Consequences of an increased extraction of forest biofuel in Sweden

A synthesis from the bioenergy feedstock research programme 2007-2011, supported by Swedish Energy Agency

Summary of the synthesis report

This report presents a summary of the conclusions reached in a research synthesis report (Swedish Energy Agency report number ER2012:08, in Swedish) on environmental effects of forest biofuel extraction in Sweden.

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CONSEQUENCES OF AN INCREASED EXTRACTION OF FOREST BIOFUEL IN SWEDEN – A SYNTHESIS FROM THE BIOFUEL RESEARCH PROGRAMME 2007-2011.

SUMMARY OF SYNTHESIS REPORT

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The Swedish Energy Agency

Technical report

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KEY MESSAGES

- There is a potential for increasing extraction of forest fuel in Sweden, from current levels of approximately 50 PJ to almost 90 PJ, without negative consequences for the environment or forest production objectives.
- Extraction of branches and tops is least problematic, and while there are some question marks regarding extraction of stumps, an increase of stump extraction also appears possible.
- Such increased extraction of forest fuel is tied to a number of conditions that has to be fulfilled such as, ash recycling, nutrient compensation, good general environmental considerations, that extraction is dominated by branches/tops and stumps of conifers, that soil disturbance is prevented etc.
- If these conditions are not fulfilled, increased extraction will hamper achievement of the Swedish Environmental Quality Objectives.
- With more intense forest management the production of forest raw material, including fuel, can be increased further. However, there are significant risks in terms of biological diversity and eutrophication that have to be considered. Landscape planning, including intensive management, is one method that might allow for further increases.

FORWARD

This report is a summary of the conclusions reached in a research synthesis on environmental effects of forest biofuel extraction in Sweden. The full report (de Jong *et al*., 2012, in Swedish) can be ordered from the Swedish Energy Agency (report number ER 2012:08) or be downloaded from www.energimyndigheten.se.

The Energy Agency's research programme entitled "Sustainable supply and processing of solid biofuel ", also known as "the Bioenergy Feedstock Programme", ran from 1 January 2007 until 30 June 2011. The results of the programme were presented in synthesis reports on its various subsections. The purpose of the synthesis reports was to compile obtained knowledge in different areas, identify knowledge gaps that need to be explored further, and to place and discuss the collated research results in a broader energy and social context, including a connection to the Swedish Environmental Quality Objectives as well as to environmental and production objectives of forestry policy.

This report summarizes the synthesis on the subsection "Forest fuel and environmental effects". It deals primarily with results from projects within the "Bioenergy Feedstock Programme", financed by the Swedish Energy Agency, but other research results are considered as well.

The project group that produced the report was Cecilia Akselsson (Lund University), Håkan Berglund (the Swedish University of Agricultural Sciences, SLU), Gustaf Egnell (SLU) and Bengt Olsson (SLU). Text contributions were also made by Rasmus Sörensen (SLU), Lina Lönnberg (CBM, the Swedish Biodiversity Centre at SLU, and Uppsala University) and Karin Gerhardt (CBM). Work was coordinated by Johnny de Jong and Henrik von Stedingk at CBM.

The report has been reviewed by the Swedish Energy Agency. A reference group provided valuable feedback during the process. The project group takes sole responsibility for the analysis and conclusions.

It is our hope that this synthesis report will give the reader an insight into the state of knowledge in this area. The target group for the report includes researchers, authorities, businesses and business organisations in the bioenergy sector, and others whose activities are in some way involved in bioenergy issues.

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Cover Picture: Forwarder with forest fuel. Photographer - Ivar Palo

1 EXECUTIVE SUMMARY

This report summarizes the state of knowledge with respect to possibilities for increasing the extraction of forest fuel in Sweden and the consequences of such increases on soil, water and biodiversity. It is based, above all, on research carried out within the Swedish Energy Agency's research programme "the Bioenergy Feedstock Programme" (2007-2011), as well as on other, related projects financed by the Energy Agency.

The goal of the study was to investigate and highlight

1. New knowledge emerged from the Bioenergy Feedstock Programme;
2. The link between research results and national environmental objectives and forestry guidelines;
3. What questions remain to be answered in order to allow for a long-term and sustainable production and use of forest fuels.

The result shows that there is a considerable potential for increasing forest fuel extraction without decreasing possibilities of achieving other societal, environmental and forest production objectives. The current extraction level of approximately 50 PJ can be increased to 87 PJ, at least. Branches and tops are the least problematic, while some questions remain regarding the consequences of stump extraction. Nevertheless, limited stump extraction should be possible. This increased extraction is linked to a number of conditions which must be fulfilled in order for negative effects to be avoided, i.e.:

1. That the general environmental considerations in forestry are not negatively affected.
2. That extracted branches, tops and stumps mainly comes from conifers.
3. That compensation for loss of base cations by means of ash recycling is done where needed, using good-quality ash.
4. That it is possible to limit soil damage as felling residues and stumps, when harvested, cannot be used to reinforce the strip roads (extraction of branches, tops and stumps can only be done on land with good load-bearing capacity).
5. That extraction is not done near woodland key habitats and nature reserves, where an increase in the amount of deadwood exposed to sunlight is likely to be more beneficial for biodiversity than if it is left elsewhere in a managed forest landscape.

2 INTRODUCTION

2.1 Extraction of forest fuel – the report’s background and structure

The biofuel market in Sweden began to grow after the two oil crises in the 1970s. At first it was mainly the forest industry which began to use its residual products as a source of energy. Since then, concerns about climate change and the goal of a secure energy supply have led to policies of incentives to boost the market for domestic renewable energy. In a forested country like Sweden, this has brought a growing use of forest biomass for energy, in which district heating and electricity production in cogeneration power plants is the fastest growing market today. Just about all mill resides from the forest industry are being used today, meaning that further forest biomass has to be extracted from forests. The focus is currently on felling residues, i.e. branches and tops, but in the future stumps and small trees from clearing and thinning may also be included in the fuel mix. The Swedish biofuel market is currently growing by about 11 PJ a year, which is equivalent to approx. 1.5 million cubic metres of wood.

Forest fuel includes stemwood and felling residues such as branches and tops and stumps, but also industrial residues such as shavings, sawdust and bark are also included. Peat is another energy source from forest land which is likely to increase in importance. Intensive forest management is also being discussed as a way of increasing the supply of forest biomass. Altogether, this adds up to a more intensive management of the whole forest landscape with its peat lands and waters.

Bioenergy, (including municipal waste and peat in Swedish statistics) represented just over 22% of Sweden’s total energy supply (2009). The use of bioenergy has more than doubled since the 1980s. The greatest increase has been in district heating (Swedish Energy Agency, 2010).

Biomass from the forest is the major bioenergy source (about 85 %) and it is procured from forests dominated by two tree species, Scots pine and Norway spruce (80 % of the growing stock), with an even aged management system, including one or several thinnings and final felling.

This report limits itself to primary forest fuel, which we define as forest fuel originating from trees or tree parts, which previously had no industrial use and therefore was left in the forest at harvest.

To ensure sustainable use of forest fuel the Energy Agency is investing in research. This report is a knowledge compilation and a synthesis of the results that have emerged primarily within the Agency’s own research programmes, but also in other, related programmes and projects. Also the synthesis links the research results to the possibility to achieve other societal goals in addition to a secured energy supply.

2.2 Research into extraction of forest fuel – the Bioenergy Feedstock Programme

The Energy Agency’s research programme “the Bioenergy Feedstock Programme” began on 1 January 2007. The programme received SEK 40 million in support per year and was completed, following an extension, on 30 June 2011. Parts of the Bioenergy Feedstock Programme are a continuation of the earlier research programme “Biofuel and the environment” (2000-2004) with results and conclusions compiled in a previous synthesis report (Egnell *et al.*, 2006).

The Bioenergy Feedstock Programme consisted of three theme areas: Agriculture, Forest and Processing, and an overarching section, Strategic Knowledge, which touched on all theme areas. The theme area "Forest and Processing" was further subdivided into two parts: "Forest management for sustainable increased fuel production" and "More efficient forest fuel systems".

The present synthesis report will primarily analyse results from the "Forest management for sustainable increased fuel production" sub-area, which in turn consisted of "Soil and ecosystem", "Management" and "Peat" (peat is excluded in this summary), and a sub-area within Strategic Knowledge, "Biodiversity". Other research was also included which had been pursued outside of the Bioenergy Feedstock Programme but which was related to these sub-areas, as well as projects which were included in the previous programme ("Biofuel and the environment") with results published after the previous synthesis (Egnell *et al.,* 2006).

2.3 Environmental Quality Objectives

The Swedish Environmental Quality Objectives (Swedish Environmental Protection Agency) were formulated between the end of the 1990s and the early 2000s. The Parliament adopted 15 overall objectives in 1997. A few years later, the Parliament adopted interim targets as well as a 16th objective. The Environmental Quality Objectives that are most relevant for forest fuel extraction are Reduced Climate Impact, Natural Acidification Only, Zero Eutrophication, Sustainable Forests, and A Non-Toxic Environment. Below are the overall definitions of the objectives most connected with forest fuel extraction. Set interim targets for the objectives have been partially superseded, since most of them only applied until 2010. Some were achieved, others were not. The objectives are currently in the process of being more closely specified. Interim targets will be replaced by milestone targets in the near future. The most relevant Environmental Quality Objectives for this study are:

- Reduced Climate Impact "The UN Framework Convention on Climate Change provides for the stabilisation of concentrations of greenhouse gases in the atmosphere at levels which ensure that human activities do not have a harmful impact on the climate system. This objective must be achieved in such a way and at such a pace that biological diversity is preserved, food production is assured and other goals of sustainable development are not jeopardised. Sweden, together with other countries, must assume responsibility for achieving this global objective."

- Natural Acidification Only "The acidifying effects of deposition and land use must not exceed the limits that can be tolerated by soil and water. In addition, deposition of acidifying substances must not increase the rate of corrosion of technical materials located in the ground, or water mains systems, archaeological objects and rock carvings."

- Zero Eutrophication "Nutrient levels in soil and water must not be such that they adversely affect human health, the conditions for biological diversity or the possibility of varied use of land and water."

