



**HAL**  
open science

## Impact of short and very short rotation coppices of *Populus* and *Salix* species on soil C, N and P cycling

René Guénon, Jean-Charles Bastien, P. Thiébeau, Guillaume Bodineau,  
Isabelle Bertrand

### ► To cite this version:

René Guénon, Jean-Charles Bastien, P. Thiébeau, Guillaume Bodineau, Isabelle Bertrand. Impact of short and very short rotation coppices of *Populus* and *Salix* species on soil C, N and P cycling. EUROSOIL congress, Jul 2012, Bari, Italy. 2012, OCDE. hal-01268431

**HAL Id: hal-01268431**

**<https://hal.science/hal-01268431>**

Submitted on 3 Jun 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**Proceedings of the Workshop**  
**W6.1 Forest bioenergy and soil sustainability**  
**at EUROSIL Congress**  
**2<sup>nd</sup> July to 6<sup>th</sup> July 2012, Bari, Italy**



**Heljä-Sisko Helmisaari and Elena Vanguelova (Editors)**

## Contents

Policy issues discussed at the Workshop "Forest Bioenergy and Soil Sustainability" and the Round Table "Forest Bioenergy Guideline Development".....	3
Description of the Workshop.....	4
Outcome of the discussions at the Workshop .....	5
Conclusions of the Round Table discussions .....	6
Programme and page numbers for short papers and abstracts.....	7
Presentation short papers .....	9
Poster abstracts .....	64

## Preferred citation

Helmisaari, H-S. & Vanguelova, E. (eds.). 2013. Proceedings of the Workshop W6.1 Forest bioenergy and soil sustainability at EUROSIL Congress 2<sup>nd</sup> July to 6<sup>th</sup> July 2012, Bari, Italy. 72 p. Available at: [www.helsinki.fi/forestsciences/eurosoil/index.html](http://www.helsinki.fi/forestsciences/eurosoil/index.html) and at: [www.oecd.org/agriculture/crp](http://www.oecd.org/agriculture/crp)

The opinions expressed and arguments employed in this publication are the sole responsibility of the authors and do not necessarily reflect those of the OECD or of the governments of its Member countries.

## **Policy issues discussed at the Workshop "Forest Bioenergy and Soil Sustainability" and the Round Table "Forest Bioenergy Guideline Development"**

*National developed and updated guidelines for sustainable use of forest bioenergy should be reviewed and compared, including their linkages to research.* Forest biomass harvesting guidelines do not appear to exist in countries outside Europe and North America. As such guidelines serve to benefit global markets and trade, it is important to know if they exist, especially in countries with high potentials for forest energy production. In most cases, it is not clear how guidelines and recommendations are linked to specific research projects, if at all, or whether they are based on some other source of expert knowledge. Therefore, it is not possible to identify the most urgent research-based knowledge gaps.

Comparisons of forest biomass harvesting guidelines should be updated, as several new guidelines have been developed during recent years for new jurisdictions. *There is a need to compile an overview of similarities and differences among guidelines, and to investigate whether some of the differences are rooted in different intents.* If guidelines aim at different levels of sustainability for certain issues, it might be useful to discuss the reasons behind these differences and to explore whether there are good reasons for keeping them.

*Recommendations and guidelines should be better linked to legislative and certification scheme initiatives that address sustainable biomass, biofuel and bioenergy schemes.* We need to know how guidelines are implemented and enforced and how these and related protocols may be strengthened for development of sustainable energy markets. Many jurisdictions have laws, policies, guidelines and recommendations, and have ratified several international conventions for sustainable forest management (SFM). These governance mechanisms may not be specific to forest biomass harvesting, although they may cover some of the relevant issues. It is important to know how well such general SFM initiatives address forest biomass harvesting and production for energy in each jurisdiction or region.

## Description of the Workshop

Forest biomass is increasingly being used as an energy source in Europe. The economic opportunity through bioenergy management poses a threat to soil sustainability via acidification, physical damage such as compaction or erosion and nutrient and carbon loss. The increased removal of forest residues may cause changes in soil carbon and nutrient availability, nutrient leaching to watercourses and groundwater, soil carbon sequestration potential and soil biodiversity, with possible long-term consequences for soil sustainability potential for forest biomass production. However, the effects are site-, soil- and practice-specific. Research in soil sustainability in relation to forest bioenergy is increasing in Europe, and there is a need for constant updating of long-term research findings and national guidelines for sustainable use of forests for energy.

## Aims

- 1) To present and discuss recent research and findings on the impacts of forest energy-harvesting activities on soil sustainability, including soil physical, chemical and biological properties in addition to soil ecosystem services, and
- 2) to compare the national developed and updated guidelines for sustainable use of forest bioenergy for long term soil and forest sustainability.

The main product of the Workshop will be a review on national guidelines for sustainable forest bioenergy use for long term soil and forest sustainability.

## Conveners

Prof. Heljä-Sisko Helmisaari, University of Helsinki, Dept. of Forest Sciences, Finland  
[helja-sisko.helmisaari@helsinki.fi](mailto:helja-sisko.helmisaari@helsinki.fi)

Dr. Elena Vanguelova, Forestry Commission, Forest Research, United Kingdom  
[elena.vanguelova@forestry.gsi.gov.uk](mailto:elena.vanguelova@forestry.gsi.gov.uk)

## Sponsor

The workshop was sponsored by the OECD Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems, whose financial support made it possible for the speakers to participate in the workshop.

<http://www.oecd.org/tad/researchprogrammeonbiologicalresourcesinagriculture/>

## Outcome of the discussions at the Workshop

It was apparent from the workshop presentations, posters and discussions that different countries vary greatly in the demand for bioenergy from forestry, how bioenergy forests are harvested and in the type and implementation of guidelines for forest protection.

Although the approaches to soil sustainability vary in the existing guidelines of different countries, there are also many similarities. The present guidelines for forest energy harvesting are largely based on expert judgement utilising the scientific knowledge as well as practical experience of managing forest soils. Even in those countries in which soils are well considered in the guidelines (e.g. in Great Britain), uncertainties remain about the long-term sustainability of bioenergy harvesting on different soil types. Some effects are better known, whereas we have less scientific results concerning other effects, e.g. carbon emissions or leaching into watercourses. Scientific results especially on changes in the carbon cycle are needed in order to support full life-cycle analyses for a comparison of forest bioenergy with other bioenergy systems. Nutrient mass-balances are frequently calculated and reported for analysing potential net losses of nutrients caused by bioenergy harvesting. It was brought up in the workshop that mass-balances may lead to incorrect conclusions as there are considerable uncertainties in especially weathering estimates as well as in deposition and leaching rates over time.

An important aim in the development of guidelines is to identify and judge the harvesting strategies in a trans-disciplinary way, which would combine ecological, environmental and economic suitability, leading to an optimized compromise for maximization of politically realistic forest energy harvesting and maintenance of soil quality at the same time.

It was also pointed out that the effects of forest bioenergy harvesting on soils are species-, site- and practice-specific, and therefore each country or region must apply local scientific knowledge or expert opinion, and consider the ecological conditions and management in the guideline development for that country/region. However, knowledge and analysis of criteria from guidelines developed elsewhere may be a great asset in the development of the national/regional guidelines.

The ecological conditions in different countries vary, and must be taken into account in developing bioenergy guidelines in order for them to be properly implemented to fulfil their intent. Delay in the application of guidelines can be caused by specific forestry conditions, such as in mountainous areas (e.g. in Austria), but also by social conditions. For example, an ownership structure with many small-scale forest owners may in some countries lead to a less controlled use of residues for small-scale heating.

Finally, it was concluded that there is a need for a more thorough analysis of the recommendations given in forest biomass harvesting guidelines and their background, both in terms of the ecological and social frameworks and the science on which the guidelines are based. Additional recommendations have been made on better use of available data from extensive and intensive forest monitoring and research networks in Europe and elsewhere to scientifically underpin and improve the guidelines. In addition, the continuation of existing short term experiments and carrying out more long term experiments were highlighted as necessary for the scientific underpinning of guidelines for long term sustainability of forest energy practices.

## Conclusions of the Round Table discussions

The workshop "Forest bioenergy and soil sustainability" was followed up with a Round Table discussion on the present state and future development of guidelines for sustainable forest bioenergy harvesting.

Dr. Inge Stupak presented a table on the status of guidelines in different countries and on what the guidelines are based on (scientific studies or expert judgement or both), followed by a discussion on the implementation of the guidelines in the countries present, and pointed out that most countries still lack biomass harvesting guidelines. This may be due to low relevance, but it is not always the case. Sometimes more general existing guidelines and recommendations, for example for sustainable forest management or soil conservation, cover a large part of the relevant issues, but often some relevant issues are not addressed.

The Round Table participants decided to write a joint peer-reviewed paper on the comparison of guidelines and their development in as many as countries as possible, followed up by an analysis of the knowledge on which the guidelines are based. The paper should provide joint recommendations for guideline development.

Dr. Inge Stupak and Dr. Brian Titus were chosen to be the first authors of the paper, and 21 participants from 11 countries (Austria, Canada, Denmark, Finland, France, Germany, Italy, Japan, Sweden, United Kingdom, and United States) expressed an interest in participating in the writing procedure. It was decided that everybody actively participating will be a co-author of the paper, and additional key persons outside the group may also contribute.

The participants decided that the aim is that the paper would be submitted within six months of the end of the Eurosoil conference.

## Programme and page numbers for short papers and abstracts

<b>Workshop W6.1: Forest bioenergy and soil sustainability</b>	
Tuesday 3.7.2012 at Eurosoil Congress, Bari, Italy, Room MIRTO	
<b>13.30-17.00</b>	<b>Oral sessions</b>
13.30-13.35	<b>Opening by Conveners</b>
13.35-13.45	<i>Leena Finér</i> : Presentation of OECD Co-operative Research Programme
13.45-14.15	<i>Rolf Björheden</i> : Economic and technological potential of forest bioenergy and the conditions for development..... 9
14.15-14.30	<i>Inge Stupak</i> : Approaches to soil sustainability in guidelines for forest biomass harvesting and production in forests and plantations..... 14
14.30-14.45	<i>Brian Titus</i> : Harvesting residue removal guidelines to protect soils in Canada and the science behind them..... 22
14.45-15.00	<i>Tom Nisbet</i> : Development of Forest Bioenergy Guidelines for Soil and Water Protection - Experience from the UK..... 31
15.00-15.30	<b>Break: coffee and refreshments</b>
15.30-15.45	<i>Gustaf Egnell</i> : Forest biomass for energy and sustainable management of forest soils - what do we need to know?..... 36
15.45-16.00	<i>Klaus Katzensteiner</i> : Impacts of increased biomass use on soil sustainability in Austria..... 40
16.00-16.15	<i>Elena Vanguelova</i> : Forest bioenergy and soil sustainability in the UK..... 45
16.15-16.30	<i>Klaus v. Wilpert</i> : Assessing harvest potential and nutrient sustainability in temperate forests based on monitoring data..... 50
16.30-16.45	<i>Rene Guénon</i> : Impacts of short and very short rotation coppices of <i>Populus</i> and <i>Salix</i> species on soil C, N and P cycling..... 58
16,45-1700	<i>Heljä-Sisko Helmisaari</i> : Forest bioenergy and soil sustainability in Finland..... 63

**17.00-1830 Poster session**

<i>Viktor Bruckmann J.:</i> Biomass utilization and its consequences for soils - a retrospective view... ..	66
<i>Linnea Hansson:</i> Impacts of disc trenching on soil water and heat flows in a forest regeneration area in Sweden.....	66
<i>Ryan Heiderman:</i> Examining whole site productivity when intercropping giant miscanthus ( <i>Miscanthus × Giganteus</i> ) with loblolly pine ( <i>Pinus taeda</i> ) for bioenergy feedstock production in south-eastern United States.....	67
<i>Lilli Kaarakka:</i> Whole-tree harvest at final felling: long-term effects on soil properties in a Norway spruce stand.....	67
<i>Eero Kubin:</i> Effects of forest biomass harvesting on hydrological processes and leaching of nutrients .....	68
<i>Nicholas Nguyen:</i> Soil biological activity in eucalyptus and poplar SRC.....	68
<i>Stefania Papa:</i> Enzyme activities in the soil profile of two beech forests on the Campania Apennines.....	69
<i>David Paré:</i> Getting quantitative: how much slash should remain on site to sustain tree growth?.....	69
<i>Anna Repo:</i> Forest bioenergy climate impact can be improved by allocating forest residue removal.....	70
<i>Hendrik Stark:</i> Nurse crops: long term effects on forest soil nutrient and carbon pools.....	70
<i>Brian Titus:</i> Results from intensive harvesting field trials: how does Europe compare with North America?.....	71
<i>Gregory van der Heijden:</i> Long-term sustainability of forest soil fertility assessed by nutrient input-output budgets and a modelling approach.....	71

**18.30-20.00 Round Table Discussion: Forest bioenergy guideline development**

## Presentation short papers

### Economic and technological potential of forest bioenergy and the conditions for development

Rolf Björheden

Skogforsk, the Forestry Research Institute of Sweden ([rolf.bjorheden@skogforsk.se](mailto:rolf.bjorheden@skogforsk.se))

#### Abstract

The economic and technological potential of forest bioenergy and the conditions for development are analyzed. Although the data are based on Swedish experiences and perspectives, it is attempted to generalize from the Swedish case.

In Sweden, the current large scale use of forest bioenergy is equally a result of a foreseen shortage of fiber and efforts to reduce the dependence on imported fossil fuels, made painfully clear by repeated 'oil crises' since the 1970s. The R&D program 'Whole Tree Utilization' running 1974-77 marked the start. A more complete utilization of forest resources is still part of the rationale, but currently the need for sustainable energy systems and for mitigating climate change is often emphasized.

The most accessible sources of forest biomass for energy, by-products from forest industries and recycled woody products, are already fully utilised in Sweden. The remaining supply consists of primary forest fuels, such as logging residues, stumps and small trees. After reductions for ecological or techno-economic reasons, the remaining annual net is around 17 Mm<sup>3</sup> of stumps and logging residues from final felling and over 5 Mm<sup>3</sup> of small trees from young stands. With a current use of around 7 Mm<sup>3</sup>, it seems possible to more than double the annual utilization.

Practical forest energy operations are challenging. The forest fuel feedstock combines difficult properties such as unwieldiness, bulkiness, small piece size and scattered occurrence with low value, heterogeneity and contaminations increasing ash content, wear and damage to equipment and machines. The working environment must be acceptable. Nevertheless, operations must be economic, while performed under the constraints of a sensitive environment with minimized impact on soil, water and any growing forest stand. The development of current systems should be seen in the light of these diverse problems.

#### Introduction

Wood is the foremost traditional energy source in Sweden, but current industrial-scale utilization has developed in the period after the 'oil crises' of the 1970s. At that time, practically no forest biomass was harvested for energy (Silveira 2001).

The development of forest fuel operations started in a simple way. Logging resources were becoming available as a result of continuous rationalization. Surplus forwarders could be employed in residue extraction with limited modification. Chippers mounted on forwarder chassis provided in-terrain platforms capable of both extraction and production of an acceptable fuel. Apart from the availability of machinery and skilled labour, four other drivers have played an important role in the Swedish development (Björheden 2011).

Firstly, the emergence of a functioning market and bio-energy infrastructure has been a key element. Two segments stand out, the first being district heating, which started using wood fuels in a small scale around 1980. In 2010 an amount equivalent to 17 million solid cubic meters of wood fuels was used every year in this application. The other important player, using a similar volume, is the forest industry itself which has developed from being heavily dependent of fossil fuels into being a self-sustained net seller of green energy.

Secondly, the political will to escape from dependence on imported fuels and, instead, to secure a domestic supply of energy has been persistent and mostly sound. The Swedish government has not imperatively demanded that market players should take any particular action, but taxation (especially the tax on “fossil” carbon dioxide), tariff and certificate systems has made it ‘good business’ to develop efficient renewable alternatives. Since competition from fossil and other energy sources is always present, the incentive for continuous improvement is also present.

A third driver for increased use of forest biomass in energy conversion is the recent concern over risks of global climate change. The European Commission has set targets to increase the share of renewable energy sources, the so called 20/20/20 targets with the goal to mitigate climate change. In order to meet these objectives, a large share of this increase must be based on forest biomass (European Commission 2008). The energy sector, particularly district heating and combined heat and power production is increasing the use of forest biomass as fuel. Recent studies indicate that EU’s forests could supply ca. 200-400 Mm<sup>3</sup> (1500-2900 PJ) woody biomass for energy annually by 2020 (Asikainen et al. 2008, Verkerk et al. 2011). The Council of Europe has decided that the EU countries should produce 20 % of their energy by using renewable sources, including bioenergy, by 2020. Each member state has an individual target; for Sweden, 50.2 % of the energy should be renewable by 2020 (Swedish..2010). In 2011, the share of renewables was around 48 % (Swedish Bioenergy Association 2012).

Around 85 per cent of the renewable fuels from forests in Sweden are “secondary fuels”, i.e. consequential by-products from conventional forest industry, such as black liqueurs, bark, saw dust and shavings. All such by-products are fully utilized. To increase the supply further, supply systems are now being developed for such fractions that were previously left in the forest after logging; small trees, logging residues and stumps. These fractions, referred to as primary forest fuels or, simply “forest chips”, are still only marginally utilized. But they may contribute significant and important volumes. Under Nordic conditions, the biomass of top, branches, stumps and coarse roots correspond to about 50 % of the merchantable bole volume from a tree in final felling (Swedish Forest Agency 2008, Thorsén et al. 2011).

The Swedish consumption of forest chips was 8.4 Mm<sup>3</sup>solid in 2010, corresponding to 17 TWh. The harvesting potential of forest chips in Sweden has been approximated to be 20-25 Mm<sup>3</sup> per year (Swedish Forest Agency 2008). Logging residues have been the most important raw material for forest chips in Sweden (4.3 Mm<sup>3</sup> i.e. approximately half the possible potential) in 2010. The use of small diameter wood was 1.3 Mm<sup>3</sup> (20 % of the potential), stump wood 0.3 Mm<sup>3</sup> (2-3 per cent of the potential and roundwood 2.5 Mm<sup>3</sup> in 2010 (Brunberg et al. 2011).

Thus, the biomass volumes needed to reach the set goals are available, but in order to mobilize them, harvesting must be economic, ecologically sound and socially acceptable. Are these sustainability criteria possible to achieve?

## Discussion

In practice, economy remains the basic driver. Methods and technologies have been scrutinized by practice and by several development efforts. Most recently, since 2007, a national R&D programme, *Efficient forest fuel Supply Systems* has been funded by the Swedish forest and energy sectors, strongly supported by the Swedish Energy Agency. The principal aim is to increase the use of forest biomass for energy and the means are increased efficiency, lower costs and higher quality of the produced fuels. Results include new technology, efficient supply chain design and in-depth knowledge of the operational milieu of forest fuel operations (Thorsén et al. 2011). Cost reductions of up to 30 % have been demonstrated even with current technology, and additional savings are possible through:

- Purpose-built technology for key forest fuel operations
- Deepened integration of fuel operations with logging operations
- Operator training improving performance and quality of work
- Improved information chains for better management of production
- Increased co-operation between the supply chain tiers
- Re-engineering of supply chains to enable efficient use of expensive machinery
- Improved intermodal transport systems making distant fuel sources accessible

This purposeful development has yielded results. Although transportation distances have increased as a result of strongly increased demand, the current real cost of forest chips is only ¼ of the cost 30 years ago (Junginger et al. 2005). Thus, forest fuels are competitive with e. g. oil, but still uneconomical compared to fossil coal. Even after thirty years of development, the economics of forest fuel production thus still depend on the fossil carbon tax.

The ecological sustainability of operations must also be maintained. The increased intensity of harvesting resulting from forest energy operations impacts on ecology through the following principal mechanisms:

- Nutrient exports may lead to unacceptable negative effects on forest yield
- Harvested material may be essential for the biodiversity as food source or habitat
- Soil disturbance through harvesting and increased transport intensity may induce e.g. soil compaction and rutting, affecting both yield and water quality. In addition, less material is available for soil reinforcement.
- Loss of recreational value due to the harvesting practices used may decrease the value of the forest landscape as a setting for recreational activities

The dominating areas of the boreal forests are largely characterized by evolving climax dynamics, ended by calamities such as stormfelling, pests and/or forest fire (Kuusela 1992). The interannual variation is high concerning precipitation, temperature and length of the vegetation period. Soils are generally young, barely withered and with most nutrients contained in the mineral soil (Shugart et al. 2005). Therefore, the boreal forest ecosystem is highly resilient to strong variations and heavy disturbances and calamities.

