas

Harvesting from non-commercial forests

- Non-commercial forests may have considerable value for biodiversity due to the (probably) limited harvesting activities of such forests in the past and their location in often steep and varied terrain.
- Harvesting will be negative for those biodiversity components associated with old forests, including several red-listed species.

Increased afforestation

- Afforestation of former agricultural land and other areas used for farm animal grazing and fodder production will be negative for species associated with open landscapes and the traditional harvesting activities that kept these areas open.
- Afforestation on mires will require drainage, a practice no longer warranted for intact mires according to environmental requirements for forest certification, as this will have drastic effects on the mire ecosystem processes.

Harvesting from currently non-commercial forests

Current non-commercial forests make up a substantial part of Norway's productive forest areas (cf chapter 4.1.3). Compared to commercial forest areas they tend to be further away from roads, have a higher proportion of old forest and deciduous trees, and to be located in steeper and more varied terrain. This should imply that there may be a considerable potential for high biodiversity values in such non-commercial forests. However, this has not been systematically investigated. Bollandsås et al. (2004b) found that transport distance was positively related to the frequency of potential habitats for red-listed species (based on the Complementary Hotspot Inventory methodology, cf Gjerde & Baumann 2002). Although there is a general positive relationship between site productivity and species richness (Stokland 1997, Gjerde et al. 2005), non-commercial forests

of low productivity may still be important sites for red-listed and other priority species (cf Cederberg et al. 1997, Sverdrup-Thygeson & Ims 2005). Many hotspots for red-listed species are found in less productive forest types such as dry broadleaved forests and calcareous forests, and often in broken and heterogeneous terrain where little forestry activity has occurred in the past (Sverdrup-Thygeson et al. 2007). In summary, the fact that non-commercial forests probably have not been much exploited for timber resources for some time indicates a potential value of such forest areas for biodiversity. Increased cutting and biomass harvesting from such forests will change their old forest characteristics, remove key resources for many red-listed species, and increase the fragmentation of the remaining un-harvested forests. Such activities may therefore be quite negative for biodiversity. There is at least a great need for more detailed knowledge of the amount and location of the biodiversity-related values of such forests before sustainable biomass harvesting activities should start.

Although Finland and Sweden have a much smaller proportion of such non-commercial forest area than Norway, the characteristics of such forests are likely to be similar, as are the consequences of increased biomass harvesting from such non-commercial forests.

In Finland there is an objective to restore drained mires (by closing ditches and removing trees) to return these ecosystems to species communities and ecological processes typical for the original mire area. Some of the targets of restoration can be achieved directly after restoration, whereas most of the objectives require a longer period to be realized (Rassi et al. 2003). Although the restoration of ditched mire ecosystems are considered as deforestation in the Kyoto protocol, the harvest of tree biomass from these mires and the restoration of ecological values to these ecosystems can be seen as a win-win solution for both biodiversity and bioenergy (at least in the short term for bioenergy).

Increased afforestation

Increased afforestation of agricultural land may have positive or negative effects on biodiversity, depending on where afforestation takes place and how it is done. Positive effects may occur if the species associated with open land remain in the area for a few decades and if the area develops to herb-rich forest. However, due to changes in the physical and chemical conditions of soils, as a result of agricultural practices, these habitats cannot be compared to peat soils or mires. Further, the resulting biodiversity values may be lost if the afforested areas are subjected later to biomass harvesting.

Afforestation is one of the reasons for a significant loss of many open areas dominated by traditional resource harvesting for farm animals, such as unimproved meadows and woodland pastures. These habitats have especially high biodiversity value. Increased use of bioenergy will be a

threat to such traditional biotopes if it leads, for example, to afforestation, energy crop cultivation or fertilization. Hence, afforestation and energy crop cultivation should not be conducted on land dominated by valuable biotopes characterised by traditional agricultural management (Tonteri et al. 2008).

In the past, afforestation has often taken place on mires. This requires that the mires are drained by ditches, a drastic and often irreversible impact in the ecosystem of the mires due to the changes in the local hydrology and the more rapid decomposition of the peat. Such ditching of mires is no longer common practice. According to the environmental standards for forest certification as well as the forest regulation, ditching of intact mires is not allowed (Living Forest 2006), except as a temporary measure in connection with cutting (in Sweden).

4.3 Effects on landscape appearance and outdoor recreation

4.3.1 Additional biomass harvesting from managed forests and woodlands

- Logging residues left after tree cutting are generally perceived as untidy and disturbing to landscape appreciation. Such residues will also reduce the accessibility to the affected forest stands. Hence, removal of logging residues for bioenergy purposes may be seen as positive for landscape appreciation, as long as harvesting activities do not cause additional damage to the ground or the trees.
- Stump harvesting is likely to have a negative effect on landscape appreciation as well as for perceived accessibility to affected forest stands, as will other forms of radical disturbance to the ground such as ground ploughing.
- Harvesting of non-standard wood resources like dead, damaged or small, sub-standard trees may be perceived as positive for the visual qualities in the forest landscape and will increase accessibility to affected forest stands. Removal of large or old trees or trees with characteristic shapes will, however, be perceived as negative for landscape appreciation.
- Harvesting of woody residues from trees cut along power line corridors will increase the visual quality and accessibility of the landscape in much the same way as removal of logging residues. Removing bushes and trees along roads will open up the landscape and provide more distant views.

Harvesting of logging residues

Logging residue (e.g., branches, tops, short logs, small trees, non-standard trees) left after harvesting is one of the most disturbing factors for people's appreciation of harvested forests, whether the harvesting is based on even-aged methods (clear-felling, seed-trees or shelterwood) or selective methods (group or single tree selection) (e.g. Mattsson & Li

1994, Mattsson et al. 1995, Holg en et al. 2000). Several studies show that logging residue decreases the visual quality of the forests or felling areas (Heino 1974, Hultman 1983, Aasetre 1993, 1994, Kardell et al. 1977, 1993, Kardell & Lindhagen 1998, Lindhagen & H ornsten 2000, Karjalainen 2006, Gundersen & Christensen 2008). The effects of logging residue are reduced as time passes and when there is enough vegetation to hide the woody debris. The main reason for the dislike of logging residue may be the reduced accessibility to the logged forest area. In addition, logging residue may create a perception contrary to the desired sense of a healthy and thriving forest.

Fresh group selection cuttings with residue are much less appreciated than old group cuttings under regeneration, where residue is no longer visible (Hultman 1983, Lindhagen & H ornsten 2000). The effects of logging residue on people's appreciation can be illustrated by the fact that more people accept clearcut areas in winter, when stumps and logging residues are hidden by snow (Haakenstad 1972, Lind et al. 1974). The amount of logging residues after tending or thinning seemed to be a key factor for people's appreciation of stands treated with intermediate cuttings (Hultman 1983, Karjalainen 2000, Silvennoinen et al. 2002). The nation-wide photo survey by Hultman (1983) showed that freshly tended young stands (pre-commercial thinning) with visible logging residues were little appreciated by the public, whereas similar stands with a path through them or with completely decayed residues got a higher score.

As large piles of logging residues decrease the visual value of the landscape, it would be best if the residues could be transported away from the stand as soon as possible and stored, e.g. in terminals. In forests the energy wood piles should be placed so that the outdoor recreation routes are free of residues. Harvesting of logging residues could cause soil damage which might reduce both aesthetics and accessibility to the forest. Increasing the number of harvesting machines will cause additional damage to soil and residual trees.

Logging residues and tops from spruce and pine harvest are much smaller in size than most hardwood tops. Hardwood tops, such as oak and beech, take longer to decay than spruce tops, and it is even more important to remove these to enhance people's accessibility to clearcuts.

Removing logging residue for bioenergy purposes seems to be beneficial for people's landscape appreciation, as long as it does not cause considerable visible damage to the ground or trees.

Stump harvesting

Very few studies have been conducted on the visual effects of whole-tree harvesting including stump harvesting. Kardell et al. (1977), repeated by Kardell & M ard (1989), studied attitudes to a forestry practice that was used in some parts of Sweden during a few years around 1980, namely clear-felling with whole-tree harvesting including stump harvesting in

order to utilize the entire tree biomass for forest industry products and for bioenergy. Forest scenes depicting stump harvesting got very low scores among the respondents (Kardell et al. 1977, Kardell & Mård 1989). Respondents that were taken to the forest ranked selected areas shortly after harvesting in 1976, and twelve years later a similar group of respondents ranked the same areas again. The authors concluded that the areas in question got a higher mean score in 1988 than in 1976, because the traces of the cutting and stump harvesting had become less noticeable. However, the respondents in the 1988 survey were much more sceptical to the principle of whole-tree harvesting with stump harvesting than their predecessors in 1976. To underline the negative effects of stump harvesting for people's appreciation of forest land, studies showing photos depicting a much more moderate kind of soil disturbance, namely soil preparation for natural regeneration, also got negative evaluations (see chapter 4.3.2.)

People's reasons for avoiding forest areas with stump harvesting seem to be much the same as for logging residues. Stump harvesting reduces both the mental and physical accessibility and creates a view of an 'un-caring' forest management.

Non-standard woody resources, including deciduous trees

In general, harvesting of non-standard wood resources like dead or dying trees (or broken, stag-headed and leaning trees, fire-scarred trees, snags and stumps, and downed logs in various stage of decomposition) will have positive effects for people's landscape appreciation as it provides a more managed forest setting with easy access. Snags and broken or leaning trees make a visual contrast in the forest stand, which will either enhance the visual diversity or be recognized as a 'messy' forest structure for the user of the stand, depending on the context in which these structures occur. New research indicates that dead wood in general causes negative responses among users, but if it occurs in a natural forest setting, for example a nature reserve, it is much more acceptable than in a managed stand (Gundersen & Christensen 2008). For people's preferences for dead wood and windfall, see chapter 4.3.2. for a broader presentation.

Tönnes et al. (2004) studied the scenic impact of retention trees. Retention trees left on a clearcut will, in the same way as leaving seed trees (Kardell et al. 1977, Hultman 1983, Kardell & Mård 1989, Kardell 1990, Mattsson & Li 1994, Silvennoinen et al. 2002), reduce the negative visual effects of the clearcuts. Grading of photos showed that solitary retention trees left on clearcuts provided a higher aesthetic value than a similar number of retention trees in groups (Tönnes et al. 2004). Leaving fewer retention trees than corresponding to a volume of 3 m³ ha⁻¹ did not significantly improve the scenic value of a clearcut area.

Large sizes and old trees or trees with full shapes, as well as trees with holes and cavities, will normally be positive elements in the forests ac-

according to people's preferences (Gundersen 2005). Removal of small trees in pre-commercial thinning stands will most likely enhance the visual quality of the stand (Tyrväinen et al. 2003, Gundersen & Christensen 2008). In general, people prefer well-managed stands including both pre-commercial and commercial thinning activities before the final clearcutting, compared to untouched stands including self-thinning (Gundersen & Christensen 2008).

Removal of spruce understorey and large trees in beech forests or other southern deciduous forests will have positive effects on people's preferences as it will provide a more open stand structure for visual penetration, light and view.

Harvesting of wood resources under power lines and along roads

Harvesting of bushes and small trees and removal of logging residue for bioenergy purposes along power lines will have more positive effects on recreation than non-removal, if damage to soil and water can be avoided in the additional mechanized harvesting activities.

Removal of bushes and trees along roads will also have positive effects on people's appreciation, as it will provide more open space and better visual penetration in the forests and to scenic backgrounds.

4.3.2 Measures to increase production of harvestable biomass

- Soil preparation is generally perceived as a negative disturbance to the forest by the public, especially more radical forms like ground ploughing and deep scarification. Less is known about the public's reaction to light patch scarification, but long term effects may be positive as soil scarification allows natural forest regeneration, resulting in a more varied forest than planting.
- More intensive silviculture to increase biomass production may have a positive effect on landscape appreciation where thinning and removal of logging residues open up dense forest stands and thereby create a more varied forest landscape with better accessibility. However, removal of all understorey bushes and trees and well-developed deciduous trees, as well as present signs of forest operations (machinery, damage to trees or ground, fresh residues), will be perceived as negative.
- Introduction of non-native trees to increase biomass production may not be perceived as negative for landscape appreciation as long as the exotic trees do not stand out as very deviant landscape elements or have properties unsuitable for recreational use of the forest stands (e.g. dense spruce plantations). However, the concept of 'alien' species will stand in strong contrast to the perception of 'naturalness' that is a highly valued landscape characteristic.
- Increased transport, physical disturbance and noise as a result of increased harvesting of biomass will be seen as very negative for landscape appreciation, both with respect to visual quality and perceived disturbances to nature. However, forest roads will generally be used for recreational access to forest areas.

This chapter covers various silvicultural treatments whose main focus is on establishment of new forests as well as tending and thinning activities in all development stages from young forests to mature and over-mature forests.

Soil preparation

Karjalainen (2006) clearly demonstrated that soil preparation has negative effects on the visual quality of the regeneration areas studied. Clear-felled areas including soil preparation and logging residues were ranked as the lowest of all photos. The photos displaying relatively heavy soil preparation and large amounts of logging residues were ranked lower than the photos not showing these elements. It was not possible to isolate the effects of soil preparation from the effects of logging residues in this study. Very few previous studies have been conducted on the visual effects of soil preparation. The more common management practices today are patch scarification for enhancing natural regeneration or lighter forms of soil preparation in partial cuttings, and these have not been studied. Patchy scarification is likely to be preferred to continuous rows, according to research on drainage of peatland (Hultman 1983). Ground ploughing and other kinds of deeper soil scarification for natural regeneration were not appreciated by the public in several studies (Korhonen 1983, Kardell & Mård 1989, Sievänen 1993, Karjalainen 2006). In general, based on knowledge from preference research one may assume that increased intensity of soil scarification correlates negatively with people's appreciation for the forest stand and landscape.

Soil preparation on clearcuts causes in most cases negative visual effects, and should be done carefully in a manner giving adequate consideration to areas of hiking trails and landscapes of visual importance. However, the visual effects of soil preparation are limited to a few years after the treatment has been carried out, because field vegetation will hide the signs in most cases. On the other hand, soil preparation will enable establishment of naturally regenerated forest stands that often have a larger diversity in tree species, stratification and density than forest established by planting.

Increased cultivation and thinning, planting of new forest trees

Most tending (often referred to as pre-commercial thinning) and thinning operations are low to medium intensity disturbances compared to high intensity disturbances such as clearcutting and prescribed burning. Thinning intensity, frequency, stand age when thinned, uniformity of thinning, amount of wooden debris left in the stand and disturbance from harvesting operations all influence forest stand structure.

Stand openness and density

Utilizing the woody biomass from tending and commercial thinning is in general positive for people's appreciation of forests, as it provides a more

open forest structure. Semi-open forests give a better view and sense of safety than dense forests, and openings in a forest provide perceptible space and visual access to more distant areas. The clearly documented positive effects of thinning related to preferences for stand openness could be reduced or even become negative if a large amount of logging residue is visible from the place of the observer, until the logging residue is removed, decayed or hidden under snow cover.

Various investigations have pointed out that forests with possibilities for views of the surroundings are preferred (Haakenstad 1972, 1975, Lind et al. 1974, Kellomäki & Savolainen 1984). People tend to appreciate visibility in the forest (Haakenstad 1972, 1975, Hultman 1983), at least to some extent. In a small study with visual stimuli, Kellomäki & Savolainen (1984) concluded that the scenic value culminated when visibility passed 40–50 m. In a slideshow study featuring young stands of various densities, Rydberg (1998) found that dense stands were preferred; a substantial part of his respondents were children and teenagers.