- Sustainable Forests "The value of forests and forest land for biological production must be protected, at the same time as biological diversity and cultural heritage and recreational assets are safeguarded. The aim is for the Environmental Quality Objective to be achieved within a generation."

- A Non-Toxic Environment "The occurrence of man-made or extracted substances in the environment must not represent a threat to human health or biological diversity. Concentrations of non-naturally occurring substances will be close to zero and their impacts on human health and on ecosystems will be negligible. Concentrations of naturally occurring substances will be close to background levels."

2.4 Forest policy objectives and sector goals

The forest policy decision from 1993 (govt. bill 1992/93:226) specifies a production objective and an environmental objective.

2.4.1.1 The production objective

"The forest and forest land shall be utilised efficiently and responsibly so that it provides a sustainably positive yield. The emphasis of forest production shall be to provide freedom to manoeuvre in matters concerning the use of what the forest produces."

2.4.1.2 The environmental objective

"The natural production capacity of the forest land shall be preserved. Biodiversity and genetic variation in the forest shall be secured. The forest shall be utilised so that plant and animal species that naturally belong in the forest are provided the conditions necessary to survive under natural conditions and in a viable population. Endangered species and types of nature shall be protected. The forest's cultural environmental capital and its aesthetic and social capital shall be safeguarded."

These objectives are equally important to achieve. The production objective, the environmental objective, and the Environmental Quality Objectives are the foundation for the sector goals formulated by the forestry sector. The sector goals comprise overall, long-term goals which are more like a vision for the future and are a further development of the forest policy objectives, as well as 24 short-term and more concrete milestone targets to be achieved (Swedish Environmental Protection Agency. These 24 targets also include the interim targets of the Sustainable Forests objective. The result of the Bioenergy Feedstock Programme is in part connected with some of the targets. An example of this is the target for the natural production capacity of forest land: "No later than in 2010, there will be guidelines for how the natural production capacity of forest land is to be preserved, which will include balanced access to nutrients and adaptations in forest management", and the equilibrium target for land and water: "No later than in 2010, the acreage receiving ash will be at least as large as the acreage on which felling residues (branches and tops) are harvested in regeneration felling". Another example is the target for environmental considerations in regeneration felling. While the target is most relevant for the agency's advisory role, it is nevertheless directly connected to the Bioenergy Feedstock Programme in respect of which considerations are most effective for biodiversity.

3 PURPOSE AND METHOD

The overarching purpose of the study was to investigate the following:

1. What new knowledge has emerged within the Bioenergy Feedstock Programme regarding the extraction of forest fuel from forest? The state of knowledge today will be compared with the state of knowledge when a previous synthesis report was produced (Egnell *et al.*, 2006).
2. What questions remain to be answered in order to be able to guarantee long-term and sustainable production and use of forest fuels?

3. The link between research results and national environmental objectives and forestry guidelines (e.g. the Environmental Quality Objectives and the recommendations of the Swedish Forest Agency), and EU directives, e.g. the Renewable Energy Directive (EU directive 2009/28/EC).

The study was carried out in two stages, of which the first comprised a knowledge review including the identification of knowledge gaps, completed in 2010, and the second, a synthesis, was completed in 2011. The study is based on an overall description of the state of knowledge in which completed projects are included.

The knowledge review continued where the previous synthesis report left off (Egnell *et al.*, 2006) and is based primarily on results and publications produced within the framework of the Bioenergy Feedstock Programme and related projects since 2004. Additionally, an overall literature search was made of other relevant publications produced in other research programmes, both in Sweden and internationally. All project coordinators who are running or have run projects within the Bioenergy Feedstock Programme since 2007 were interviewed. The aim of the interviews was to pick up preliminary results that have not yet been published, to discuss what has been done within the projects in relation to the project plan, and to identify knowledge gaps. The research being done regarding extraction of forest fuel in Finland is of particular interest. For that reason, some researchers in Finland were also interviewed.

Facts for the report were also collected via a number of seminars. A research seminar on climate-related projects was held on 23-24 March 2009, a seminar on the consequences of stump extraction on 7-8 May 2009, and on 2-3 November 2009 a research seminar was held which covered the other projects within the Bioenergy Feedstock Programme.

The full report was reviewed and complemented by a number of specialists (see “Acknowledgements”), and was discussed at seminars on 1 December 2009 and 21 March 2011.

Current knowledge about environmental consequences of different forms of forest fuel extraction and knowledge gaps implying research needs are summarized in chapters 4-7. In chapter 8 we evaluate the consequences of increased forest fuel extraction against the objectives adopted by the Swedish parliament: the Environmental Quality Objectives and forestry policy objectives. This is done for a number of harvest intensity scenarios at the stand and at the landscape level. The consequences of these scenarios were evaluated in relation to Environmental Quality Objectives based on literature reviews and expert seminars (several workshops in which a number of experts within different disciplines were involved). Finally we estimate an extraction level of forest biomass which does not counteract the possibility of achieving the environmental quality objectives.

4 FOREST PRODUCTION

4.1 Branches and tops

Forest production research concerning the effects of extraction of branches and tops is based on long-term studies, to evaluate long-term effects and to determine the size and duration of growth effects. Most of the studies of Norway spruce indicate growth reduction in planted seedlings following extraction of stems, branches and tops as compared to stem-only harvest in regeneration felling, although the growth reduction is not always statistically significant, whereas a growth reduction was not found in Scots pine (figure

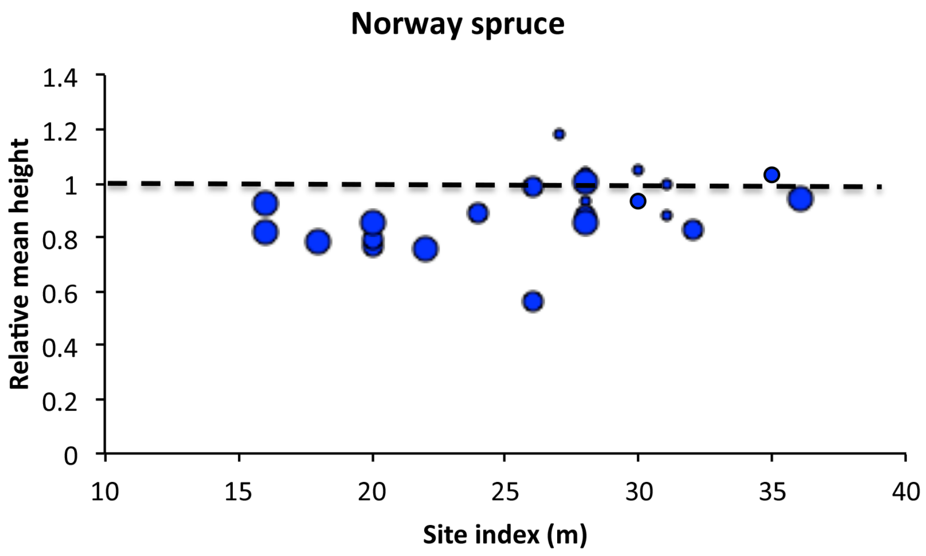
4.1). The growth reduction for individual trees is sometimes compensated for by increased plant survival rates, particularly in pine plantings. In practical forestry the growth reduction can be compensated for through earlier stand establishment, better conditions for site preparation and planting operations when felling residues are removed, and fertilization.

Since nitrogen usually is the most important nutrient for tree growth in boreal and northern temperate forests (Tamm, 1991), it is likely that the growth reduction is caused by the additional nitrogen harvested when nutrient rich branches and tops are extracted. The growth effect appears to be temporary and not a permanent decrease in site and stand productivity (Egnell 2011).

The results from a large number of studies with forest fuel extraction in thinnings were recently published, 15-25 years after thinning (Helmisaari *et al.*, 2011). Several of the trial stands had been thinned a second time with repeated forest fuel extraction. The overall result show that extraction of branches and tops in thinning has significantly reduced growth in the remaining stand – during the two first ten-year periods in spruce stands and only during the second ten-year period in pine stands. Compensation fertilization, i.e. addition of the nutrients extracted along with branches and tops, compensated for the growth reduction. These results are in line with results of earlier studies. From an economic point of view a forest owner therefore has to take future growth losses and the cost for fertilising into account when deciding to deliver branches and tops from thinnings or not.

4.2 Stumps

Unpublished data from field studies indicates that stump harvesting does not appear to affect forest production in the short term, while the amount of available data is insufficient for assessing long-term effects. But as the nitrogen content of stumps is considerably lower than that of branches and tops, there is no reason to expect dramatic effects of stump harvesting. Furthermore well implemented stump harvesting can reduce root rot in the next forest generation (Vasaitis *et al.*, 2008), while at the same time soil disturbance caused by the harvest stimulates the release of nutrients and natural regeneration. This can affect forest production in a positive direction. On the other hand, stump harvest increase the risk of rutting and soil compaction, which can have negative effects on plant establishment and growth, and due to logistic reasons, when another assortment is to be harvested, transported, and temporary stored in the forest, there is a risk for a delay in reforestation operations.



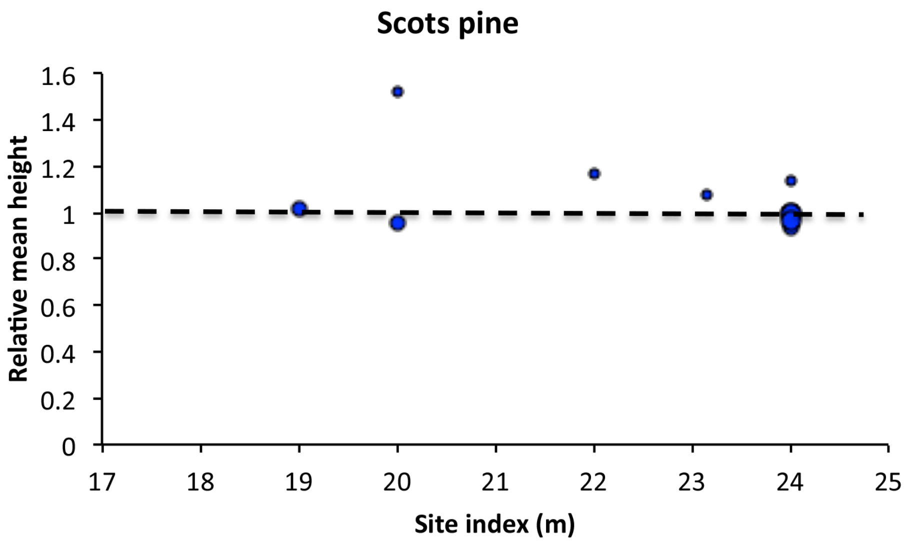


Figure 4.1 Relative mean height (Stem+branch and top harvesting/stem harvesting alone) for Norway spruce and Scots pine planted following whole-tree harvest (all biomass above the stump harvested) as compared with conventional harvest, in which only the stemwood is harvested. Dot size indicates the time since planting, 5-10 years ago for the smallest and over 20 years ago for the largest. Data obtained from long-term studies in Sweden and plotted against the site index (expected height (m) of dominant trees at age 100 years), which is an index describing potential tree growth on a site.