Nutrient balance of intensified harvesting has been thoroughly investigated. It seems clear that under Swedish conditions, export of logging residues (or of full trees in thinning) will entail yield losses corresponding to a prolongation of the rotation period by 1-2 years (Mattsson 1999). A result is the exclusion of weaker soils from residue harvesting, rules for recirculating pure wood ash to compensate for the loss of base cations and in some parts of Sweden compensatory fertilization to sustain or improve the soil fertility (Rekommendationer..2008). For stump harvesting, the increase of nutrients is low but increased mobilization of the available nutrients has been observed, especially in cold, fine grained soils.

The value of the new biomass fractions has also been investigated from a biodiversity perspective (Jonsell 2007, 2008, Stubbskörd...2009). With few exceptions, logging residues and stumps from pine and spruce appear to be utilized mainly by common generalists, whereas only a few more demanding species of invertebrates and fungi seem to favour these artificial substrates. But observations of rare species, especially on matured stumps have been reported and stumps of broadleaved trees are considered to be of importance. Logging residues are not affected by rules on biodiversity, except for top layers of species such as oak, aspen and beech which should be excluded from chipping and stumps of broadleaved trees, which should not be harvested. It is also attempted to improve the conditions for rare and endangered species by actively swapping larger volumes of low quality residues and stumps with high grade material, such as "high stumps" (snags), placed in the preferred parts of the felling area.

Soil disturbance, rutting and compaction are severe problems for mechanized forestry (Grigal 2000). They become more difficult when the harvest levels increase (Eliasson & Wästerlund 2007), because this is coupled with increased traffic intensity and decreased supportability of the soil (with time, due to increased humidity or through disturbance, as after stump lifting). To alleviate the problems, no harvesting should take place on wet or moist soils and a buffer distance of 25 m should be maintained to riparian zones and moist areas. The rules are that if soil damage cannot be avoided, logging residues and stumps should be used to protect the soil and not be harvested. It is also attempted to decrease soil damages through active measures such as improved machine design, reinforcement of the soil surface, and improved striproad planning.

A few investigations have been made on the effects of forest fuel harvesting on the attractiveness of land for recreational activities. In general, most surveys show that both energy thinning and residue harvesting have a positive effect on the attractiveness of the logging area, mainly because visibility and mobility are improved (Kardell & Mård 1989, Björheden et al. 2003). Stump harvesting is generally considered to be very negative, but the rating of stumped areas improves quite rapidly as the felling is covered by vegetation (Kardell & Mård 1989)

## **Conclusions**

Even after 30 years of development, the economy of Swedish forest fuel operations may be improved substantially. Biomass from the forests is already supplying a third of the country's energy needs and its importance is projected to increase further. There are still large volumes of forest biomass available that may be harvested at negligible or low cost to biodiversity or the environment.

The Swedish standpoint is that sustainable, well managed forests may play an important role in a switch-over to renewable energy systems with low impact on climate and environment. The conditions are particularly good for the majority of boreal forests, which are resilient to heavy disturbance and have very long rotation periods to recover from negative impacts. But even so, with intensified operations and increased harvesting regimes, compensatory actions should be performed and knowledge on how to avoid or compensate for negative effects must be made available and put into practice.

There will be economic as well as ecological costs of an intensified use of forest biomass in Sweden, but compared to the effects of continuous overutilization of non-renewable energy sources and dependence on imported fuels from other parts of the world, these costs seem reasonable.

## References

- Asikainen, A., Liiri, H., Peltola, S., Karjalainen, T. & Laitila, J. 2008. Forest Energy Potential in Europe (EU27). Working Papers 69. Finnish Forest Research Institute, Joensuu.
- Björheden, R., Gullberg, T. & Johansson, J. 2003. Systems analyses for harvesting small trees for forest fuel in urban forestry, *Biomass and Bioenergy* 24: 389–400.
- Björheden, R. 2011. Making bioenergy systems work. Proceedings of 4th Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change. 5-7 April 2011, Stellenbosch University.
- Brunberg, T. 2011. Skogsbränsle: sortiment, metoder och kostnader 2010. (Forest fuel: assortments, methods and costs 2010). Skogforsk Resultat nr 8, 2011.
- Eliasson, L. & Wästerlund, I. 2007. Effects of slash reinforcement of strip roads on rutting and soil compaction on a moist fine-grained soil. *Forest Ecology and Management* 252: 118–123.
- European Commission, 2008. Combating climate change The EU leads the way. Europe on the move series. 24 pp.
- Grigal, D. F. 2000. Effects of extensive forest management on soil productivity. *Forest Ecology and Management* 138: 167–185.
- Jonsell, M. 2007. Effects on biodiversity at forest fuel extraction, governed by processes working on large scale. *Biomass and Bioenergy* 31: 726-732.
- Jonsell, M. 2008. The Effects of Forest Biomass Harvesting on Biodiversity. In Asikainen et al. (eds.) Sustainable Use of Forest Biomass for Energy. *Managing Forest Ecosystems* 12: 129-154.
- Junginger, M., Faaij, A., Björheden, R. & Turkenburg, W. 2005. Technological learning and cost reductions in woodfuel supply chains in Sweden. *Biomass and Bioenergy* 29: 399-418.
- Kardell, L. & Mård, H. 1989. Attitudes of some groups to stump harvesting 1976 and 1988. SUAS, Section of Environmental Forestry, Report 41.
- Kuusela, K. 1992. The Dynamics of Boreal Coniferous Forests, SiTRA, 1992, 172 pp.
- Mattsson, S. 1999. The economic consequences of growth loss and less expensive regeneration after forest fuel harvesting -stand level examples. Skogforsk, Work report 425, 1999.
- Rekommendationer vid uttag av avverkningsrester och askåterföring, 2008. (Recommendations for logging residue harvesting and for ash recycling), The Swedish Forest Agency, Meddelande 2, 2008.
- Shugart, H.H., Leemans, R. & Bonan, G.B. 2005. A Systems Analysis of the Global Boreal Forest, Cambridge University Press, 565 p.
- Silveira, S. Ed. 2001. Building sustainable energy systems. The Swedish National Energy Administration. 550 pp.
- Stubbskörd - kunskapsammanställning och Skogsstyrelsens rekommendationer, 2009. (Stump harvesting – review of knowledge and recommendations of the Swedish Forest Agency). The Swedish Forest Agency, Meddelande 4, 2009.
- Swedish Bioenergy Association; [www.svebio.se/english/bioenergy-facts](http://www.svebio.se/english/bioenergy-facts) accessed 2012-06-03
- Swedish Forest Agency, 2008. Skogliga konsekvensanalyser 2008 (Forest sector consequential analyses). Rapport 2008: 25.
- Swedish National Action Plan for the promotion of the use of renewable energy in accordance with Directive 2009/28/EC and the Commission Decision of 30.06.2009, Annex to Government Decision 2010-06-23.
- Thorsén, Å., Björheden, R. & Eliasson, L. (eds.). 2011. Efficient forest fuel supply systems, composite report from a four year R&D programme 2007-2010. Skogforsk. 113 p.
- Verkerk, P.J., Anttila P., Eggers, J., Lindner, M. & Asikainen, A. 2011. The reliable potential supply of woody biomass from forests in the European Union. *Forest Ecology and Management* 261: 2007–2015.

## Approaches to soil sustainability in guidelines for forest biomass harvesting and production in forests and plantations

Inge Stupak<sup>1</sup>, Brian Titus<sup>2</sup>, Nicholas Clarke<sup>3</sup>, Tat Smith<sup>4</sup>, Andis Lazdins<sup>5</sup>, Iveta Varnagiryte-Kabasinskiene<sup>6</sup>, Kestutis Armolaitis<sup>6</sup>, Milica Peric<sup>7</sup> & Claudia Guidi<sup>8</sup>

<sup>1</sup>Forest & Landscape, University of Copenhagen, Denmark ([ism@life.ku.dk](mailto:ism@life.ku.dk)), <sup>2</sup>Canadian Forest Service, Canada, <sup>3</sup>Norwegian Forest and Landscape Institute, Norway, <sup>4</sup>University of Toronto, Canada, <sup>5</sup>SILAVA, Latvia, <sup>6</sup>Lithuanian Research Centre of Agriculture and Forestry, Lithuania, <sup>7</sup>University of Belgrade, The Republic of Serbia, <sup>8</sup>Fondazione Edmund Mach, Italy.

### Introduction

Plantations are typically used for efficient production of forest products such as solid wood, pulp or energy feedstocks, but the objective of most forest management is integrated production of multiple goods and services, including a mixture of consumptive and non-consumptive outputs such as non-timber forest products (NTFP) and ecological and recreational services. During recent decades, utilization of previously unutilized biomass such as harvesting residues and small trees from silvicultural thinning operations as feedstock for bioenergy has become an additional harvest assortment from forestry, especially in Fennoscandia (Röser et al. 2003).

In Sweden, concern over environmental impacts led to the development of national good practice guidelines for forest biomass harvesting and wood ash recycling as early as the late 1970s, with the latest versions implemented in 2002 and 2008. Finland followed with the first version of their forest biomass harvesting guidelines in 2005. The United Kingdom also developed whole-tree harvesting guidelines in the late 1990s, but addressed harvesting systems in general and did not focus solely on biomass for energy.

Rapidly expanding markets for energy biomass in Europe have generated increased interest in exporting forest residues for biomass fuels from North America and the Baltic countries. In the mid-2000s, some states in the USA initiated processes to develop forest biomass harvesting guidelines; the number of states has increased over time and there are now specific biomass harvesting guidelines for 10 states and two regions of the U.S. (Evans et al. 2010, Titus et al. 2013).

In Canada, one province (New Brunswick) has specific biomass harvesting guidelines, although all 10 provinces have regulations and guidelines that are relevant to forest biomass harvesting (Waito and Johnson 2010, Roach 2012). Further development of guidelines, either under existing sustainable forest management processes or as specific biomass guidelines, is under way in several provinces. Similarly, Norway has reviewed existing guidelines and indicated where additional sustainability measures are needed (Phan & Clarke 2012), and a similar work was initiated for the Republic of Serbia (Peric & Stupak, 2012). Sustainable forest biomass harvesting is governed by a multiple layer of governmental and private governance measures as much as by specific jurisdictional guidelines (Kittler et al. 2012, Stupak et al. 2007). These include, for example, forestry and environmental legislation and regulations, various guidelines for related issues such as soil conservation, water and biodiversity protection, private forest certification schemes, and the businesses' own guidelines. The need for forest biomass harvesting guidelines may thus vary between countries, also depending on the pressure on forest resources and the sensitivity of the areas involved.

Existing forest biomass harvesting guidelines address several issues, with soil sustainability usually being a crucial criterion. This paper explores approaches to soil sustainability in existing forest biomass harvesting

guidelines (see also Titus et al. 2013). We also address briefly the scientific basis for development of the guidelines, and their implementation and enforcement. Recommendations for further work are suggested. An overview of existing guidelines is given in Table 1.

Table 1. Global overview of existing guidelines of forest biomass harvesting. The list may not be complete and we urge readers to contact us if they wish to share information on additional biomass harvesting guidelines (see also Titus et al. 2012, and Forest Energy Portal, <http://www.forestenergy.org/>)

<b>Country</b>	<b>Reference of relevant guidelines</b>
Canada	New Brunswick (NB): New Brunswick Department of Natural Resources. 2008. Forest biomass harvesting. Policy No. FMB 019 2008. Other provinces in Canada do not have specific biomass harvesting guidelines, but have other regulations and guidelines that are relevant. These were examined by Murray (2012), but have not been included here.
Denmark (DK)	Billeschou, A. & Klitgaard, O. 1983. Økologisk forsvarlig udnyttelse af marginal træressourcer- Skovstyrelsens retningslinier for statskovene [Ecologically acceptable utilisation of marginal wood resources - the Forest Agency's recommendations for the State Forests]. Skoven 12:374–5 (in Danish).
Finland (FI)	Äijälä, O., Kuusinen, M. & Koistinen, A. (eds.) 2010. Råd i god skogsvård för uttag och produktion av energived [Recommendations for best practices in silviculture for removal and production of energy wood]. Skogsbrukets utvecklingscentral Tapio, 32 pp.
France (FR)	Cacot, E., Eisner, N., Charnet, F., Leon, P., Rantien, C. & Ranger, J. 2006. La récolte raisonnée des rémanents en forêt [Good practice for harvesting of forest residues]. Agence de l'Environnement et de la Maîtrise de l'Energie, Angers, France. 36 p (in French).
Ireland (IE)	Forest Service 2000. Forest Harvesting and the Environment Guidelines. Forest Service 2000. Forestry and water quality guidelines.
Latvia (LV)	Stump extraction for biofuel production, 20 pp. (in Latvian) Biofuel production from harvesting residues in final felling, 20 pp. (in Latvian) Short rotation hybrid poplar for roundwood and biofuel production, 20 pp. (in Latvian) Management of naturally afforested farmlands, 36 pp. (in Latvian)
Lithuania (LT)	Ozolinčius R., Armolaitis K., Mikšys V. & Varnagirytė-Kabašinskienė I. 2010. Recommendations for compensating wood ash fertilization (2nd revised edition). Ministry of Environment of the Republic of Lithuania/Institute of Forestry of Lithuanian Research Centre for Agriculture and Forestry, Girionys. - 17 p. (In Lithuanian with English summary). Sadauskienė L., Aleinikovas M., Armolaitis K. & Varnagiryte-Kabasinskiene I. 2012. Study on the use of stumps for biofuels: assessment of the resources, technological, economic and environmental aspects. Report. Institute of Forestry, Lithuanian Research Centre of Agriculture and Forestry. 59 p. [in Lithuanian].
New Zealand (NZ)	Good Practice Guide Production of wood fuel from forest landings. EECA Business. Technical Guide 9.0, 44 pp.
Norway (NO)	Living Forests 2006. Standard for sustainable forest management in Norway.
Sweden (SE)	Skogsstyrelsen 2008. Rekommendationer vid uttag av avverkningsrester och askåterföring [Recommendations for removal of forest harvesting residues and ash recycling]. Skogsstyrelsen, Meddelande 2-2008. (In Swedish).
United Kingdom (UK)	Nisbet, T., Dutch, J. & Moffat, A. 1997. Whole-tree harvesting – a guide to good practice. Forest Practice Guide, Forest Authority, Forestry Commission, Edinburgh. British Biogen. 1999. Wood fuel from forestry and arboriculture - the development of a sustainable energy production industry. Moffat, A.J., Jones, W.M. & Mason, W.L. 2006. Managing brash on conifer clearfell sites. Forestry Commission Practice Note 13, Forestry Commission, Edinburgh. Forest Research 2009. Guidance on site selection for brash removal. Forest Research, Forestry Commission, UK, May 2009. 15 p. Forest Research 2009. Stump harvesting: interim guidance on site selection and good practice. Forest Research, Forestry Commission, UK, April 2009. 18 p.
USA	Kentucky (KY): Kentucky Division of Forestry. 2011. Recommendations for the harvesting of woody

	<p>biomass. Oct. 2011. Kentucky Division of Forestry. 5 pp.</p> <p>Maine (ME): Benjamin, J.G. (Editor). 2010. Considerations and recommendations for retaining woody biomass on timber harvest sites in Maine. University of Maine, Maine Agricultural and Forest Experiment Station, Orono, ME. Miscellaneous Publication 761. 68 p. + Benjamin, J.G. 2010. Woody Biomass Retention Guidelines, 2 pp.</p> <p>Maryland (MD): Pinchot Institute. 2010. A guide to forest biomass harvesting and retention in Maryland. September 2010. Pinchot Institute and Maryland Dept. of Natural Resources. 25 p.</p> <p>Massachusetts (MA): Renewable Portfolio Standard - Biomass Policy Regulatory Process. <a href="http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/biomass/renewable-portfolio-standard-biomass-policy.html">http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/biomass/renewable-portfolio-standard-biomass-policy.html</a></p> <p>Michigan (MI): Michigan DNRE. 2010. Michigan woody biomass harvesting guidance. Michigan Department of Natural Resources and Environment, Forest Management Division. IC4069 (05/10/10). 18 p. <a href="http://www.michigan.gov/documents/dnr/WGBH_321271_7.pdf">http://www.michigan.gov/documents/dnr/WGBH_321271_7.pdf</a></p> <p>Minnesota (MN): Minnesota Forest Resources Council. 2007. Biomass harvesting on forest management sites. Minnesota Forest Resources Council, St. Paul, Minnesota. 42 p. + Minnesota Forest Resources Council. 2007. Woody biomass harvesting for managing brushlands and open lands. Minnesota Forest Resources Council, St. Paul, Minnesota. 55 p.</p> <p>Missouri (MO): Missouri Dept. of Conservation. Undated. Missouri woody biomass harvesting best management practices manual. Missouri Dept. of Conservation. 38 p. [watermarked "draft"]</p> <p>New Hampshire (NH): Bennett K. 2010. Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire.</p> <p>Northeast: Forest Guild Biomass Working Group. 2010. Forest Biomass Retention and Harvesting Guidelines for the Northeast. Forest Guild, Santa Fe, NM.</p> <p>Pennsylvania (PA): Pennsylvania Department of Conservation and Natural Resources. 2008. Guidance on harvesting woody biomass for energy in Pennsylvania. Department of Conservation and Natural Resources, Harrisburg, PA. 50 p. <a href="http://www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf">http://www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf</a></p> <p>Southeast: Forest Guild Southeast Biomass Working Group. 2012. Forest Biomass Retention and Harvesting Guidelines for the Southeast. Forest Guild, Santa Fe, NM.</p> <p>Vermont (VT): Biomass Energy Development Working Group. 2011. Biomass Energy Development Working Group: Final Report. Vermont Legislative Council. 196 p.</p> <p>Wisconsin (WI): Herrick, S.K., J.A. Kovach, E.A. Padley, C.R. Wagner, and D.E. Zastrow. 2009. Wisconsin's Forestland Woody Biomass Harvesting Guidelines. PUB-FR-435-2009. WI DNR Division of Forestry and Wisconsin Council on Forestry; Madison, WI. 51 pp.</p>
--	--

## Soil sustainability

Tóth et al. (2007) defined soil sustainability as 'management of soil in a way that does not exert any negative effects - that are irreparable under rational conditions - either on the soil itself or any other systems of the environment.' Potential impacts of intensive forest biomass harvesting on soil include effects on soil physical and chemical parameters and secondary effects on, for example, soil and plant biodiversity, water quality and quantity, and wood production (Lattimore et al. 2009). Soil physical effects include, for example, exposure of the soil surface, compaction and erosion, whereas soil chemical impacts include loss of soil organic matter, carbon, nutrients and acidification. If fertilization with mineral or organic fertilizers is used to compensate for nutrient removal or to counteract acidification then there may also be additional effects of adding nutrients and other elements to the soil, including effects on pH, and potentially on organisms (Ozolinčius et al. 2010).

## Approaches to soil sustainability in forest biomass harvesting guidelines

Forest biomass harvesting guidelines generally separate sites into different classes of susceptibility to impacts of forest biomass harvesting (Table 2). The simplest classification defines sites as either sensitive or robust (e.g. Raulund-Rasmussen et al. 2008), but can have several classes of susceptibility (e.g. FR, UK). These classification systems are often based on soil criteria such as soil type and soil fertility, or secondary

indicators such as wood productivity, forest type, tree species, or soil compaction risk (Stupak et al. 2008). Atmospheric deposition of nitrogen is also used as an indicator of nitrogen inputs and availability or risk of acidification, whereas slope is often used to indicate a risk of erosion. It should be noted, however, that a number of criteria for site sensitivity focus on sustainability of other values, such as water protection, biodiversity, cultural heritage, landscape and recreational values.

Table 2. Sites classified as sensitive to intensive harvesting due to soil or soil-related properties. Canada: NB – New Brunswick, the USA: KY – Kentucky, MA – Massachusetts, MD –Maryland, ME – Maine, MI – Michigan, MN – Minnesota, MO – Missouri, NE – Nebraska, NH – New Hampshire, VT – Vermont, WI – Wisconsin, Europe: DK – Denmark, FI – Finland, FR – France, IE – Ireland, NO – Norway, SE – Sweden, UK – United Kingdom. No: Number of jurisdictions using the criterion in specific biomass harvesting guidelines in Canada, the USA and Europe (after Titus et al. 2012).