A large body of research has demonstrated that, in general, thinning of densely stocked stands of spruce and pine improves the vigour of trees that are left in the stand, with improved tree health and growth, and resistance to insect attacks. Tree health and stand stability are key aspects of people's appreciation of forests, and people prefer well-managed semi-open forests with a green field layer. In the case of increasing risk of windfall in the thinned stand, the positive effects of thinning can be reduced.

Tree species composition

An overall conclusion from preference research is that people's preferences for tree species and species composition strongly depend on the context of other factors like openness and visibility, the amount of light in the stand and stratification, as well as what kind of forest people are used to. In some cases, for example removal of spruce in old southern deciduous forests like beech, the positive effects on people's stand appreciation are obviously positive because beech forests are among the most preferred forests in the Nordic countries (Koch & Jensen 1988, Hultman 1983). Shade-tolerant beech forest will provide stability with respect to openness and possibilities for view and sight.

Elements of deciduous trees in coniferous forests are generally considered positive (Haakenstad 1972, Lind et al. 1974, Hultman 1983) and removal of these would be considered negative.

Tree age and size

Low thinning, which is probably the most appropriate for bioenergy, will increase the overall tree diameter in the stand. Numerous Nordic surveys have shown that preferences increase with increasing tree age, or, more precisely, with tree size, and with advancing stage of stand development (Haakenstad 1972, 1975, Lind et al. 1974, Kellomäki 1975, Saastamoinen

1982, Hultman 1983, Korhonen 1983, Kellomäki & Savolainen 1984, Pukkala et al. 1988, Kardell 1990, Hallikainen 1998, Karjalainen 2000, Lindhagen & Hörnsten 2000, Silvennoinen et al. 2001, Tyrväinen et al. 2001). Young, dense stands received a relatively low score regardless of tree species (birch, pine, or spruce) (Haakenstad 1972, Hultman 1983, Pukkala et al. 1988), probably because open stands are easier to penetrate.

Stand stratification

Stand stratification, or vertical structure, depends a lot on the thinning characteristics (e.g. low thinning, high thinning, selective thinning), but for biomass production this will most often have the character of low thinning and removal of all understorey trees. This will in most cases reduce the stand stratification. Since the early 1990s there has been an increasing focus on alternative silvicultural systems and forest practices that embrace a broader range of values, including forest structural complexity.

Stratification is closely related to openness, species composition and age. Several surveys have indicated that the public tends to give high scores to irregular stands with a mixture of trees of different sizes, as long as they are not disturbed by obvious traces from cutting operations (Lind et al. 1974, Hultman 1983, Kellomäki & Savolainen 1984, Kardell 1990, 2001, Lindhagen & Hörnsten 2000). Kellomäki & Savolainen (1984) found that in a regular, rural forest stand, the presence of some undergrowth would increase the scenic value. In the Helsinki city forests, Tyrväinen et al. (2003) came to the opposite conclusion. The most disliked stand type was dense and closed forest vistas with abundant undergrowth, where young coppices limit sight and visibility. Respondents of Kardell (1990) gave a high score for a stratified stand, but when the study was repeated after removal of all small and medium sized trees, creating an open pine stand with a view towards a lake, the stand got a still higher score.

Undergrowth (small trees, saplings, shrubs) may be important in structuring the forest view and is well liked by the public (Koch & Jensen 1988, Silvennoinen et al. 2001, Tahvanainen et al. 2001), as long as it is not too dense (Kellomäki & Savolainen 1984) and does not hinder visibility. Savolainen & Kellomäki (1981) observed that whereas conifer undergrowth was perceived positively, deciduous undergrowth was experienced negatively.

The field layer

In general, opening up densely stocked stands increases understorey plant biomass and bushes which in turn increases plant diversity and the possibilities for appreciation of a continuous green field layer. Overstorey stand structure strongly influences understorey plant communities by controlling the amount of light that penetrates the canopy. Uniform thinning leaves evenly spaced trees and usually a compositionally simple

understorey. Irregular or variable density thinning that creates openings and tree patches of different sizes can increase understorey biodiversity. Understorey response to thinning, especially by shrubs, is typically correlated with the amount of canopy removed. With very light thinning, impacts of the initial disturbance may outweigh the benefits of making more resources available to understorey plants. However, heavy thinning with even spacing can reduce moisture availability due to increased wind and sunlight. Understorey species (grasses, herbs) are often an important aesthetic component of forests. A major concern with thinning is the potential for such activities to introduce and/or spread invasive exotic species in the field layer.

There are, surprisingly, very few Nordic surveys that have included specific questions about the field layer in forests, but there are indications from many studies that a majority enjoys a continuous green field layer and the mental image of walking on a green mat of forest mosses (Lind et al. 1974, Aasetre 1993, Jensen 2000). There are no Nordic studies looking at people's appreciation for exotic species in the field layer. A green field layer is appreciated by respondents from other places and other forest ecosystems (Schroeder & Daniel 1981, Schroeder & Brown 1983, Brown & Daniel 1986, Ribe 1989, Pings & Hollenhorst 1993). In these studies the importance of the green field cover is explained as enhancing visual diversity, vividness, ease of movement, the smoothness of ground texture, and the impression of depth.

Tending and thinning may have significant effects on harvesting of non-wood products like forest berries, mushrooms, wild herbs and other products. The most economically important berries are cowberry (*Vaccinium vitis-idaea*), bilberry (*Vaccinium myrtillus*) and cloudberry (*Rubus chamaemorus*). The most important mushroom species are chanterelle (*Chantarellus cibarius*), ceps (especially *Boletus edulis* and *B. pinophilus*) and northern milk cap (*Lactarius trivialis* and *L. utilis*). Effects of bioenergy harvesting on these species are unclear. Tending and thinning in dense spruce and mixed conifer stands seem to have positive effects on the amount of berries as they increase the amount of light reaching the forest floor.

Dead standing trees and windfalls

A thinned stand will in general have less dead wood and windfalls than an unthinned stand, because thinning reduces the competition for light and self-thinning processes. In the long term, thinning also enhances the stand stability and reduces the risk of windfalls and snowbreaks. Repeated light thinning in young stands would have favourable effects on people's appreciation of forest stands compared to untended stands with late thinning, mainly because of the amount of dead wood in the stand. The appreciation of dead wood is not well studied in a Nordic context, but the few exceptions that include questions about dead or downed wood

found that most respondents disliked such sceneries (Hultman 1983, Kardell 1990, Karjalainen 2000, Jensen 2000, Lindhagen & Hörnsten, 2000, Tyrväinen et al. 2001, 2003, Gundersen & Christensen 2008). Dead wood seems to be experienced among many as a ‘messy’ element in the forest, and fresh windfalls always got a low preference score (Gundersen & Christensen 2008). The content of dead wood depends both on the character of dead wood (size, level of decomposition, free standing, downed wood, leaning etc) and the stand characteristics. Large rotten wood in a natural setting always gives a higher preference score than small size or fresh dead wood in a managed forest (Gundersen & Christensen 2008). Dead wood in a natural setting increases the coherence, complexity and mystery of the forest (Karjalainen 2006).

Reduced rotation time

One of the most common features from Nordic preference research is that people’s preferences for a forest stand increase with increasing tree size and advancing stage of stand development (Gundersen & Frivold 2008). Thus, reduced rotation time will in most cases (partly depending on the stand characteristics) have a negative effect on people’s appreciation of the stand.

Introduction of high-yield non-native tree species or GMOs

Far from all forest visitors are able to recognize differences between native and exotic tree species at all (Kardell & Wallsten 1989), so survey questions about exotic species can be difficult to formulate and answers difficult to interpret (cf Haakenstad 1972). There exist, however, some studies of people’s attitudes and preferences for the use of exotic species compared with a forest management based on native species.

Almost 60% of the respondents in the verbal mail survey of Haakenstad (1972) did not want areas with exotic tree species in the forests around Oslo. Only 13% answered that they would like such areas. In these forests practically all tree species are indigenous. In some parts of the municipal forests of Trondheim, however, afforestation with foreign conifer species has a long tradition (Aaeng 1923). Here, forest visitors were more positive to the presence of such species than Haakenstad (1972) found for residents of Oslo. Provided with the information that 20–30 foreign tree species were already more or less present in the municipal forests, 38% wanted areas with foreign tree species, 30% did not want them and 32% were indifferent (Andreassen 1982): approximately the same scores as if respondents had answered at random. Norway spruce (*Picea abies*) is a foreign species in most parts of western Norway, and visually clearly different from indigenous Scots pines (*Pinus sylvestris*) and broadleaved trees. It has been widely used in afforestation there since the beginning of the 20th century (Irgens 1968). Strumse (1996) found that photos from dense Norway spruce plantations in West Norway

got low scores compared with pastoral agrarian landscapes. Some large forest holdings in North Sweden planted the American lodgepole pine (*Pinus contorta*) over large areas (0.5 million hectares) from the 1960s through the 1980s because it was expected to grow more rapidly than the native Scots pine (Kardell 2004). Kardell & Wallsten (1989) invited respondents for a forest walk in the neighbourhood to test their preferences for two *P. contorta* stands and three stands with indigenous trees species (pure Scots pine, pure Norway spruce and a mixed spruce and birch stand). All stands were middle aged and structurally similar. *P. contorta* has a greyer bark and a more intense green colour than Scots pine. The authors concluded that the two *P. contorta* stands were perceived as slightly lighter and less natural than the other stands, but no less suitable for outdoor recreation. Ordinary people among the respondents turned out to be rather indifferent both about forestry in general and about the use of *P. contorta* in particular.

Attitudes towards the term and concept of exotic species seem to be very different, and much more negative, than the pure visual effects of such trees on outdoor recreation. Most people are not able to recognize the origin of a tree species and if the structural effects are not very different from those of native species, people accept it to a high degree. However, the very perception of ‘alien species’ or genetically modified trees appears to contradict the attractive landscape values of naturalness, authenticity, intactness or old cultural values. The attitudes are in general strong for natural elements in nature, and people dislike both non-native species and manipulated species.

Increased fertilization

Increased fertilization may have negative effects on the field layer, e.g. the amount of bilberry (*Vaccinium myrtillus*) versus wavy hair-grass (*Avenella flexuosa*), but there is no evidence that correlates effects of increased fertilization to people’s appreciation of forest and landscape. Likewise, to recycle ash generated in energy plants and forest industry by returning it to forests may have very short-term negative effects on people’s appreciation of the forest stand, but there is less evidence on the long-term effects. Fertilization using ash may cause minor short-term visual effects in the forest stand, as long as the ash is visible on the forest floor, but there are no studies that verify these. Long-term effects of fertilization will be larger trees and a denser stand character. Large trees are preferred among the visitors, and as long as the visual penetration of the stand is about 30–40 m, the fertilization will not cause any significant effects on people’s appreciation of the stand.

Increased transport and disturbance

Substantial tracks from logging and off-road extraction, like deep wheel tracks, will have a negative impact on people’s appreciation, as long as

people have experienced this kind of impact (Hultman 1983, Aasetre 1994, Lindhagen & Hörnsten 2000, Gundersen & Christensen 2008). Logging residues are usually used as bedding in conventional tree harvesting, to avoid damage to soil and water. This is not practiced in forest stands where logging residues shall be extracted for bioenergy, as this will affect the fuel quality. Consequently, harvesting logging residues for bioenergy will increase the damage to the soil and increase the extent of wheel tracks with as much as 60% (Andersson 2005).

Increased biomass extraction from newly established forests may need an expanded forest road network, which to a large extent affects people's access to the forest landscape. Accessibility, both physical and mental, seems to be a key factor in people's preferences for forests. Therefore, people's experience with forest infrastructure, from small trails to heavy forest roads, has been the subject of several investigations. Results indicate that forest visitors ideally prefer a moderately prepared forest path for walking (Haakenstad 1972, Lind et al. 1974, Hultman 1983, Aasetre 1993, 1994, Hallikainen 1998, Gundersen & Christensen 2008), although most forest visitors actually walk on forest roads (Haakenstad 1975, Aasetre 1994). Gundersen & Christensen (2008) used 17 photos to describe the gradient from small paths to forest roads in a forest environment. The preference scores decreased significantly with increasing size of the infrastructure; small unmarked paths received the highest score and new forest roads the lowest.

Bioenergy extraction increases the disturbance of the stand and road network by creating noise and aesthetic disadvantage. Chipping in the forest stand decreases the disturbance caused by transportation of loose chipping material and the number of operating days in the forest. In contrast, chipping at e.g. a terminal decreases the disturbance in the forest.

The best time for bioenergy harvesting is late in the autumn or in the winter when outdoor recreation is minor, and when visual traces from cutting operations are less.

4.3.3 Biomass production and harvesting from non-commercial forests and non-forest areas

- Harvesting of biomass from current non-commercial forests will generally be perceived as negative for landscape appreciation as it will represent human disturbance of the natural forest landscape. Forestry activities may also create barriers to accessibility through logging residues on clearcuts and paths.
- Afforestation on former agricultural land or other open land, especially land considered to be visually attractive, is generally seen as very negative for landscape appreciation. Afforestation in connection with established forests is seen as less negative.

Harvesting from current non-commercial forests

This kind of bioenergy extraction includes harvesting from areas with low productivity, high harvesting costs or technical difficulties such as steep terrain, lack of roads etc, as well as areas set aside for different reasons (economic, biodiversity, special landscape values). Such forest areas are of considerable importance for people's appreciation of forest landscapes because they provide variation in the forest landscape and often have an open character or are connected to natural openings in the landscape that provide possibilities for sight and views. Larger tracts of untouched forest provide opportunities for wilderness experiences, which are important for people who prefer to walk on small paths in natural settings far away from other people and with possibilities to experience solitude and silence (e.g. Hallikainen 1998).

Several surveys have shown that natural openings in a forest (e.g. nonproductive forest land and bogs, shore lines etc) were considered more positive among respondents than openings resulting from clearcuts (Lind et al. 1974, Haakenstad 1975, Aasetre 1994, Hallikainen 1998). Above, in the section on stand openness and density, we have documented the importance of an open stand structure and visual penetration for people's appreciation, both at stand level and for the view of scenic backgrounds like lakes and hills.

Harvesting and road building in natural forests or wilderness areas will have negative effects on people's preferences. In North Finland, Saastamoinen (1982) observed a positive preference for natural forest stands. Saastamoinen (1982) explained this preference with the idea of a natural stand being a part of a larger wilderness area, Urho Kekkonen National Park, in which people neither expected to find permanent constructions like forest roads nor temporary traces from harvesting. Jaatinen (1976) found from a study in Helsinki that the existence of primeval forests was more preferred in the distant area than in the urban area. Hallikainen (1998) identified from a national survey that Finns' mental images of wilderness were of uninhabited areas covered mainly with primeval forests, devoid of roads and artificial trails, and without the effects of e.g. timber harvesting.

On the other hand, bioenergy extraction by thinning in more 'untouched' stands could increase the preference value as it opens up the stand structure and reduces the amount of dead wood. Leaving standing and fallen dead trees for natural decay is generally claimed to be a disturbing factor and a 'messy' element in the forests (Hultman 1983, Kardell 1990, Karjalainen 2000, Lindhagen & Hörnsten 2000, Tyrväinen et al. 2003, Gundersen & Christensen 2008). On the other hand, dead wood could increase the complexity and mystery of the forest, important factors for forest experience (Karjalainen 2006). Research on the effects of dead wood in forests is limited, and it is unclear how people's preferences varies for different kinds of dead wood in various stand conditions.

Forest edges are important landscape elements for people's preferences for forest landscapes, although there is limited research on the cumulative effects as the amount of edges increases (Ode & Fry 2002). People appreciate in most cases a multistoried forest edge structure forming a gradient to open land (fields, mires and wetland), as it will provide a softer visual contrast between the nature types (Krarup 2003). In consequence, selective thinning of forest edges will in most cases be a better method of bioenergy extraction than clearing all trees in the edge zone. Selective thinning includes trees removed from all size classes, so that the remaining stand has a mix of sizes, quality and tree spacing, and therefore provides a more natural and less coppice or plantation look. This is also a requirement in the environmental standard Living Forests for forest certification in Norway (Living Forest 2006).