4.3 Ash recycling

The Swedish Forest Agency recommends ash recycling following forest fuel extraction - primarily to counteract the soil acidifying effect as a result of increased extraction of base cations, and not to secure short-term site and stand productivity.

Ash recycling and liming have been shown to affect forest production in different directions on different sites (Norstedt, 2001). It is therefore important to make clear on which sites there is a risk of forest production reductions from ash recycling, and on which sites a growth increase can be expected instead. Unpublished data show that both ash recycling and lime can lead to slightly reduced growth on nitrogen-poor sites, unchanged growth on intermediate sites, and slightly increased growth on nitrogen-rich sites. However, these effects are small and often not statistically significant in individual studies. The most likely explanation for the differences in growth effect on different sites is that nitrogen availability is affected differently in different site types, with immobilisation on poor sites and a net release on more fertile sites.

4.4 Increased forest production

The rapidly expanding bioenergy market in Sweden has warranted research projects that seek ways to increase biomass production from forests. These projects deal with fast-growing tree species, optimised fertilization of spruce forests, and modifications of current silvicultural systems in order to increase biomass production in young stands. Several of these studies are focusing primarily on determining potential production levels and identifying risks, e.g. nitrate leaching or nitrous oxide emissions. Looking ahead, if more intense forestry practices increase its share, developments in technology and logistics will also be required that render economically sustainable production while at the same time limiting effects on the surrounding environment.

4.5 Need for research

Today there is a large amount of empirical data available for analysing growth effects of forest fuel extraction (branches and tops, stumps, small stems) and ash recycling. So far, individual series of studies have been analysed separately. It is now time to move from analyses of individual studies to analyses of larger materials, with greater chances of generating more general knowledge on if and where, and if so how much, forest production is affected. In order to make it possible to study more long-term effects of one or several forest fuel harvests, it is important to stress the need for continuation of long-term field studies. Additionally, the environmental performance of more intense forestry practices, with the potential for increasing biomass production in forests, needs to be evaluated.

5 SOIL AND WATER – EUTROPHICATION, ACIDIFICATION AND POLLUTANTS

Different types of human activity affect flows of elements from the forest into surface waters. Air pollutants in the form of sulphur and nitrogen contribute to acidification and eutrophication of soil and water, and acid precipitation can also affect the mobility of pollutants, e.g. mercury. Forestry operations affect the nutrient cycle of the soil, partly through the removal of nutrients at harvesting, and partly through soil disturbance and changes in flow routes from e.g. felling, soil scarification, stump extraction and soil compaction caused by forest machinery. The removal of nutrients can be negative from a nutrition and acidification perspective, but can reduce the amount of nitrogen in areas with a high nitrogen load and leaching. Forestry operations that include the addition of nutrients can compensate for the loss of important nutrients, but can also affect nitrogen leaching initially. Certain products for nutrient compensation may include pollutants, which are consequently added to the system.

5.1 The Zero Eutrophication objective

An increased extraction of forest fuel is deemed to be reconcilable with the Zero Eutrophication objective. Nutrient optimization (frequent fertilizations with a balanced fertiliser based on needle nutrient content), or increased practice of other fertiliser regimes, however, may imply reduced possibilities of achieving the objective.

In theory, extraction of branches and tops and ash recycling should not bring any greater risk of an increase in nitrogen leaching. On the contrary, regional mass balances of nitrogen show that extraction can bring some nitrogen reduction to areas with a high nitrogen load. Experimental studies show, as theory suggests, that extraction of branches and tops and ash recycling have only a very limited effect on nitrogen leaching if they are carried out in accordance with the Swedish Forest Agency's recommendations. With respect to stump extraction it is not clear how soil disturbance and possible deep ruts from forest machines affect leaching during the clear-cutting phase. This should be investigated further, along with effects on other environmental objectives of stump extraction, but the effects on nitrogen leaching are estimated to be of minor significance. Since the contribution that forestry operations make to eutrophication of lakes and seas is currently small in comparison with other sources of eutrophication, the assessment is made that extraction of branches and tops and ash recycling neither increase nor reduce the possibilities of achieving the zero eutrophication objective.

Field studies show that the effects of nutrient optimization vary depending on stand characteristics and methodology. In unfavourable cases, nitrogen leaching following nutrient optimization may be considerable, while the increase in nitrogen leaching is marginal in other cases. Further research will be needed in order to be able to minimise the risk of greatly increased nitrogen leaching. A quantification is also needed of nitrogen leaching in connection with final felling of fertilised stands.

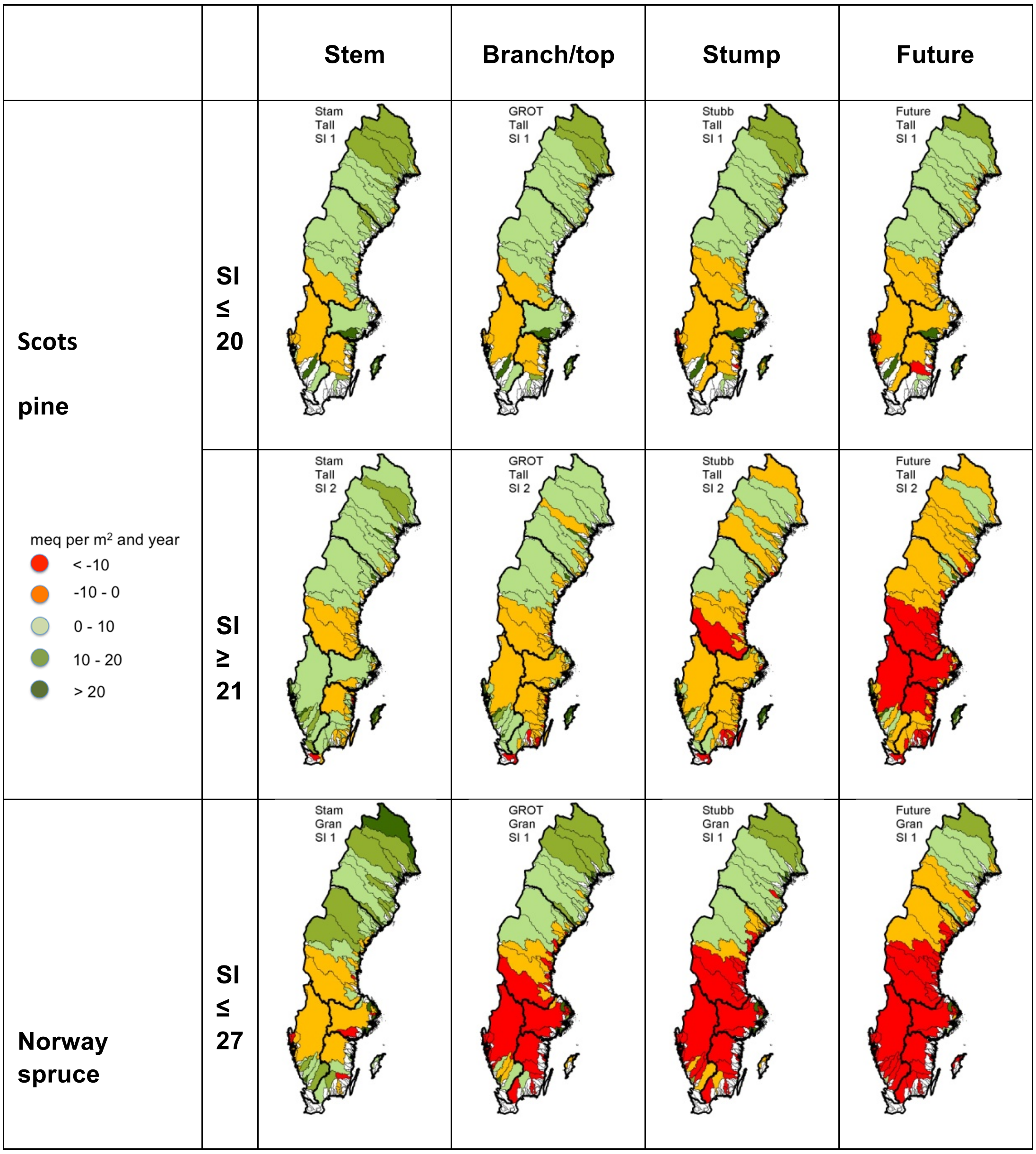
5.2 The Natural Acidification Only objective

An increased extraction of forest fuel is deemed to be reconcilable with the Natural Acidification Only objective, provided that ash recycling or some equivalent nutrient compensation is done in sensitive areas.

Forestry operations contribute to acidification since the trees' uptake of nutrients acidifies the soil, and the removal of biomass during the harvest means that the nutrients are not returned to the soil, where they can counteract acidification. This has been demonstrated in long-term field studies, dynamic modelling and regional mass balances (Figure 5.1). In more intensive forestry operations, it is above all large extractions of nutrient-rich biomass which can affect the environmental objective Natural Acidification Only. The extraction of branches and tops therefore has a considerable effect compared with stem harvesting alone, while nutrient depletion is lower for extraction of stumps than of branches and tops, albeit noticeable. Some uncertainties still remain as to the scope and time aspect of the effects on the soil, and even more as to the effects on water, but results from both field studies and models indicate that the extraction of biomass has an effect on the possibilities of achieving the natural acidification objective.