<b>Criterion</b>	<b>Number</b>	<b>Jurisdictions (Canada; USA; Europe)</b>
Low fertility	-, 4, 3	-; ME, NE, NH, VT; FI, DK (conifers), UK
Shallow	1, 10, 1	NB; MA, MD, ME, MO, MN, MI, NE, NH, VT, WI; FI(logging residues + stumps)
Sandy (coarse), dry, nutrient poor	1, 7, 2	NB; MA, MD, ME, MN, NE, VT, WI; DK(broadleaves, Jutland), FR
Low pH, acidified	-, -, 2	-; -; FR, SE
Rocky, stony	1, -, 1	NB; -; FI(logging residues + stumps)
Organic - wetlands, poorly drained, dysic Histosols, ombrotrophic, nutrient poor, low pH	1, 8, 4	NB; KY, MA, MD, ME, MN, NE, NH, WI; IE, NO, SE, UK
Mineral	-, -, 1	-; -; FI(spruce)
Steep, erosion-prone sites	-, 9, 3	-; KY, MA, MD, ME, MO, MN, NE, NH, VT; FI(stumps), FR, IE, NO
Low nitrogen deposition	-, -, 1	-; -; SE
Exceptions for other sites	-, -, 1	-; -; FI(Boron deficiency in spruce, production classes of peatland)
Groundwater protection areas and water protection zones	-, 1, 3	-; NH (Riparian areas); FI (Stumps), IE, NO (Buffer zones)

Various types of harvesting restrictions are recommended when a site has been classified as sensitive to intensive harvesting (Stupak et al. 2008). Sometimes intensive harvesting should be completely avoided on the most sensitive sites, while other sites can be harvested only when precautionary measures are taken (Table 3).

Table 3. Types of harvesting restrictions on sensitive sites in European biomass harvesting guidelines.

<b>Harvesting restriction</b>	<b>Number</b>	<b>Jurisdictions</b>
Types of extraction	4	FI, UK, SE, NO
Used technology	3	UK, FI, IE
Leave certain tree species	3	FI, DK, NO
Number of extractions during the rotation	3	SE, DK, FR
Time between two slash removals	1	FR
Pre-drying	2	DK, FI (spruce)
Proportion of material left in single harvesting operation	1	FI
Spatial distribution of the residues left	1	SE
Size of the nutrient removal	1	SE
Minimise physical soil damage	4	UK, SE, IE, NO
Timing (season, stand development stage)	2	DK, NO
Wood ash fertilization	3	FI, SE, DK
Other fertilization than wood ash fertilization	3	SE, FI, FR

It should be kept in mind that management measures aimed at compensating or counteracting adverse impacts may mask site degradation; this is likely to be the case if inputs to the system are relatively high and the compensating and counteracting effects are relatively small (Mead & Smith 2012).

## Scientific basis

The scientific basis for development of guidelines includes different levels of knowledge (Fig. 1). Scientific experiments are designed to answer specific questions and test hypotheses according to generally accepted scientific methods. Knowledge gained from such experiments has high credibility, but conclusions can rarely be extrapolated to other site types, regions or countries. Short-term experiments will certainly also have limitations when considering the long-term effects; long-term experiments are rare, and future conditions might be different from those of the past (e.g. because of climatic change and/or changes in management practices). Another complication is that many short-term effects disappear over time as stands age and drivers of ecological processes change. Modelling exercises may be used to overcome the difficulties associated with short-term empirical field studies but at the ecosystem level models must, at some point, be based on empirical data and a robust conceptual framework. When empirical, field-based scientific experiments or modelling studies do not exist, experts with general knowledge about ecosystem processes and forest dynamics may be able to predict impacts that are likely to arise from various management practices. The scientific basis for development of guidelines may thus take different forms in different countries depending on the amount of available national research (Table 4). In the absence of scientific knowledge, local knowledge about the forest and the impacts of the forest management must be used.

Furthermore, it may be difficult for managers to apply relevant research to their practices if no guidance has been formulated through discussions between managers and researchers. As such, stakeholder processes may also be part of the process of developing guidelines, and a means of balancing science-based recommendations with what is practically possible. Stakeholder processes can also be used to balance trade-offs between economic, environmental and social benefits and impacts. Documenting these stakeholder processes creates transparency that strengthens credibility, extends the lessons learned to other jurisdictions, and will no doubt provide a useful resource when re-examining guidelines in future adaptive management processes. Documentation arising from processes that lead to forest biomass harvesting guidelines is sometimes available for states in the USA (e.g. Minnesota<sup>1</sup> and Wisconsin<sup>2</sup>).

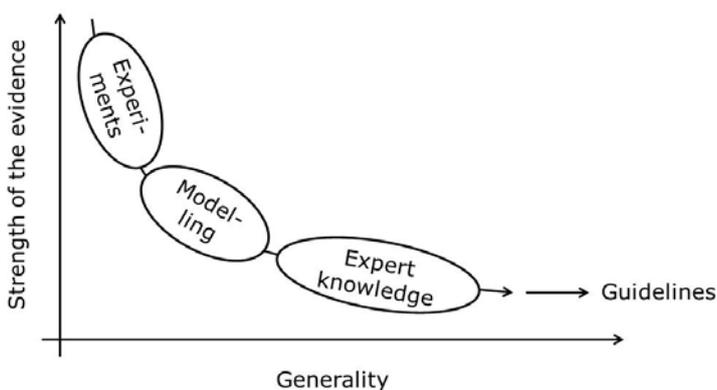


Figure 1. Conceptual model of the scientific basis for development of guidelines

<sup>1</sup> [http://www.frc.state.mn.us/initiatives\\_sitelevel\\_management\\_revision.html](http://www.frc.state.mn.us/initiatives_sitelevel_management_revision.html)

<sup>2</sup> <http://council.wisconsinforestry.org/biomass/>

Table 4. Knowledge basis for existing forest biomass harvesting guidelines in Europe. See Table 2 for acronyms of jurisdictions.

Knowledge basis	No	Jurisdictions
Reviews of national research	2	SE
Synthesis of national research work	3	FR, UK, LT
National expert involvement and/or stakeholder processes	3	FI, IE, NO
Review of literature and guidelines from other countries	2	DK, LT
Local experience	1	DK

## Implementation and enforcement

The implementation of voluntary guidelines depends on e.g. educational activities and political commitment, including the strength of enforcement protocols, which again depend on the type and frequency of control measures and related sanctions for non-compliance (Fig. 2). The enforcement of forest biomass guidelines has so far been weak, although Swedish guidelines are to some extent supported by self-reporting (Stupak et al. 2008) and Canadian guidelines sometimes become legislative when included in forest management plans (Murray 2012). The strength of the enforcement of sustainable biomass initiatives is of increasing interest, as the variability between systems is wide (van Dam 2010, van Dam et al. 2010, NL Agency 2012). If forest biomass harvesting guidelines should feed into such schemes or otherwise act as proof of biomass sustainability, the strength of the enforcement will increasingly become an issue.

As a kind of ‘soft law’ (i.e. a non-binding instrument which still holds potential for morphing into ‘hard law’), guidelines may however be a faster route to legal commitment than ‘hard laws’ or other stronger commitments. Experiences from international law show that uncompromising commitments and immediate costs for enforcement systems make laws less likely to be approved by all parties. This suggests that the uptake of a ‘soft law’ may in some cases be faster than a negotiation process leading to a ‘hard law’ or stronger commitments (Abbott & Snidal 2000).

## Conclusions

There is a diversity of approaches to soil sustainability in jurisdictional guidelines for forest biomass harvesting and production, but there are also many similarities. Might we benefit from aligning approaches and standards, and learn from each other to increase transparency and credibility? This would require a closer analysis of the recommendations in various forest biomass harvesting guidelines and the background for these recommendations, both in terms of the ecological and social frameworks and the science upon which the guidelines have been based. Although alignment may be helpful, especially if guidelines feed into other means of governance (including trade restrictions), its greatest use may be in identifying broad categories of criteria that should be considered and then defined in more detail for local site-specific conditions; uncritical alignment that simply applies prescriptions without building a local basis for them may be counter-productive when it comes to sustaining soils and values. Another important issue to consider is how implementation and enforcement of forest biomass harvesting guidelines can contribute to proving sustainability of the biomass trade.

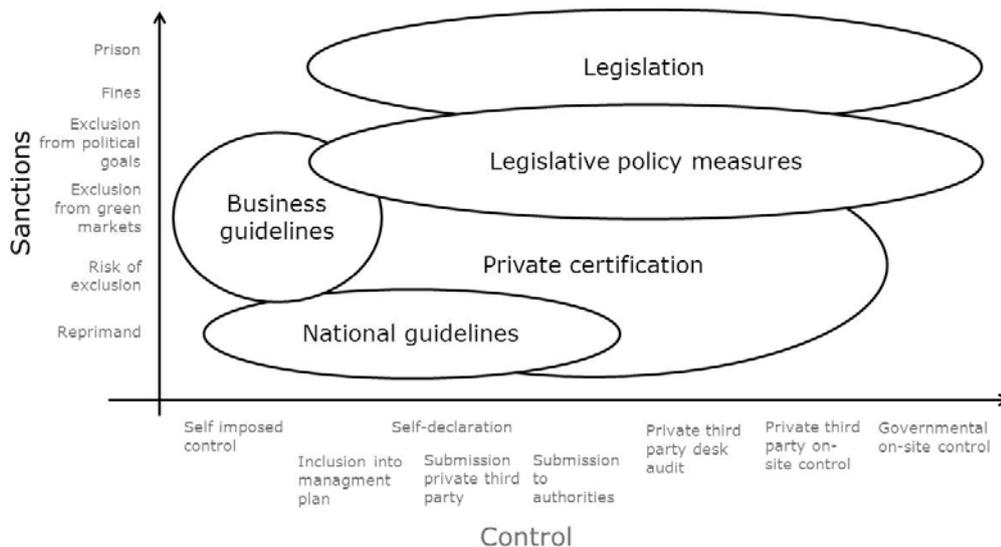


Figure 2. Conceptual model of control and sanctions for multiple levels of governance. Legislative policy measures refer to legislation similar to the EU Renewable Energy Directive (EU RED), where non-compliance with biomass sustainability criteria for liquid biofuels excludes the bioenergy production from counting towards national goals for renewables (Annex I to EU RED), but is not illegal per se.

## Acknowledgements

The corresponding author thanks the OECD for funding enabling participation in the Eurosoil 2012 workshop 'Forest Bioenergy and Soil Sustainability', and Heljä-Sisko Helmisaari and Elena Vanguelova for organizing the workshop, together with OECD administrator Janet Schofield. Nicholas Clarke's participation was funded by the Research Council of Norway through the Bioenergy Innovation Centre CenBio.

## References

- Abbott, W. & Snidal, D. 2000. Hard and Soft Law in International Governance. *International Organization*, 54 (03): 421 – 456. doi: <http://dx.doi.org/10.1162/002081800551280>
- Evans, A.M., Perschel, R.T. & Kittler, B. 2010. Revised assessment of biomass harvesting and retention guidelines. Forest Guild, Sante Fe, NM.
- Kittler, B., Price, W., McDow, W. & Larson, B. 2012. Pathways to Sustainability. An Evaluation of Forestry Programs to Meet European Biomass Supply Chain Requirements. Environmental Defense Fund, 64 pp.
- Lattimore, B., Smith, C.T., Titus, B., Stupak, I. & Egnell, G. 2009. Sustainable woodfuel harvesting: environmental risks and criteria and indicators for sustainable practices. *Biomass & Bioenergy* 33:1321-1342.
- Mead, D.J. & Smith, C.T. 2012. Principles of nutrient management for sustainable forest bioenergy production. *WIREs Energy Environ* 2012, 1: 152–164 doi: 10.1002/wene.3
- Murray, J. 2012. Sustainability of certified solid wood bioenergy feedstock supply chains: Ecological, operational, certification standards and international policy perspectives between Canada and the EU. Draft report, IEA Bioenergy Task 40 and 43/University of Toronto (unpublished), 57 pp.
- NL Agency, 2012. Selecting a biomass certification system – a benchmark on level of assurance, costs and benefits. NL Agency, Ministry of Economic Affairs, Agriculture and Innovation, March 2012, 113 pp.
- Ozolinčius, R., Varnagirytė-Kabašinskienė, I., Armolaitis, K. 2010. Compensations of nutrients removed through extraction of forest fuel. In Sarsby & Meggyes (eds): *Contraction for a Sustainable Environment* London, Taylor & Francis Group, p. 493-500.
- Peric, M. & Stupak, I. 2012. Environmental aspects of Forest and Agricultural Biomass Utilization. *Forest Energy Observer*, Study report, 16 pp.

- Phan, T.L. & Clarke, N. 2012. D4.2.9. Comparison of forest management guidelines for sustainable harvesting of biomass for bioenergy. Norwegian Forest and Landscape Institute, 22 pp.
- Raulund-Rasmussen, K., Stupak, I., Clarke, N., Callesen, I., Helmisaari, H-S., Karlton, E., Varnagiryte-Kabasinskiene, I. 2008. Chapter 3. Effects of very intensive forest biomass harvesting on short and long term site productivity. In: Röser, D., Asikainen, A., Raulund-Rasmussen, K. & Stupak, I. (eds.). 2008. Sustainable Use of Forest Biomass for Energy. A Synthesis with Focus on the Baltic and Nordic Region. Springer, Managing Forest Ecosystems, 12:29-78.
- Roach, J. 2012. Forest biomass harvesting policy in Canada. Contract report prepared for B.C. Ministry of Environment.
- Röser, D., Asikainen, A., Gjølsjø, S., Jaskelevicius, B., Johansson, D., Jylhä, P., Kairiuktis, L., Konstantinova, I., Lileng, J., Lunnan, A., Mandre, M., Nurmi, J., Pärn, H., Salka, T., Silkanen, L., Suadicani, K., Toropainen, M. & Vilkriste, L. 2003. Wood fuel resources and bottlenecks of utilization in Baltic and Nordic countries. Finnish Forest Research Institute, Joensuu Research Centre. Research Papers 901, 68 pp.
- Stupak, I., Asikainen, A., Jonsell, M., Karlton, E., Lunnan, A., Mizarete, D., Pasanen, K., Pärn, H., Raulund-Rasmussen, K., Röser, D., Schroeder, M., Varnagiryte, I., Vilkriste, L., Callesen, I., Clarke, N., Gaitnieks, T., Ingerslev, M., Mandre, M., Ozolincius, R., Saarsalmi, A., Armolaitis, K., Helmisaari, H-S., Indriksons, A., Kairiuktis, L., Katzensteiner, K., Kukkola, M., Ots, K., Ravn, H. & Tamminen, P. 2007. Sustainable utilisation of forest biomass for energy - possibilities and problems, policy, legislation, certification and recommendations in the Nordic, Baltic and other European countries. Biomass & Bioenergy 31: 666-684.
- Stupak, I., Asikainen, A., Röser, D. & Pasanen, K. 2008. Chapter 7. Review of recommendations for forest energy harvesting and wood ash recycling. In: Röser, D., Asikainen, A., Raulund-Rasmussen, K. & Stupak, I. (eds.). 2008. Sustainable Use of Forest Biomass for Energy. A Synthesis with Focus on the Baltic and Nordic Region. Springer, Managing Forest Ecosystems, 12:155-196.
- Stupak, I., Hoekstra, T. & Kvetny, M. 2009. Task 4: Identification of feasible verification options. In: Londo, M. (ed.). Technical assistance for an evaluation of international schemes to promote biomass sustainability. European Commission, Directorate-General for Energy and Transport, p. 103-157. [http://ec.europa.eu/energy/renewables/transparency\\_platform/doc/2010\\_report/2010\\_02\\_25\\_report\\_international\\_schemes.pdf](http://ec.europa.eu/energy/renewables/transparency_platform/doc/2010_report/2010_02_25_report_international_schemes.pdf)
- Titus, B.D., Thiffault, E., Paré, D., Berch, S.M. & Morris, D. 2013. Harvesting residue removal guidelines to protect soils in Canada and the science behind them. In Helmisaari, H-S. & Vanguelova, E. (eds.). Proceedings of the Workshop W6.1 Forest bioenergy and soil sustainability at EUROSOIL Congress 2<sup>nd</sup> July to 6<sup>th</sup> July 2012, Bari, Italy.
- Tóth, G., Stolbovoy, V. & Montanarella, L. 2007. Soil Quality and Sustainability Evaluation. An Integrated Approach to Support Soil-Related Policies of the European Union. A JRC Position Paper, EU 22721 EN. European Commission, Directorate-General Joint Research Centre, Institute for Environment and Sustainability, 52 pp.
- Van Dam, J. 2010. Task 3: Applicability of existing certification schemes. In: Londo, M. (ed.). Technical assistance for an evaluation of international schemes to promote biomass sustainability. European Commission, Directorate-General for Energy and Transport, p. 103-157. [http://ec.europa.eu/energy/renewables/transparency\\_platform/doc/2010\\_report/2010\\_02\\_25\\_report\\_international\\_schemes.pdf](http://ec.europa.eu/energy/renewables/transparency_platform/doc/2010_report/2010_02_25_report_international_schemes.pdf)
- van Dam, J., Junginger, M & Faaij, APC. 2010. From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning. Renewable and Sustainable Energy Reviews 14: 2445–2472. doi:10.1016/j.rser.2010.07.010
- Waito, B. & Johnson, L. 2010. A national scan of regulations and practices relevant to biomass harvesting. Report prepared for World Wildlife Fund - Canada and The Forest Products Association of Canada.

## Harvesting residue removal guidelines to protect soils in Canada and the science behind them

B.D. Titus<sup>1</sup>, E. Thiffault<sup>2</sup>, D. Paré<sup>2</sup>, S.M. Berch<sup>3</sup> and D. Morris<sup>4</sup>

<sup>1</sup>Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC, Canada ([BTitus@NRCan-RNCan.gc.ca](mailto:BTitus@NRCan-RNCan.gc.ca)), <sup>2</sup>Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Ste-Foy, QC, Canada, <sup>3</sup>B.C. Ministry of Environment, Victoria, BC, Canada, <sup>4</sup>Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources, Thunder Bay, ON, Canada

### Introduction

Mandatory or voluntary site-level guidelines are one of several governance mechanisms for ensuring that soils are protected when removing harvesting residue from forests for bioenergy production (Stupak et al., 2013). This removal includes residue at roadside or landings when whole-tree harvesting (WTH) is used and stems are processed off-site, and residue collected in second-pass systems when stems are processed at stump and tops and limbs are left on-site. Regulations and guidance specifically for site-level harvesting residue (or biomass, biofibre) removals have been developed in over a dozen jurisdictions globally, and consideration of these may inform their evolution in jurisdictions in Canada where they are under development. We therefore briefly describe (i) the context for harvesting residue removal guidelines in Canada, (ii) the science behind them, (iii) the definition of sensitive soils within existing policies and guidelines in North America (and sometimes in Europe, for making specific points), and (iv) current and future research in Canada that will feed into their refinement through adaptive management processes.

### Forest management in Canada

Forest management, and hence harvesting residue removals, comes under the jurisdiction of the 10 provinces and three territories in Canada, and increasingly First Nations as land claims are settled; however, the federal government has overarching jurisdiction over water, fisheries and air when they are affected by forestry practices. About 94% of the forests in Canada are publicly owned, although the proportion is generally lowest in eastern provinces that have been settled by Europeans the longest. Certification is a parallel mechanism that complements government processes: >150 million ha of Canadian forests are certified, accounting for 40% of the world's certified forest area<sup>3</sup>.

Ecologically, there is a wide range of forest ecosystems in Canada, from temperate coastal rainforests to forests in dry zones, and from temperate hardwoods to boreal forests<sup>4</sup>; there is a concomitant wide range of soils (see reviews in Pennock et al. 2011). In addition to diverse natural ecological processes, the sites most potentially sensitive to critical load exceedence are found in southern Ontario and Quebec, as well as in southern and eastern Nova Scotia and parts of New Brunswick (Carou et al. 2008). The challenge in developing guidelines for harvesting residue removals is therefore large because of the size of the country

---

<sup>3</sup> FPAC, Certification in Canada, accessed 18 June 2012 at [http://www.certificationcanada.org/english/status\\_intentions/status.php](http://www.certificationcanada.org/english/status_intentions/status.php)

<sup>4</sup> Canadian Forest Service, Total growing stock by ecozone, accessed 18 June 2012 at <http://cfs.nrcan.gc.ca/pages/354>; Ecological Framework of Canada, Ecozone and Ecoregion Descriptions, accessed 18 June 2012 at <http://ecozones.ca/english/zone/index.html>

(10% (398 million ha) of the world's forests are in Canada<sup>5</sup>) and the range of natural conditions and anthropogenic effects.