Increased harvesting of pine and deciduous trees in the place of spruce could have some effects on people's appreciation, as pines and deciduous trees in some areas are preferred to spruce (cf section on tree species composition above).

Visual landscape consequences of increased harvesting of mountain birch forests have not been studied in Fennoscandia.

Increased afforestation

Non-managed, overgrown fields and afforestation of such abandoned fields were considered the most disturbing factors in the local cultural landscape for land-owners, landscape planners, and people participating in the planning process in several rural landscapes and villages in Finland (Komulainen 1998). Nousiainen et al. (1998) discovered that local inhabitants did not accept afforestation, but potential tourists preferred the alternatives that contained wide areas of afforestation. Karjalainen & Komulainen (1998) showed manipulated slides of various options for afforestation of abandoned farmland and all options were perceived as disturbing despite the afforested area in each option being small. The location of the afforested area was more important for the scenic beauty than the tree species used. Afforestation near the edge of an adjacent forest was preferred to a location in the middle of the field. Using a similar method with respondents from East Finland, Tahvanainen et al. (1996) found that moderate afforestation (1/3 of the original farmland area) could have positive effects on scenic beauty, but that afforestation was little appreciated if it was applied to originally attractive cultural landscapes (cf Strumse 1996). The more attractive the original landscape is, the greater the negative effect of afforestation (Tahvanainen et al. 1996). A survey in Sweden (Kardell 1990) showed very heterogeneous opinions among respondents when asked about their impression of a field afforested with Norway spruce. Some management guidelines can be derived from these studies on where to avoid afforestation (old cultural landscapes). Afforestation should preferably be located at the edge of existing

forests, and the new edge should fit well with the surrounding landscape (Karjalainen 2006).

Afforestation has until recently mainly been driven by other concerns than scenic aspects, and aims such as soil reclamation and wood production will possibly always have priority. Forest managers have started to consider the effect of visual changes in landscapes caused by afforestation (Jensen 1993, Tahvanainen et al. 2001, Karjalainen 2006). Both the arrangement of the forest stands in the landscape and the choice of tree species has major visual effects on the landscape. The afforestation can occur in different parts of the landscape. In hilly or mountainous areas, the location of forests with respect to the elevation and with respect to each other will determine the overall visual impression of a landscape. To evaluate effects of increased afforestation on landscape values and outdoor recreation is very complex, and indeed depends strongly on the context of each place. In Norway, effects of afforestation on outdoor recreation and visual landscape values have recently been reviewed and discussed in two reports (Gundersen & Bentsdal 2009a,b). A main result in these reports is that afforestation areas often operate as distinct stands or patches in the landscape, with reduced connectivity to other stands or landscape elements. Many of the plantations are arranged in rectangular forms, although irregular patches will be perceived as more natural by people. Straight lines, e.g. afforestation along property borders, are immediately caught by the eye and are mostly related to non-natural structures. The visual effects depend strongly on the choice of tree species. On the west coast of Norway, the dark green colour of the spruce plantations makes a clear contrast to the lighter green of the open fields, natural pine and hardwood forests. A visual effect strongly determined by the choice of tree species is the colour of the forests throughout the year. Light coloured species may smooth the transition between spruce plantations and softer, unplanted hillsides. Visual landscape analyses including use of digital visualization tools are standard procedures to evaluate effects of afforestation in landscapes in the UK, especially Scotland.

Natural afforestation of abandoned agricultural land has particular landscape effects and is discussed in chapter 5.3.

4.4 Effects on cultural heritage values

Even though large parts of the cultural heritage has a strict legal protection, investigations show that remains and monuments in forests are exposed to a rather high degree of obliteration and damage. In Sweden, projects carried out for the last 15 years show that many cultural remains, monuments and environments situated in forest areas are damaged (Eriksson & Lindqvist 1999). Investigations concentrated on areas where felling of timber was carried out recently and followed by scarification,

showed that from 36% and up to 80% of cultural remains had been exposed to damage in certain forest areas (Riksantikvarieämbetet 2000, 2006, Dolk & Norman 2007). Figures from Norwegian projects showed a somewhat lower damage rate where 15–16% of cultural remains situated in forests have been damaged (Narmo 1997, Risbøl 2006). It might be an explanation that the use of scarification is more widespread in Sweden compared to Norway but the difference between the two countries is most likely also connected to the methodical background of the projects. The Swedish projects were concentrated specifically on logging areas whereas the Norwegian figures come from projects carried out in forest without being concentrated only to logging areas. This explanation is supported by a Swedish project from Västernorrland that was accomplished without any specific connection to logging areas and resulting in a damage rate of 20% (Jönsson 1994) which is quite close to the Norwegian results.

We do not have similarly reliable figures for damages to cultural environments. Results from analysis carried out in Sweden of damage done to areas with cultural remains are available though and can be used to illustrate the problem. In areas exposed solely to logging, damages are documented to affect 49%, 60% and 56% of the areas where cultural remains and monuments are situated, respectively in three studies (Riksantikvarieämbetet 2000, 2006, Dolk & Norman 2007). In areas where scarification is carried out in addition to logging the numbers are 75%, 87% and 83% with a calculated national average of 76–90% (Dolk & Norman 2007).

Studies of the condition of cultural remains and monuments in forest areas show that almost all damages can be related to forestry activities – 80% in one case (Jönsson 1994), and 87% and 96% in two others (Risbøl 2006, Riksantikvarieämbetet 2000, see also Stenvik 1992). The projects carried out in areas exposed to forestry have shown that between 35% and 74% were damaged by scarification, between 53% and 70% by driving and transport in relation to logging and 42–50% by covering⁸ the cultural remains (Riksantikvarieämbetet 2000, 2006). Damages caused by driving and transport can be directly destructive to the remains and monuments as well as causing a compression of the soil which can be harmful to cultural layers. In a Norwegian case, driving activities were responsible for 42% of the damages, scarification 28%, forest road construction 15% and other types of activities 15% (Risbøl 2006).

The figures presented here show very clearly that forestry is not carried out in a sustainable manner when it comes to the cultural heritage. A very large number of cultural remains, monuments and environments are removed or damaged by forestry activities. It is particularly worrying that almost all damages are a result of the introduction of heavy machinery: the timber feller, the forest harvester, the forwarder etc which have been

⁸ According to the cultural heritage legislation in Finland, Norway and Sweden one is not allowed to cover (hide) cultural remains covered by the laws.

in use for only a couple of generations (Risbøl 2006). This mechanisation of forestry represents a great threat to the cultural heritage.

4.4.1 Additional harvesting from current production forests

Effects of removal of logging residues:

- Removing of logging debris will result in increased transport with a high potential for destroying cultural remains.
- The use of logging residues to increase the carrying capacity of the ground in order to prevent wheel track damages might be reduced.
- It is positive that removal of logging residues will result in less covering of cultural monuments and remains and thereby contribute to a better experience and protection of these.
- Removal of logging residues is also positive in the sense that it will make the landscape more tidy.

Effects of stump harvesting:

- Stump harvesting interferes with the ground in such a way that it will be devastating in areas with present cultural monuments, remains and layers.
- Negative effects are also connected to transport with heavy loads as this will cause damage to the ground.

Harvesting of non-standard woody resources:

- The use of non-standard forest resources will increase logging activities and involve a general pressure on the cultural heritage with the same negative effects as is seen with ordinary forestry.
- Harvesting of non-standard resources might have a positive effect on cultural environments as it to some degree reduces natural forest re-growth.

Resources under power lines and along roads:

- The utilization of resources along roads and especially under power lines will cause transportation which represents a potential to damage cultural heritage values.
- Removal of debris is a positive measure by reducing the covering and hiding of cultural monuments and remains.
- A reduction of forest re-growth might have a positive effect on cultural environments.

Additional harvesting involves removal of logging residues, harvesting of stumps and other non-standard forest resources like small trees, dead wood, broken trees etc. In addition there is a potential to increase biomass harvesting by utilizing wood resources under power lines and along roads.

Where logging residues are not utilized they are left on the felling area where to some degree they are used as cover with the purpose of reducing wheel track damages on the ground from heavy machinery. This has a substantial effect on the extent of disturbances made by wheel tracks (Andersson 2005). Removal of logging residues result in more transport, an activity that represents almost 50% of damages done to cultural re-

mains and monuments (Risbøl 2006). In some felling areas more than 50% and up to 70% of the damages can be related to transport (Riksantikvarieämbetet 2000, 2006).

It is not allowed to cover cultural remains and monuments according to the Cultural Heritage Acts of the Fennoscandian countries. In some projects on the analysis of damages to the cultural heritage in forests, covering of remains is one of several damage categories that are dealt with (Riksantikvarieämbetet 2000, 2006, Dolk & Norman 2007). In other studies this is left out as a cause of damages (Jönsson 1994, Risbøl 2006) due to its reversible character but also because it is difficult to make a clear definition of coverage. How many twigs and branches can be left on top of a cultural remain or monument before it can be called a violation of the law? This is a question that needs to be discussed further by the cultural heritage management sector. An important reason to deal with this damage category is not only because it hides cultural heritage remains in a way that prevents people from experiencing man-made structures as a part of the forest landscape, but also because hidden remains and monuments evidently are faced with a larger risk of destruction when they are not visible for the forest workers. In that sense removal of logging residues is a positive initiative. But still the question remains if this compensates for the damages resulting from increased transport. With regard to cultural environments, removal of logging residues will result in a more tidy landscape which in most cases will have a positive influence on the visual qualities of importance to the experience of the cultural environment.

Harvesting of stumps implies removal of the stumps by cutting the roots around it and pulling it out of the ground by the help of equipment developed for that specific purpose. Stump harvesting is quite new and is so far only in use in Finland whereas Sweden and especially Norway have taken a waiting attitude towards whole-tree harvesting. So far no investigation concerning the effects of stump harvesting on the cultural heritage has been carried out. However, the action is of such a character that there is all possible reasons to be worried about the possible effects. The removal of the stumps interferes with the soil on rather large areas and to a considerable depth, representing a severe threat to cultural remains and monuments as well as cultural layers not visible above ground. Such interference can cause direct damage to the cultural heritage and increased risk of disturbing the preservation conditions in the ground through changes in oxygen and humidity conditions. The additional driving and transport will increase with resulting negative consequences. Knowledge about the effects of scarification on cultural heritage remains and layers can to a great extent be transferred to stump harvesting. Swedish investigations show that up to 74% of cultural remains and monuments in felling areas exposed to scarification have been damaged (Riksantikvarieämbetet 2000, Åhlin 2001). A Norwegian project showed that in an investigated forest area almost 30% of the cultural remains were damaged by

scarification (Risbøl 2006). Besides, analyses show that scarification is the damage category that produces the most severe damages (Riksantikvarieämbetet 2006:12). With this in mind, there is no doubt that an increase in stump harvesting will present a great management challenge if carried out in areas where cultural heritage remains are present. Stumps left in place do not represent a threat to cultural heritage in any way.

Harvesting of other non-standard forest resources will presumably not result in any specific negative consequences except for what increased driving and general pressure on forest areas bring about. The removal of understory and deciduous trees might have a positive effect on overgrown cultural environments that presuppose a more open landscape to be comprehended.

The negative effects connected to the use of forest resources under power lines and along roads are also related to an increase in transportation. Today bushes and small trees below power lines are cut and the waste is left on the spot. If this resource is going to be exploited it has to be transported out of the area. On the other hand the removal of residues in such areas will prevent cultural remains and monuments from being overgrown or hidden below debris. Removal of trees and bushes along roads will open the view of the landscape, something which is positive for people travelling through the landscape and their possibility of experiencing the scenery, including the cultural environment.



Piles of logging residue. Photo: Raimo Heikkilä

4.4.2 *Increased production from current production forests*

Increased production from current production forests

- This will not imply new forms of threats but add to the ones known from current forestry connected to logging and transportation plus scarification if relevant.

Increased fertilization

- A supply of nitrogen will increase soil acidification which causes a worsening of the preservation conditions for cultural layers and objects of antiquity.
- Recycling of wood-ash from energy plants will also imply a deterioration of the preservative conditions in the soil layers.

Increased transport and disturbance

- Negative effects on the ground and high potential for damaging cultural heritage values.

Introduction of high-yield non-native species or GMOs

- This implies the introduction of new and unfamiliar species which might cause a negative influence on the visual qualities of traditional cultural environments and landscapes.

Increasing the current biomass production will be based on an intensification of forest culture and management as well as increased use of non-native growing-stock. An intensification of current forestry will not bring any new challenges to the interaction between forestry and the cultural heritage but it will increase the known effects connected to felling, transport and scarification. As mentioned above, these are the most severe causes for damage to the cultural heritage in forests. The negative effects of increased transport and general disturbance to the ground are also described above and will not be further discussed here.

Increased fertilization

Increased fertilization of the forest floor is possible by supplying nitrogen and/or recycling of wood-ash from energy plants. Research has been done to examine the degradation of cultural layers and objects in these and the factors influencing their condition. An accelerating deterioration of archaeological items (mainly metal items) has primarily been linked to an increase in soil acidification (Nord & Lagerlöf 2002). Acidic soil and high nitrogen and sulphur values as well as the presence of soot and soluble salts in the soil contribute to a degradation of archaeological objects. The use of nitrogen and wood-ash in order to increase fertilization in forests will most likely imply a deterioration of the preservative conditions of antiquities and cultural layers situated in forests.

Introduction of high-yield non-native species or GMOs

Depending on species changes from native to non-native growing stock imply negative effects on cultural environments. The value of cultural environments is based on a mixture of diverse cultural and natural elements creating complex entities. The presence of cultural heritage values in forests is usually closely connected to some kind of traditional utilization or exploitation of certain tree species or other forest resources (Risbøl 2005). To replace native growing stock might break this connection and cause a reduction of the authenticity of the cultural environments.

4.4.3 Harvesting from non-commercial forests and non-forest areas

Harvesting from non-commercial forests

- Harvesting from non-commercial forests involves a pressure on new areas where cultural heritage values so far have been spared from the damaging effects of forestry.
- This initiative will bring along a need for the construction of new forest roads which constitute a threat to cultural monuments and remains.
- The construction of new roads requires good planning in order to diminish their negative visual influence on cultural environments and landscape.
- Harvesting in new forest areas might have positive effects by reducing forest re-growth and thereby improving the visual qualities of cultural environments and landscapes.

Increased afforestation

- Afforestation contradicts the general desire to enhance the visual quality of open landscapes by reducing the amount of woody vegetation, thus having a negative influence on cultural environments and landscapes.
- Roots from trees represents a potential threat to cultural layers.
- Trees on cultural remains, monuments and layers represent a risk of wind falls that can damage these.
- Increased acidification of the soil brought about by conifers can contribute to a deterioration of cultural layers.

Non-commercial forests

Harvesting from currently non-exploited forests will basically lead to a potential for damage and destruction of cultural heritage remains which today are situated outside areas of highly efficient and mechanised forestry. Such forestry activities may damage a range of cultural heritage values due to timber felling, transport, scarification etc. The access to areas with non-commercial forests will require the construction of more forest roads. Construction of forest roads often leads to complete destruction of or damage to cultural remains and monuments. Two investigations showed that damages caused by road construction amounted to respectively 25% and 15% of all damages (Jönsson 1994, Risbøl 2006). Modern forest road construction is a comprehensive intrusion in the landscape, especially in steep and difficult terrain where the non-commercial forests

resources often are situated. On the other hand increased harvesting can contribute to a more open landscape that may benefit cultural environments in some areas.