The areas where the risks of acidification due to forestry operations are greatest are those that are badly affected by acidification from air pollutants. These are also the areas where an increase in forest fuel extraction at the landscape level from e.g. 20 to 60 or 80% is likely to have the biggest effect on water quality, again at the landscape level. Today there is already considerable regional variation in terms of the size of extraction, and for that reason there is also considerable regional variation in terms of the risk of acidification effects due to forestry and the need for compensation.

With ash recycling all nutrients except nitrogen are returned to the forest ecosystem. There are uncertainties about this measure in terms of the scope and time aspect of effects, particularly effects on water. The effects of ash recycling following extraction of both branches and tops and stumps have not been studied at all. Between 2000 and 2004, branches and tops were extracted from about 30 000 hectares annually in Sweden, while ashes were spread on only 5 000 hectares. A mismatch between extraction and compensation is likely to persist in the future, partly due to a shortage of suitable-quality ash. This is an argument for adapting ash recycling to sites, and concentrating it on areas where the need is greatest, such as areas that previously had a high acidification load or forest sites on drained peat-land typically deficient in P and K, rather than N.



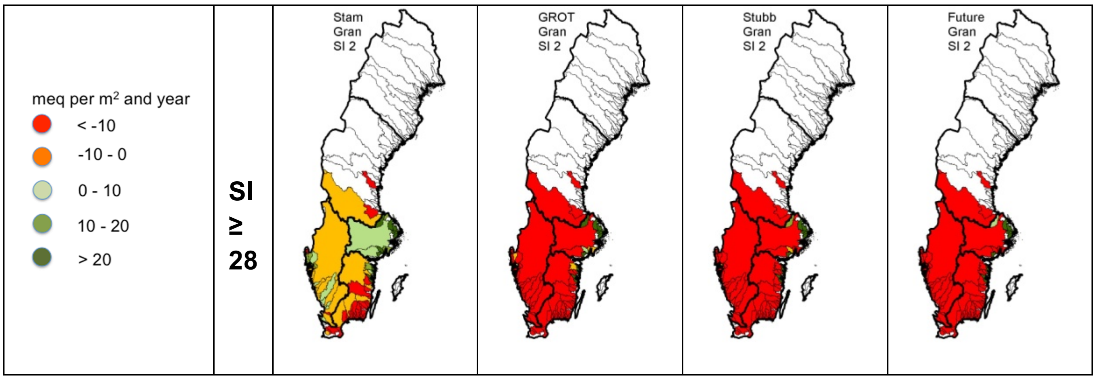


Figure 5.1 Regional mass balances of base cations (Ca, Mg, K, Na) for different harvesting scenarios, i.e. the balance between weathering on the one hand (according to the PROFILE model) and harvesting depletion of base cations on the other. The median value for Sweden's five water management districts are shown at the catchment level (principal catchments) for Scots pine and Norway spruce, divided into two different intervals for the site index (SI, expected height (m) of dominant trees at age 100 years). A negative value means that the removal via extraction is greater than the addition via weathering (Hellsten *et al.*, 2010).

In nutrient optimization, both nitrogen and other nutrients are added. The addition of base cations means that the conditions are in place for this production method not to affect the Natural Acidification Only objective adversely. However, if nutrient optimization leads to considerable nitrification this can imply increased acidification, so its effects on acidification should be studied together with its effects on nitrogen leaching.

5.3 The objective for A Non-Toxic Environment

Forest fuel extraction, which implies a greater frequency of disturbance from forest machines on moist, humus-rich soil, increases the risk of a raised incidence of the formation and spread of methyl mercury in forest land, and is therefore a potential risk for the Environmental Quality Objective A Non-Toxic Environment. Ash recycling is compatible with the objective provided suitable doses and qualities of ash are spread.

The assessment of how different scenarios affect the objective for a non-toxic environment in forest land is dominated by the problem with mercury enriched in forest soils primarily as a result of coal (lignite) burning and the risk that contaminated ashes are spread in the forest. The risk of methylation of mercury and its further transport to aquatic food chains is likely to increase with any increase in soil disturbance and machine rutting in moist, peat-rich or fine textured soils with a low load-bearing capacity. It is thought that stump extraction on such soil may cause increased transport and methylation of mercury due to more soil disturbance, but this also applies for branch and top extraction to the extent that it causes more machine disturbance to moist soil.

In order to assess the consequences of an increase from a moderate to a high degree (60 to 80%) of both branch/top and stump extraction at the stand level, it may be assumed that the risk of machine disturbance increases (increased transports combined with less branches and tops padding the transport routes), and that an increase at the landscape level from minor (20%) to dominant (60 to 80%) similarly increases the risk of extraction on unsuitable soil. An expansion in these respects therefore implies not just a greater total load, but the risk is also compounded because a greater amount of unsuitable soil is made use of.

The ability to identify and separate ashes unsuitable for spreading on forest land is decisive for the effect of ash recycling on the Environmental Quality Objective. This requires that the current ash quality criteria by the Swedish Forest Agency, including maximum content of toxic elements, are adhered to.

6 GREENHOUSE GASES

6.1 The greenhouse gas balance in production, procurement and energy conversion

The climate benefits of replacing fossil fuels with forest fuels must be calculated from a holistic perspective which includes greenhouse gas balances for the ecosystems where the biomass is produced, the energy systems where the biomass is being used, and the energy systems which are being replaced. LCA studies show that branches/tops and stumps yield a lot of energy in relation to the input energy required for harvesting, chipping and transportation to the heating plant. In total, the input energy represents about 2-5% of the energy content of the delivered biomass. The climate benefit in energy conversion depends on the energy efficiency in the energy conversion, where combined heat and power production have a favourable balance, while electricity production alone – in which surplus heat is cooled away – or conversion into transport fuel are less favourable. Last but not least, climate benefits depend on the energy carrier that is being displaced by forest fuel. The climate benefit is gained by displacing fossil alternatives, primarily coal, followed by oil and natural gas.

6.2 The greenhouse gas balance in the forest ecosystem

The greenhouse gas balance in the forest ecosystem is determined by how different greenhouse gas flows are affected by forestry including forest fuel extraction. The large fluxes here are the plants' carbon dioxide uptake through photosynthesis, the capture of carbon in biomass and soil, and soil respiration. Soil respiration is a result of soil organic material being decomposed by soil organisms, which leads to CO_2 release into the atmosphere. The balance between the build-up of new biomass and soil respiration determines if the forest is a carbon source (soil respiration dominates) or a carbon sink (biomass production dominates) in relation to the atmosphere. Added to this are any effects of forest fuel extraction on the flows of other important greenhouse gases, such as nitrous oxide and methane. It is the sum of these flows that determines the final greenhouse gas balance in the forest ecosystem with or without forest fuel extraction, and ultimately the use of forest fuel.

The results of these calculations are highly influenced by the temporal and spatial perspective chosen. If the spatial perspective is limited to an individual forest stand subject to final felling, the greenhouse gas balance changes considerably with the development of the stand. Final felling means that the forest ecosystem initially becomes a carbon source (soil respiration > biomass production), but the establishment and growth of the new stand eventually leads it to become a carbon sink again (soil respiration < biomass production) with time. Viewed over the entire rotation period (stand establishment to economically mature stand), the forest can constitute a significant carbon sink. The full impact of forestry on the carbon balance has to consider changes in soil and stand carbon stocks and how the harvested biomass is used. If felling residues are left in the forest, CO_2 is slowly released as it decomposes. If branches and tops are instead used as forest fuel, carbon in the biomass is released immediately into the atmosphere during combustion. It takes a number of years for CO_2 emissions from combustion to be balanced by the corresponding lack of emissions from decomposition. The time difference between the direct emission during combustion and the slow emission during decomposition matters in assessing the climate characteristics of forest fuel. From a short-term perspective (< 20 years), the combustion of branches and tops will largely have been balanced by the avoided decomposition. Stumps decompose more slowly than branches and tops, thus some decades more are needed to reach the same balance. The length of the rotation period is also significant, as it takes longer for the entire forest ecosystem to reach a positive carbon balance in northern boreal forests than in temperate and more fertile forests. Climate benefits from extracting biomass for energy from a stand in long-rotation forestry need to be assessed over at least one rotation period to determine the true effect.

An alternative, giving the same result as an assessment of the greenhouse gas balance of forest fuel at the stand level over one rotation period, is to assess it across a managed forest landscape where all age-classes are evenly represented, from newly planted forest to economically mature stands ready for final cut. Here the direct carbon emission from branches/tops and stumps are compensated for by both capture of carbon in stands whose development is in the most intensive growth phase and by avoided decomposition in all stands. Model simulations of carbon balances, scaled up from the stand to the landscape level, and where all development phases of a stand are evenly represented, show that increased forest fuel extraction has a positive effect on the carbon balance already in the short term if additionally extracted biomass is used efficiently (figure 6.1).