There are two other notable features of Canada's forests: the proportion harvested annually is very small (<0.2%) relative to the growing stock, and is small (688,000 ha in 2010) compared to the area affected by insect defoliation and fire (>12 million ha<sup>6</sup> and >3 million ha<sup>7</sup> in 2010, respectively). These natural disturbances can result in large amounts of coarse woody debris that persist into the next rotation as legacy effects, which has positive implications for site- and landscape-level biodiversity, although perhaps a smaller impact on future site productivity.

For the most part, Canada practices extensive rather than intensive forest management<sup>8</sup>. Natural regeneration can be the main method of reforestation in some provinces; for example, only 20% of harvested areas are planted in Quebec (Bureau du forestier en chef 2010). Thinning is not a common practice, and ranged from only 10% to 20% of the area harvested annually between 1990 and 2010. This extensive management presumably increases deadwood production and hence biodiversity values compared to plantations with optimal spacing and reduced density-dependent mortality.

The short-lived energy crisis of the 1970s led to interest in the use of harvesting residue as feedstock for bioenergy; however, the increased use of WTH (called "full-tree" in Canadian operations<sup>9</sup>) in the 1980s was driven by cheaper log production costs for traditional forest products. Harvesting residue is typically left in piles at the roadside or on landings, and is often burnt. The use of full-tree harvesting varies across the country, and requires suitable site and stand conditions for safe and efficient machinery operation. This single-pass system may reduce physical disturbance to sites compared to multiple-pass systems, and also leaves relatively large amounts of biomass on-site: 37% and 51% of harvesting residue (not including standing residual trees) were left on the ground in two mixed wood sites in Ontario, and 32% on a black spruce site (calculated from field sampling data in Ralevic et al. 2010).

### Relevant science in Canada

The scientific foundation of regulations and guidelines in Canada was briefly reviewed by Thiffault et al. (2010). Nutrient budgets (including steady-state mass balance models) and resultant expert opinion suggest that there are two main groupings of sites that are potentially sensitive to removal of harvesting residue: dry, coarse textured soils and wet soils with build-up of organic matter. Specific recommendations include dry sites with low reserves of organic matter and low exchange capacity (Weetman and Weber 1972; expert opinion<sup>10</sup>); many jack pine stands, which are common on dry sites with coarse-textured soils (Bhatti et al. 1998); and sites with thin soils or on glacio-fluvial sands, especially for balsam fir and trembling aspen (Paré et al. 2002); and (ii) wet sites with excessive accumulation of organic matter (Weetman and

<sup>5</sup> Natural Resources Canada – Forests, accessed 18 June 2012 at <http://www.nrcan.gc.ca/statistics-facts/forests/897#sec3>

<sup>6</sup> National Forestry Database, accessed 18 June 2012 at [http://nfdp.ccfm.org/data/compendium/html/comp\\_41e.html#bookMark\\_Ha](http://nfdp.ccfm.org/data/compendium/html/comp_41e.html#bookMark_Ha)

<sup>7</sup> National Forestry Database, accessed 18 June 2012 at [http://nfdp.ccfm.org/data/compendium/html/comp\\_31e.html](http://nfdp.ccfm.org/data/compendium/html/comp_31e.html)

<sup>8</sup> National Forestry Database, Silviculture Statistics, accessed 18 June 2012 at [http://nfdp.ccfm.org/data/compendium/html/comp\\_61e.html](http://nfdp.ccfm.org/data/compendium/html/comp_61e.html) and National Forestry Database, Area of Stand Tending, accessed 18 June 2012 at [http://nfdp.ccfm.org/data/compendium/html/comp\\_69e.html](http://nfdp.ccfm.org/data/compendium/html/comp_69e.html)

<sup>9</sup> See discussion of harvesting systems in Canada, including graph showing increase of full-tree systems, accessed 19 June 2012 at [http://flash.lakeheadu.ca/~repulkki/ctl\\_ft.html](http://flash.lakeheadu.ca/~repulkki/ctl_ft.html)

<sup>10</sup> Authors created nutrient budgets for a mesic and a rich site and concluded that there would be no nutritional problems with WTH; they then made recommendations for sites not studied, based on deductions from their nutrient budget work.

Weber 1972; expert opinion). Allometric equations and a nutrient database for Canadian tree species were recently combined to create a simple nutrient calculator so that users can estimate nutrient removals from sites and do their own scenario testing<sup>11</sup>. Spatial application of steady-state mass balance models has also been used to identify sites that could be potentially sensitive to harvesting residue removals in New Brunswick (NB DNR 2008; Appendix 6 in Titus et al. 2008) and Nova Scotia (Noseworthy 2011); similarly, sites potentially sensitive to excessive acidity as a result of WTH have been mapped in Quebec (Ouimet and Duchesne 2009).

There are longer-term (>15-year-old) “first-generation” field trials that compare whole-tree and stem-only clearcut harvesting on approximately 46 sites across Canada (Titus et al. 2008), although some sites have only single replicates of larger trials. There is no evidence of growth decline with harvesting residue removals in Canada (e.g., Kabzems 2012) except on one jack pine site on coarse textured soils in Quebec (D. Paré, pers. comm.), where soil and foliar analyses suggested a nutrient-induced growth limitation (Thiffault et al. 2006). However, additional removal of forest floor by blading induced growth reduction in black spruce on two poor sites on sandy soil in Ontario (D. Morris, pers. comm.) and in aspen and white spruce on a moderately well drained Orthic Luvisc Gleysol (20-30cm of silt loam over clay loam) in northern B.C. (Kabzems 2012), suggesting that some level of guidance could be given to these sites, even though they are not so sensitive that WTH alone reduced growth.

Results for harvesting residue removal are thus in keeping with 10-year results from 45 installations in the Long-Term Soil Productivity network in the U.S. and Canada that show growth declines only on some poor P-deficient sites in the Southeast, and some dry sites in California if there is no vegetation control (Ponder et al. 2012). Older Canadian trials were established after felling previously un-managed stands, and it is therefore not surprising that the findings contrast with growth reductions found in UK and some Nordic trials (e.g. Thiffault et al. 2011, Mason et al. 2012) because of different forest site and management histories. Many older Canadian trials had operational removal of harvesting residue (e.g. NB<sup>12</sup>, NL, NS, LTSP trials in ON) and this can leave sizeable proportions of biomass on site (Ralevic et al. 2010); results from old trials with artificially total removals (e.g. LTSP trials in BC) are more conservative and a “worst-case” operational scenario.

### Harvesting residue removal guidelines in Canada

Only one province (NB) has specific site-level guidance for harvesting residue removals for bioenergy that apply provincially. Another province (QC) has recently begun devolving land management decision-making, including site-specific guidelines for removing harvesting residue for bioenergy, to regional levels but still retains overarching responsibility for forest management (e.g. regions cannot restrict WTH but can restrict second-pass collection of residue). However, all provinces (including NB and QC) have relevant criteria within their sustainable forest management (SFM) policies and regulations. These have been reviewed by Waito and Johnson (2010) and more recently by Roach (2012), who concluded that: *“All of the provinces have some sort of guidelines related to forest biomass retention and removal from logged sites [within SFM], including guidance for slash distribution and piling. Consistent themes are the requirement to re-distribute unutilized slash over cutblocks and to retain residues at the stump where soils are dry, coarse-*

---

<sup>11</sup> Biomass calculation tool, accessed 30 July 2012 at <https://apps-scf-cfs.mcan.gc.ca/calc/en/calculateur-calculator>.

<sup>12</sup> **AB** = Alberta, **BC** = British Columbia, **MB** = Manitoba, **NB** = New Brunswick, **NL** = Newfoundland and Labrador, **NS** = Nova Scotia, **ON** = Ontario, **PE** = Prince Edward Island, **QC** = Quebec, **SK** = Saskatchewan.

*textured, and/or nutrient-poor.*" (Roach 2012); this reflects current knowledge about these sites (e.g. Bhatti et al. 1998, Paré et al. 2002, Thiffault et al. 2011) and expert opinion (e.g. Weetman and Webber 1972).

A range of governance approaches are applied by provincial governments in Canada, from moratoria, through SFM, to specific guidelines:

- (i) a moratorium on harvesting residue removal for electrical production (NS) or guidance that WTH not be practised and residue be left on-site (NL), to
- (ii) the implied assumption that SFM policies cover WTH (BC, AB, SK, MB), to
- (iii) a reiteration of SFM and other policies within a specific biomass policy that identifies exclusion of some material (OMNR (2008); Puddister et al. (2011)), to
- (iv) limited but specific guidance on coarse woody debris retention (BC Chief Forester (2010); Berch et al. (accepted)), to
- (v) specific region-level guidance in QC (which varies in approach between regions), to
- (vi) specific provincial-level guidance on WTH that identifies potentially sensitive sites to be avoided (NB; NB DNR 2008) or sites at risk of exceedence of acidity with WHT (QC; Ouimet and Duchesne 2009); some other provinces are currently developing either relevant or specific site-level guidance on harvesting residue removals (e.g., SK, ON, NL provincially, and QC regionally; from Roach 2012), but not always with feedstock for bioenergy as the sole objective (e.g. ON policy applies to all "biofibre" for all products).

### **Protecting soils**

The wider contents of guidelines have been reviewed (e.g. Stupak et al. 2008, Evans et al. 2010, Abbas et al. 2011, Stewart et al. 2011) and we restrict ourselves to two aspects that are most directly related to soils: (i) the definition of sensitive soils where harvesting residue removal is not recommended, and (ii) the amount of harvesting residue that should be left on-site. We do not address BC's CWD retention guidance because it primarily addresses biodiversity. Rather, we address NB's provincial policy and general aspects of Quebec's regional policies, which are the only ones with specific site-level guidance for biomass removals for bioenergy; however, we include Ontario because their SFM guides provide site-specific guidance for WTH in north-western Ontario and these are covered by their biofibre policy.

New Brunswick's guidance operates in two stages. In the first stage, four "high risk areas" are excluded: (i) wetlands (as defined for NB); (ii) shallow soils (<30 cm); (iii) rocky and stony areas; and (iv) dry and poor soils. In the second stage, the Forest Biomass Decision Support System (a spatially explicit nutrient budget model developed by P. Arp at the University of New Brunswick; Noseworthy 2011) is then applied to potentially eligible sites to refine decision-making; harvesting residue removals can take place on "low risk" areas, as defined by the model. (No specific amount of harvesting residue must be left on low-risk areas, as it is assumed that operations cannot remove ecologically unacceptable amounts; S. Morehouse, NB DNR, pers. comm.)

Quebec's guidance includes a range of approaches across different regions, from application of provincial acidity exceedence maps (Ouimet and Duchesne 2009), to indicators of site sensitivity, or a mixture of both;

these approaches may include mapping, in that sensitivity is either explicitly or implicitly recognized because each region must produce maps of allocation of biomass for bioenergy.

Ontario's guidance for the north-western part of the province does not recommend harvest residue removal on very shallow soils where the O horizon + mineral soil is less than 20 cm deep, and conditionally recommends only WTH but not additional residue removal on dry, coarse sandy outwashes (OMNR 1997).

General categories of sensitive soils in various jurisdictions in North America<sup>13</sup> include:

- low in nutrients or fertility (ME, VT; NE),
- shallow depth (NB, ON; MA, MD, ME, MI, MN, MO, VT, WI; NE),
- sandy, coarse-textured, dry, nutrient poor soils (NB, ON; MA, MD, ME, MN, VT, WI; NE),
- rocky, stoney soils (NB),
- wetlands, dysic Histosols, organic, poorly drained, ombrotrophic organic (NB; KY, MA, MD, ME, MN, WI; NE), and
- steep, erosion-prone sites (KT, MA, MD, ME, MN, MO, VT; NE).
- Maryland includes: highly acidic, thin litter layer, low organic content, low available water content, highly weathered, low buffering capacity.

All of these categories are better defined for some jurisdictions than others (e.g. some include depth that constitutes "shallow" soil, etc.; MA and WI include detailed descriptions from USDA Natural Resource Conservation Service (NRCS ) for dry nutrient-poor sandy soils).

Internationally, some jurisdictions have used different approaches: the French guidelines define risk based on only humus type (or pH of A horizon where there is not enough humus to classify) and dominant texture (sand, silt or clay) of the top 20 cm of mineral soil (Cacot et al. 2006). However, the most detailed soil information is applied in three jurisdictions that use soil type as the key indicator (the UK, Wisconsin and Maryland)<sup>14</sup>; regrettably, a comparable in-depth knowledge of soils and/or accurate forest soil mapping is currently lacking for much of the Canadian managed forest.

Once sensitive sites are excluded, how much harvesting residue should be retained on suitable sites? Jurisdictions in North America stipulate retention of 15 to 35% of harvesting residue, with Michigan suggesting more than their recommended 17-33% if pre-harvest levels of material are low, with two exceptions: (i) NB accepts whatever is left operationally, and (ii) Maine accepts as much as possible (Briedis et al. (2012) found that 45% of harvesting residue (34-57%; CWD plus FWD) was left on 12 sites in this state).

---

<sup>13</sup> **NB** = New Brunswick (NB DNR 2008); **ON** = northwestern Ontario (OMNR 1997); **KY** = Kentucky (Kentucky Division of Forestry 2011); **MA** = Massachusetts (Massachusetts DOER 2012); **MD** = Maryland (Pinchot Institute 2010); **ME** = Maine (Benjamin 2010); **MI** = Michigan (Michigan DNRE 2010); **MN** = Minnesota (Minnesota Forest Resources Council 2007a,b); **MO** = Missouri (Missouri Dept. of Conservation ,Undated); **PA** = Pennsylvania (Pennsylvania Dept. of Conservation and Natural Resources 2008); **VT** = Vermont (Biomass Energy Development Working Group 2011); **WI** = Wisconsin (Herrick et al. 2009); **NE** = Northeastern States (Forest Guild Biomass Working Group 2010); and **SE** = Southeastern States (Forest Guild Southeast Biomass Working Group 2012).

<sup>14</sup> Note that QC exceedence maps are based on detailed listing of sensitive ecosystem types (Ouimet and Duchesne 2009), similar to soils by UK, WI and MD.

## Current and future directions in Canada

Guidelines from several jurisdictions have already been revised at least once (e.g. UK, Sweden, Finland) or are under revision (e.g. Minnesota) as new scientific and operational knowledge is generated and fed into adaptive management processes. Learning from past experience, new “second-generation” field trials in Canada now include a wider range of stand histories, silvicultural systems, and removal treatments: most are installed after harvesting 2<sup>nd</sup> rotation stands; one is a shelterwood cut in hardwoods; some are thinning trials; most include several levels of harvesting residue removal; some use larger plots to allow greater integration of biodiversity and nutritional research; and some include compensatory ashing treatments. A novel “mini-plot” approach has also been used in one trial series to test the impact of leaving several precise quantities of slash on site, from which quantitative slash-ecosystem response curves can be derived (D. Paré, pers. comm.). Field trials are expensive to install and maintain, and cannot always reflect operational conditions; a network of operational monitoring plots with randomized and replicated treatments is therefore also being installed by companies as part of routine forest harvesting (Thiffault et al. 2011), creating a series of “legacy trials” in which industry can leave a potential knowledge legacy for future generations through its routine operations.

Synthesizing knowledge continues: a major biodiversity impact review for Canadian conditions (C. Messier, pers. comm.) and a meta-analysis of tree and soil data collected from harvesting residue removal trials from around the world (R. Fleming, pers. comm.) are under way. A major project in BC is collating data and synthesizing information on impacts of harvesting residue removal and stumping on soils and biodiversity (S. Berch, pers. comm.; Berch et al. accepted; Hannam et al. 2012). Predictive forest soil mapping is being explored in an attempt to disaggregate current polygons in the Soil Landscapes of Canada and thereby increase accuracy and precision (S. Smith, pers. comm.). Synthesizing of spatial data is also taking place, in which clusters of cells with common attributes are used to predict site suitability for harvesting residue removal based on soil and site indicators (E. Thiffault, pers. comm.); this and other spatial applications of indicators can then be fed into operational harvesting and logistics models to game with scenarios resulting from the effects of different guideline criteria on forest biomass supply chains (E. Thiffault, pers. comm.), and to better estimate environmentally sustainable biomass inventories (Titus et al. 2009).

## Conclusions

Overall, guideline development in Canada is progressing, and new applications may increase their use (especially of indicators) beyond site management to supply chain analyses and biomass inventories. Critical examination of global trends in guideline development is helpful in guideline development, but each jurisdiction or region must apply local scientific knowledge, expert opinion, and operational experience to tailor global trends to their own situations. Consideration of criteria from guidelines developed elsewhere may encourage convergence that helps simplify certification processes and market access at a global level, but the temptation to uncritically apply criteria developed elsewhere must be resisted when developing guidance; consideration of local ecological conditions and operational contexts must always be paramount.

## Acknowledgements

The authors acknowledge their many colleagues who have influenced their thinking on science and guidelines over the years. The senior author also gratefully acknowledges partial funding from the OECD that allowed participation in the Eurosoil 2012 workshop on forest bioenergy, and the work of the

organizers (Heljä-Sisko Helmisaari and Elena Vanguelova) and OECD administrator (Janet Schofield) that made this workshop possible.