Increased afforestation

Planting of trees in open areas will affect cultural environments and landscapes considerably. The spontaneous invasion of woody vegetation and afforestation of open landscapes are considered a negative development because it contributes to conceal the elements that construct cultural environments and generally disturb the view of the landscape (Moen & Framstad 1998, Hoel 2006). In cultural heritage management it is highly desirable to counteract the invasion and re-growth by woody vegetation. Planting of trees in areas with important cultural environments will contribute to a further closing of the landscape, something considered to have negative consequences for the visual qualities of the landscape. Planting of trees in open areas in forests resulting from summer farming or other types of human activity with a certain time-depth will be very devastating to the values of these sites.

Trees on or near cultural remains or monuments will also increase the risk of damages caused by roots disturbing structures and cultural layers and the risk of damages caused by windfalls. The cause of this damage category can be ascribed to natural circumstances (strong wind and heavy snow) but is closely connected to human actions as well. Planting of trees on or near cultural remains and monuments will increase the risk of destruction by windfall. This risk is further strengthened when adjacent trees near cultural monuments are felled with the result that trees growing on areas with cultural heritage values are exposed to strong wind (Hertz 2001, Haugen & Risan 2007). When trees are felled by wind, the stumps and root system are pulled up and causes damage to the ground and soil structure.

It has been documented that archaeological findings in cultural monuments and cultural layers are degraded by acidification of the soil in which they are found. Increased acidification is caused by air pollution but it is also a fact that conifers contribute to acidify the soil (Nord & Lagerlöf 2002). Hence, other species than conifers should be preferred if planting of trees is considered, especially in areas with cultural layers.

5. Agricultural land

Agriculture in Fennoscandia has undergone revolutionary changes over the last 150 years or so (Gjerdåker 2002). Up until the advent of industrial fertilizers at the end of the 1800s, the production of arable fields was entirely dependent on organic fertilization from manure or plant matter. This had the consequence that large areas outside the arable fields and other intensively managed infields, in forests, mires and mountains, had to be mobilised for grazing and fodder for livestock. This harvesting of biomass for the purpose of food production – as well as the extensive needs for woody material for buildings, fences and energy – had a profound effect on the landscape (Birks et al. 1988, Christensen 2002). In parts of western Norway, for instance, woody biomass was a very scarce resource that was exploited to an extreme degree, leaving a denuded landscape with very few bushes and trees. During the last 100 years the situation has changed profoundly. Thanks to the extensive use of industrial fertilizers, new animal and plant breeds, machinery and chemical pest control, the productivity on the best arable land has increased tremendously. The use of biomass resources from forests, mires and mountains for food production is greatly reduced (although, more sheep are grazing in forests and mountains in Norway than ever before (SSB 1995, 2000)). On the other hand, extensive areas of marginal agricultural land, especially much of the unimproved grasslands but also marginal arable land, have been converted to forest through active afforestation efforts over the last 50 years or more, or simply through a process of spontaneous re-growth of bushes and trees. Much of the agricultural land around cities and towns has also been occupied by urban and suburban sprawl. Due to a parallel process of cultivation of new agricultural land, the total amount of arable land has been fairly stable over the last 100 years in Norway (SSB 1995, 2000), whereas Finland and Sweden have had a reduction in agricultural area over the last few decades (Table 7, Figure 7).

Whether one wants to define the forest and mountain areas used for grazing and fodder production in the past (or present) as agricultural land, is a matter of perspective. However, partly due to the challenges of quantifying these areas and partly because they now have other dominant land use, we here focus on land where agriculture is the dominant current land use and only partly consider land formerly used for agricultural purposes. We have applied the following definition for agricultural land to be considered for biomass production for bioenergy (from FAOSTAT⁹):

⁹ <http://faostat.fao.org/site/379/DesktopDefault.aspx?PageID=379>

Table 7 Agricultural area in total (ha) and on which crops are grown for energy purpose. For Finland, energy crop figures only include area entitled to farming support. There is no commercial production of energy crops on farmland in Norway.

	Finland	Norway	Sweden
Total agricultural area in active use	2 295 000	1 033 000	3 136 000
of which arable	2 253 000	854 000	2 643 000
of which fallow	232 000	2 000	281 000
of which permanent crops and grasslands	42 000	179 000	493 000
Change in agricultural area 1961-2007	-17.3%	-0.1%	-26.0%
<i>Agricultural area for energy purposes</i>			
Cereals	439	0	30 000
Oil crops	821	0	25 000
Salix	7	0	14 000
Reed canary grass	15 763	0	600
Ley crops	0	0	300
Other	36	0	0
Total	17 065	0	c. 70 000

Sources: Agricultural area: FAOSTAT (<http://faostat.fao.org/site/377/default.aspx#ancor>); energy crops in Finland: Antikainen et al. (2007); Sweden: Jordbruksverket (2006).

- *arable land*: land under temporary agricultural crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years).
- *permanent crops*: land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees)
- *permanent meadows and pastures*: land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land)

The area of these land categories in Finland, Norway and Sweden is presented in Table 3 (and Table 7). The total agricultural area is extensive in Fennoscandia and some of this area will have a potential for biomass production. However, compared to central Europe, the proportion of agricultural land in relation to forests is relatively low in Fennoscandia.

Agricultural crops such as straw, ley crops, oilseed crops and cereals, but also fast-growing trees (e.g. *Salix* or *Populus*) can be used for heat, electricity or transport fuels and may become an important complement to forest biomass in replacing fossil fuels. In the transport sector, so-called first-generation biofuels such as biodiesel and bioethanol (mainly produced from annual crops such as oilseed rape and cereals) dominate the biofuel sector today. A shift towards second-generation biofuels, produced from mainly ligno-cellulosic biomass (perennial crops such as *Salix* grown in short rotation or reed canary grass *Phalaris arundinacea*), is expected for the future. Apart from solid and liquid fuels, the agricultural sector can also produce biogas from the anaerobic digestion of ma-

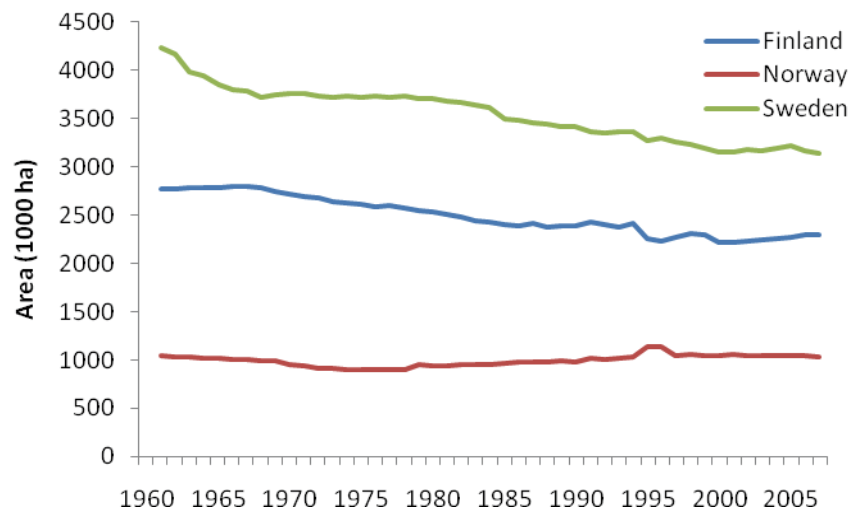


Figure 7 Change in agricultural area in Finland, Norway and Sweden (FAOSTAT <http://faostat.fao.org/site/377/default.aspx#ancor>).

nure. Biogas can then be used for heating and electricity production or be upgraded to vehicle fuel. Biomass for bioenergy purposes from agricultural areas can thus be generated by means of traditional agricultural crops or dedicated biomass crops (e.g. *Salix*, reed canary grass) used for energy purposes, the harvesting of biomass from trees grown on marginal agricultural land, or by the utilization of residues and waste products from agricultural production.

The cultivation of *Salix* on agricultural land is today commercially viable in Sweden, but cereals and oilseed crops are currently grown on much larger agricultural areas than *Salix* (Table 7). The share of bioenergy derived from the agricultural sector is small at present. In total, around 2% of Sweden's arable land is used solely for biomass production with an energy purpose. In Finland, the major bioenergy crop from agricultural land is reed canary grass, with only minimal production from other crops (Table 7). In Norway, there is still virtually no agricultural area dedicated to bioenergy production. In fact, the government's stated policy is that arable land should not be used specifically for energy crops (LMD 2009). Most of the Norwegian bioenergy from agriculture originates from agricultural wastes (cf Table 2).

5.1 Increased harvesting of biomass from agricultural land

Energy crops on arable land (cereals, oil seed, maize, energy grasses)

Wheat and other cereal crops can be grown for the production of bioethanol that can be blended with petrol. Also sugar beet can be grown for the production of bioethanol and biobutanol, both blended with petrol. Oil-

seed rape may be grown for the production of biodiesel, which is a natural replacement for mineral diesel. Normally biodiesel and mineral diesel are mixed to produce a blend. Maize and other forage crops (e.g. grassland leys) can be converted by anaerobic digestion into a biogas that can be used to produce electricity and heat. The lignocellulose in some forage crops (e.g. reed canary grass) represents also a biomass feedstock for conversion into solid biomass to generate heat and electricity, or also other energy-related end products. For example, in Finland large areas of former peat production are regularly taken out of production (ca. 1000 to 2000 ha annually), and these areas are regarded as suitable for the cultivation of reed canary grass. An advantage of using cereals, oil crops, forages and other traditional crops for bioenergy is that farmers are familiar with their management and know their economy. In addition, many of these crops offer flexibility in management because they can be used for biomass, food or forage and the land can easily be put into crop rotation.

Short rotation forestry on arable land and on marginal agricultural land

The culture of deciduous trees such as willows (*Salix*) and poplars (*Populus*) on agricultural land is an alternative for the production of bioenergy on fertile agricultural land, particularly because these trees can achieve very high biomass yields with relatively low input of nitrogen fertilizer and are regarded as very efficient nitrogen users with high energy efficiencies (Karp & Shield 2008). Although *Salix* is a woody species, the establishment of willow coppice plantations has more in common with agricultural crops than forestry (Weih 2008a). A *Salix* energy crop plantation consists of densely planted, high-yielding varieties of willow. The above-ground shoots are harvested during winter on a 2 to 5 yr cycle. The rootstocks or stools remain in the ground after harvest with new shoots emerging the following spring. A plantation could be viable for more than 20 years before re-planting becomes necessary, although this depends on the productivity of the stools and the development of pests and diseases. Weed control (mechanical or chemical) is only necessary during the establishment year, in which, however, no nutrient fertilization is needed. In the year following establishment and after each harvest, nutrient fertilization is usually applied to ensure high yield and to counteract nutrient depletion of the soil. The fertilization is often done by applying commercial fertilizer, but in Sweden also sludge from municipally waste treatment plants is used.

Trees can also be grown on agricultural land under more extensive management scenarios, especially on less fertile marginal land. Apart from poplars and aspens (*Populus*) and willows (*Salix*), native species such as birch and alder are suitable tree species and harvests would then be performed after 15–20 years. These trees can grow to greater dimensions and use is then not restricted to biomass for energy (wood chips), but may also include the production of veneer or other material use. Es-

pecially when the trees grow to greater dimensions, the management is very similar to silvicultural practices and the plantations may be regarded as a forestry enterprise, rather than agriculture.

Harvesting of wood resources from abandoned marginal farmland

Marginal agricultural fields that have been taken out of production can be planted with trees that are regularly harvested for biomass production (cf extensive management above). Alternatively, these marginal lands can be left for natural succession towards woodlands through the spontaneous establishment of native shrubs and trees originating from the surroundings, and biomass can be harvested either from all shrubs and trees, or selectively to allow valuable trees to grow larger (e.g. to benefit biodiversity). Depending on the growth conditions and the target products for the woody biomass, trees may be harvested over a rotation of 6–10 years for wood chips or over several decades for non-energy use of the wood. The total area of such marginal farmland and its geographical distribution will determine whether the woody or other biomass resources from such land may be practical to exploit. Although precise figures for abandoned farmland are lacking, the total area of abandoned farmland over the last 50 years is considerable in all three countries (Bernes 1993). Harvesting of biomass from marginal abandoned farmland is probably most realistic from marginal fields or grasslands associated with otherwise actively managed farms where harvesting can be part of the overall farm operations, as opposed to distant abandoned fields where exploitation costs may be too high. However, in perhaps most cases, remote abandoned farmland may already have been converted to forest (cf the section of afforestation in chapter 4.2.4 above).

Harvesting of organic waste materials from agriculture

The potential for using agricultural wastes such as animal manure and straw from crops for bioenergy is considerable (cf chapter 2.2). Today such wastes are partly used for soil improvement, partly for bioenergy (biogas, heat) and partly disposed of as wastes. In general, using more of these wastes for bioenergy should have a beneficial effect on biodiversity by reducing the harmful effects (eutrophication, health risk) of releasing such wastes in nature. Organic wastes are also resources for soil improvement (nutrients, organic content) and only part of such wastes should be used for bioenergy purposes. Biogas production may, however, actually improve the quality of the residues for soil improvement (Tuomisto 2005).

Introduction of high-yield non-native species or GMOs

It is conceivable that genetically improved crops (cereals, oilseed crops) and fast-growing trees (willows, poplars) will yield a higher return of material for bioenergy purposes than the original varieties. Above, we

have briefly discussed some of the environmental issues associated with the use of genetically modified trees (chapter 4.2.3). There is much public and political opposition to the use of GMO plants. In addition to the perspectives raised for trees, any use of GMO crops that may also spread transgenic properties to food plants can be expected to meet even more opposition. We therefore see little point in elaborating this topic further.

5.2 Effects on biodiversity

Energy crops on arable land

- Annual energy crops on arable land will have about the same effect on biodiversity as other annual crops, and perennial crops should in general be more beneficial for biodiversity than annuals.
- Many unimproved grasslands have high species richness and represent important habitats for many red-listed species. Bioenergy crops should not be cultivated on such grasslands of high conservation value.
- Crop rotation should be applied and remnant biotopes (shrubs, small trees etc) should be preserved in order to maintain landscape diversity.

Short rotation forestry

- Effects of willow or poplar plantations on biodiversity will depend on the circumstances of their establishment. If grown on arable land in an intensively managed agricultural landscape, the effect will probably be positive, by increasing landscape and habitat diversity.
- Willow or poplar plantations on marginal fallow land or permanent grasslands are likely to have negative effects by closing open habitats important for many species.

Harvesting of woody biomass from abandoned farmland

- Keeping abandoned farmland open by harvesting shrubs and trees will in most cases have a positive effect on overall landscape quality and biodiversity.
- Succession to woodland may have a positive effect in landscapes dominated by agriculture.
- Harvesting of woody biomass from abandoned farmland is unlikely to be adequate to preserve populations of the most vulnerable species dependent on traditional management of unimproved grasslands.

The various types of production of bioenergy from agricultural land may be considered in a gradient of intensity in management – from more physical cultivation, fertilizer, and herbicides use for annual crops on arable land to less of such activities and inputs for perennial crops and extensive harvesting of wood resources. The impact on biodiversity should in general be inversely related to the intensity of management. Species and ecosystems dependent on traditional, extensive management will be an exception in that they will benefit from management to keep the land open, but not if it is heavily fertilized or manipulated in other ways. There may also be exceptions for some species groups, e.g., ground

beetle species richness may be higher in conventional than organic farming systems (Weibull et al. 2003), and the individual cropping systems may provide different opportunities for wild species.