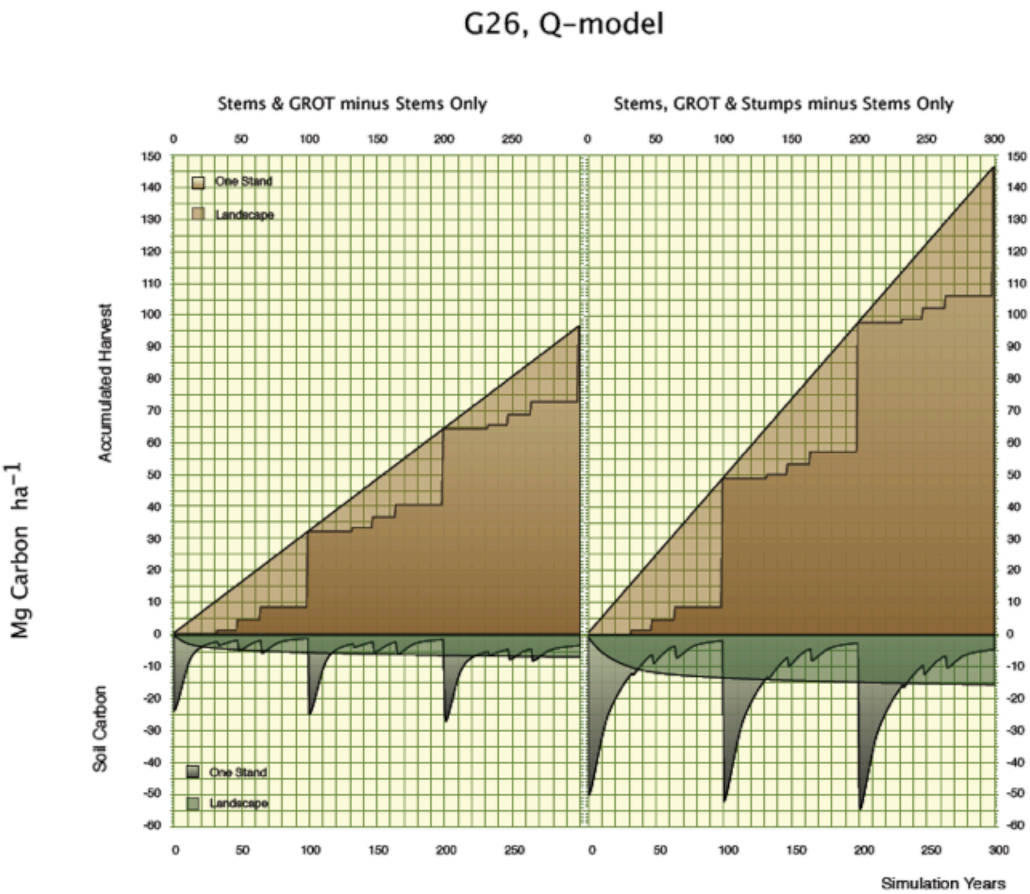


Figure 6.1. Model simulations over 300 years of the total carbon balance in a simulated landscape with spruce forests felled every 100 years and in which every age class from 0-100 years is represented with the same acreage. The upper, brown part of the diagrams shows the accumulated amount of additional carbon extracted in felling residues and stumps as compared to a stem-only scenario at the landscape level (straight line) and the site level (jagged curve), respectively. The lower,

green part shows the accumulated decrease in the soil carbon stock over time, caused by the additional carbon extracted in felling residues and stumps as compared to a stem-only scenario at the landscape level (smooth line) and at the site level (jagged curve), respectively. The left-hand diagram shows harvesting of 80% of all available branches/tops. The right-hand diagram includes harvesting of 50% of all stumps.GROT is the Swedish abbreviation for branches and tops. (Eliasson *et al*., 2011).

The simulations show that the additional amount of carbon in harvested felling residues and stumps is much greater than the total soil carbon loss as compared to a stem-only scenario. By using the biomass in harvested branches/tops and stumps wisely, e.g. to replace fossil fuels, a prompt positive effect on the greenhouse gas balance is achieved.

Uncertainties not considered in the reasoning above include (i) that extraction of nutrient-rich biomass for energy purposes may have a negative effect on forest production in the new stand, which in turn can influence the carbon balance (see the section on forest production), (ii) increased soil disturbance after harvesting of branches/tops and above all of stumps, can affect decomposition rates and thereby CO_2 release from the soil. However, an increase in decomposition has the potential to increase nutrient availability, which in turn can stimulate growth in the new stand, including field and bottom vegetation. This can be corroborated by results from field studies where effects of mechanical site preparation are studied. In this way, the soil carbon stock can be reduced and the stock in living biomass increased without affecting the total carbon balance. It is therefore important, when evaluating a measure, to consider changes in all carbon stocks. Changes in the flows of other greenhouse gases such as nitrous oxide and methane can also affect the final result, though these flows are typically minor on nitrogen limited forest soils (Dalal & Allen, 2008).

6.3 Ash recycling on drained peat land

Although wood ash has a limited growth effect on upland soils, one way of increasing forest production is to use wood ash as a fertiliser on Sweden's 5 million hectares of drained, forested peatlands. But there are concerns that the carbon capture achieved by the documented increased forest production may be counteracted by increased greenhouse gas flows from the peat layer. Field studies have shown that ash recycling on drained low productive peat lands leads to unchanged greenhouse gas emissions, or at least not increased ones, while ash addition on fertile peatlands can lead to reduced greenhouse gas emissions, at least in the short term. Continued follow-ups of greenhouse gas emissions, as well as a better understanding of what mechanisms cause the net flows, are needed in order to assess the long-term effects of ashes on drained forested peatlands.

6.4 Greenhouse gas balance in more intensive forest production

In more intense forest production methods, such as optimised fertilisation (currently not practised in Sweden), or conventional fertilisation regimes, more nutrients (primarily nitrogen) are added to the forest stands on sites with intermediate fertility. This result in increased CO_2 sequestration and more forest biomass for energy and material substitution. This practise could potentially induce a risk of increased nitrous oxide emissions, which if they grow large, could counteract the positive climate effects brought on by increased forest production. However, a consolidated conclusion in the form of a Swedish environmental impact assessment study (the MINT inquiry), based on literature studies and model simulations (the COUP model), notes that both fertilised and unfertilised Swedish forests are positive for the greenhouse gas balance. Despite the fact that modelled calculations indicated increased nitrous oxide emissions with fertilisation, (1400 kg N per hectare and century) these never reduced the positive effect of the increased carbon uptake by more than 2 %. Caution is urged, however, in interpreting the results of the model simulations as they may contain errors caused by both uncertainties in empirical data and in the models themselves.

7 BIODIVERSITY

The issue of how forest fuel extraction affects biodiversity is principally about consequences for wood-living species. The issue can be narrowed down further, to apply primarily to consequences for wood-living species that are dependent on sun-exposed dead wood in clearings, as it is there that the biggest extraction of forest fuel currently is being done. Probably, felling residues and stumps compensate for the absence of sun-exposed wood substrate that forms naturally in forest fires or in storm-felled forests. For many red-listed wood-living species, the shortage of dead wood is the biggest threat. Therefore, it is important to increase the amount of coarse dead wood in order to guarantee the survival of these wood-living species. With respect to forest fuel extraction, it is particularly important to ensure that environmental considerations in felling are maintained or improved[1].

7.1 Branches/tops and stumps

Branches and tops contribute to biodiversity of managed forests by providing substrate and habitats for many different forest species. However, many species using branches/tops as a micro-habitat, or as a growing substrate, are rather unspecific in their habitat requirements. Therefore as a result of environmental considerations these species will have relatively good chances of surviving the clear-cutting phase, and then gradually to recolonize the area.

Fine woody debris of spruce appears rarely to host red-listed wood-living species. These species instead require coarse dead wood (10 cm in diameter or coarser) or wood from less common tree species in Sweden (aspen, goat willow, oak, beech and other hardwoods) for their survival and reproduction (Jonsell *et al.*, 1998; Dahlberg & Stokland, 2004). Often wood-living species using fine woody debris of spruce have broad habitat requirements, and are able to use other wood qualities (both coarse and fine) of several tree-species. Current knowledge indicates that the consequences of extracting fine woody debris such as branches/tops of spruce in final felling are relatively limited, in relation to the total effects of other forestry operations and the measures taken to promote biodiversity.

However, extraction of more rare wood substrates, e.g. branches/tops from rare or declining tree species, can increase the threat against red-listed wood-living species.

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[1] The Swedish Forestry Act defines *environmental considerations* as the measures taken to conserve nature values, groundwater, cultural values including the biological cultural heritage and social values. Environmental considerations are to be taken in all forestry operations e.g. to conserve dead wood, old trees, hollow trees or special habitats (de Jong *et al.*, 1999). Two different levels of environmental considerations exist, the minimum level and the recommended level. All land owners must accept requirements up to the minimum level, and considerations up to this level are not seen to as an obstacle to land use. The Swedish Forest Agency have defined the minimum level in relation to the net income of felling, and currently land owners must accept setting aside values corresponding to between 5 and 10% of the net income for environmental considerations. This will usually only cover part of the nature values of a given property. The Swedish Forest Agency advises land owners of what values exist on their land, but any considerations over the minimum level (that is considerations as advised) are voluntary.

Branches/tops from valuable hardwood in particular, but also from aspen, have been shown to be capable of hosting a number of different red-listed insects and fungi (Nordén *et al.*, 2004; Jonsell *et al.*, 2007; Hedin *et al.*, 2008).

Piles of branches/tops can become “traps” for red-listed wood-living insects. This has emerged in studies of the effects of branch/top extraction from valuable hardwood. Egg-laying individuals of red-listed beetles, with a larval development of 1-2 years, are attracted to piles of branches and tops, and reproduce in them. Eggs and larvae are then lost if the branches/tops are turned into chips and burned before the beetles have had time to hatch (Hedin *et al.*, 2008).

One risk with increased extraction of branches/tops is that other, for biodiversity more valuable wood, which should be left on the site for conservational purposes, is destroyed or extracted as fuel (Gustafsson, 2004; Andersson, 2005; Rudolphi & Gustafsson, 2005). Additionally, extraction of branches and tops appears to cause more disturbance to the soil and small wetlands than conventional felling does (Gustafsson, 2004).

Increased extraction of branches and tops is estimated to have relatively minor effects on the studied organisms representing different functional groups (Olsson & Staaf, 1995; Bråkenhielm & Liu, 1998; Åström, 2006; Åström *et al.*, 2005; Bengtsson *et al.*, 1997, 1998; Persson *et al.*, 2005). None of the functional groups (plants or soil organisms) appear to be extinct locally or become very abundant due to extraction of branches and tops. Therefore, it seems rather unlikely that extraction would cause changes to the ecosystem functions maintained by plant and soil organism populations in the clearings.

One of the consequences of stump extraction is an increased homogenisation of the clearing environment, i.e. certain habitats disappear, which in turn has effects on the living conditions of many different species. Stumps make up the largest part (about 80%) of the coarse dead wood that currently exists in managed forests (Egnell *et al.*, 2006, Dahlberg *et al.*, 2011). Stumps are similar to many other natural wood types, which are formed when trees die by drought stress, flooding, wind, fire or snowfall. Thus, stumps might compensate for the lack of sun-exposed wood substrate that existed after forest fires or in storm-felled forests in natural forests. In this way, stumps in clearings can contribute to maintaining the populations of sun-loving wood-dependent insects (Jonsell *et al.*, 2007; Jonsell, 2008a;b; 2010).