## References

- Abbas, D., Current, D., Phillips, M., Rossman, R., Brooks, K.N. & Hoganson, H. 2011. Guidelines for harvesting forest biomass for energy: A synthesis of environmental considerations. *Biomass and Bioenergy* 35: 4538-4546.
- BC Chief Forester, 2010. Chief Forester's Guidance on Coarse Woody Debris Management, May 2010. 7 p. (Accessed on 19 June 2012 at <http://www.for.gov.bc.ca/ftp/hfp/external!/publish/frep/extension/Chief%20Forester%20short%20CW D.pdf>)
- Benjamin, J.G. (ed.). 2010. Considerations and recommendations for retaining woody biomass on timber harvest sites in Maine. University of Maine, Maine Agricultural and Forest Experiment Station, Orono, ME. Miscellaneous Publication 761. 68 p.
- Berch, S.M., Bulmer, C., Curran, M., Finvers, M. & Titus, B.D. Accepted. Provincial government standards (criteria and indicators) for sustainable harvest of forest biomass in British Columbia: soil and biodiversity. *International Journal of Forest Engineering*.
- Berch, S.M., Curran, M., Dymond, C., Hannam, K., Murray, M., Tedder, S., Titus, B. & Todd, M. Accepted. Criteria and guidance considerations for sustainable tree stump harvesting in British Columbia. *Scand. J. For. Res.*
- Bhatti, J.S., Foster, N.W., Oja, T., Moayeri, M.H. & Arp, P.A. 1998. Modeling potentially sustainable biomass productivity in jack pine forest stands. *Can. J. Soil Sci.* 78: 105–113.
- Biomass Energy Development Working Group 2011. Biomass Energy Development Working Group: Final Report. Vermont Legislative Council. 196 p.
- Briedis, J.L., Wilson, J.S., Benjamin, J.G. & Wagner, R.G. 2012. Biomass retention following whole-tree, energy wood harvests in central Maine: Adherence to five state guidelines. *Biomass and Bioenergy* 35: 3552-3560.
- Bureau du forestier en chef, 2010. Bilan d'aménagement forestier durable au Québec 2000-2008. Gouvernement du Québec, Roberval, Québec, 290 p.
- Cacot, E., Eisner, N., Charnet, F., Leon, P., Rantien, C. & Ranger, J. 2006. La récolte raisonnée des rémanents en forêt. Agence de l'Environnement et de la Maîtrise de l'Énergie, Angers, France. 36 p.
- Carou, S., Dennis, I., Aherne, J., Ouimet, R., Arp, P.A., Watmough, S.A., DeMerchant, I., Shaw, M., Vet, B., Bouchet, V. & Moran, M. 2008. A National Picture of Acid Deposition Critical Loads for Forest Soils in Canada. A report prepared for the CCME Acid Rain Task Group. Canadian Council of Ministers of the Environment, PN 1412, ISBN 978-1-896997-82-7 PDF, 6 p.
- Evans, A.M., Perschel, R.T. & Kittler, B. 2010. Revised assessment of biomass harvesting and retention guidelines. Forest Guild, Sante Fe, NM.
- Forest Guild Biomass Working Group, 2010. Forest Biomass Retention and Harvesting Guidelines for the Northeast. Forest Guild, Sante Fe, NM.
- Forest Guild Southeast Biomass Working Group, 2012. Forest Biomass Retention and Harvesting Guidelines for the Southeast. Forest Guild, Sante Fe, NM.
- Hannam, K. 2012. The use of stumps for biomass in British Columbia – a problem analysis. Government of British Columbia, Victoria, B.C. Tech. Rep. 066. (Accessed on 1 Aug. 2012 at [www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr066.htm](http://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr066.htm))
- Herrick, S.K., J.A. Kovach, E.A. Padley, C.R. Wagner & D.E. Zastrow. 2009. Wisconsin's Forestland Woody Biomass Harvesting Guidelines. PUB-FR-435-2009. WI DNR Division of Forestry and Wisconsin Council on Forestry; Madison, WI. 51 pp. plus Appendix D. Identifying sites limited under Guidelines 3.B. 4.B and 5.B. 4 pp. and Appendix D. Soil map units limited by biomass harvesting guidelines. July 2009. 20 p.
- Kabzems, R. 2012. Aspen and white spruce productivity is reduced by organic matter removal and soil compaction. *For. Chron.* 88: 306-316

- Kentucky Division of Forestry, 2011. Recommendations for the harvesting of woody biomass. Oct. 2011. Kentucky Division of Forestry. 5 pp.
- Mason, W.L., McKay, H.M., Weatherall, A., Connolly, T. & Harrison, A.J. 2012. The effects of whole-tree harvesting on three sites in upland Britain on the growth of Sitka spruce over ten years. *Forestry* 85: 111-123.
- Massachusetts DOER, 2012. Massachusetts Executive Office of Energy and Environmental Affairs, Department of Energy Resources, Renewable Energy Portfolio Standard – 225 CMR 14.00. Forest Derived Eligible Biomass Woody Fuel Guideline. Accessed on 19 June 2012 at <http://www.mass.gov/eea/docs/doer/renewables/biomass/biomass-eligibility-and-certificate-guideline-doer-042712.xlsx>
- Michigan DNRE, 2010. Michigan woody biomass harvesting guidance. Michigan Department of Natural Resources and Environment, Forest Management Division. IC4069 (05/10/10). 18 p.
- Minnesota Forest Resources Council, 2007a. Biomass harvesting on forest management sites. Minnesota Forest Resources Council, St. Paul, Minnesota. 42 p.
- Minnesota Forest Resources Council, 2007b. Woody biomass harvesting for managing brushlands and open lands. Minnesota Forest Resources Council, St. Paul, Minnesota. 55 p.
- Missouri Dept. of Conservation. Undated. Missouri woody biomass harvesting best management practices manual. Missouri Dept. of Conservation. 38 p.
- NB DNR. 2008. New Brunswick Department of Natural Resources, 2008. Forest biomass harvesting. Policy No. FMB 019 2008. 9 p. (Accessed on 19 June 2012 at <http://www.gnb.ca/0078/Policies/FMB0192008E.pdf>)
- Noseworthy, J. 2011. A mass balance biogeochemical framework for assessing forest biomass harvest sustainability. Unpublished MSF thesis, Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, N.B. 223 p.
- OMNR. 1997. Silvicultural guide to managing for black spruce, jack pine, and aspen on boreal forest ecosites in Ontario. Book II: Ecological and management interpretations for northwest ecosites. Ontario Ministry of Natural Resources, Queen's Printer for Ontario, Toronto.
- OMNR. 2008. Forest biofibre – Allocation and use. Ontario Ministry of Natural Resources, Forest Management, Forest Resource Disposition, Directive FOR 03 02 01. 5 p. (Accessed on 19 June 2012 at <http://www.mnr.gov.on.ca/244743.pdf>)
- Quimet, R. & L. Duchesne. 2009. Évaluation des types écologiques forestiers sensibles à l'appauvrissement des sols en minéraux par la récolte de biomasse. Hors série, Gouvernement du Québec, Ministère des Ressources naturelles et de la Faune, Direction de la recherche forestière. 26 p.
- Paré, D., Rochon, P. & Brais, S. 2002. Assessing the geochemical balance of managed boreal forests. *Ecological Indicators* 1: 293–311.
- Pennock, D., Arocena, J.M. & Smith, C.A.S. 2011. Soils of Canada – Preface. *Canadian Journal of Soil Science* 91: 671-673, doi:10.4141/CJSS2011-503.
- Pennsylvania Dept. of Conservation and Natural Resources, 2008. Guidance on harvesting woody biomass for energy in Pennsylvania. Department of Conservation and Natural Resources, Harrisburg, PA. 50 p.
- Pinchot Institute, 2010. A guide to forest biomass harvesting and retention in Maryland. September 2010. Pinchot Institute and Maryland Dept. of Natural Resources. 25 p.
- Ponder, F., Jr., Fleming, R.L., Berch, S., Busse, M.D., Elioff, J.D., Hazlett, P., Kabzems, R.D., Kranabetter, J.M., Morris, D.M., Page-Dumroese, D., Palik, B.J., Powers, R.F., Sanchez, F.G., Scott, D.A., Stagg, R.H., Stone, D.M., Young, D.H., Zhang, J., Ludovici, K.H., McKenney, D.W., Mossa, D.S., Sanborn, P.T. & Voldseth, R.A. 2012. Effects of organic matter removal, soil compaction and vegetation control on 10th year biomass and foliar nutrition: LTSP continent-wide comparisons. *For. Ecol. Manage.* 278:35-54.
- Puddister, D., Dominy, S.W.J., Baker, J.A., Morris, D.M., Maure, J., Rice, J.A., Jones, T.A., Majumdar, I., Hazlett, P.W., Titus, B.D., Fleming, R.L. & Wetzels, S. 2011. Emerging opportunities and challenges in the forest bioeconomy: Ontario's approach to sustainable use of forest biofibre. *Forestry Chronicle* 87: 468-477.

- Ralevic, P., Ryans, M. & Cormier, D. 2010. Assessing forest biomass for bioenergy: Operational challenges and cost considerations. *Forestry Chronicle* 86: 43-50.
- Roach, J. 2012. Forest biomass harvesting policy in Canada. Contract report prepared for B.C. Ministry of Environment. 147 pp.
- Stewart, W., Powers, R.F., McGown, K., Chiono, L. & Chuang, T. 2011. Potential positive and negative environmental impacts of increased woody biomass use for California. California Energy Commission. Publication Number: CEC-500-2011-036, 217 p.
- Stupak, I., Asikainen, A., Röser, D. & Pasanen, K. 2008. Review of Recommendations for Forest Energy Harvesting and Wood Ash Recycling. *In*: R. Röser, A. Asikainen, K. Raulund-Rasmussen and I. Stupak (editors). *Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on the Baltic and Nordic Region*, pp. 155-196. Springer, Dordrecht, the Netherlands.
- Stupak, I., Titus, B., Clarke, N., Smith, T., Lazdins, A., Varnagiryte-Kabasinskiene, I., Armolaitis, K., Peric, M., & Guidi, C. 2013. Approaches to soil sustainability in guidelines for forest biomass harvesting and production in forests and plantations. *In* Helmisaari, H-S. & Vanguelova, E. (eds.). *Proceedings of the Workshop W6.1 Forest bioenergy and soil sustainability at EUROSOIL Congress, 2<sup>nd</sup> July to 6<sup>th</sup> July 2012, Bari, Italy.*
- Thiffault, E., Paré, D., Bélanger, N., Munson, A.D. & Marquis, F. 2006. Harvesting intensity at clear felling in the boreal forest: Impact on soil and foliar nutrient status. *Soil Sci. Soc. Am. J* 70: 691-701.
- Thiffault, E., Paré, D., Brais, S. & Titus, B.D. 2010. Intensive biomass removals and site productivity in Canada: A review of relevant issues. *Forestry Chronicle* 86: 36-42.
- Thiffault, E., Hannam, K., Paré, D., Titus, B., Hazlett, P., Maynard, D. & Brais, S. 2011. Effects of forest biomass harvesting on soil productivity in boreal and temperate forests – A review. *Environmental Reviews* 19: 278-309. Available at doi:10.1139/A11-009.
- Thiffault, E., Paré, D., Dagnault, S. & Morissette, J. 2011. Guidelines - Establishing permanent plots for monitoring the environmental effects of forest biomass harvesting. Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Québec, QC. 80 p.
- Titus, B.D., Berch, S.M., Morris, D.M, Fleming, R.L., Hazlett, P.W., Paré, D. & Arp, P.A. 2008. Synopsis of on-going Canadian research on biomass harvesting and site productivity. Workshop on The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies, Toronto, Ontario, 18-21 Feb. 2008. 38 p. (Accessed on 18 June 2012 at [http://www.sfmn.ales.ualberta.ca/en/Events/NetworkWorkshops/\\_media/sfmn/Events/NetworkWorkshops/Documents/Biomass\\_currentsiteproductivityfieldtrialsCanada.ashx](http://www.sfmn.ales.ualberta.ca/en/Events/NetworkWorkshops/_media/sfmn/Events/NetworkWorkshops/Documents/Biomass_currentsiteproductivityfieldtrialsCanada.ashx))
- Titus, B.D., Maynard, D.G., Dymond, C.C., Stinson, G. & Kurz, W.A. 2009. Wood energy: Protect local ecosystems. *Science* (12 June 2009) 324 (5933): 1389 – 1390.
- UK Forestry Commission, 2007. Guidance on site selection for brush removal. Forest Research, Forestry Commission, UK, May 2009. 15 p.
- Waito, B. & Johnson, L. 2010. A national scan of regulations and practices relevant to biomass harvesting. Report prepared for World Wildlife Fund - Canada and The Forest Products Association of Canada. 45 p. (Accessed 19 June 2012 at [http://assets.wwf.ca/downloads/biomass\\_report\\_2010.pdf](http://assets.wwf.ca/downloads/biomass_report_2010.pdf))
- Weetman, G.F. & Webber, B. 1972. The influence of wood harvesting on the nutrient status of two spruce stands. *Can. J. For. Res.* 2: 351-369.

## Development of Forest Bioenergy Guidelines for Soil and Water Protection – Experience from the UK

Thomas R Nisbet

Centre for Forestry and Climate Change, Forest Research, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, UK  
([tom.nisbet@forestry.gsi.gov.uk](mailto:tom.nisbet@forestry.gsi.gov.uk))

### Introduction

The UK has a target for 15% of its energy consumption to be from renewable sources by 2020. Delivering this target is expected to increase the demand for biomass feedstocks in the heat and power sectors. Two potential sources attracting increased attention in recent years are the production of forest energy crops and the harvesting of wood fuel. Energy crop systems such as short rotation forestry (SRF) and short rotation coppice (SRC) have the potential to deliver greater volumes of biomass from the same land area than shorter biomass crops. An added advantage is that they are suitable for growing on lower-grade agricultural land, previously forested land or reclaimed land, reducing competition with food crops on better quality soils. The harvesting of wood fuel from existing woodlands and forests includes bringing under-managed woodlands into productive management and the harvesting of forest residues and tree stumps.

### Risks and benefits for soil and water

The production of forest energy crops and the harvesting of wood fuel, especially the increased utilisation of residues and removal of stumps, present a number of risks to soil and water resources, potentially threatening sustainable forest management (Nisbet et al., 2011a; Moffat et al., 2011). Negative impacts include soil infertility, acidification, soil carbon loss, ground damage and diffuse water pollution. In addition, the potential high water utilization of SRF and SRC crops can reduce water resource availability and the maintenance of ecological flows in rivers. On the other hand, well designed and managed forest bioenergy systems offer a number of soil and water benefits, such as waste treatment, reduced nutrient and sediment delivery to watercourses, and the attenuation of flood flows (Nisbet et al., 2011b). The main risks and benefits are described in more detail in Table 1.

Table 1 Main risks and benefits to soil and water resources associated with the development of forest bioenergy.

<b>Production of energy forest crops – Risks</b>
Higher crop water use reducing surface flows and groundwater recharge from a given area, depending on tree species and site factors. This could also concentrate pollutants such as nitrate in drainage waters, reducing water quality.
Machine trafficking during harvesting, especially if constrained to winter periods, causing physical soil damage such as compaction, rutting and erosion, leading to soil loss and increased turbidity and siltation of local watercourses.
Removal of essential major and micro nutrients (e.g. nitrogen, phosphorus, potassium and boron), eventually leading to lower soil fertility and potential loss of tree growth in subsequent rotations.
Canopy scavenging of sulphur and nitrogen pollutants and removal of base cations (calcium, magnesium, sodium and potassium) in harvested crops, leading to reduced soil buffering capacity

and increased soil and stream water acidification.
<b>Production of energy forest crops – Benefits</b>
Planting on or around pollutant source areas and along pathways, reducing delivery of pollutants to watercourses; energy crops can be particularly effective at reducing nutrient losses and intercepting pesticide spray drift. Crop systems can be specifically designed to treat wastewater.
Lower nutrient and pesticide loadings to the soil and less frequent soil disturbance compared to previous agricultural land use, improving water quality.
Planting in riparian zones and on the floodplain may increase hydraulic roughness and slow down flood flows, potentially reducing downstream flood risk. The high water utilization of crops and associated soil drying could increase the capacity of soils to retain rain water and reduce the generation of flood flows.
<b>Harvesting of residues and stumps – Risks</b>
Machine trafficking causing soil physical damage such as compaction, rutting and erosion, leading to soil loss and increased turbidity and siltation of local watercourses.
Soil disturbance and removal of residues and stumps causing increased carbon loss, leading to reduced soil carbon stock.
Removal of essential major and micro nutrients leading to lower soil fertility and potential loss of tree growth in subsequent rotations.
Removal of base cations reducing soil buffering capacity and leading to increased soil and stream water acidification.
Soil disturbance, especially associated with stump removal, mixing and damaging buried artifacts.
Loss of deadwood, habitat/shelter and nesting sites, reducing soil and site biodiversity.
<b>Harvesting of residues and stumps – Benefits</b>
Quicker site revegetation and renewed N uptake, reducing the risk of nitrate leaching and associated acidification.
Soil disturbance due to stump harvesting, reducing the need for ground preparation/cultivation prior to replanting.

### UK Forestry Standard and Guidelines

The risks associated with forest bioenergy are addressed by the UK Forestry Standard and supporting guidelines. The Standard sets out the governments' approach to sustainable forestry and describes the legal and good forestry practice requirements for the planning, design and management of forests and woodlands in the UK (Forestry Commission, 2011a). At the core of the Standard is the need to protect forest soil and water resources. There are no requirements specifically targeted at energy forestry but a number are very relevant to the risks posed by these more intensive forest management systems. This includes three soil (S) and one water (W) good forestry practice requirement (GFPR):

SGFPR1: The quality of forest soil should be protected or enhanced in terms of its physical, chemical and biological properties.

SGFPR2: Forest soil fertility levels should be maintained to safeguard the soil's character and productive potential.

SGFPR3: Forest operations should be planned and managed to avoid damage to soil structure and function; should damage occur, reinstatement measures should be undertaken and adverse effects mitigated.

WGFPR12: Where new woodlands are proposed, the sensitivity of downstream water bodies and wetlands to a reduction in water quantity should be considered; where this is an issue, advice should be sought from the water regulatory authority and conservation agency.

Specific measures designed to minimise the impact of energy forestry are contained within four of the seven sets of Forestry Guidelines that underpin the UK Forestry Standard and requirements (Forestry Commission, 2011b). The Forests and Soil (SG), Forests and Water (WG), Climate Change (CC) and Historic (HG) Guidelines list the following measures:

SG11: Maintain adequate brash mats throughout extraction operations.

WG4: On soils classified as at high risk of increased soil and water acidification, avoid short rotation forestry or short rotation coppice, and the harvesting of whole trees, forest residues and tree stumps.

WG74: Where the maintenance of water flows is an issue, consult stakeholders before carrying out large-scale woodland planting - especially involving conifer or short rotation forestry crops with high water utilization.

CG3: Avoid removing stumps unless for tree health reasons or where a risk-based assessment has shown that adverse impacts can be reduced to acceptable levels.

HG14: Take particular care to avoid sites of historic interest where SRC crops are proposed.

HG27: Avoid the establishment of SRC in areas where change in hydrology may affect preserved remains.

### **Guidance on good practice measures**

More detailed advice on site selection and good practice to comply with the requirements and guidelines are set out in various guidance notes. For forest energy crops, a Forestry Commission Practice Note provides general guidance on the establishment and management of SRC, which addresses elements of soil and water protection (Tubby and Armstrong, 2002). Specific hydrological guidelines for SRC were published in 2003 by the Department of Trade and Industry (Hall, 2003). These guide site selection by considering the water requirements to support a productive crop, local impacts on water resources and potential risks and benefits for water quality.

A minimum summer rainfall of 300 mm and annual total of 700 mm is recommended to support productive SRC crops (yields >12 oven-dry tonnes/ha), which limits the scope for planting across parts of central and south-eastern England. This is also the area where water resources are considered to be at greatest risk from the potential high water utilization of crops. SRC is expected to use all of the effective precipitation where there is <600 mm annual rainfall and consequently the guidelines recommend that only a small proportion of any catchment should be planted in these areas. Guidance is provided on the percentage reduction in effective rainfall as a function of annual rainfall and fractional coverage of SRC.

The SRC guidelines on water quality focus on the nitrate issue. The planting of energy crops is generally thought to have a beneficial effect by reducing nitrate leaching, with the main risk arising where crops are subject to N fertiliser or sewage sludge applications. Targeting planting to riparian buffer strips is recommended as an effective measure for reducing nutrient and sediment run-off from adjacent farmland.

Two sets of guidance address the impacts of harvesting residues (Nisbet, 2009) and tree stumps (Nisbet et al., 2009). Both adopt a similar risk-based approach and rank soils in terms of their susceptibility to ground damage, infertility, acidification, and in the case of stump harvesting, carbon loss. The individual risks are combined to derive an overall hazard assessment for each soil type and a number of good practice measures described according to the level of risk posed. Deep peats, podzols, rankers, and skeletal and littoral soils are among the most sensitive and consequently the harvesting of brash and stumps is considered unlikely to be sustainable. Brown earths and calcareous soils are the least sensitive, whereas gleys and ironpan soils may be suitable subject to restrictions on the timing and scale of operations, and possible use of remedial treatments. Table 2 summarises the good practice measures recommended for controlling the risks associated with stump harvesting

### Monitoring and evaluation

Much of the guidance is based on expert judgement and has an interim status due to uncertainty about the magnitude of the impacts. Studies are under way to improve our knowledge of the susceptibility of different soils to energy forestry and to test and demonstrate the effectiveness of good practice measures. The guidance will be regularly reviewed and updated as new research findings become available from national and international studies.

Table 2. Summary of recommended good practice measures to control risks associated with stump harvesting on low, medium and high risk soils (from Nisbet et al., 2009).