Energy crops on arable land (oilseed crops, cereals, energy grasses)

Agricultural activities, from converting land to annual crop production, intensive grazing, the use of inputs such as fertilizers and pesticides, and the highly specialized types of farming systems practiced today have all had a significant impact on both the landscape and biodiversity. Low-intensity farming practices usually have a weaker impact on biodiversity. In principle, the effects on landscape and biodiversity are the same irrespective of whether the crops are grown for food or energy purposes. Some oilseed crops may have a more positive effect on pollinators than alternative crops, due to the richer flowering of oilseed crop plants.

However, the growth of cereals or oilseed crops for energy purpose on areas formerly occupied by woodland will often be associated with the loss of natural and semi-natural habitats and species depending on these habitats, a decline in habitat quality (e.g. low number of rare species), fragmentation of surviving habitat patches and simplification of landscape level diversity.

In contrast to the annual character of cereals and oilseed crops, the culture of perennial grass crops (e.g. for biogas production) will frequently support improved habitat quality and the existence of more species. Such crops will also maintain the open character of the landscape, which might be an important factor for increased diversity, especially in areas dominated by forests.

Today, much of the most valuable biodiversity of the agricultural landscape is found in association with perennial grasslands. Converting such grasslands to bioenergy cropping systems will have a clear negative effect on many components of biodiversity, such as birds, butterflies, and plants (Antikainen et al. 2007, Vepsäläinen 2007). The development of increased bioenergy crop production in agriculture should therefore be avoided for meadows and other grasslands of high conservation value.

The cultivation of reed canary grass seems to have rather more negative effects on biodiversity than expected for a perennial crop (Antikainen et al. 2007). Compared to perennial grasslands the effect of reed canary grass on species diversity is the most negative of all energy crops. Due to the plant's thick and high growth, other plant species diversity on the stand is low. There is also a risk of reed canary grass dispersing outside its designated area which could be a threat to species of field verge. In addition, reed canary grass does not provide a suitable foraging habitat for birds and the timing of harvest is not suitable for the breeding cycle of birds. However, plantations offer shelter for overwintering pheasants (*Phasianus colchicus*) and for grey partridges (*Perdix perdix*) in the spring.

When harvesting biofuels from meadows or pastures, species of shrubs and small trees that are less frequent in the landscape should be left to promote increased structural and habitat variation in the landscape. For the same reason, crop rotation should be applied when annual crops are cultivated.

Short rotation forestry on arable and marginal agricultural land

In general, tree plantations may have positive or negative effects on biodiversity, depending on location, management and previous land use. Studies of biodiversity in plantations of fast-growing trees often arrive at contradictory conclusions, especially when different kinds of organisms are considered (Hartley 2002). Thus, the landscape context (forest or agricultural, Hanowski et al. 1997, Weih et al. 2003) along with the land-use type that the plantation replaces (Christian et al. 1994) and spatial scale aspects (e.g. size or shape of plantation, Christian et al. 1994, Berg 2002) influence the impact of establishment of tree plantations on biodiversity. In addition, many animals use multiple habitats and therefore depend on certain habitat combinations (With et al. 1997, Law & Dickman 1998). The diversity of land use types in a given landscape can therefore have large impacts on habitat connectivity and biodiversity.

The number of rare or endangered species is usually low in short rotation tree plantations, especially during the first years after establishment, and the flora consists mainly of generalists and early successional species. However, in comparison to managed forests and conventional farmland in Sweden and the UK, *Salix* energy plantations have been shown frequently to increase vascular plant diversity (Gustafsson 1987, Weih et al. 2003, Augustson et al. 2006). Also the diversity of the fauna (birds and mammals) is often found to be higher in *Salix* stands compared to agricultural croplands (Christian et al. 1998, Berg 2002). Thus, the more extensive management in plantations of perennials compared to intensively managed annual crops can improve habitat quality for many organisms including plants, birds, and insects (Berg 2002, Blick & Burger 2002, Dhondt & Wrege 2003, Weih et al. 2003) (but note the potential negative effects of particular growth forms, e.g., reed canary grass). If short rotation plantations replace conventional arable land, the effects on habitat quality, species richness and ecosystem functioning are therefore likely to be positive in many cases.

In contrast, if plantations of fast-growing trees are established on marginal fallow land, the effect on habitat quality and species richness might be negative, because species adapted to habitats formed by extensive farming practices might go extinct due to intensified management. In practice, marginal land is in many cases hardly suitable for the plantation of short rotation forests, because profitability will be low due to low biomass yield in combination with high investment costs for the establishment of these plantations.

The following best-practice guidelines for sustainable biomass production in short rotation plantations on agricultural land in Nordic regions are measures to increase biodiversity (after Weih 2008b):

- Avoid areas with protection status for nature conservation and/or cultural heritage.
- Avoid very large plantation sizes – plant several smaller plantations instead.
- Locate the plantations close to existing native woodlands and/or incorporate ‘islands’ of native trees within large plantations.
- Leave buffer zones without any crop or with native vegetation in the edges of plantations.
- Plant several varieties (preferably of different gender) within the same plantation; different varieties may be planted in sections or parallel stripes in order to facilitate harvest actions.
- Apply chemical weed control only during plantation establishment.
- Do not apply more nutrient fertilizer than the biomass crops demand during a growing season.
- Try to plan harvest actions to be performed only during the period of frozen ground.
- Harvest parts of plantations in different years.
- Locate, design and manage the plantations in such a way that they maximize variation in habitat type and landscape.

Harvesting of wood resources from marginal/abandoned farmland

Marginal agricultural fields planted with trees (extensive management, cf above, or afforestation, cf 4.2.4) will undergo a very rapid succession towards forest. If left as fallow, a succession towards woodland through the establishment of native shrubs and trees originating from the surroundings will develop at a slower rate. The speed of succession will depend on the soil conditions (rich, poor, peaty), type of former crops (arable, permanent grassland), the presence of potential woody colonizers in the surrounding (aspens, alders, willows), and any form of management that may influence the succession process (e.g. browsing of livestock, harvesting of wood). As former cultivated land goes through such a succession towards woodland, species richness will at first increase to reach a maximum in the ‘old meadow’ stage, after which it will decline as first tall herbs and then woody species start to dominate the vegetation. During this “old meadow” stage several of the species associated with open, unimproved grassland habitats will still remain, but as the succession progresses they will eventually disappear.

Such a succession towards woodland may favour landscape, habitat and species diversity in an open landscape dominated by agriculture. But on unimproved grassland or similar marginal agricultural land succession towards woodland would not be considered positive for landscape and

biodiversity values. In a landscape dominated by forest in particular, succession of open landscapes towards woodland will be regarded as unfavourable for landscape, habitat and species diversity, and the succession would here be associated with local loss of biodiversity. Large (and old) deciduous trees will generally have a high value for biodiversity, and even more so if they are exposed to the light and heat of the sun. Clearing of dense woody vegetation to expose such trees along field edges and roads in the agricultural landscape will therefore be of direct benefit to biodiversity.

Measures to keep such marginal agricultural land open should be considered from a biodiversity perspective. Harvesting of woody biomass from abandoned farmland represents a dilemma. Biodiversity will benefit from the land being kept open whereas optimal biomass harvesting requires a production cycles of repeated successions towards dense woody vegetation. Although removal of woody biomass for bioenergy from abandoned farmland will in most cases be positive for landscape and biodiversity, it is unlikely to have an adequate intensity and focus to be able to maintain the vulnerable species particularly associated with unimproved grasslands.

Marginal agricultural land is often located in remote areas with poor access for harvest machinery, making effective harvesting of such biomass difficult or uneconomical. Where shrubs and trees on marginal agricultural land can be harvested for bioenergy purposes, this could provide an opportunity (added value) also for increased environmental and outdoor recreation values. Nevertheless, the following conditions must be fulfilled to ensure that the harvesting of shrubs and trees on marginal agricultural land for bioenergy purposes will have positive effects on biodiversity:

- The succession from managed fields should proceed spontaneously with local species of trees and shrubs, and measures to speed up the establishment and growth of shrubs and trees should be avoided.
- Biomass harvesting of shrubs and trees should be carried out before succession has developed to later stages, so that the residual populations of species dependent on original farming activities can survive.
- Shrubs and trees in border zones to watercourses and wetlands should be developed to benefit from their ecological functions (prevent erosion and runoff, habitat for species).
- Selective harvests permitting deciduous forest trees to grow large and old will provide the basis for increased diversity of species associated with such large and old trees. For example, oaks are often regarded as valuable from a biodiversity perspective, but are easily outcompeted by too much shading.

- Species associated with the original farmland will be favoured by measures such as grazing or regular haymaking to keep the landscape open.

5.3 Effects on landscape appearance and outdoor recreation

- Energy crops on current arable land will have little effect on landscape appreciation or opportunities for outdoor recreation. Unusual crop colour (oil-seed crops) or growth form (tall grasses, woody crops) may add variety to the agricultural landscape but may also be perceived as alien. At the plot level, both tall grasses and woody crops will be seen as having the properties of 'continuously young forest' and be considered as less visually attractive and with limited accessibility.
- Open, traditionally managed farmland is among the most visually attractive landscapes in the Nordic countries. Natural afforestation or re-growth of bushes and trees in such landscapes is generally seen as negative, although less so than planned afforestation which will represent a starker contrast to the original landscape. Biomass harvesting from such naturally afforested landscapes may therefore be seen as positive if it re-establishes an open landscape but less so if it appears as ordinary forest operations.

Recreation opportunities in landscapes dominated by agriculture contribute to the quality of life of the residents, especially in areas where forests and other land with free public access are not available within walking distance. Accessibility is then strongly dependent on an infrastructure of paths and roads to walk on, and easy movement along private property borders. Recreational activities that are popular in or close to agricultural land include walking on trails, camping at designated sites, viewing of historical sites and cultural landscape elements, wildlife watching, horse riding and bicycling. To walk in an open space is a completely different experience than a walk in forests, and it is interesting to look more closely at studies that compare different nature types with regard to people's appreciation and preferences. Nordic studies of people's preferences for farmland are much rarer than the research examining preferences for forest landscapes, because limited recreational access results in less conflict between recreational values and agriculture. Knowledge from preference research has mainly been used to solve conflicts between different values or functions in the landscape. Instead, agricultural land has been measured and analysed more in terms of principles for landscape planning and design (Krarup 2003).

Several surveys give positive judgements to landscape openings originating from traditional agriculture, pastures or abandoned farmland – particularly those with a historical component (Lind et al. 1974, Hallikainen 1998, Komulainen 1998, Kaltenborn & Bjerke 2002). It seems, however, that Nordic people tend to prefer forests or wildlands to other rural environments (Jensen 1993, Kaltenborn & Bjerke 2002). Kaltenborn

& Bjerke (2002) showed that Norwegians expressed their strongest preferences for wildland scenes containing water as a dominant element. Next in preference were cultural landscapes and traditional farm environments. The least preferred category of pictures was the landscapes showing the effects of modern agricultural practices. In two Norwegian landscape studies, photos showing pastoral fields and woodlands with broadleaved trees got the highest scores of all nature types presented (Strumse 1996, 2002a,b). Correspondingly, a Finnish study reported that the highest scenic values were given to agricultural landscapes with a variation in topography and vegetation, while large, open and flat field areas were judged as being the most unattractive landscapes (Tahvanainen et al. 1996). These studies also showed that cultural monuments are experienced as a natural part of the landscape, increasing the scenic beauty, also confirming the findings of Lind et al. (1974).

People's appreciation of agricultural land is dependent on many different factors. Above we have mainly focused on traditional agriculture compared to more modern activities, and factors like largeness, uniformity and production intensity are obviously important factors for people's appreciation of agricultural landscapes. In addition, landscape elements important for landscape planning and design, like shape, scale, unity, visual force, diversity and spirit of the place (Bell 2004) are important predictors for people's appreciation for the landscape. Analysis and description of effects of afforestation on landscape values, visual aspects and outdoor recreation in Norway have been reported by Gundersen & Bentsdal (2009a,b). They emphasise the complexity of landscape values and visual aspects and how they strongly depend on the point of view of the observer or the position of the stakeholders.

Energy crops on arable land (oil seeds, grain, energy grasses)

Cultivation of such energy crops takes place in landscapes that are already completely open. What kind of agricultural production that occurs on the site has minor effects on landscape appreciation and recreational accessibility. The colour and texture of the species taken into production could have positive or negative effects on people's appreciation depending on seasonal changes and other factors, not least the public's own appreciation of the landscape's reflection of past and present production systems. If energy crops were put into production on pastoral fields, old cultural landscapes and traditional farm environments, this would obviously have negative effects on people's appreciation of the particular landscape. In wintertime, when there is free access to agricultural land, the kind of production on agricultural land has a minor influence on landscape appearance and outdoor recreation.

Harvesting of woody crops/resources

Short rotation forestry of willow (*Salix*) and poplar (*Populus*) species gives a kind of permanent young forest structure. This may have similar effects on people's appreciation as afforestation. Willow and poplar plantations on clearings in a forest-dominated landscape will have negative effects for people's appreciation of the landscape, but if the same plantations occur in open landscapes dominated by arable fields it will increase the possibilities for more diverse experiences.

Harvesting of wood resources from marginal agricultural land under natural re-growth

Old savannah-like, herb-rich fields with scattered old trees are among the most preferred landscapes in the Nordic countries (Strumse 1996, Kaltenborn & Bjerke 2002), and provide overviews over both the surroundings and possibilities to hide for the users. Many of the same results that are described in the section on increased afforestation (in chapt. 4.3.3) may apply to the natural succession of woody species on agricultural land, because both processes transform open land to forest. On the other hand, natural succession provides visually softer changes because of often more irregular shape, diverse texture and a diversity of deciduous trees making less of a contrast to existing cultural landscapes. Indirectly, it is relevant to discuss landscape effects of increased natural succession towards forest, because a focus on bioenergy may lead to an increase in the amount of such naturally 'afforested' areas. Directly, woody bioenergy extraction from naturally re-grown agricultural land will cause changes in people's use and appreciation of the landscape.

In general, people do not like visual changes in their natural and rural environments, and this is especially true for small-scale old farmland or pastures (Karjalainen 2006). Natural succession to forest, like planned afforestation, creates dramatic changes in the visual landscape experience. However, negative perceptions of natural woody re-growth might not only be caused by visual impacts, but also by the threats that such re-growth may pose to pastoral landscapes in terms of livelihoods, food production and socio-cultural traditions. In this sense, clearing woody biomass from such re-grown areas may be seen as a positive treatment in the zone between open agricultural land and the forests. The same seems to be true when removing dense expanding edges along old pastures.

Bioenergy extraction by removing all trees from naturally re-grown areas may cause some negative effects due to even denser regeneration from coppice in the next generation and this would be more difficult to penetrate. However, accessibility to agricultural land depends to a large extent on the density of walking paths, so the visual effects are probably the most relevant. Bioenergy extraction by selective thinning and coppicing has been demonstrated to design very suitable forests for people. From one single area of natural woody re-growth with a diversity of trees

it is possible to make several visually distinct forest stand types, depending mostly on tree species selection (Rydberg 1998).

5.4 Effects on cultural heritage values

Energy crops on arable land

- This implies the introduction of new and unfamiliar species and might cause a negative influence on the visual qualities of traditional cultural environments and landscape.
- If growing of energy crops implies increased ploughing depth this can be devastating to cultural layers.
- Energy crop species with a deep and powerful root system will have a negative influence on the preservation conditions, especially of cultural layers.
- If growing of perennial energy crops does not imply an increased ploughing depth the fact that ploughing frequency will be reduced is a positive effect on cultural layers.
- Another positive effect is if fertilization is reduced by a change to perennial energy crops in comparison with annual crops.