It is not likely that stump extraction will change soil processes such as decomposition and mineralisation in a way that is negative for biodiversity, and it is hardly likely to worsen conditions for mycorrhiza fungi. Their local survival and reestablishment is likely due to how many trees and groups of trees that are left in the clearing. Similar to extraction of branches and tops, stump extraction will reduce the amount of dead organic material, which in turn will reduce the abundance of important decomposers: fungi and animals in the soil ecosystem.

7.2 Ash recycling

Undesired effects of ash recycling appear to be avoidable by using hardened ashes that dissolve slowly. Forest fuel extraction and ash recycling should also be avoided in wet environments, in edge areas along watercourses and wetlands, in order to avoid the disturbance of significant conservation environments.

7.3 Intensive cultivation

Concerning intensive management (which includes e.g. nutrient optimization and exotic tree-species), the effects on biodiversity appear to depend, to a great extent, on how large proportion of the forest landscape which will be affected and on how other parts of the landscape is managed. Furthermore it is unclear whether it is better to separate production and conservation areas, or whether conservation measures should continue to be integrated into production areas. We also have an almost complete lack of basic knowledge about which species and functional groups of organisms (e.g. aphids and ants) can make use of exotic tree species like the introduced lodgepole pine, hybrids (aspen and spruce), or future genetically modified types of tree (*Populus*). Also, the risks with exotic tree species have not been sufficiently analysed, according to Gustafsson *et al*. (2009).

8 CAN WE INCREASE EXTRACTION OF FOREST FUEL WITHOUT NEGATIVE CONSEQUENCES FOR THE ENVIRONMENT?

8.1 Introduction

All forestry measures affect the soil, water, climate and biodiversity in one way or another. The consequences may be positive or negative depending on how the measures are carried out and on what objectives and values underlie them. From society's perspective, certain negative consequences may be acceptable as long as they don't lead to effects that make sustainable use more difficult. For example, it is unavoidable that felling will lead to the local disappearance of several species and to a temporary increase in nitrogen leaching. By contrast, forestry cannot be allowed to jeopardise the existence of viable populations in the landscape, or the quality of the surrounding surface water. Forestry operations must be combined with creating suitable conditions for all naturally occurring species, and with high quality of the surrounding surface water. This means that it might be possible to run fairly intensive forestry operations at the stand level, with increased biomass extraction, and still achieve society's objectives at the landscape level, but it requires high ambitions and good-quality conservation. Increased extraction causes increased stress to the ecosystem, thereby also placing higher demands on the correct implementation of the measures. For example, effective conservation is about quantities, such as allocation acreages and volumes of dead wood, as well as about functionality, i.e. qualities and distribution in the landscape.

In this chapter of the synthesis we evaluate the consequences of increased forest fuel extraction against the objectives adopted by the Swedish parliament: the Environmental Quality Objectives and forestry policy objectives.

8.1.1 Assessment approach

The assessment of effects is done principally at the stand level since the scientific review is based on research at the stand level. However, effects on biodiversity need to be assessed at the landscape level, with the focus on the risk of regional loss of species (in particular red-listed species). Effects on biogeochemical cycles and greenhouse gas balance also need to be assessed from a landscape perspective.

The assessment of effects in each environmental category does not take environmental effects of other energy alternatives into consideration, thus assessing forest fuel from a limited perspective. In most cases it is a climate advantage when biomass is used instead of fossil fuels (directly or indirectly in the energy system). However, the greenhouse gas and climate effects of forest fuel use imply some complex problems with boundaries in time and space. The choice of system boundaries, temporal perspectives and reference cases heavily influences the assessment of the climate benefits of forest fuel. Here the review of greenhouse gas balances is limited to the biomass primary production stage including the energy efficiency in procurement of that biomass and an assumed efficient energy conversion substituting a fossil fuel alternative. We limit the analysis to the effect of forest fuel extraction on carbon balances and greenhouse gas balance rather than on climate benefit, since the latter includes both a discussion about the residence time of greenhouse gases in the atmosphere and an analysis of other current alternatives in the energy system. For analyses of bioenergy climate effects from a system perspective, we refer to a parallel synthesis of strategic bioenergy research (Gode *et al.*, 2011). Nonetheless, a central assumption is that forest fuels in the form of branches/tops and stumps are used instead of fossil fuels.

One of the most crucial assumptions in this assessment is that the forestry sector is capable of following directives and recommendations from the Swedish Forest Agency and other authorities regarding considerations and nutrient compensation, even if this currently not is common practice. The relationship between our assumptions and common practise is discussed in greater detail in chapter 8.4.

8.1.2 Links to other objectives and undertakings

Sweden's ambitions in the bioenergy area are influenced by international agreements and EU directives. The Renewable Energy Directive (EU directive 2009/28/EC) on promoting the use of energy from renewable sources specifies binding national targets for the total share of final energy use (gross) from renewable sources and for the share of energy from renewable sources in the transport sector. Under the directive, Sweden has pledged that 49% of total energy use will come from renewable sources by 2020, which is the highest share of any EU member state. Each member state has to adopt a national action plan for energy from renewable sources.

The EU has specified sustainability criteria for liquid fuel and bioliquids, and encourages member states to define "sustainability criteria" and certification for solid biofuels as well, including those imported into the EU. This is intended as support for the EU's requirement that biofuels must contribute to substantial reductions in greenhouse gas emissions, and that biofuel must not come from natural forests, wetlands or protected areas. The EU directive, including the sustainability criteria, was implemented in December 2010.

8.1.3 Environment conventions that influence Swedish actions

Bioenergy is one of the many areas in which a common direction is sought for issues to do with climate change, the preservation of biodiversity and sustainable use. Both the Convention on Biological Diversity and the Framework Convention on Climate Change ("the climate convention") originated at the UN Conference on Environment and Development held in Rio de Janeiro in 1992. Since then, the two conventions have to some extent become differentiated. But biological diversity and climate change remain linked to each other in numerous ways.

Under the climate convention, the concentration of greenhouse gases in the atmosphere is to be stabilised at a level where human activity does not affect the climate system in a hazardous way. In the binding Kyoto Protocol, industrialised countries above all are urged to engage in research about renewable energy. The Kyoto Protocol has also established the CDM (Clean Development Mechanism) which further encourages industrialised countries to invest in projects to reduce emissions in developing countries as an alternative to the more costly emissions reductions in their own countries. In the future, forest management and forest fuels will play an increasingly important role in mitigating climate effects.

Sweden has also ratified the international Convention on Biological Diversity (CBD), in which we pledge to protect our biological diversity and use it in a sustainable way, so that it is not destroyed or halted. This has been incorporated into Swedish environment efforts. The framework is specified in the Environmental Code, the Forestry Act, the Environmental Quality Objectives, and in the government's nature conservation communication from 2002. Most of the work is done within the framework of the 16 national Environmental Quality Objectives.

8.2 How does increased forest fuel extraction affect the achievement of forest production objectives and the Environmental Quality Objectives?

8.2.1 Extraction today

The present situation is a good reference point when evaluating different extraction scenarios, but views and attitudes to the present situation vary from person to person and are influenced by values and experiences. It is therefore important to describe the present situation used as a baseline, or rather assumptions of the baseline made. Describing the present situation may seem a simple enough task, to be carried out with the help of official statistics. In many cases, however, the statistics are incomplete or deficient, and in others it is difficult to capture the present situation using statistics. Our intention is to describe the present situation as well as can be done with existing statistics. When reliable statistics are missing or when the area is too complicated to explain with numbers, we will describe the assumptions we are making about the present situation. It is our ambition that these assumptions are reasonable, even if there may be differing opinions as to how applicable they are to today's state of affairs.

Statistics on harvesting and consumption of branches/tops and stumps are decidedly deficient (Swedish Energy Agency, 2010). Existing statistics for energy supply do not allow for the separation of branches/tops and stumps from other wood fuels, which includes industrial residues from the forest industry and recycled wood fuels such as demolition wood and used packaging wood. Instead various estimates have to be used. From the felling reports sent to the Swedish Forest Agency we can see a clear trend of increased interest in the extraction of forest fuel (figure 8.1). Individuals within the industry claim that the extraction of branches/tops increased further during 2010. The forestry companies report that they currently extract stumps from about 3 000 hectares every year. Branch/top extraction is currently also being done in connection with thinning (according to representatives of the forest owning community). Based on available information, we estimate that branch/top extraction is currently done on 40% of all final fellings, and stump extraction on 2%. For each stand, we estimate that an average of 60 % of existing branches/tops is extracted, and an average of 40% of stumps (Table 8.1).

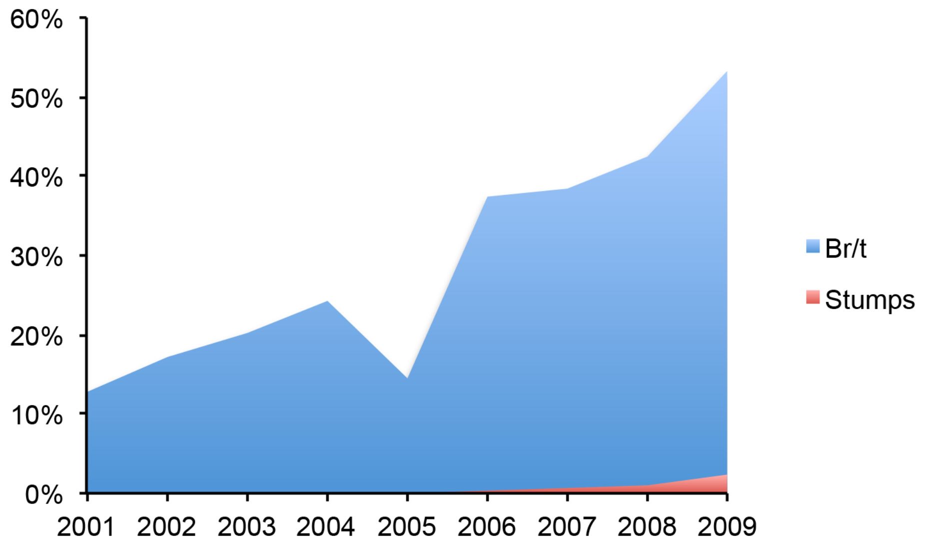

Figure 8.1. Notified area (percent of total harvest area) for removal of forest fuel 2001-2009 (Swedish Forest Agency, 2010). The drop in 2005 is likely due to severe storm-felling caused by the storm Gudrun in January 2005. Br/t = Branches and tops.