Combined Risk	Recommended Good Practice Measures to Control Risk
<b>Low</b>	<ul style="list-style-type: none"> <li>• No stump harvesting on slopes that are &gt;20°.</li> <li>• Normal good practice, including the retention of brash mats to protect the soil from trafficking by loaded forwarders.</li> <li>• Stumps retained within riparian buffers (5-20 m), along drains, breaks of slope, and around archaeological sites, veteran trees and adjacent crops (minimum 5 m).</li> <li>• Stump stacks sited away from drains to reduce the risk of blockage and increased nutrient leaching and sediment delivery to watercourses. Avoid archaeological remains.</li> <li>• Minimise the amount of soil attached to stumps.</li> <li>• Rotten stumps retained for wildlife value.</li> </ul>
<b>Medium</b>	<p><i><b>In addition to the above:</b></i></p> <ul style="list-style-type: none"> <li>• No stump harvesting on sites where brash has been harvested, either with or without needles.</li> <li>• Where possible, extract stumps while brash remains green.</li> <li>• Brash mats combined to strengthen extraction routes, especially when there is a prolonged gap between timber harvesting and stump harvesting resulting in reduced bearing capacity.</li> <li>• Brash movement to strengthen mats delayed until material is needle free. Ratio of combining mats limited to 2:1 to reduce the risk of creating wide bands of infertile and more acidic soil.</li> <li>• Stumps retained within brash mats and buffer areas.</li> <li>• Stump lifting and extraction confined to periods when the soil is relatively dry, which will most probably be between May and September, inclusive. Sites require careful monitoring during periods of high or prolonged precipitation.</li> </ul>

	<ul style="list-style-type: none"> <li>• Remedial treatments such as the application of limestone and/or wood ash could permit harvesting of both stumps and brash, but a site assessment must first confirm the suitability, cost effectiveness and sustainability of such treatments.</li> </ul>
<b>High</b>	<ul style="list-style-type: none"> <li>• Harvesting of stumps is not commensurate with sustainable forest management and should generally be avoided. One exception is where there is an operational imperative such as for disease control.</li> <li>• Stumps retained within 5 m buffers around areas of high risk soils.</li> <li>• Stump harvesting could be considered on some soil types (where high risk is confined to soil fertility and acidification factors) if nutrients and/or base cations are replaced via remedial treatments such as the application of limestone or wood ash, subject to an assessment of the suitability, cost effectiveness and sustainability of such treatments. Where stump harvesting is practised on high risk soils, the good practice measures listed for low and medium risk soils also apply.</li> </ul>

## References

- Forestry Commission, 2011a. Forests and Water; Forests and Soil; Forests and Climate Change; Forests and Historic Environment. UK Forestry Standard Guidelines. Forestry Commission, Edinburgh, UK.
- Forestry Commission, 2011b. The UK Forestry Standard. Forestry Commission, Edinburgh, UK, 108pp.
- Hall, R. L. 2003. Short rotation coppice for energy production. Hydrological guidelines. Department of Trade and Industry, (*B/CR/00783/GUIDELINES/SRC URN 03/883*), 21pp.
- Moffat, A., Nisbet, T. & Nicoll, B. 2011. Environmental effects of stump and root harvesting. Forestry Commission Research Note 9, Forestry Commission, Edinburgh (12pp).
- Nisbet, T.R. 2009. Guidance on site selection for brash removal. Forest Research, (15 pp).
- Nisbet, T.R., Nicoll, B. & Perks, M. 2009. Stump harvesting: Interim Guidance on site selection and best practice. Forest Research, UK (18 pp).
- Nisbet, T.R., Thomas, H. & Shah, N. 2011a. Short Rotation Forestry and Water in McKay, H. (ed.) (2011) Short Rotation Forestry: review of growth and environmental impacts. Forest Research Monograph, 2, Forest Research, Surrey, pp13-34.
- Nisbet, T., Silgram, M., Shah, N., Morrow, K., & Broadmeadow, S. 2011b. Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Forest Research Monograph, 4, Forest Research, Surrey, 156pp.
- Tubby, I. & Armstrong, A. 2002. Establishment and Management of Short Rotation Coppice. FC Practice Note No. 7, Forestry Commission, Edinburgh, (12pp).

## Forest biomass for energy and sustainable management of forest soils – what do we need to know?

Gustaf Egnell

Swedish University of Agricultural Sciences, Department of Forest Ecology and Management and the Future Forests Project, Umeå, Sweden ([Gustaf.Egnell@slu.se](mailto:Gustaf.Egnell@slu.se))

The set targets for renewable energy use in 2020 within the European Union will inevitably put more pressure on forest biomass within the union. In countries such as Sweden and Finland this has already resulted in an increased harvest of nutrient-rich forest biomass that used to be left in the forest during silvicultural operations oriented towards round-wood production for the forest industry. This moderate increase in biomass harvest has resulted in a large increase in nutrients removed from a site (Fig. 1).

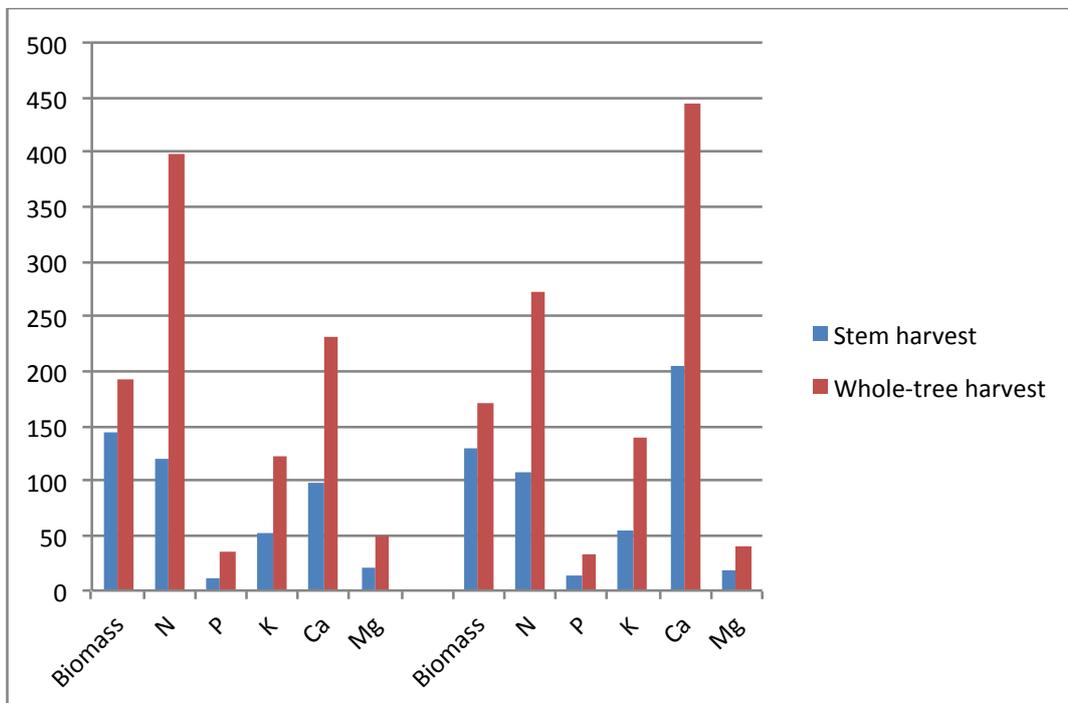


Figure 1. Estimated biomass harvest (Mg ha<sup>-1</sup>) and nutrient harvest (kg ha<sup>-1</sup>) at two different harvest intensities in final cut of two Norway spruce stands in Sweden. Stem harvest: Only stemwood harvested; Whole-tree harvest: All above stump biomass harvested. Left: Southern Sweden, standing volume 325 m<sup>3</sup> ha<sup>-1</sup>; Right: Northern Sweden, standing volume 290 m<sup>3</sup> ha<sup>-1</sup>.

This has raised concerns about the sustainability of these practices when it comes to long-term site- and stand-productivity as well as soil acidity and quality of run-off water. Modeling approaches have suggested that in many cases it will not be sustainable to harvest nutrient-rich forest biomass such as logging residues, small diameter trees, and stumps with roots. One simple and easily understandable model approach is the mass balance approach, a static model in which the loss of nutrients through harvest and leaching is balanced by input of nutrients through deposition and weathering (Fig. 2).

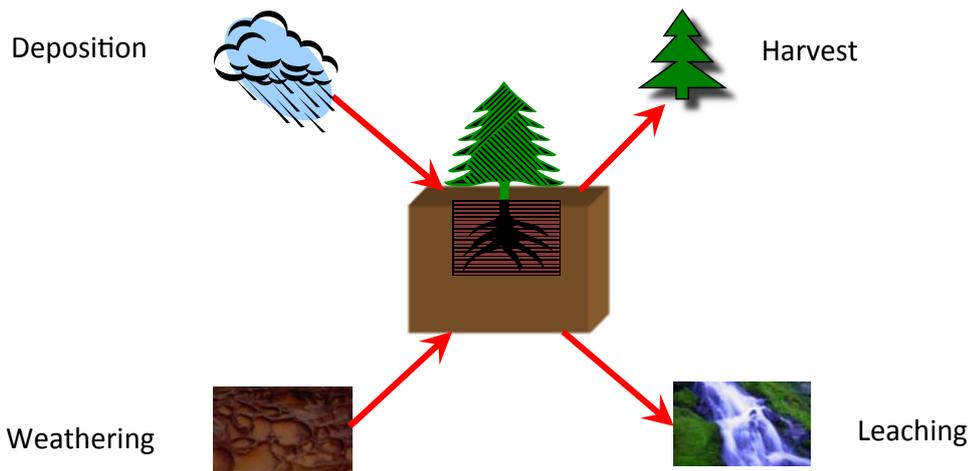


Figure 2. Principal figure showing the input and output components of a mass balance for nutrients in forestry, in which the balance is calculated as:  $\Delta = \text{Harvest} + \text{Leaching} - \text{Deposition} - \text{Weathering}$ .

Such an approach has suggested that whole-tree harvest is not sustainable over time e.g. in Sweden (Akselsson, et al., 2007) and in the Eastern US (Federer, et al., 1989). However, the reliability of these predictions depends on the quality of input and output data. Here we critically review weathering input and harvest output.

Klaminder et al. (2011) compared published weathering estimates for K and Ca for a forested catchment in Northern Sweden where a number of different methods have been applied in a number of studies. Predicted average weathering rates were  $0.67 \pm 0.71 \text{ g m}^{-2} \text{ year}^{-1}$  (mean  $\pm$  st.dev.) and  $0.39 \pm 0.38 \text{ g m}^{-2} \text{ year}^{-1}$ , for Ca and K respectively. They concluded that the precision in weathering estimates is too low to be used in nutrient budgets used to forecast the sustainability of different forest harvest intensities.

In a mass-balance calculation, nutrient losses with the harvested biomass are typically based on measured or published data on nutrient contents in different tree compartments. (Bhatti, et al. 1998) wrote: "*Nutrient demand calculations are based on nutrient concentrations in wood, bark, branches, and foliage*". One crucial question is whether the nutrient contents in different tree compartments reflect the physiological demand of the tree – i.e. whether decreased concentrations result in reduced forest production. Knecht and Göransson (2004) used experiences from nutrition optimization experiments in which the ratio between N and other nutrients in the foliage was based on the nutrient concentration needed to obtain maximum growth when all nutrients are at their limit simultaneously (no free access). These ratios (N:P:K:Mg:Ca = 100:8:30:4:2) were compared with published data on nutrient concentration in the foliage of herbaceous, deciduous, and coniferous plants grown on unfertilized soils throughout the world. Most data fell on the optimum line for P, above the optimum line for K and far above the optimum line for Mg and particularly Ca. Figure 3 shows similar foliage data from needles collected in Scots pine and Norway spruce forests in Sweden.

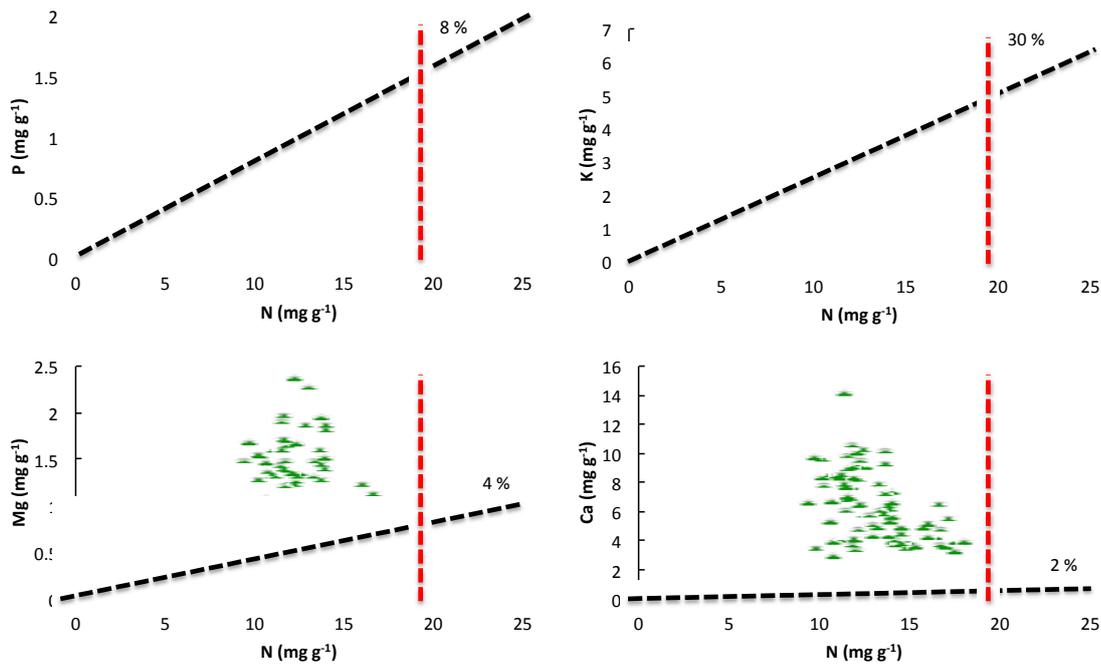


Figure 3. Nutrient concentrations relative to N in second year needles (c+1) collected in 37 Scots pine and 48 Norway spruce stands in Sweden. Dashed black line denotes optimum levels for growth relative to N contents and dashed red line denotes optimum N levels for growth.

This indicates that elements such as K, Mg, and particularly Ca are taken up in excess by plants. Concentrations of these elements are therefore not useful in a mass-balance with the aim of forecasting long-term site productivity. The strong excess uptake of Ca is most probably the reason why Ca appears as the limiting and critical nutrient in many studies (Federer, et al., 1989, Olsson, et al., 1993, Huntington, 2005). Even though any nutrient can limit growth at a certain site, N and P remain the two most important nutrients for global tracking when effects of more intense harvest practices and long-term site productivity are discussed. Furthermore, estimates of leaching and deposition over time add more uncertainty to the mass balance.

## Conclusions

For more reliable predictions of the sustainability of current forest harvest practices in Sweden (and elsewhere), including nutrient rich biomass for energy, it is important to consider:

- Uncertainties in weathering estimates
- Nutrient concentrations in the tree crop vs. physiological demand of the tree crop
- With forest production in scope – focus on N and P, rather than on other nutrients
- That the concept of “nutrient mass balance” might lead to incorrect conclusions
- Uncertainties in estimates of deposition and leaching over time

## Acknowledgements

This research was funded through the multi-disciplinary research program Future Forests and the Swedish Energy Agency. The author also acknowledges funding from the OECD that allowed participation in the

Eurosoil 2012 workshop on forest bioenergy, and the organizers (Heljä-Sisko Helmisaari and Elena Vanguelova) and OECD administrator (Janet Schofield) who made this workshop possible.

## References

- Akselsson, C., Westling, O., Sverdrup, H. & Gundersen, P. 2007. Nutrient and carbon budgets in forest soils as decision support in sustainable forest management. *Forest Ecology and Management* 238: 325-338.
- Bhatti, J.S., Foster, N.W., Oja, T., Moayeri, M.H. & Arp, P.A. 1998. Modeling potentially sustainable biomass productivity in jack pine forest stands. *Canadian Journal of Soil Science* 78: 105-113.
- Federer, C.A., Hornbeck, J.W., Tritton, L.M., Martin, C.W., Pierce, R.S. & Smith, C.T. 1989. Long-term depletion of calcium and other nutrients in Eastern-United-States forests. *Environmental Management* 13: 593-601.
- Huntington, T.G. 2005. Assessment of calcium status in Maine forests: review and future projection. *Canadian Journal of Forest Research/Revue Canadienne de Recherche Forestiere* 35: 1109-1121.
- Klaminder, J., Lucas, R.W., Futter, M.N., Bishop, K.H., Kohler, S.J., Egnell, G. & Laudon, H. 2011. Silicate mineral weathering rate estimates: are they precise enough to be useful when predicting the recovery of nutrient pools after harvesting? *Forest Ecology and Management* 261: 1-9.
- Knecht, M.S. & Göransson, A. 2004. Terrestrial plants require nutrients in similar proportions. *Tree Physiology* 24: 447-460.
- Olsson, M., Rosén, K. & Melkerud, P.A. 1993. Regional modelling of base cation losses from Swedish forest soils due to whole-tree harvesting. *Applied Geochemistry Supplement No. 2*: 189-194.

## Impacts of increased biomass utilization on soil sustainability in Austria

Klaus Katzensteiner<sup>1</sup>, Michael Englisch<sup>2</sup> and Kasimir P. Nemestothy<sup>3</sup>

<sup>1</sup>Institute of Forest Ecology, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences (BOKU) Vienna, Austria ([klaus.katzensteiner@boku.ac.at](mailto:klaus.katzensteiner@boku.ac.at)), <sup>2</sup>Institute of Forest Ecology, Federal Research and Training Centre for Forests, Natural Hazards and Landscape, Vienna, Austria, <sup>3</sup>Department of Forest, Wood and Energy economics, Austrian Chamber of Agriculture, Vienna, Austria.

### Abstract

The article describes frame conditions for the energetic utilization of forest-based biomass in Austria as well as calculation schemes and concepts for sustainable production taking nutritional sustainability into account. Concerns about other potential negative impacts of forest operations on soil, such as soil compaction and depletion of organic matter, are raised.

### Introduction

According to the Directive 2009/28/EC and the National Renewable Energy Action Plan 2010 (CEC 2010), Austria should reach a share of 34 % of renewable energy in gross final energy consumption by 2020. There are expectations of policy makers and society to meet a high proportion of the renewable energy demand from forest biomass, as there is a considerable potential in this sector which is already utilized to a certain extent.

However, there are concerns about nutritional sustainability of intensified biomass utilization, in particular in the case of whole tree harvesting, and parallels to negative effects of historic land use such as litter raking and lopping of trees on soil status and productivity of forests are frequently drawn, referring to authors such as Krapfenbauer, 1983 or Kreutzer, 1979. There is a vast literature on the effects of whole tree harvesting (WTH) on productivity (e.g. Nord-Larsen 2002, Egnell and Valinger 2003, Helmisaari et al. 2011) and Austrian experiments even show increment losses after WTH in early thinnings of more than 20 % compared to stem only harvesting (Sterba et al. 2003).

In the following sections specific Austrian potentials and restrictions for forest biomass production and utilization of bioenergy are outlined, concepts for the sustainability estimation of different harvesting intensities are presented, and concerns about negative effects of forest operations on soil properties are raised.

### Forest biomass production and bioenergy utilization in Austria

Austria has an area of 8.4 million ha, 47.6 % (4 M ha) forest cover and a total growing stock of 1135 M cubic metres solid timber over bark in production forests (BFW, 2012). Both forest area and growing stock have shown a steady increase during recent decades.

In 2010 the gross inland energy consumption of Austria was 1458 PJ, the gross final energy consumption was 1119 PJ (Statistik Austria, 2010), 30.8 % of the latter coming already from renewable sources. According to Nemestothy (2012), 45% of the 411 PJ gross inland consumption of renewable energy in 2010

was met by wood-based biomass, followed by hydropower (34 %) and other renewable sources (16 % including waste). The supply of 24.3 M solid cubic meter equivalent (cme) of primarily wood-based biomass for energetic consumption is complex (Figure 1); the main sources of wood in the Austrian wood market are the Austrian forestry production and roundwood imports of the wood-working industry (approx. 10 M cme.). Additionally, other wood sources (recycled wood, etc.) supply remarkable amounts of wood for energy consumption (6 M cme.). The net annual increment of the Austrian forest reaches 30.3 M cme and exceeds significantly the total Austrian forest production (23.7 M cme in 2010).