Short rotation forestry on arable land and on marginal agricultural land

- Tree types with deep and powerful root system will have a negative influence on the preservation conditions of cultural layers.
- Planting of woody crops on agricultural land will reduce the quality of the open landscape which is a prerequisite to experience landscape and cultural environments.
- Even though the woody crops will be harvested quite frequently they represent an element with similar negative effects on the cultural heritage as afforestation.

Harvesting of woody biomass from abandoned farmland

- This is a positive measure by reducing the cover of woody species from cultural environments in the landscape provided that cultural layers, monuments or remains are not affected.

Like in forest areas, cultural heritage in the agricultural landscape is exposed to obliteration and damage. In Norway an ongoing national project is carried out in order to document the extent of loss and damage of cultural remains and monuments that are automatically protected by law. Figures from the project show that as much as 18% of the monuments are lost during the last 1–3 decades in one of the 18 municipalities studied and that the total average for all the municipalities is nearly 7% (Sollund 2008). These figures reflect the development throughout the last 1–3 decades. During the same period almost 12% of the monuments were damaged on average, with up to 31% in the worst case. Agriculture is documented to be the main reason for the decimation whereas damage and loss caused by forestry are insignificant according to this study. This seems to be in contrast to the studies referred to in chapter 3.4.1 that documented severe results when it comes to damage to the cultural heri-

tage in forests and caused by forestry. Most likely, this can be explained by the fact that the Norwegian national project is based on an investigation of cultural remains and monuments in the national register. This register is completely dominated by visible cultural remains in the agricultural landscape whereas only a minimal part of the cultural remains and monuments situated in forests are listed. This is also the case concerning structures and cultural layers hidden below the surface. The results are inevitably influenced by this imbalance.

A project carried out in Sweden in 1994 showed that an average of 42% of cultural remains and monuments situated in the agricultural landscape was exposed to damage since they were mapped for the first time some decades earlier (Riksantikvarieämbetet 1995). The damage percentage had increased with 35% over the years and activities connected to agriculture were responsible for 12% of the damages. None of the two studies included the state of cultural layers found in arable land.

Energy crops on arable land

Cultural remains and monuments situated in agricultural land are found on remnant biotopes like field islets, near farm buildings and in outfields adjacent to arable land. A change from one kind of crop to another will presumably not have any effect on these monuments. Whether such a change will influence cultural environments and landscapes is a question of the character of these. Grass and grain growing is what we traditionally connect with an agricultural landscape and if grass and grain are replaced with completely different kinds of crops this might influence the visual experience of what is expected from a traditional farmland environment.

Cultivation and especially ploughing is a threat to cultural layers situated below the plough layer. In addition, roots from plants are a potential threat to sublayers with their destructive effect when penetrating the soil layers. To what degree this is the case depends on the plant type. Some fertilizers might also have a potentially negative effect on cultural layers as described in chapter 4.4.2. If a change to energy crops on arable land implies an increase of ploughing depth and/or the introduction of plants with deep and powerful root systems, this action will have a negative effect on cultural layers. If a change to energy crops does not imply increased ploughing depth or transition to plants with deep root systems the effect might be positive due to a lower ploughing and fertilization frequency.

Short rotation forestry on arable land and on marginal agricultural land

The effect on cultural layers as described under the previous heading applies also to planting of woody crops on arable and marginal agricultural land. Negative effects on cultural soil layers are likely to be more severe with perennial woody crops with deeper root systems than for grain, oilseed or grass crops. Planting of woody crops in what used to be an open landscape will change how this landscape is comprehended by

people. The effects will be particularly negative in small scale agricultural landscapes characterised by traditional farming and less so in large-scale open landscapes with little variation in crop types. In the former type of landscape a change to fast-growing species like *Salix* and *Populus* will most likely have a negative effect on the visual qualities of cultural environments. The introduction of small fast-growing trees harvested every 2–5 years will probably deviate from people's expected type of vegetation in a traditional farming landscape. Short rotation forestry will also represent establishment of woody species in the landscape, something considered to have negative consequences for people's possibilities to experience the visual qualities of the cultural landscape.

Harvesting of wood resources from marginal agricultural land under natural re-growth

Re-growth of bushes and trees on marginal farmland represents a major challenge for cultural heritage values, including the overall landscape. Harvesting of wood resources from marginal agricultural land may then be considered as a positive measure. It is a premise though that the harvesting is carried out in a way that does not cause damage to cultural remains and monuments found in and around the agricultural land. It is also a premise that harvesting does not interfere with the ground and soil in a way that represents a menace to cultural layers in these landscapes.

6. Other land – mires and wetlands

Apart from the biomass from forests and farmlands, bioenergy may also be harvested from other types of land. We have already discussed the possibility of harvesting woody biomass from marginal agricultural land (chapter 5) and woody resources under power lines and along roads (chapters 4.1.1, 4.2.1). Remaining areas for the harvesting of biomass for bioenergy are mainly associated with mires and wetlands. There is already extensive harvesting of peat for energy purposes in Finland and to some degree in Sweden (cf chapter 2.2, Table 2). In addition, there are potentials for harvesting reeds from cultivated mires or from natural growth in wetlands (cf below). Such plans seem to be most developed in Finland.

- Harvesting of biomass in the form of peat and reeds from mires and wetlands is negative for biodiversity where it disrupts the original ecosystem structure and processes but may have a positive effect where harvesting of reeds functions as restoration of wetlands influenced by excessive eutrophication and dense re-growth of reeds or on previously mined peatlands.
- Biomass harvesting from mires and wetlands will affect attractive landscape components and therefore will in general be considered as negative for landscape appreciation.
- Mires and wetlands are important repositories of cultural heritage relics with good preservation qualities and high symbolic significance in earlier ages. Extraction of biomass from mires and wetlands, especially peat mining from mires, where cultural relics may be found, will be a serious threat to these relics.

6.1 Effects on biodiversity

In Finland there is a large amount of old peat extraction areas (about 40 000 hectares, partly in use) or low-productive drained peatlands (1.5–2.0 million hectares) which could be utilized in bioenergy production. Old peat extraction areas are suitable e.g. for growing of reed canary grass. Another potential use could be the cultivation of *Sphagnum* species for bioenergy. Harvesting of common reeds from eutrophicated lakesides and other coastal areas has also been considered (Komulainen et al. 2008). Although less than in Finland, both Norway and Sweden also have quite extensive areas of drained peatlands for forest production, much of which is of low productivity. There are no explicit plans for the exploitation of drained peatlands or other wetlands for bioenergy purposes in Norway,

but the Swedish government is positive to modest use of peatland for bioenergy.

Reed canary grass (*Phalaris arundinacea*) is a naturally occurring plant species that can be cultivated in all kinds of soil types. The largest yields come from soils containing 20–40% organic matter and peatlands. However, the soil is acidic and poor in nutrients after peat mining, so before starting cultivation, fertilization and liming is needed. Wood ash can be used in liming and it compensates also for part of the nutrients (P, K) (Pahkala et al. 2005). Reed canary grass cultivation reduces the nutrient load of peatlands as well as carbon dioxide emissions, soil erosion and need for soil preparation. In addition, the biodiversity of soil microbes and organisms are known to be higher in perennial plant cultivations than annual plant cultivations (Tuomisto 2005). However, reed canary grass cultivations have been found to be very poor habitat for birds (Vepsäläinen 2007), and also their plant species diversity seems to be very low (R. Heikkilä, unpublished data).

Sphagnum The Finnish Forest Research Institute has an ongoing project concerning the management alternatives for low-productive drained peatlands in the future. One new possibility could be cultivation of certain *Sphagnum* species for bioenergy. According to earlier findings, the annual biomass output of sphagnum is at least equal to the annual biomass output of above-ground growing stock of ditched mires. It is also known that the consistency of sugars makes *Sphagnum* very suitable for bioethanol production (<http://www.metla.fi/uutiskirje/bio/2009-01/>). The environmental impacts of *Sphagnum* cultivation have been compared to a harvested peat mining area. Because of the rapid vegetation recovery, the area is transformed from a carbon source into a carbon sink in a couple of years. *Sphagnum* growth also effectively prevents the leaching of solid matter and nutrients into water systems and absorbs methane. Finally, cultivation would help in the restoration of the vegetation and habitats for birds and insects typical of the area. (<http://www.metla.fi/uutiskirje/bio/2009-01/>)

Common reeds (*Phragmites australis*) are typically found on lakesides and the coastal areas of the Baltic Sea. Due to eutrophication it has become more abundant and, as a result, it is often considered as a harmful plant which decreases the viability of other plant species and reduces the extent of the open water surface. As a consequence of the decline of lakeside pastures and increased spread of reed beds, the number of meadow species of the banks has decreased. Mowing and harvesting of reeds may prevent eutrophication and increase the biodiversity. On the other hand, many bird species – such as bearded reedling (*Panurus biarmicus*), reed warbler (*Acrocephalus scirpaceus*), great reed warbler (*Acrocephalus arundinaceus*), Western marsh harrier (*Circus aeruginosus*) and Eurasian bittern (*Botaurus stellaris*) – are dependent on common reeds as nesting habitats, and the reeds also function as resting places for migratory birds

(Komulainen et al. 2008). The harvesting of common reeds is done either in the late winter on the ice, when the dry straw is utilized in combustion, or in the summer when the plant material can be used in biogas production. Cutting of common reeds should be organized well to avoid methane emissions or the release of the lake floor nutrients which is a risk in the summer as the harvest machinery loosens the sediment (Komulainen et al. 2008). In addition, summer harvest should not be done earlier than at the end of July because of bird nesting (Komulainen et al. 2008). Management of large reed beds is recommended to be done in mosaic or channel structure as this is good for bird species diversity (Komulainen et al. 2008) and is unlikely to create additional release of nutrients from the sediment (Huhta 2007).

6.2 Effects on landscape appearance and outdoor recreation

Mires and wetlands are key landscape elements for recreation and nature experience in forest landscapes, and changes in these kinds of biotopes could have strong negative effects on people's appreciation of the landscape. Several surveys show that natural openings like mires and wetlands are considered as very positive preferences from respondents (Lind et al. 1974, Haakenstad 1975, Aasetre 1994, Hallikainen 1998).

6.3 Effects on cultural heritage values

Mires and wetlands offer the best preservation conditions for cultural objects and constructions. Many of the best preserved findings and cultural remains are found in mires and wetlands. In prehistoric times offerings were often placed in wetlands or in lakes that by time turned to mires. In addition, these areas were a challenge to people with regard to transport. People coped with this problem by making roads and bridges. Remnants of these are now and again found in excellent condition thanks to the good preservation situation. Another example of cultural remains in mires is certain constructions dug into mires and used for tar production in some regions. It is also worth mentioning the importance of mires and wetlands in paleo-botany, a science commonly used by archaeologists as well as paleo-ecologists. Analysis of pollen from mires is often used to support and amend interpretations based on customary archaeological findings. Consequently, mires and other wetland constitute very important parts of the landscape also in terms of cultural heritage values.

In order to increase biomass production, harvesting of grassy species and reeds from mires and wetlands as well as extraction of peat are measures in question. These actions have a potential to destroy and/or damage

cultural heritage values in these areas. The degree of damage and destruction will depend on how the harvesting is executed. Peat extraction is of course the most dramatic as it removes the peat, with the obvious consequences this will have on cultural remains and findings located in mires. Drainage represents a large problem for cultural heritage values found in mires because of the devastating effect dehydration will have on the preservation conditions. It is unclear if exploitation of biomass resources from mires (other than peat extraction) implies draining of the peat. The effects on cultural environments and landscapes will also be negative if dramatic measures will be carried out on wetland and mires as it changes the landscape in a way that reduces the visual qualities. However, harvesting of naturally occurring reeds and other biomass from mires and wetlands without disturbing the ground or soil should have minimal effect on the cultural heritage values associated with these nature types.

7. Conclusions

Increased use of energy from biomass, for heat, electricity generation or fuel, is an important element in the strategy of the Nordic countries and the European Union to reduce emissions of CO₂. However, these countries also have ambitious objectives for sustainable development, including the maintenance of biodiversity, landscape qualities, opportunities for outdoor recreation, and the cultural heritage. The increased harvesting of biomass from forests, farmland and other land will affect these other environmental values. Hence, to be sustainable, harvesting of biomass should not have unacceptable effects on biodiversity, landscape values and outdoor recreation, or cultural heritage values.

Much relevant knowledge may be applied to an assessment of many of the effects of increased biomass harvesting from forests, farmland and other types of land. However, there are still important gaps in knowledge that need to be filled before satisfactory assessments of all effects can be made. These are addressed in chapter 7.3.

7.1 Most likely biomass harvesting activities

A range of biomass harvesting options exists but they are not all equally likely in the Nordic countries. Without conducting a detailed technical and economical analysis we cannot give a precise indication of the kinds of biomass harvesting activities that will occur where and in what format. Much will also depend on future technological development and economical constraints (in markets or government support). However, our overall impression from the various recommendations and the current debate on the use of biomass indicates that the following options will at least be seriously considered.

Future biomass harvesting from forests:

- Increased harvesting of logging residues, stumps, trees from tending and thinning of young forest, and non-standard wood from current logging areas, especially from forestry districts near roads and facilities for effective use of the biomass resources (e.g., heating plants, industrial facilities).
- Increased intensity of forest cultivation activities, such as building of forest roads, soil preparation, nitrogen fertilization, planting, various thinning regimes, use of high-yield varieties or species, and shorter rotation time, on current logging areas.

- Increased harvesting of woody residues from clearing of power line corridors and along roads where effective transportation to facilities for use of the biomass is possible.
- Increased harvesting from currently non-commercial forest as well as increased afforestation may be relevant under suitable economical constraints, especially in Norway.

Future biomass harvesting from farmland:

- Increased cultivation of energy crops on arable land, such as grains, oilseed crops, and grasses, primarily in Finland and Sweden.
- Increased short rotation forestry with willows and poplars on farmland, primarily in Finland and Sweden.
- Increased harvesting of wood resources from marginal agricultural land, field edges etc, to a limited extent where the biomass can be exploited locally.
- Increased use of plant and animal wastes from agricultural production for energy purposes.

Future biomass harvesting from mires and wetlands may primarily be in the form of harvesting of peat resources and reeds in Finland.



Surveys from Finland, Norway and Sweden have shown that recently logged large clear-cuts are not appreciated by the public. If logging residue dominates the negative impression is even stronger. Photo: Lars Helge Frivold.

7.2 Effects of biomass harvesting on environmental values

Overall effects of biomass harvesting activities on environmental values

Acceptable harvesting measures

- Harvesting of logging residues, including trees from tending of young forest and thinning, seems to be among the more acceptable forms of biomass harvesting. It will probably have only marginally negative or no effects on biodiversity and cultural heritage values and a positive effect for landscape appreciation and outdoor recreation. This requires, however, that the general environmental concerns in forestry are strengthened and that appropriate measures are taken to avoid damage to important resources for biodiversity (e.g., coarse dead wood, old deciduous trees) and cultural heritage remains.
- Harvesting of biomass from power line corridors and along roads will have similar limited effects for biodiversity and cultural heritage values and positive effects for landscape appreciation as removal of logging residues.
- Harvesting of bushes and trees from marginal farmland is likely to have mainly positive effects for biodiversity, landscape appreciation and cultural heritage values as it will reduce the negative effects of succession to woody vegetation. However, particular measures are needed to avoid damage to cultural heritage values and to preserve valuable resources for biodiversity, especially old/large deciduous trees.