8.2.2 Future extraction

The extraction of branches/tops and stumps can be varied in different ways in extraction scenarios. Extraction intensity can vary within a stand, i.e. in terms of how large a share of the branches/tops and stumps in a clear-cut stand are extracted. Additionally, extraction intensity at the landscape level can vary, i.e. in terms of how large a share of the clear-cut stands in a forest landscape are used for extraction of branches/tops and stumps. The alternatives presented in Table 8.1 are judged to be fairly realistic. Branch/top extraction reaching 80% of the area at the stand level and 60% of the regeneration-felled stands at the landscape level, then, means that branches/tops are extracted on 48% of the area in the landscape, over the course of a forest generation. Extracting a very small share of the branches/tops and stumps per clearing is not economically realistic. For stump extraction, we have limited ourselves to two extraction levels, 80 and 40%, meaning that the least profitable part of the clearing is forgone.

Table 8.1b also shows how possibilities of achieving the Environmental Quality Objectives are affected by different variants of forest fuel extraction. The arrows do not show the actual likelihood of achieving the objective, but simply in which direction that likelihood is affected. The likelihood of achieving the objective is affected by a number of different factors, where forest fuel extraction is one. A negative arrow (pointing downwards) may be counteracted by some other factor, such that the objective again becomes achievable. Only those Environmental Quality Objectives most relevant to the forest fuel synthesis are shown. Table 8.1c shows how the production potential is affected by different extraction variants. Table 8.2 shows how much of the annually created new coarse dead wood, larger than 10 cm in diameter, that would be removed with increasing stump harvest intensities at the stand and landscape levels as a basis for judgement on impacts on biodiversity – an important part of the objective Sustainable Forests.

Table 8.1. Energy value of harvested biomass (PJ) from different extraction combinations (a), and consequences of different extraction alternatives for the achievement of the Environmental Quality Objectives (b), as well as for forest production objectives (c). The arrows indicate whether the likelihood of achieving the objective increases (↑) or decreases (↓) depending on what extraction combination is used. Horizontal arrows (→) indicate that achievability of the objective is not affected at all by the measure. In certain cases the assessment is that the consequences will have some positive or negative effect on achievability, which is shown by diagonal arrows pointing upwards or downwards. The Environmental Objectives Council's assessment was that none of the objectives will be reached by 2020. Achievability depends on many different factors, and an upward-pointing arrow in the table does not mean that the objective will be achieved, but that the measure increases the likelihood of the objective being achieved The direction of the arrows only applies under certain conditions which are further specified in the text (e.g. that primarily conifer branches/tops and stumps are extracted, that general environmental considerations are not adversely affected, that ash recycling using high-quality ash is done where needed, and that extraction is only done on land with a high load-bearing capacity – see the text for further details). Branches and tops can be extracted in thinning and in final felling. As consequences are slightly different if branches/tops are extracted in both thinning and final felling, or only in final felling, both of these alternatives are shown in the table of effects on production conditions. Greenhouse gas balances for various scenarios are shown both over the short term (20 years) and the long term (100 years). The estimated optimum level of extraction is marked with a yellow field.

a)

	Extraction alternatives, share (%)				Total extraction share, landscape (%)		Energy (PJ)	
	Stand		Landscape					
	Br/t	Stumps	Br/t	Stumps	Br/t	Stumps	Final felling only	Final felling + thinning
Br/t and stumps	80	80	80	40	64	32	139.3	185.4
	60	80	40	40	24	32	87.5	104.8
	80	80	80	20	64	16	111.2	157.3
	60	80	40	20	24	16	59.4	76.7
	80	40	80	40	64	16	111.2	157.3
	60	40	40	40	24	16	59.4	76.7
	80	80	80	10	64	8	97.2	143.3
	60	80	60	10	36	8	60.8	86.8
	60	80	40	10	24	8	45.4	62.6
	80	40	80	20	64	8	97.2	143.3
	60	40	40	20	24	8	45.4	62.6
	80	40	80	10	64	4	90.0	136.1
	60	40	40	10	24	4	38.2	55.4
Br/t	80	0	60	0	48	0	62.3	96.8
	80	0	40	0	32	0	41.8	64.8
	60	0	80	0	48	0	62.3	96.8
	60	0	60	0	36	0	46.8	72.7
	60	0	40	0	24	0	31.3	48.6
Current extrac-tion	60	40	40	2	24	0.8	32.4	49.7

b)

	Extraction alternatives, share (%)				Sustainable forests	Acidification	Eutrophication	Non-toxic environment	Climate	
	Stand level		Landscape level							
	Br/t	Stumps	Br/t	Stumps					Short term	Long term
Br/t & Stumps	80	80	80	40	↓	↘	→	↘	↗	↗
	60	80	40	40	↓	→	→	↘	↗	↗
	80	80	80	20	↘	↘	→	↘	↗	↗
	60	80	40	20	↘	→	→	↘	↗	↗
	80	40	80	40	↘	↘	→	↘	↑	↑
	60	40	40	40	↘	→	→	↘	↑	↑
	80	80	80	10	↘	↘	→	→	↑	↑
	60	80	60	10	→	→	→	→	↑	↑
	60	80	40	10	→	→	→	→	↑	↑
	80	40	80	20	↘	↘	→	→	↑	↑
	60	40	40	20	→	→	→	→	↑	↑
	80	40	80	10	↘	↘	→	→	↑	↑
	60	40	40	10	→	→	→	→	↑	↑
Br/t	80	0	60	0	→	↘	→	→	↑	↑
	80	0	40	0	→	→	→	→	↑	↑
	60	0	80	0	↘	↘	→	→	↑	↑
	60	0	60	0	→	→	→	→	↑	↑
	60	0	40	0	→	→	→	→	↑	↑
Curre	60	40	40	2						

c)

	Extraction alternatives, share (%)				Total extraction share, landscape (%)		Forest production	
	Stand		Landscape					
	Br/t	Stumps	Br/t	Stumps	Br/t	Stumps	Final felling only	Final felling + thinning
Br/t and stumps	80	80	80	40	64	32	◻	↘
	60	80	40	40	24	32	◻	◻
	80	80	80	20	64	16	◻	↘
	60	80	40	20	24	16	◻	◻
	80	40	80	40	64	16	◻	↘
	60	40	40	40	24	16	◻	◻
	80	80	80	10	64	8	◻	↘
	60	80	60	10	36	8	◻	◻
	60	80	40	10	24	8	◻	◻
	80	40	80	20	64	8	◻	↘
	60	40	40	20	24	8	◻	◻
	80	40	80	10	64	4	◻	↘
	60	40	40	10	24	4	◻	◻
Br/t	80	0	60	0	48	0	◻	↘
	80	0	40	0	32	0	◻	◻
	60	0	80	0	48	0	◻	↘
	60	0	60	0	36	0	◻	◻
	60	0	40	0	24	0	◻	◻
Current extrac-tion	60	40	40	2	24	0.8		

Table 8.2. Share of annually created new coarse dead wood (> 10 cm diameter) that would be removed at different levels of stump extraction.

Share of stand (%)	Share of landscape (%)					
	100	80	60	40	20	10
100	63	50	38	25	13	6
80	50	40	30	20	10	5
60	38	30	23	15	8	4
40	25	20	15	10	5	3
20	13	10	8	5	3	1
10	6	5	4	3	1	1

8.3 Comments on assessed consequences of forest fuel extraction

The directions of the arrows in Tables 8.1b and 8.1c are based on the reasoning in the introductory section of the synthesis chapter (which in turn is based on the knowledge compilation). Some further comments follow, in order to clarify the results in the tables. Note that the reasoning itself is predicated on certain conditions being fulfilled – these are specified below under 8.4. The optimal level of extraction (maximum energy output, but minimum negative impact) in table 8.1b means that 36 % of all available biofuel is harvested, i.e. both at the stand level and at the landscape level 40 % of available biofuel is not harvested. The discussion below is based on the condition that the avoided areas are carefully selected, i.e. sites where disturbances should be avoided, such as moist areas or sites near woodland key habitats.

It is our assessment that an increased extraction of forest fuel is reconcilable with the Sustainable Forests Environmental Quality Objective under certain conditions, e.g. that only a selection is extracted (branches/tops and stumps of conifers) in limited amounts, while at the same time certain conservation measures are strengthened, e.g. general environmental considerations.

An increased extraction of forest fuel is deemed to be reconcilable with the Natural Acidification Only Environmental Quality Objective on condition that ash recycling or some equivalent nutrient compensation is carried out in sensitive areas.

Increased extraction of forest fuel is deemed to be reconcilable with the Zero Eutrophication Environmental Quality Objective. Increased fertilization (nutrient optimization), however, may imply reduced possibilities of achieving the objective.

Ash recycling in connection with forest fuel extraction is compatible with the Environmental Quality Objective A Non-Toxic Environment provided suitable doses and qualities of ash are spread. Disturbance from machines on moist, humus-rich, fine textured soil, increases the risk of a raised incidence of the spread of methyl mercury in forest land. Forest fuel extraction implies a greater frequency of machine work and therefore operations should be limited on such soils in order to minimize conflicts with the objective.

A decisive incentive for increasing the use of forest fuels in society is that over the long term it will increase the possibility of achieving the Reduced Climate Impact Environmental Quality Objective. This effect is achieved by forest fuels being used instead of fossil fuels.

Even if forest fuel extraction can lead to reduced forest production, increased extraction can be reconcilable with direct or indirect production objectives, provided that suitable compensation measures are applied.