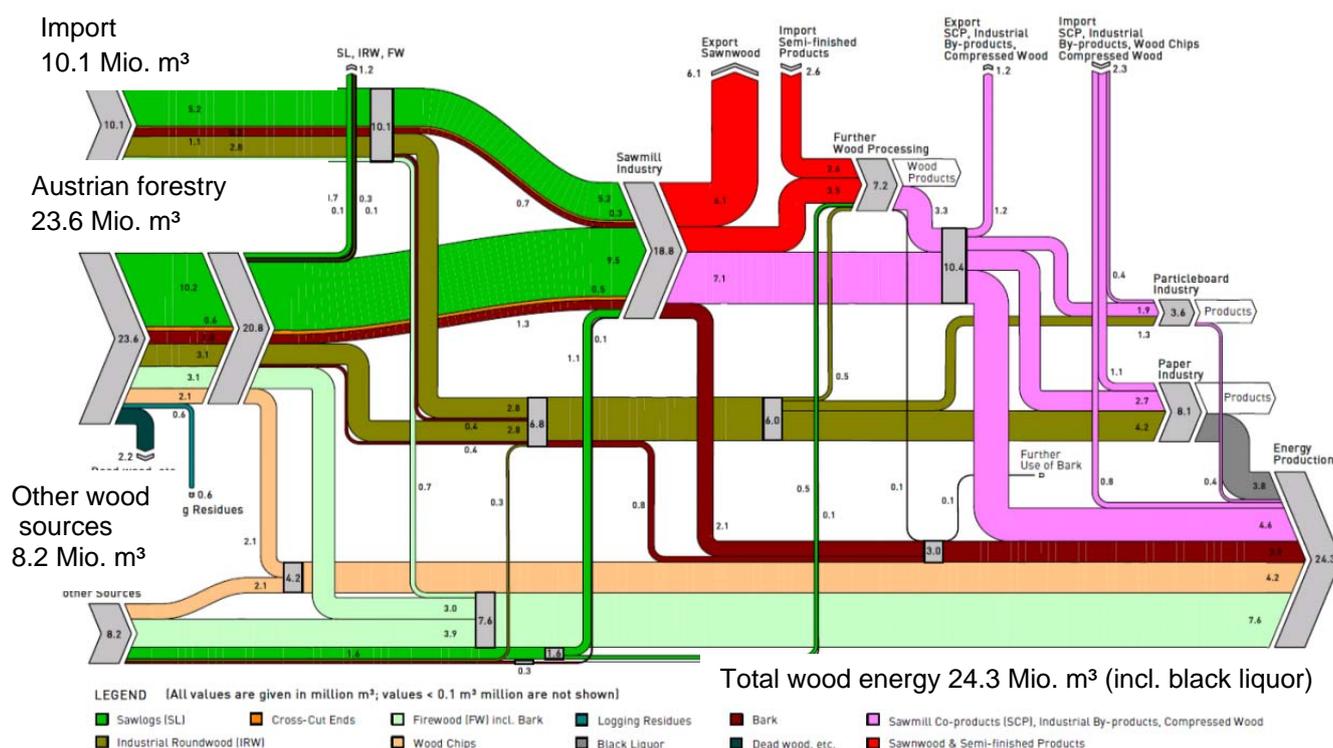


Figure 1. Flows of wood and wood products in Austria in 2010 (modified after Nemestothy 2012).

By-products of the wood industry are by far the most important source (2.9 M cme of bark and 5.8 M cme of trimmings, sawdust, woodshavings etc.). Black liquor from the paper industry provides another 3.8 M cme. Out of 7.6 M cme of solid firewood only 3.0 M cme are evident in the annual forest production statistics. Approximately half of the 4.2 M cme (wood chips, including wood harvest residues) used in automatic biomass furnaces is provided by forestry. Nemestothy (2012) estimated an increase in the demand for woody biomass of 3 M cme from the year 2010 until 2020 mainly in the segments chips and pellets. A high and spatially well distributed number of district heating plants (e.g. 1800 devices with an average capacity of 1 MW per plant), object heating plants and combined heating and saw electric power plants allow for regional supply with low transport distances.

The above statistics show that bioenergy utilization must be optimized as part of the overall wood supply and processing chain.

## Estimates of the sustainable forest biomass utilization potential for Austria

The Austrian Forest Inventory (BFW 2012) provides the basic data for the prognosis of the sustainable biomass utilization potential including marginal dimensions (Schadauer 2009). In order to estimate the theoretical potential, different utilization scenarios were calculated by Ledermann and Neumann (2009). In addition to legal restrictions (protective forests, protected areas) and economic restrictions (costs of harvesting), nutritional sustainability has been taken into account in order to estimate the available biomass potential (Englisch and Reiter, 2009). Mannsberger (2009) estimated that the theoretical potential without restrictions lies in a range between 32.7 and 38.4 M cme (standing, solid over bark); the available potential considering restrictions is 24 to 31 M cme (solid over bark, including harvest losses).

The estimation of nutritional sustainability by Englisch and Reiter (2009) is based on available information from different data sources using a nutrient balance approach. Actual soil nutrient stocks have been calculated using the dataset of the Austrian Forest Soil Inventories of 1988/89 and 2007/09 (BFW, 2012) and extrapolated to the production forest plots of the Austrian Forest Inventory using transfer functions. Atmospheric deposition was up-scaled by combining input data of 20 monitoring sites of the ICP Forest Level II plots (Fürst and Kristöfel 2012) and precipitation data available in high resolution. Long term supply by weathering was calculated after Sverdrup (1990) using the above-mentioned soil information, a coarse scale hydrogeological map (1:500 000; Schubert 2003), and interpolated soil temperatures as input. Leaching was estimated using literature values. For nutrient extraction estimates, literature values and data from the Austrian Bio-Indicator grid (Fürst 2009) for nutrient concentrations of tree compartments were used. They were combined with utilization calculations for the different tree compartments in WTH-scenarios (extraction of timber with bark minus harvest losses and extraction of 70 % of branches, twigs and needles both in thinning and final harvest operations) over a rotation period of 150 years carried out with the growth simulator PROGNAUS (Ledermann 2006). Potential extractions were compared to short to medium term available stocks of Ca, Mg and K (exchangeable soil stocks + atmospheric input + weathering input - leaching) and to the long-term available N- and P-stocks. A sustainability classification was based on the ratio of nutrient amounts extracted via whole tree harvesting to these soil nutrient stocks (Table 1).

Table 1. Sustainability of whole tree harvesting based on the percentage of nutrients extracted via whole tree harvesting in relation to the available soil nutrient pool (Englisch and Reiter 2009).

	N	P	Ca	Mg	K
Not sustainable	> 60	> 40	> 100	> 100	> 100
Sustainable with restrictions	30-60	25-40	50-100	50-100	50-100
Sustainable	< 30	< 25	< 50	< 50	< 50

If no nutrient fell into one of the classes 'not sustainable' or 'sustainable with restrictions', WTH was considered to be sustainable. If at least one nutrient was in the class 'sustainable with restrictions', WTH

was seen as problematic. If even one nutrient met the class not sustainable, WTH should not be applied. According to this scheme potassium is the most limiting nutrient at 23 % of the sites (not sustainable), followed by phosphorus (38 % of the sites in the class sustainable with restrictions). According to this evaluation, WTH is seen as sustainable at 49 % of the Austrian Forest Inventory plots, at 27 % it is seen as problematic, and at 24 % no WTH would be allowed.

### **Forest regulations and guidelines for forest biomass utilization.**

Besides the Austrian Forest Act § 16.1, which prohibits actions damaging the productive capacity of forest soils and sets a minimum rotation time for high forests, and a 'living forest standard', there are currently no binding regulations or guidelines for extraction intensity in practical forest operations. Though rarely applied in practical forestry, guidelines for forest fertilization and for the application of biomass ashes have been worked out by the Austrian Advisory Council for Soil Protection and Soil fertility (Baumgarten 2012). Nutritional sustainability estimates for the support of forest planning would be possible applying the concepts of Englisch and Reiter (2009) if sufficient site information would be available at the scale of forest management units (e.g. Katzensteiner 2011). However, for Austria there exists no institutionalized forest site classification system. Except for the Austrian Federal Forests and a few private enterprises no forest site maps with proper resolution and background data are available. A possible solution to overcome this deficit in the near future would be new mapping methods combining site surveys and conceptual models based on high resolution terrain models and geological maps as currently applied in the province of Tyrol.

### **Potential threats for forest soil sustainability in Austria**

Due to steep terrain, timber is forwarded with cable cranes and processed on the forest road at approximately 20 % of the Austrian forests. Whole tree harvesting is therefore applied frequently on poor sites independently of the later utilization of marginal dimensions. A further hindrance for the application of practical guidelines is the ownership structure of the Austrian forestry. A high share of the increment (64 %) takes place in forests of owners with property sizes of less than 200 ha, frequently even of less than 1 ha. European and national programs to enhance renewable energy utilization are relevant drivers for additional wood demand and cause an increased utilization of marginal dimensions for the production of chips without taking site properties into account.

A severe recent threat is soil compaction due to a frequently uncontrolled and unrestricted use of heavy machinery in forest operations in all forest property types.

Due to complex mountainous terrain conditions in approximately 70 % of Austrian forests, stump harvest would cause severe erosion problems and is not seen as a management option.

A fact that is currently rarely considered in practical guidelines and models is soil organic matter management. In some eco-regions of Austria, soils with high organic matter content or thick forest floor layers probably rely on a certain input of woody debris to retain their function. There are however still research gaps on this topic.

## References

- Baumgarten A. 2012. Fachbeirat für Bodenfruchtbarkeit und Bodenschutz. Download 2012-08-15: <http://www.ages.at/ages/landwirtschaftliche-sachgebiete/boden/fachbeirat-f-bodenfruchtbarkeit/>.
- BFW, 2012. The Austrian Forest Inventory 2007/09; Download 2012-08-15, <http://bfw.ac.at/rz/wi.home>.
- CEC, 2010. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC Download 2012-08-15: [http://ec.europa.eu/energy/renewables/action\\_plan\\_en.htm](http://ec.europa.eu/energy/renewables/action_plan_en.htm).
- Egnell, G. und Valinger, E. 2003. Survival, growth, and growth allocation of planted Scots pine trees after different levels of biomass removal in clear felling. *Forest Ecology and Management* 177: 65-74.
- Englisch, M. und Reiter, R. 2009. Standortliche Nährstoff-Nachhaltigkeit der Biomassenutzung. BFW-Praxisinformation 18-2009: 13-15.
- Fürst, A. 2009. Austrian Bioindicator Grid. Download 2012-08-15: <http://bfw.ac.at/rz/bfwcms.web?dok=2824>.
- Fürst, A. and Kristöfel, F. (2012): Level II online, download 2012-08-15: <http://bfw.ac.at/db/bfwcms.web?dok=9269>.
- Helmisaari, H.-S., K. H. Hanssen, et al., 2011. Logging residue removal after thinning in Nordic boreal forests: Long-term impact on tree growth. *Forest Ecology and Management* 261(11): 1919-1927.
- Katzensteiner, K. 2011. Nährstoffbilanzmodelle und forstliche Standortskarten als Basis für eine nachhaltige Biomasseproduktion (Combining nutrient balance models and site maps as a basis for sustaining forest biomass production). In: Gerzabek M. & Glöckl J., Präsentation von geförderten Projekten der Stiftung '120 Jahre Universität für Bodenkultur'; Elektronische Publikation zur Vortragsveranstaltung der Stiftung am 25.10.2011, download 2012-08-15: [http://www.boku.ac.at/fileadmin/\\_H13/Stiftungen\\_und\\_Preise/Elektronische\\_Publikation\\_120\\_Jahre\\_BOKU.pdf](http://www.boku.ac.at/fileadmin/_H13/Stiftungen_und_Preise/Elektronische_Publikation_120_Jahre_BOKU.pdf).
- Krapfenbauer A. 1983. Von der Streunutzung zur Ganzbaumnutzung. *Cbl. Ges. Forstwesen* 100: 143-174.
- Kreutzer K. 1979. Ökologische Fragen zur Vollbaumernte. *Forstw. Cbl.* 98: 298-308.
- Ledermann, T. 2006. Description of PrognAus for Windows 2.2. *Sustainable Forest Management* 71-78.
- Mannsberger G. 2009. HOBI-Studie: Zusammenschau und Schlußfolgerungen. BFW Praxisinformation 18: 20-21.
- Nemestothy K.P. 2012. Die Bedeutung von Holz als erneuerbarer Energieträger. BFW Praxisinformation 28: 5-8.
- Ledermann T. and Neumann M. 2009. Prognose des Waldwachstums und des Nutzungspotentials. BFW Praxisinformation 18: 5-7.
- Nord-Larsen T. 2002. Stand and site productivity response following whole tree harvesting in early thinnings of Norway spruce (*Picea abies* (L.) Karst.). *Biomass and Bioenergy* 23-1: 1-12.
- Schadauer K. 2009. HOBI – ein umfassender Ansatz zum zukünftigen Holz- und Biomasseaufkommen. BFW Praxisinformation 18: 3-4.
- Schubert G. (ed.) 2003. Hydrogeologische Karte der Republik Österreich im Maßstab 1:500.000. Geologische Bundesanstalt Wien.
- Statistik Austria, 2010. Energiebilanzen. Download 2012-08-15 [http://www.statistik.at/web\\_de/statistiken/energie\\_und\\_umwelt/energie/energiebilanzen/index.html](http://www.statistik.at/web_de/statistiken/energie_und_umwelt/energie/energiebilanzen/index.html).
- Sterba H., Brunner H., Gugganig H., Hauser B. 2003. Stammzahlreduktion ja, aber nicht als Ganzbaumnutzung. *Österr. Forstzeitung* 10/03, 18-19.
- Sverdrup H. 1990. The Kinetics of Base Cation Release due to Chemical Weathering. Lund University Press, Lund, Sweden, 246 p.

## Forest bioenergy and soil sustainability in the UK

Elena Vanguelova

Centre for Forestry and Climate Change, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, UK  
([elena.vanguelova@forestry.gsi.gov.uk](mailto:elena.vanguelova@forestry.gsi.gov.uk))

The ongoing drive to develop renewable energy is generating increasing interest in energy forestry. Woody biomass from both forest residues and short rotation forestry has the potential to make a significant contribution to climate change mitigation through fossil fuel substitution. However, there is a danger of practice running ahead of understanding of the environmental impacts. Consequently, there is an urgent requirement for scientifically underpinned guidance on best management practices to ensure soil protection, including sustaining forestry's key role in carbon capture.

This paper addresses the main soil sustainability issues emerging from an expansion of energy forestry in Great Britain. It focuses on evaluating the impacts on ground damage, soil fertility, acidification and carbon stocks. Results from relevant long-term experiments are reviewed, new research studies described and recent developments in risk-based guidance explained.

### Introduction

UK and EU energy policies are driving the development of renewable energy sources as a way of cutting greenhouse gas emissions. Woody biomass is one of the more reliable renewable fuels and has the potential to make a significant contribution to meeting renewable energy targets (Forestry Commission 2007). There are a number of different sources of woody biomass, including existing woodland, woodland creation, arboricultural arisings, sawmill co-products and recovered wood. Two sources that have attracted increasing attention in recent years are the harvesting of woody residues, in the form of branches, tree tops and stumps, from existing conifer plantations and the creation of Short Rotation Coppice (SRC) and Short Rotation Forests (SRF) dedicated to growing biomass.

The harvesting of woody residues in the form of the whole tree or as separate components has the potential benefit of providing another commercial product in addition to conventional timber. Other possible advantages include easier and cheaper ground preparation, planting and maintenance of restocked crops on the cleared ground. By contrast, the establishment of SRC or SRF involves a change in land use. The conversion of farmland or brownfield land offers the potential of growing a very high-yielding tree crop with a much shorter payback time compared to traditional forestry. There may also be opportunities for using these systems to reduce diffuse pollution, to recycle organic materials such as sewage sludge or to treat waste water.

However, the economic and carbon mitigation gains from exploiting these sources of woody biomass could be offset by their impacts on soil. In particular, the removal of woody residues poses a number of hazards to the forest environment that could threaten sustainable forest management (LTS International, 2006). There are three principal threats:

1. Machine trafficking causing physical soil damage such as compaction, rutting and erosion, leading to increased turbidity and siltation of local watercourses.

2. Removal of essential nutrients (nitrogen, phosphorus and potassium) and carbon in residues, leading to lower soil fertility, potential loss of tree growth in subsequent rotations, and reduced soil carbon storage.
3. Removal of base cations (calcium, magnesium, sodium and potassium) reducing soil buffering capacity and leading to increased soil and stream water acidification.

SRC and SRF are thought to pose less of a threat to soil, especially in relation to the previous land use. Impacts are limited by the better conditions that characterise planting sites, such as gentler slopes and higher quality soils. The main risks are considered to be:

1. Machine trafficking causing physical soil damage such as compaction and rutting.
2. Removal of essential nutrients in biomass, leading to lower soil fertility and potential loss of tree growth in later rotations.
3. Increased crop water use resulting in reduced groundwater recharge and ecological flows.

The following assessment describes our present state of knowledge on the impacts of the harvesting of woody residues and establishment of SRC and SRF systems on ground damage, soil fertility, acidification and carbon stocks.

### **Harvesting of woody residues**

#### *Ground damage*

Much is known about the risk of ground damage since the same site types and machinery are generally involved as in conventional timber harvesting. The risk is mainly enhanced by the additional trafficking involved in the collection and extraction of the residues, accentuated by the extended period of operations. The latter results in reduced ground bearing capacity due to gradual deterioration in the condition of protective brush mats. The greatest risk is posed by the extraction of tree stumps because of the larger quantities of biomass and the high level of soil disturbance caused by stump lifting. Steep ground is most vulnerable to soil slumping/slippage and surface runoff delivering eroded sediment to watercourses. The propensity for damage depends on site sensitivity and on many sites can be effectively controlled by good forest planning and management.

#### *Soil infertility*

Past experience of site nutrition and fertiliser practice in upland silviculture provides a reasonably good, qualitative, understanding of the threat posed to site fertility. Infertile sites reliant on fertiliser applications to achieve tree establishment are most at risk from the additional removal of nutrients in the extracted residues. The removal of fresh branches and tree tops presents the greatest risk since about half to two thirds of the nutrients present reside within the green needles. Delaying the extraction of residues for a period of 3-9 months after felling can help by promoting needle fall, although this will be offset by the increased risk of ground damage due to the reduced bearing capacity of the aged protective brush mats. Advances in nutrient budget modelling will help to underpin practical understanding of site suitability for residue extraction, supported by improved knowledge of soil and tree nutrient stocks for different forest

ecosystems gained from EU/pan-European forest and soil monitoring networks (e.g. ICP Forest Monitoring - Level I, Level II and BioSoil projects, Vanguelova et al. 2009, 2010, 2012).

#### *Soil acidification*

Less information is available to assess the risk of soil acidification from the greater removal of base cations in woody biomass. Conceptually, the risk is thought to be directly related to the impact on site fertility and therefore the same qualitative understanding of site suitability applies. However, this may not be the case and thus there is a need to refine the assessment through base cation budgets and acidification models. Knowledge is improving on the quantities of base cations removed in different tree fractions for the main productive species from integrated forest monitoring networks and studies of the impacts of whole-tree versus conventional harvesting. Similarly, there is an improved understanding of the base cation stocks in the main soil types from Biosoil and related soil monitoring networks. Less information is available on the supply and loss of base cations from soils due to weathering and leaching, respectively, and how these processes are affected by forest management and climate change.

#### *Soil carbon*

The extraction of woody residues presents two main threats to soil carbon. Firstly, removal of the carbon within the residues will reduce inputs to the soil, leading to a possible reduction in soil carbon stocks. The risk is thought to be greatest for tree stumps and large branches because a larger component of this material would be slow to degrade. It may be less of an issue for finer residues comprising needles, branches and tree tops due to their shorter half-life, with most of the carbon being quickly returned to the atmosphere as CO<sub>2</sub> by soil decomposition. Consequently, there is likely to be a much larger carbon gain from harvesting finer woody residues for fossil fuel substitution, assuming that energy use in extracting, transporting and processing it can be constrained by good practice.

A much greater threat is believed to be posed by the soil disturbance associated with residue extraction, especially in the case of stump removal. More carbon is generally stored in soil in the form of litter, soil organic matter and biomass than in the aboveground parts of forests. Stump extraction involves extensive soil disturbance in terms of relative area and depth, with the result that decomposition rates are likely to increase, thereby increasing CO<sub>2</sub> release from the soil. The Biosoil project has greatly improved our knowledge of carbon stocks in the main soil types, and information is currently being gathered on their vulnerability to disturbance by assessing soil C pools and their turnover times.

### **Short rotation coppices and short rotation forestry**

#### *Ground damage*

The main threat of ground damage from SRC and SRF systems would be from the eventual harvesting of the crops. Heavy, poorly drained agricultural soils would be most at risk, especially if harvesting was constrained to winter periods in order to avoid impacts on breeding birds or disturbance to other wildlife. Good practice measures would need to be developed in order to protect soils from compaction and rutting.