Mainly negative harvesting measures

- Harvesting of stumps will have a negative effect particularly on landscape appreciation and cultural heritage values. The effects on biodiversity are inadequately known.
- Intensification of silviculture will magnify the various negative effects of current forestry activities for biodiversity, landscape appreciation and cultural heritage values through a more schematic and less diverse forest landscape, less un-exploited forest area, shorter rotation time, more extensive use of non-native species, and more disturbance. Shorter rotation time will be particularly negative for biodiversity.
- Harvesting of biomass from currently non-commercial forests is likely to have a negative effect on biodiversity, landscape appreciation and outdoor recreation, as well as cultural heritage values, since such forest areas probably have had less human impact in the recent past. However, we need better information about the distribution of biodiversity and cultural heritage values in such areas.
- Natural succession of woody vegetation or planned afforestation on former marginal agricultural land will have a strong negative effect on biodiversity, landscape appreciation and cultural heritage values as open landscapes characterised by extensive traditional farming activities are among the most valuable for biodiversity and landscape appreciation as well as often important locations for cultural heritage remains.
- Increased use of bioenergy crops like reed canary grass and short rotation forestry with willows etc on arable land will in most cases have a negative effect on biodiversity and landscape appreciation through its dense and closed vegetation, and on cultural heritage values both by changing the cultural environment and by risking disturbance of remains in the soil through deep and powerful root systems. The effects of reed canary grass and willows on biodiversity and landscape appreciation may be more positive in landscapes dominated by intensive agriculture.

Effects on biodiversity from biomass harvesting in forests

Effects of logging residue and stump harvesting

- Negative effects of harvesting logging residues from spruce (conifers) seem small. The lack of coarse woody debris will remain the main threat to red-listed species irrespective of harvesting of logging residues.
- Harvesting of residues of aspen and broadleaved tree species (e.g. oak, linden, elm, ash) can pose a significant threat to red-listed species.
- Residue harvesting tends to weaken the general environmental considerations for sustainable forestry; coarse woody debris tends to be extracted or destroyed, along with the harvesting of residues.
- Residue harvesting will decrease the input of nutrients (nitrogen, minerals) to the soil and may decrease tree growth.
- Stumps comprise the bulk (60–80%) of coarse woody debris in managed forests, but the information on their importance for biodiversity is incomplete. More data is required for a thorough assessment of the effects of stump harvesting.
- Stump harvesting will strengthen most of the threats to species and habitat structures that are induced by residue harvesting (see above).
- Effects of residue and stump harvesting on plant community composition (vegetation) and soil functions (mycorrhiza, decomposition and mineralization) seem to be tolerable and overshadowed by the effects of clearcutting.

Effects of harvesting non-standard woody resources

- Increased harvesting of non-standard woody resources may result in additional reduction of coarse woody debris and valuable host trees.
- Increased harvesting under power lines and along roads will have similar effects as removal of logging residues on cleared areas, but may also expose larger trees along forest edges, thereby benefiting tree-living species demanding light and heat.

Forest management to increase biomass production

- Increased intensity of forest management will lead to a heavier exploitation of coarse woody debris, deciduous trees and other key resources for priority species; it will also lead to a more homogeneous forest at both forest stand and landscape scale.
- Soil preparation in the form of patch scarification will have marginal effects on biodiversity; more drastic ground ploughing will affect soil properties (structure, hydrology) and organisms and will increase decomposition of organic material.
- Planting of new trees and increased cultivation efforts will speed up the re-establishment of new forest and reduce the diversity of tree species, age classes, ground vegetation and amount of fine and coarse

woody debris, leading to lower species diversity in general and of saproxylic species in particular.

- Reduced rotation time will reduce the amount of old forest stands and old/large trees in the forest landscape and have a particularly negative effect on species (often red-listed) that depend on long-term wood resources and forest stand stability.

Introduction of high-yield non-native trees or GMOs

- Planting of non-native Norway spruce and sitka spruce will lead to increased soil acidification and, for most of the production cycle, a denser tree layer and more shaded ground layer with fewer possibilities for light-demanding species.
- Planting of lodgepole pines seem mainly to result in a somewhat more intensive forest management compared to managed forest stands of native Scots pine.
- Introduction of GMO trees in biomass production raises a host of problem issues, mainly related to the risk of spreading transgenic properties to non-target organisms; this risk is accentuated by the long life span, wide pollen and seed dispersal, frequent hybridization and unstable genetic structure of most forest trees.

Nitrogen fertilization

- Especially in regions where nitrogen critical loads are already exceeded, fertilization may lead to leaching of nitrate to water systems, resulting in acidification and eutrophication.
- Fertilization will benefit nitrophilous plant species, leading to changes in the ground vegetation that may persist for decades.
- Shifts in the carbon-nitrogen balance will affect the biotic community and ecological processes in the soil.

Wood-ash recycling (mineral fertilization)

- Negative effects on the ground vegetation and soil functions can be reduced by using stabilized (granulated) ashes of moderate doses (<3 Mg/ha).
- The effects on aquatic biodiversity are highly uncertain and more research is needed.

Increased transportation and disturbance

- At the regional and national level, increased road building will reduce the remaining area without roads and other human infrastructure, thus reducing the value of the Norwegian national indicator for the extent of such areas.
- At the landscape level, increased road building will fragment remaining forest patches and reduce habitat quality for interior forest species.

- Increased traffic may increase mortality rates for small animals.
- Increased disturbance and pollution risk during harvesting operations and transport will reduce habitat quality and damage important habitat elements like coarse woody debris, retention trees, mires etc.

Harvesting from non-commercial forests

- Non-commercial forests may have considerable value for biodiversity due to the (probably) limited harvesting activities of such forests in the past and their location in often steep and varied terrain.
- Harvesting will be negative for those biodiversity components associated with old forests, including several red-listed species.

Increased afforestation

- Afforestation of former agricultural land and other areas used for farm animal grazing and fodder production will be negative for species associated with open landscapes and the traditional harvesting activities that kept these areas open.
- Afforestation on mires will require drainage, a practice no longer warranted for intact mires according to environmental requirements for forest certification, as this will have drastic effects on the mire ecosystem processes.

Effects on biodiversity from biomass harvesting from farmland

Energy crops on arable land

- Annual energy crops on arable land will have about the same effect on biodiversity as other annual crops, and perennial crops should in general be more beneficial for biodiversity than annuals.
- Many unimproved grasslands have high species richness and represent important habitats for many red-listed species. Bioenergy crops should not be cultivated on such grasslands of high conservation value.
- Crop rotation should be applied and remnant biotopes (shrubs, small trees etc) should be preserved in order to maintain landscape diversity.

Short rotation forestry

- Effects of willow or poplar plantations on biodiversity will depend on the circumstances of their establishment. If grown on arable land in an intensively managed agricultural landscape, the effect will probably be positive, by increasing landscape and habitat diversity.
- Willow or poplar plantations on marginal fallow land or permanent grasslands are likely to have negative effects by closing open habitats important for many species.

Harvesting of woody biomass from abandoned farmland

- Keeping abandoned farmland open by harvesting bushes and trees will in most cases have a positive effect on overall landscape and biodiversity qualities.
- Succession to woodland may have a positive effect in landscapes dominated by agriculture.
- Harvesting of woody biomass from abandoned farmland is unlikely to be adequate to preserve populations of the most vulnerable species dependent on traditional management of unimproved grasslands.

Effects on biodiversity from biomass harvesting from mires and wetlands

- Harvesting of biomass in the form of peat and reeds from mires and wetlands is negative for biodiversity where it disrupts the original ecosystem structure and processes but may have a positive effect where harvesting of reeds functions as restoration of wetlands influenced by excessive eutrophication and dense re-growth of reeds or on previously mined peatlands.

Effects on landscape and outdoor recreation

- Logging residues left after tree cutting is generally perceived as untidy and disturbing to landscape appreciation. Such residues will also reduce the accessibility to the affected forest stands. Hence, removal of logging residues for bioenergy purposes may be seen as positive for landscape appreciation, as long as harvesting activities do not cause additional damage to the ground or the trees.
- Stump harvesting is likely to have a negative effect on landscape appreciation as well perceived accessibility to affected forest stands, as will other forms of radical disturbance to the ground such as ground ploughing.
- Harvesting of non-standard wood resources like dead, damaged or small, sub-standard trees may be perceived as positive for the visual qualities in the forest landscape and will increase accessibility to affected forest stands. Removal of large or old trees or trees with characteristic shapes will, however, be perceived as negative for landscape appreciation.
- Harvesting of woody residues from trees cut along power line corridors will increase the visual quality and accessibility of the landscape in much the same way as removal of logging residues. Removing bushes and trees along roads will open up the landscape and provide more distant views.
- More intensive silviculture to increase biomass production may have a positive effect on landscape appreciation where thinning and removal of logging residues open up dense forest stands and thereby create a

more varied forest landscape with better accessibility. However, removal of all understory bushes and trees and well-developed deciduous trees, as well as present signs of forest operations (machinery, damage to trees or ground, fresh residues) will be perceived as negative.

- Introduction of non-native trees to increase biomass production may not be perceived as negative for landscape appreciation as long as the exotic trees do not stand out as alien landscape elements or have properties unsuitable for recreational use of the forest stands (e.g. dense spruce plantations). However, the concept of ‘alien species’ will stand in strong contrast to the perception of ‘naturalness’ that is a highly valued landscape characteristic.
- Harvesting of biomass from current non-commercial forests will generally be perceived as negative for landscape appreciation as it will represent human disturbance of the natural forest landscape. Forestry activities may also create barriers to accessibility through logging residues on clearcuts and paths.
- Afforestation on former agricultural land or other open land, especially land considered as visually attractive, is generally seen as very negative for landscape appreciation. Afforestation in connection with established forests is seen as less negative.
- Increased transport, physical disturbance and noise as a result of increased harvesting of biomass will be seen as very negative for landscape appreciation, both with respect to visual quality and perceived disturbances to nature. However, forest roads will generally be used for recreational access to forest areas.
- Energy crops on current arable land will have little effect on landscape appreciation or opportunities for outdoor recreation. Unusual crop colour (oilseed crops) or growth form (tall grasses, woody crops) may add variety to the agricultural landscape but may also be perceived as alien. At the plot level, both tall grasses and woody crops will be seen as having the properties of ‘continuously young forest’ and be considered as less visually attractive and with limited accessibility.
- Open, traditionally managed farmland is among the most visually attractive landscapes in the Nordic countries. Natural afforestation or re-growth of bushes and trees in such landscapes is generally seen as negative, although less so than planned afforestation which will represent a starker contrast to the original landscape. Biomass harvesting from such naturally afforested landscapes may therefore be seen as positive if it re-establishes an open landscape but less so if it appears as ordinary forest operations.
- Biomass harvesting from mires and wetlands will affect attractive landscape components and therefore will in general be considered as negative for landscape appreciation.

Effects on cultural heritage values

- Cultural remains and monuments are damaged and destroyed in large numbers by ordinary forestry and agricultural management. Increased biomass harvesting from forests and farmland aggravates the threats to cultural heritage values situated in affected areas.
- Cultural remains in forests are seldom surveyed or mapped and therefore exposed to decimation by forestry to an alarming degree. Increased harvesting of biomass resources will aggravate this problem.
- Afforestation of landscapes with marked cultural historic impact is a clear negative effect.
- Increased biomass harvesting from farmland may affect the presence of cultural layers in arable land if a change to energy crops, especially short rotation forestry, results in interference with the subsoil. It is of utmost importance to unveil if cultural layers or structures are found below the ploughed soil level before biomass production activities with a potential to affect these are carried out.
- Increased biomass harvesting from farmland may also change the visual influence on cultural environments and landscape, especially with energy crops of deviant colour (e.g., oilseeds) or growth form (e.g., reed canary grass, willow plantations) compared to the original crops. Landscape analysis should be conducted to clarify the visual effects of such energy crops.
- In some forest and farmland areas protection can be combined with biomass harvesting if the right precautions are taken, while in other areas the cultural heritage values are vulnerable in such a way that they ought to be kept devoid of biomass harvesting. Only thorough mapping can tell if an area subjected to these actions falls within one or the other of these categories.
- Mires and wetlands are important repositories of cultural heritage relics with good preservation qualities and high symbolic significance in earlier ages. Extraction of biomass from mires and wetlands, especially peat mining from mires, where cultural relics may be found, will be a serious threat to these relics.

7.3 Key gaps in knowledge

Although we are confident that the various consequences of biomass harvesting indicated above are relevant and likely effects, our assessments will not always be as precise as needed for effective advice on future management of bioenergy resources. This is partly due to the lack of specific plans for development of biomass harvesting, such as its geographical location and specific management activities. It is also due to our inadequate knowledge of many aspects of the effects of such harvest-

ing. The main gaps in knowledge that may affect our ability to give robust advice on effects of biomass harvesting are indicated below.

Effects on biodiversity

- Although the value of coarse woody debris (CWD) to biodiversity has been extensively documented over the last few decades, we lack adequate knowledge about the function of the CWD in the form of logging residues and stumps for biodiversity. There is also a great need to know more about the function of the fine woody debris (FWD) for biodiversity in order to properly assess the effects of increased harvesting of logging residues and other biomass resources from logged areas.
- Increased biomass harvesting will directly affect the amount of biomass left to decompose in the affected ecosystems, and the release of nutrients, nitrogen and organic carbon to other ecosystem compartments. These are key processes for the long-term viability of the affected ecosystems, with implications for both ecosystem functions and effects on the carbon cycle and the thereby the climate system. Hence, there is a great need to improve our knowledge of the soil ecosystem structure and function in general, how increased biomass harvesting will affect this ecosystem and its role in the circulation of carbon and nitrogen in particular.
- A possible source of increased biomass harvesting is non-commercial forests where little or no logging occurs today. However, our knowledge of the biodiversity qualities in such non-commercial forests is quite limited. Our knowledge of the biodiversity values in such forests needs to be greatly improved in order to assess where increased biomass harvesting may safely occur without conflicting with biodiversity.
- The perspectives for increased biomass harvesting for energy purposes are ambitious and may lead to both higher intensity of harvesting from currently logged areas and harvesting from much wider areas than today. Where several harvesting actions are combined, e.g. harvesting of logging residues, stumps, and non-standard woody resources, the cumulative effects may be greater than that of the sum of each individual action. The long-term and landscape effects of such intensive harvesting over wide areas are largely unknown. There is a great need to know more about such accumulated effects in order to provide a realistic picture of the effects of increased biomass harvesting. Hence, there is a clear need to follow the various biomass harvesting measures with systematic, long-term monitoring to discover any unforeseen negative effects.
- An important consideration in a landscape context is the cumulative effects of various logging and biomass harvesting activities on the one

hand and the various measures to promote biodiversity (e.g. nature reserves, set-aside areas, general biodiversity concerns) on the other. We still lack knowledge of how the various management actions in the managed landscape interact with measures made to promote biodiversity. Intensive management for biomass production in certain areas of the forest landscape might be sustainable if these actions are balanced on the landscape scale by measures aimed to recover and maintain biodiversity.

Effects on landscape values and outdoor recreation

- Increased bioenergy production and extraction will mainly be based on 'classical' silvicultural and harvesting methods in boreal forest, and research knowledge and experience from e.g. the more than 60 preference studies may give adequate knowledge to determine some of the effects on outdoor recreation and landscape values. There is, however, lack of knowledge about effects of different 'special' methods like removal of logging residues, whole-tree harvesting and transformation of agricultural land on outdoor recreation and visual landscape values.
- The basic concept of bioenergy enhances positive feelings and attitudes among people (because it could replace non-sustainable energy sources), and it is interesting for the forestry sector to know more about how knowledge about bioenergy influences people's evaluation of landscapes important for bioenergy production and extraction. Hence, there is a need to get more knowledge about the dynamic between rational knowledge-based evaluations of complex forest ecosystem and more pure emotional evaluations and preferences of forest scenes.
- Most preference surveys are designed to capture people's experience of near-forest views by mainly using photos of forest stand structures or silvicultural treatments. Effects of bioenergy production and extraction may be perceived differently in near-distance than long-distance views.
- There is in general little knowledge about effects of afforestation on outdoor recreation and landscape values, both empirical knowledge about people's use and preferences, as well as development of different planning and visualization tools at both local and regional landscape scale.
- It is important to be aware that landscapes are diverse and can be repositories of history, rituals, cultural and spiritual meanings, social and personal identities, and emotional memories; values that are not measured directly in quantitative preference or landscape surveys. Such surveys alone can hardly capture people's true attachment to a particular place in the landscape. With bioenergy extraction in mind,

more focus should be put on qualitative, place-related research in the future, including methods like in-depth interviews, focus group meetings and other kinds of methods for investigating stakeholders' engagement and involvement in areas of special importance for bioenergy production and extraction at local scale.