8.4 Conditions and assumptions underlying the assessments

Table 8.1 shows that there is a clear potential for increased extraction of forest fuel in Sweden, without adverse effects on the achievability of the Environmental Quality Objectives. However, this conclusion is based on a series of conditions which are not only linked to how and where forest fuel is extracted, but also to current forestry practices. One such condition is that general environmental considerations work as intended, i.e. at least at the level specified in the Swedish Forestry Act, and in certain cases at the advisory level (depending on the values present in the landscape). There are examples, however, of how environmental considerations deteriorate in areas where branches/tops and small wood is extracted, and this has also been shown in a study (Gustafsson 2004). Nevertheless, our assessments are based on the assumption that branch/top and stump extraction do not affect environmental considerations adversely. On the contrary, increased extraction of e.g. stumps is likely to require intensified considerations in other areas in order to avoid a general reduction in the amount of dead wood at the landscape level.

The analysis is based on the assumption that it is principally branches/tops and stumps from conifers that are extracted. Deciduous trees should be avoided altogether in conifer-dominated stands. In deciduous-dominated stands, only branches and tops of the dominant type of tree should be extracted, but generally a greater restrictiveness should apply to extraction in deciduous forest, and it is important to make regional assessments, e.g. on the basis of species incidence. A large number of red-listed species are linked to broadleaved trees, and extraction of branches/tops and stumps from broadleaved trees would therefore alter the assessments in Table 8.1. One exception, however, is thinning with the aim of restoring the natural values, e.g. in stands allocated to conservation. For such extraction, a careful assessment is made of what measure most benefits the natural values.

Extraction of branches/tops without nutrient compensation (principally of nitrogen) should be limited in connection with thinning, in order to avoid too large negative effect on production. Increased branch/top and stump extraction involves more machine movement and less padding material for the strip roads, which brings an increased risk of soil damages. Extraction of branches/tops and stumps should therefore only be done on soils with good load-bearing capacity. Extraction should also be avoided in the proximity of woodland key habitats and nature reserves, where an increase in the amount of sun-exposed dead wood is likely to be more beneficial for biodiversity than if it is left elsewhere in a managed forest landscape.

The assessment assumes that ash recycling using good-quality ash is carried out to compensate for the nutrient depletion which occurs with increased extraction. However, ash recycling is not needed everywhere, and 100% ash recycling is anyway not feasible, since ashes are also used for other purposes and since certain ashes do not fulfil the requirements for ashes to be spread on forest land. This argues in favour of adapting recommendations to the site, so that ashes are used where the risks of negative effects with respect to acidification and nutrient supply are greatest. Our assessments assume that ash recycling is done on those sites where it is needed, but also that ash recycling on a sufficient scale to counteract negative effects is not possible in the most intensive branch/top scenarios, with extraction of 80% of branches/tops at the stand level and 60% at the landscape level.

The climate objective is the only one for which achievability is facilitated by the use of forest fuel. This assumes, however, that forest fuel directly or indirectly replaces fossil fuels.

The table assumes that existing policy instruments (guidance, information, the Forestry Act etc.) apply. If new policy instruments are developed in the future which allow for better control of forest fuel extraction (e.g. in terms of volume, location in the landscape, selection of stands for intensive cultivation etc.), the potential for forest fuel could improve further.

Our assessment is that the conditions and assumptions presented above are realistic, even if current forestry operations do not fulfil all of them completely. For example, environmental considerations are not practised everywhere according to the forestry act, and ash recycling is done on a very limited scale.

8.5 Consolidated assessment

By increasing extraction of forest fuel, fossil fuels can be replaced by renewable fuels. It is important, however that this is done in such a way that forests can be managed sustainably and that extraction does not adversely affect different environmental and production objectives. Table 8.1b presents an overview of how the Swedish Environmental Quality Objectives are affected at different extraction levels. Table 8.1c shows how conditions for forest production are affected. One Environmental Quality Objective (Climate) is affected in a positive direction. For the others, the effect is either negative or of limited significance, depending on intensity and methods for biofuel harvesting. Extraction of branches and tops of Norway spruce appears to be the least problematic, while a number of question marks remain about extraction of stumps with a risk of negative consequences. The optimal balance between forest fuel extraction and its environmental consequences thus appears to involve extraction of a fairly large proportion of conifer branches and tops, and a limited proportion of stumps.

An adverse effect for a specific scenario in Table 8.1 need not mean, however, that the alternative is out of the question from an environment point of view. Increased extraction must be viewed in relation to what else is happening in the forest landscape. If the natural values (and the production values?) can be reinforced in a different way, then perhaps a small adverse effect on the Sustainable Forests Environmental Quality Objective can be accepted.

Table 8.1 makes it clear that there are potential goal conflicts. By substituting forest fuel for fossil fuels as much as possible, achievement is facilitated of the climate objective above all (in the long term). However, this would hamper the achievement of Sustainable Forests, and also of A Non-Toxic Environment and Natural Acidification Only. The Parliament has decreed, however, that all objectives must be achieved, and that it is a matter of finding a balance that has the greatest possible positive effect on achievement.

Our assessment is that extraction of branches and tops of 60% at both the stand and the landscape level, combined with limited stump extraction of 80% at the stand level and 10%

at the landscape level, would not adversely affect achievability for any of the Environmental Quality Objectives. This would imply an increase from approx. 50 PJ, which is obtained today, to approx. 87 PJ (Table 8.1). However, this includes branch and top extraction in thinning, and therefore presupposes nutrient compensation. Increases beyond this would hamper achievability today, but are of course possible if the landscape is reinforced in other ways.

There are a number of uncertainties in the assessment. In particular, the effects of soil disturbances caused by stump extraction with current technology are unclear. It is possible that stump extraction could be increased if this soil disturbance were minimised, and provided that only soils with good load-bearing capacities were used.

9 OVERALL CONCLUSIONS

9.1 More forest fuel can be extracted

The conclusions of the synthesis (Chapter 8) show that there is a clear potential for increasing extraction of forest fuel in Sweden without negative consequences for the environment or production objectives. Extraction of branches and tops is least problematic, and while there are some questions marks regarding extraction of stumps, an increase of stump extraction also appears possible. Such increased extraction of forest fuel is tied to a number of conditions, however, and there are certain risks that must be considered.

The increase is tied to a number of conditions such as ash recycling, nutrient compensation, good general environmental considerations, that extraction is dominated by branches/tops of conifers, that soil disturbance is prevented etc. These conditions lie largely within the framework of current advisory specifications from the Swedish Forest Agency, so their fulfilment should not be unrealistic. If these conditions are not fulfilled, increased extraction will hamper achievement of the Environmental Quality Objectives. With intensive management the production of forest raw material, including fuel, can be increased further. However, there are significant risks in terms of biological diversity and eutrophication that have to be considered. Landscape planning, which also includes intensive management, is one method that might allow for further increases (presupposes new policy instruments).

Both stumps and branches/tops give a greenhouse gas balance that is positive from a climate perspective, provided they are used instead of fossil fuels. If stump extraction is very large, however, there is some uncertainty. Stumps cause more negative environmental effects than branches/tops in respect of biological diversity and environmental toxins. Extraction of branches/tops is more negative in terms of acidification and production, but it is possible to compensate for this in part.

9.2 A great deal of research has been done, but continued research is needed

We note that a considerable research effort has been made over the past decade in terms of possibilities for increasing forest fuel extraction and of what consequences such an increase might have for the ecosystem. Despite these efforts, a number of important issues remain. One characteristic that all the areas of research share is that large-scale studies over extended periods of time are often required to answer the questions posed. This is expensive and complicated. An alternative is to carry out cautious extraction with environmental monitoring which will provide timely signals of any negative consequences.

However, this is not easy to organise either, and there is always the risk that negative consequences are not discovered in time. Since it is not always possible to finish research first and then act, we will have to make do for the time being with estimates as the basis for how forest fuel extraction should be formulated.

In respect of forest production there is no need for studying completely new aspects, but rather for in-depth studies of some already explored areas. Above all, however, it is important to make use of large quantities of available data to draw more general conclusions about long-term effects. Examples of areas that are important to highlight include:

- the magnitude of growth effects after forest fuel extraction and ash recycling on different soils in clearing, thinning and regeneration felling
- the duration of growth effects on different soils
- growth effects from the combination of compensation with woodash and a nitrogen fertiliser
- soil disturbance and compaction following extraction of branches/tops and stumps,
- technology and logistics in harvesting, interim storage and transportation
- growth rates of fast-growing tree species and management systems for them
- management systems for optimising biomass production for the energy market
- forest production potential in ash recycling on drained peat land

There is a fairly large amount of documented knowledge about the consequences of forest fuel production for soils and water. This knowledge is based on regional nutrient balances, studies and modelling. There are nevertheless a number of important areas in which knowledge needs to be augmented. These include:

- effects on surface water
- connections between soil disturbance (stump extraction) and methylation and transport of mercury
- forest fuel extraction and ash recycling, uptake and decomposition
- increased process knowledge (studies and modelling)
- follow-ups of long-term studies
- interaction between carbon and nitrogen in the soil
- identification of ash compensation needs
- optimal dosages in nutrient optimization
- inclusion of climate change effects in scenario analyses

In the overall assessment of environmental impacts of forest fuels, effects on greenhouse gas balances are a key issue. The assessment is much influenced by the chosen system boundaries, time periods analysed, and assumptions made. No single assessment approach can therefore be decisive alone. It is therefore a need for research on relevance of altering methods and how well they reflect a likely scenario and the actual impact on net greenhouse gas emissions. There is also a general need for more knowledge about greenhouse gas balances of the forest when harvest and production intensity increase, focusing on all three dominant greenhouse gases: carbon dioxide, methane and nitrous oxide.

The influence of production intensity on biodiversity and other ecosystem services is a crucial issue. The goal is to find a way of maintaining a high level of forest fuel production at a low environmental cost. The consequences of forest fuel extraction on biodiversity are described in greater detail in Chapter 7.

Examples of knowledge gaps regarding biodiversity include:

- consequences for biodiversity over longer timescales and at the landscape scale
- the importance of different wood substrates
- capture/trap effects in storage of forest fuel
- nature considerations in forest fuel extraction
- the importance of conservation management
- the effects of increased branch/top and stump extraction on aquatic ecosystems

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IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

IEA Bioenergy Task 43 – Biomass Feedstock for Energy Markets – seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This will be achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstock, including biomass markets and the socioeconomic and environmental consequences of feedstock production. Task 43 currently (Jan 2011) has 14 participating countries: Australia, Canada, Denmark, European Commission - Joint Research Centre, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, USA.

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