Effects on cultural heritage values

- The critical threat to cultural heritage values in forests is mainly due to a mixture of lacking records and good management routines. However, forest management can be improved to minimize the negative consequences for cultural heritage values. Results from Sweden show that only 3–4% of forest areas contain cultural heritage values (Skogsstyrelsen 2007) and even in the majority of these areas it is possible to combine protection with forestry.
- A fundamental prerequisite for sustainable management of cultural remains and monuments is reliable records including a precise mapping of where the objects are situated in the landscape. This is a basic premise which together with good planning routines to a great extent makes it possible to increase biomass harvesting without violating laws, conventions and general sustainability ambitions for cultural heritage values.
- On a general level more knowledge is desirable on the intersection between how forestry is conducted and the effects on cultural heritage values. This includes research on how changes in forestry technology and logging methods can contribute to better protection of the cultural heritage.
- Similarly, in the agricultural landscape we need better knowledge on the various components of the production systems and their interactions with the cultural heritage layers and remains. This includes better knowledge about the effect of different roots types and how they affect cultural layers, as well as the impacts of ploughing and the use of fertilizers on cultural layers.
- More knowledge is also needed to understand the complex processes increased biomass harvesting will inflict on landscape values.

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Yhteenveto

Osana ilmastonmuutoksen torjunnan strategiaa Pohjoismaat suunnittelevat suurta uusiutuvan energian tuotannon ja käytön lisäämistä. Bioenergia on yksi tärkeä uusiutuvan energian muoto, jossa erityisesti Suomella, Norjalla ja Ruotsilla on merkittävä potentiaali. Biomassan energiakäytön huomattava lisäys voi kuitenkin aiheuttaa laaja-alaisia seurauksia maankäyttöön ja siihen liittyviin ympäristöarvoihin. Tämän katsauksen tarkoitus on tarkastella nykyistä tietoa biomassan korjuuseen perustuvan bioenergian tuotannon vaikutuksia luonnon monimuotoisuuteen, maisema-arvoihin (erityisesti luonnon virkistyskäyttöön) ja kulttuuriarvoihin Fennos-kandiassa. Katsaus perustuu olemassaoleviin selvityksiin ja yleiseen tietoon tuotanto- ja korjuujärjestelmistä ja niiden vaikutuksista.

Nykyinen uusiutuvan bioenergian käyttö on Suomessa 83 TWh, Norjassa 15 TWh ja Ruotsissa 104 TWh. Enemmän kuin 90% siitä saadaan metsäsektorilta. Arviot bioenergian kokonaistuotannosta vuonna 2020 vaihtelevat. Suuruusluokat ovat 126 TWh Suomessa, 34 TWh Norjassa ja 151 TWh Ruotsissa. Biomassan korjuumahdollisuuksia on useita, mutta eroavat eri Pohjoismaiden kesken. Useiden suositusten ja nykyisen asiasta käytävän keskustelun perusteella seuraavia biomassan korjuun optioita metsistä, viljelymailta, soilta ja kosteikoista tulee tarkastella.

- Hakkuutähteiden, kantojen, nuorten metsien harvennuspuun sekä teollisuuden käyttöön soveltumattoman puun tehostettu korjuu nykyiseltä hakkuualalta, erityisesti tiestön sekä biomassan käyttökohteiden (esimerkiksi lämpö- ja teollisuuslaitokset) lähistöltä
- Metsänhoidon tehostaminen, kuten metsäautoteiden rakentaminen, metsämaan muokkaus, typpilannoitus, istuttaminen, puuston harvennukset, tuottavien kantojen tai lajien käyttö tai kiertoajan lyhentäminen nykyisellä hakkuualalla
- Puuaineksen korjuun tehostaminen voimalinjojen alla ja teiden varsilla, missä tehokas biomassan kuljetus käyttökohteisiin on mahdollista
- Korjuun lisääminen nykyisin hyödyntämättömistä metsistä sekä metsittämisen lisääminen, jos se on taloudellisesti kannattavaa, erityisesti Norjassa
- Energiakasvien kasvattamisen lisääminen viljelymailla, esimerkiksi viljat, öljykasvit ja heinäkasvit, pääasiassa Suomessa ja Ruotsissa
- Lyhytkiertoisien metsätalouden (pajut, poppelit) lisääminen viljelymailla, pääasiassa Suomessa ja Ruotsissa.
- Puubiomassan korjuun lisääminen marginaalisilta maatalousmailta, pellonreunoilta jne., rajoitetusti paikalliseen biomassan käyttöön

- Biomassan korjuu soilta ja kosteikoilta voi tapahtua entisillä turpeennostoalueilla kasvatettavan rahkasammalen tai ruokohelven hyödyntämisenä tai järviruokobiomassan korjuuna matalista vesistöistä.

Seuraavat biomassan korjuutavat ovat useimmissa tapauksessa hyväksyttäviä tai niillä on vain vähäisiä haittavaikutuksia:

- Hakkuutähteitten korjuu, mukaanlukien nuorten metsien harvennuspuu, näyttää olevan hyväksyttävimpiä biomassan korjuun muotoja. Sillä on todennäköisesti vain marginaalisia haittavaikutuksia, jos lainkaan, monimuotoisuudelle ja kulttuuriarvoille, ja positiivisia vaikutuksia maisemalle ja virkistyskäytölle. Tämä edellyttää kuitenkin, että ympäristön huomioonottamista metsätaloudessa yleensä vahvistetaan, ja että huolehditaan riittävästi, ettei vahingoiteta monimuotoisuudelle tärkeitä resursseja (esim. järeää lahopuuta ja vanhoja lehtipuita) eikä kulttuuriperinnön kannalta arvokkaita kohteita.
- Biomassan korjuu voimalinjojen alta ja teiden varsilta aiheuttaa vastaavia rajoitettuja vaikutuksia monimuotoisuudelle ja kulttuuriarvoille, ja positiivisia maisemavaikutuksia, kuin hakkuutähteiden korjuu.
- Puiden ja pensaiden korjuulla marginaalisilta viljelymailta on todennäköisesti pääasiassa positiivisia vaikutuksia monimuotoisuudelle, maisemalle ja kulttuuriperinnölle, koska se vähentää umpeenkasvun negatiivisia vaikutuksia (vrt. luontainen metsittyminen jäljempänä). Erityistä huomiota tulee kuitenkin kiinnittää kulttuuriarvojen turvaamiseen ja monimuotoisuudelle arvokkaiden resurssien (erityisesti vanhat/suuret lehtipuut) säilyttämiseen.

Seuraavilla biomassan korjuutavoilla on pääasiassa kielteisiä, jopa hyvin haitallisia ympäristövaikutuksia:

- Kantojen korjuu vahingoittaa erityisesti maisema- ja kulttuuriarvoja. Monimuotoisuusvaikutukset ovat puutteellisesti tunnettuja.
- Metsänhoidon tehostaminen suurentaa nykyisten metsätaloustoimien monia kielteisiä vaikutuksia monimuotoisuudelle sekä maisema- ja kulttuuriarvoille muuttamalla metsämaisemaa monotonisemmaksi ja kaavamaisemmaksi, vähentämällä käsittelemätöntä pinta-alaa, lyhentämällä puuston kiertoaikaa sekä lisäämällä tulokaslajien käyttöä ja häirötä. Lyhyt kiertoaika on erityisen haitallista monimuotoisuudelle.
- Biomassan korjuu nykyisin hyödyntämisen ulkopuolella olevista metsistä vaikuttaa todennäköisesti haitallisesti monimuotoisuuteen, maisema-arvoihin ja virkistyskäyttöön, sekä myös kulttuuriarvoihin,

koska ihmisvaikutus tällaisiin metsiin on ollut vähäisempää lähimenneisyydessä. Tieto monimuotoisuudesta ja kulttuuriarvoista tällaisilla alueilla on kuitenkin puutteellista, ja tietoa tarvitaan lisää.

- Luontainen tai aktiivinen metsitys marginaalisilla maatalousalueilla (mukaanlukien perinnemaisemat) vaikuttaa voimakkaan haitallisesti monimuotoisuuteen sekä maisema- ja kulttuuriarvoihin, koska perinteistä maataloutta kuvastavat avoimet maisemat ovat erittäin arvokkaita monimuotoisuudelle ja maisema-arvoille sekä sisältävät usein muinaisjäänteitä ja muita kulttuurikohteita.
- Bioenergiakasvien kuten ruokohelven lisääntynyt kasvattaminen ja lisääntynyt lyhytkiertometsätalous (esim. pajujen kasvatusta) maatalousmaalla vaikuttaa useimmiten kielteisesti monimuotoisuuteen ja maisema-arvoihin muodostamalla tiheää ja sulkeutunutta kasvillisuutta, ja kulttuuriarvoihin sekä muuttamalla kulttuuriympäristöjä että aiheuttamassa mahdollisesti vahinkoa kulttuurijäänteille maaperässä syvään ulottuvilla vahvoilla juurisysteemeillä. Ruokohelven ja pajujen vaikutus monimuotoisuuteen ja maisemaan on ehkä positiivisempaa intensiivisen maatalouden alueilla.

Sammendrag

Som del av strategien for å motvirke klimaendringene har de nordiske landene som mål å øke produksjonen og bruken av bioenergi i betydelig grad. Bioenergi er en viktig form for fornybar energi hvor spesielt Finland, Norge og Sverige har et betydelig potensial. En stor økning i bruken av bioenergi kan imidlertid ha vidtrekkende konsekvenser for forvaltningen av arealene og tilhørende miljøverdier. Målsettingen for denne utredningen er å gi en oversikt over dagens kunnskap om effekter av høsting av biomasse til bioenergiformål på biomangfold, landskap, friluftsliv og kulturminner i Fennoskandia. Utredningen er basert på eksisterende studier og generell kunnskap om produksjons- og høstingssystemer og deres effekter.

Dagens forsyning av fornybar bioenergi i Finland, Norge og Sverige tilsvarer henholdsvis 83 TWh, 15 TWh og 151 TWh, hvorav mer enn 90% kommer fra skogsektoren. Vurderinger av det totale tilbudet av bioenergi innen 2020 varierer, men er rundt 126 TWh, 34 TWh og 151 TWh for henholdsvis Finland, Norge og Sverige. Mange muligheter for høsting av biomasse finnes, men de er ikke alle like sannsynlige i de nordiske landene. Basert på ulike offentlige anbefalinger og dagens debatt om bruken av bioenergi, må følgende muligheter vurderes fra skog, jordbrukslandskap, myr og våtmark.

- Økt høsting av hogstavfall, stubber, tynningsvirke og annet ukurant skogsvirke fra hogstflater, spesielt fra skogområder nær veier og anlegg for effektiv bruk av biomasseressursene (varmesentraler, industrianlegg etc).
- Økt intensitet i skogkultur og -skjøtsel, som veibygging, markberedning, nitrogengjødsling, planting, tynning, bruk av høytytende provenienser og treslag, og kortere omløpstid, på eksisterende hogstområder.
- Økt høsting av skogsavfall fra rydding under kraftlinjer og langs veier hvor effektiv transport til anlegg for bruk av biomassen er mulig.
- Økt høsting av biomasse fra skog som ikke høstes i dag (nullområder) så vel som økt skogreisning kan være relevant under hensiktsmessige økonomiske rammebetingelser, spesielt i Norge.
- Økt dyrking av energivækster på dyrket mark, som korn, oljevekster og gras, i hovedsak i Finland og Sverige.
- Økt dyrking av rasktvoksende energiskog av vier og poppel på jordbruksland, i hovedsak i Finland og Sverige.
- Økt høsting av skogressurser på marginal jordbruksmark, langs åkerkanter etc, i begrenset grad hvor biomassen kan utnyttes lokalt.

- Biomassehøsting fra myrer og våtmark kan bli i form av høsting av torvmose og strandrør på myrer tidligere utnyttet til torvtekt, samt høsting av takrør langs grunne strender, i hovedsak i Finland.

Følgende tiltak for høsting av biomasse vil i de fleste tilfellene ha akseptable eller bare minimale negative effekter:

- Høsting av hogstavfall, inkludert tynningsvirke, synes å være blant de mer akseptable formene for biomassehøsting. Slik høsting vil bare ha marginale negative eller ingen effekter på biomangfold og kulturminner og positive effekter på landskapsopplevelse og friluftsliv. Dette krever imidlertid at generelle miljøhensyn i skogbruket blir skjerpet og at hensiktsmessige tiltak blir tatt for å unngå skade på viktige ressurser for biomangfoldet (f.eks. grov død ved, gamle løvtrær) og på kulturminner.
- Høsting av biomasse under kraftlinjer og langs veier vil ha tilsvarende begrensede effekter for biomangfold og kulturminner og positive effekter for landskapsopplevelse som fjerning av hogstavfall.
- Høsting av busker og trær på marginal jordbruksmark vil i hovedsak ha positive effekter for biomangfold, landskapsopplevelse og kulturminner siden dette vil redusere den negative effekten av gjengroing. Spesielle tiltak er imidlertid påkrevet for å hindre skade på kulturminner og for å bevare verdifulle ressurser for biomangfoldet, spesielt gamle/store løvtrær.

Følgende tiltak for høsting av biomasse vil i hovedsak ha negative eller svært negative miljøeffekter.

- Høsting av stubber vil ha særlig negative effekter på landskapsopplevelse og kulturminner. Effektene på biomangfoldet er utilstrekkelig kjent.
- Intensivert skogkultur vil forsterke de ulike negative effektene av dagens skogbruk for biomangfold, landskapsopplevelser og kulturminner ved et mer skjematisk og mindre variert skoglandskap, mindre utnyttet skogareal, kortere omløpstid, økt bruk av ikke stedeegne arter, og mer forstyrrelse. Kortere omløpstid vil være spesielt negativt for biomangfoldet.
- Høsting av biomasse fra skogområder som ikke drives i dag ('nullområder') vil sannsynligvis ha negative effekter på biomangfold, landskapsopplevelser, friluftsliv og kulturminner, siden slike skogområder sannsynligvis har hatt mindre menneskelig påvirkning i nyere tid. Vi trenger imidlertid bedre informasjon om forekomsten av biomangfold og kulturminner i slike områder.
- Naturlig gjengroing med busker og trær eller skogreisning på tidligere marginal jordbruksmark vil ha sterk negativ effekt på biomangfold, landskapsopplevelser og kulturminner, siden åpne landskap

karakterisert av tradisjonell jordbruksdrift er blant de mest verdifulle for biomangfold og landskapsopplevelser samt viktige for lokalisering av kulturminner.

- Økt bruk av energivekster som strandrør og hurtigvoksende vier- og poppelarter på jordbruksmark vil oftest ha negativ effekt på biomangfold og landskapsopplevelser ved sin tette vegetasjon samt på kulturminner både ved endring i kulturmiljøer og ved risikoen for forstyrrelse av gjenværende kulturminner i jorda ved dype og kraftige røtter. Effektene av strandrør og vierarter på biomangfold og landskapsopplevelser kan være mer positive i landskap dominert av intensiv jordbruksdrift.