#### *Soil infertility*

Ex-agricultural soils are likely to be sufficiently nutrient-rich to sustain the nutrient needs of SRC and SRF systems for at least one or two harvesting cycles. In time, however, soils will become impoverished and nutrient deficiencies will arise and constrain productivity unless countered by fertiliser treatments. Nitrogen demands are unlikely to exceed those of arable crops due to the higher carbon to nitrogen ratio of woody biomass. There is an opportunity to meet nutrient requirements through applications of recycled

organic materials such as sewage sludge, providing the added benefit of aiding waste treatment. Alternatively, by targeting planting to riparian buffer areas or mid-slope locations, crop needs could be sustained by the supply of nutrients within waters draining from adjacent agricultural land. This would also help to improve water quality by reducing diffuse nutrient loads to watercourses.

#### *Soil acidification*

The establishment of SRC and SRF will inevitably lead to soil acidification, primarily due to the cessation of liming treatments previously required to maintain suitable conditions for agricultural crops. Soil pH will return to the naturally acidic levels that characterise organic rich, woodland topsoils. Conditions are unlikely to become strongly acidic unless planting occurs on more acid-sensitive sandy soils or crops are subject to repeated inorganic fertiliser applications or high acid deposition.

#### *Soil carbon*

Land use change from arable or brownfield land to SRC or SRF can be expected to increase soil carbon stocks. Leaf litter inputs and tree rooting would enrich the very low soil carbon levels that characterise these land covers, improving soil quality and biodiversity. The impact on the higher carbon stocks of grassland soils is less certain although any reductions are likely to be more than outweighed by the carbon gain in woody biomass and the contribution to reductions in CO<sub>2</sub> emission arising from fossil fuel substitution.

### **Guidance**

A range of guidance has been developed by the Forestry Commission and others to help address the threats posed to soil and water by the harvesting of woody residues or planting of SRC. The likelihood and magnitude of damage depends on site sensitivity and on many sites can be effectively controlled by good forest planning and management. On some sites and locations the risks are considered to be too high to support such practices and it is recommended that these be avoided. Recent guidance published by Forest Research adopts a risk-based approach to identifying suitable sites for brash removal and stump harvesting (Forest Research 2009a,b).

### **On-going research**

The available guidance is largely based on expert judgement of the scientific issues arising from the practical experience of managing forest soils. Uncertainties remain about the long-term sustainability of energy forestry on certain soil types and locations, especially in terms of carbon loss, but also concerning soil fertility, acidification and water use. There is a particular need for data on soil carbon to support full life-cycle analyses and to compare energy forestry with other bioenergy systems. Work is required to quantify impacts and clarify the susceptibility of different soils, as well as to evaluate opportunities for using energy forestry in a more targeted way to benefit diffuse pollution and flood management.

Various studies are planned or under way to address these issues, especially in relation to the harvesting of woody residues and the establishment of SRF systems. Information needs on most of the impacts of SRF are met by a series of earlier reviews and reports (LTS 2006, Vanguelova and Pitman 2011). Environmental impacts of stump harvesting have been reviewed by Pitman (2008) and Walmsley and Godbold (2009). Studies on the impact of harvesting brash are on-going at Kielder in North England (Vanguelova et al., 2010), and Beddgelert in North Wales (Walmsley et al. 2009), while one on evaluating the environmental impacts of stump harvesting is being conducted in mid Wales, with other sites being sought in South

Scotland. A number of extensive studies on stump harvesting have also recently commenced in Finland and Sweden. Work on SRF involves baseline soil assessments at five recently acquired farms distributed across Scotland and six in England that are being planted with a range of potential tree species. Two of the sites in Scotland and one in England will be the subject of studies to assess the impact of SRF on water quality and/or quantity and on all sites soil baselines have been established. The results from these studies will be fundamental to the testing and further development of existing guidance, improvement of carbon accounting models and in demonstrating whether the guidance is fit for the purpose.

## References

- Forestry Commission, 2007. A woodfuel strategy for England. Forestry Commission England, Bristol.
- Forest Research, 2009a. Guidance on site selection for brash removal. Forest Research, Farnham, UK.  
[http://www.forestresearch.gov.uk/pdf/Brash\\_residue\\_protocol.pdf/\\$FILE/Brash\\_residue\\_protocol.pdf](http://www.forestresearch.gov.uk/pdf/Brash_residue_protocol.pdf/$FILE/Brash_residue_protocol.pdf)
- Forest Research, 2009b. Stump harvesting: Interim guidance on site selection and good practice. Forest Research, Farnham, UK.  
[http://www.forestresearch.gov.uk/pdf/FC\\_stump\\_harvesting\\_guidance\\_April09.pdf](http://www.forestresearch.gov.uk/pdf/FC_stump_harvesting_guidance_April09.pdf)
- LTS International, 2006. *A Review of the potential impacts of Short Rotation Forestry*, LTS International Ltd, Edinburgh.
- Pitman, J.I. 2008. A review of the environmental impacts of tree stump harvesting on UK coniferous forests. Forest Research Report, Forest Research Contract CR2007/08/164, May, 2008.
- Vanguelova, E.I., Pitman, R., Luro, J. & Helmisaari H-S. 2010. Long term effects of whole tree harvesting on soil nutrient sustainability in the UK. *Biogeochemistry* 101: 43-59.
- Vanguelova, E.I., Benham, S., Pitman, R., Moffat, A., Broadmeadow, M., Nisbet, T., Durrant, D., Barsoum, N., Wilkinson, M., Bocheureau, F., Broadmeadow, S., Hutchings, T., Crow, P., Durrant-Huston, T. & Taylor, P. 2010. Chemical fluxes in time through forest ecosystems in the UK – soil response to pollution recovery. *Environmental Pollution* 158 (5): 1857-1869.
- Vanguelova E & Pitman R. 2011. Impacts of Short Rotation Forestry on Soil Sustainability. In McKay, H. (ed.) *Short Rotation Forestry: review of growth and environmental impacts*. Forest Research Monograph, 2, Forest Research, Surrey, 212pp. ISBN 978-0-85538-827-0.
- Vanguelova, E.I., Nisbet, T., Moffat, A., Broadmeadow, S., Sanders, T. & Morison, J. 2012. A new evaluation of carbon stocks in UK forest soils. *Soil Use and Management* (*in press*).
- Walmsley, J.D. and Godbold, D.L. 2009. Stump Harvesting for Bioenergy –A Review of the Environmental Impacts. *Forestry* 83: 17-38.
- Walmsley, J.D., Jones D.L., Reynolds, B., Price M.H., & Healey J.R. 2009. Whole tree harvesting can reduce second rotation forest productivity. *Forest Ecology and Management*. 257: 1104-1111.

## Assessing harvesting potential and nutrient sustainability in temperate forests based on monitoring data

Klaus v. Wilpert<sup>1</sup>, Bernhard Bösch<sup>1</sup>, Heike Puhlmann<sup>2</sup> and Dietmar Zirlewagen<sup>3</sup>

<sup>1</sup>Forest Research Institute Freiburg, <sup>2</sup>Institute of hydrology, Univ. Freiburg, <sup>3</sup>INTERRA, Bureau for Environmental Survey and Research ([Klaus.wilpert@forst.bwl.de](mailto:Klaus.wilpert@forst.bwl.de))

### Introduction, problem and aim of the study

Nutrients circulate almost without loss in natural, unmanaged forest ecosystems. Mineral weathering fully compensates the low losses. (Ebermayer, 1882). Recycling and mobilization of nutrients takes place from comparably stable binding in organic substances or stable minerals of the bedrock (Silicates, carbonates). Thus nutrient export with seepage water is minimized.

Human impacts, however, have substantially accelerated nutrient export in Central Europe for many decades. Reasons for this are on the one hand acid deposition and subsequently increased element export with seepage. On the other hand intensified harvest intensity and new harvesting techniques extracting more nutrient – rich tissues (e.g. twigs or bark) result in increased nutrient export. Both the load caused by environmental change and the increased nutrient export must be quantified in order to judge the nutrient sustainability of any harvesting strategy.

An increased demand for fuel wood harvest results from actual political efforts towards enhancing the proportion of energy supply from renewable sources. (Bündnis90/Die Grünen und SPD Baden-Württemberg 2011). Forest timber is the largest wood biomass pool accessible for renewable energy production.

The overall aim of the project was on the one hand to develop a methodical frame for quantification of the fuel wood potential which can be mobilized in a sustainable way. The term „sustainability“ is not restricted to the fuel wood amount, but rather is focused mainly on nutrient availability. Valid instruments are required for the spatially discrete determination of the fuel wood potential obtainable while maintaining or re-enabling nutrient sustainability.

The pilot-study presented was conducted in the pre-alpine glacial region, which is among the most productive growth regions in Baden-Württemberg, South-West Germany. Its forest area comprises ca. 140.000 ha. All categories of forest owner were included in the study. The Region is characterized by an over-proportionally wide range of soil qualities, from rich calcareous sediments to poor, heavily acidified sands.

### Methods

Assortment masses and biomass compartments were determined individually at each of the 523 sampling points of the NFI in the project region using the computer software “Waldentwicklung und Holzaufkommens Modellierung” WEHAM (Bösch 2005).

Quasi continuous maps (technical resolution 25x25m) of soil properties were extrapolated from the 8x8 km grid points of the soil survey by means of multiple linear regression models using landscape morphology

and geologic and soil characteristics as transfer keys (Zirlewagen und v.Wilpert 2010). Thus the transfer of the soil information, needed for calculation of nutrient balances, to the NFI sampling point was enabled. The nutrient amount exported with harvested wood biomass was calculated as a product of assortment masses (or biomass compartment masses) calculated individually for different harvesting strategies with WEHAM, and nutrient concentrations were determined by compartment-differentiated measurements on 60 spruce and 40 beech trees from the region.

Five different harvesting strategies were modelled on this basis. The nutrient effect of these strategies was dominated by the fact that, where biomass compartments and their nutrient content are concerned, if they are exported or accumulated on skid trails they will be “lost” for the nutrient cycle of the stand; if they remain, well distributed on the stand area, or their nutrient content is recycled with wood-ash, they will remain in the nutrient cycle.

Five different harvesting strategies were modelled on the basis of this data material which either exports biomass compartments, leaves them on the stand area or recycles nutrients with wood ash in the case of fuel wood harvest. They were defined as follows:

**Scenario 1** = conventional assortments without fuel wood harvest, fully mechanized harvesting technique, accumulation of all crown material on the skidding trails which is de facto a full-tree harvest.

**Scenario 4** = Crown material is additionally harvested as fuel wood and wood ash is recycled.

**Scenario 5** = as for 4, but additionally all pulp wood assortments are used as fuel wood and wood ash is recycled.

Moreover two scenarios (2, 3) were calculated which include exclusively motor-manual harvesting techniques and also de-barking by hand. Thus bark and crown material remains more or less equally distributed on the stand area. These two scenarios are included for heuristic reasons to demonstrate which soil preservation potential would be generated with these „historic“ techniques - or what soil preservation effect was lost by giving them up for economic reasons. The results demonstrate that their beneficial effect on the nutrient cycle is as high as that of the scenario with maximum fuel wood harvest and wood ash recycling. In the following the focus will be on the Scenarios with fuel wood harvest and Scenario 1 as a practically relevant control.

Quantification of nutrient sustainability was achieved by spatially discrete calculation of nutrient balances. These were calculated individually at all NFI grid points (2x2km). They comprise **nutrient input with deposition, nutrient mobilization with mineral weathering, nutrient export with seepage water and with wood biomass harvest.**

The single balance elements are derived from regular environmental monitoring data: the nutrient input with deposition from deposition measurements in the Level II network, the mobilization of nutrients from mineral weathering from the base saturation of soil monitoring data, the nutrient export with seepage water from mean element concentrations measured in the water extracts derived from soil monitoring, which are multiplied with mean water fluxes as assessed by means of pedo-transfer functions based on primary soil physical parameters of soil monitoring. Nutrient exports with timber harvest are the product of assortment masses from NFI and biomass-compartment differentiated measures of 60 spruce and 40 beech trees. This was an additional measuring campaign complementing routine monitoring data. All four balance elements displayed a comparable mean amount in the project region and thus were comparably important for nutrient sustainability: nutrient deposition (calcium, magnesium and potassium) on average 0.7

kmol<sub>c</sub>/ha/a, mineral weathering 1.2kmol<sub>c</sub>/ha/a, export with seepage 0.8 kmol<sub>c</sub>/ha/a and export with timber harvest in the different harvesting scenarios between 0.8 and 1.2 kmol<sub>c</sub>/ha/a (v. Wilpert et al. 2011).

A simplified balance approach, based only on soil stock and nutrient-export with harvest was used for trace elements, particularly phosphate, since export with seepage is minimal for them. Multiple linear regression functions were fitted to the statistical material of wood biomass assortment data and nutrient balance data at the 523 NFI sampling points in the project region, in order to transfer this information from the discrete sampling points to the whole forest area, where they are needed as decision support tools for sustainable forest management. Transfer keys for the biomass data were stand parameters (tree species, age, height and stand density) from local forest inventory data, as well as landscape morphology characteristics derived from a digital height model. Transfer keys for extrapolation of nutrient deficits caused by timber harvest were the same stand parameters as those used for assessment of wood biomass pools. The same parameters were also used for assessment of landscape morphology, as well as some parameters from soil and geological maps. These regressions for the assessment of fuel wood potentials and nutrient balances (presented here for potassium) showed no assessment bias and could explain between 60 and 70% of the parameter variance (Fig. 1). The data for derivation of these transfer functions have been split into a training-data set for model development and a second data set for validation of model quality. The proportion of explained variance decreased with the model application to the validation data set only by 3 – 5%. Thus in all stands or forest enterprises where sufficiently detailed inventory data are available, the information on biomass pools and nutrient balances can be referred to while applying the transfer functions.

## Results

The spatial variability of nutrient-balances is substantially high, and depends much on stand and soil properties. The main predictor of these target variables is the harvested wood biomass, and soil properties or the age of stands play a somehow secondary role. The balance elements „mineral weathering“ and „nutrient export with seepage“, obviously depend more on geological and soil factors. This high spatial variability of nutrient balances can easily be equalized via soil protective liming, which should be combined with wood-ash recycling in order to supplement the nutrient content of Dolomite lime with the essential trace nutrients potassium and phosphorous.

If nutrient balances are averaged over all NFI sampling points of the project region, the mean nutrient balances (Table 1) are very close to the balance equilibrium for scenario 4 which uses only the crown biomass as fuel wood, and is unambiguously positive for scenario 5 in which fuel wood use is maximized and complete wood-ash recycling is performed.

The table shows also that conventional, fully mechanized timber harvesting is the most incriminating technique for nutrient sustainability since it enables no technically realistic option for nutrient re-cycling.

The downscaling functions which allow for the transfer of fuel wood potentials and nutrient balances from the NFI sampling point to the area where practical forest management takes place are presented for a 8300 ha wide forest district in Figs. 2 and 3. The maximum amount of fuel wood which can be mobilized (scenario 5) varies between values close to zero and up to ca. 40 m<sup>3</sup>/ha/a, with an average between 0 and 10 m<sup>3</sup>/ha/a (Fig. 2). Areas with high and low fuel wood potential are equally and randomly distributed over the whole district without larger systematic deviation. This pattern is dominated by the age of the stands and thus the amount of their biomass. Analogously to the spatial pattern of the fuel wood potential in Fig.

3, the pattern of nutrient balances is given for the nutrients calcium and potassium which both display latent deficiency in the project region. Thus the need for nutrient compensation is quantified in small scaled spatial patterns. For that district a tendency for increasing nutrient deficits from NW to SE will be triggered for both elements with maximal fuel wood harvest. This pattern is caused by two soil characteristics. On the one hand the soils in the NW of the example district are clay soils with high exchange capacities and low seepage rates, whereas towards the SW highly permeable sandy soils are dominating.

With the example of downscaling of fuel wood potentials and nutrient compensation it could be demonstrated that practical decision support instruments could be derived with the models from the pilot project at a small-scale range, with relevance for forest management decision-making.

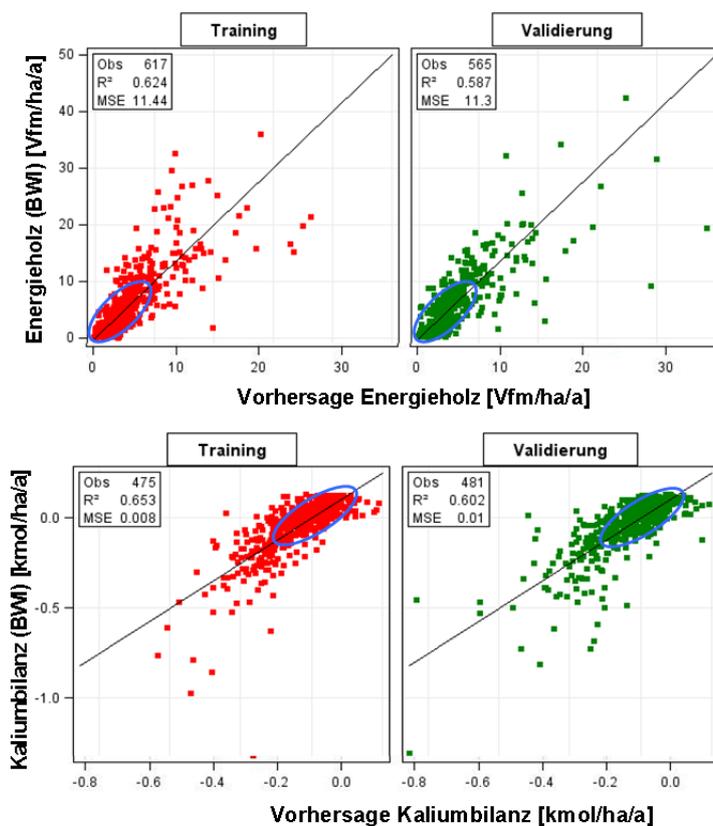


Figure 1. Measured data and model assessments of the maximal fuel - wood potential (above) and the Potassium balance (below) at the 523 grid point of NFI in the project region. Left respectively the training data set, used for model definition and right the validation data set for the independent identification of model quality.

	Scenario 1	Scenario 4	Scenario 5
<b>Ca</b> [kmol <sub>e</sub> /ha/a]	- 0.2880	- 0.0443	0.2560
<b>Mg</b> [kmol <sub>e</sub> /ha/a]	0.0873	0.1290	0.1750
<b>K</b> [kmol <sub>e</sub> /ha/a]	- 0.0947	- 0.0440	0.0137

Table 1. Mean nutrient balances for calcium, magnesium and potassium (ion-equivalents/ha/year) over all NFI-points of the project region. Negative balances are shaded grey.

Szenario 5

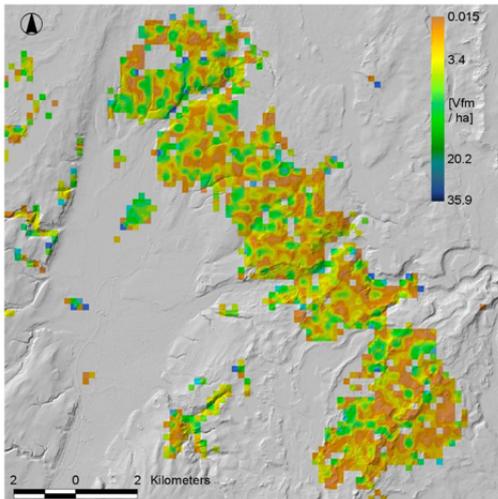
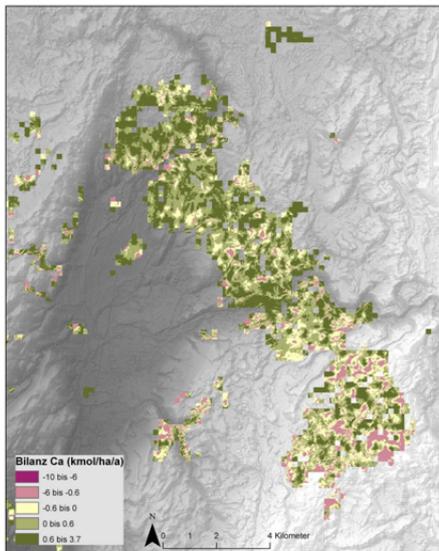


Figure 2. Spatially discrete assessment of the fuel – wood potential ( $\text{m}^3/\text{ha}/\text{a}$ ), for an 8200 ha wide test stand. Data have been transferred from NFI grid points to the whole area by multiple linear regression technique. The technical resolution in space is 25x25m.

Calcium



Kalium

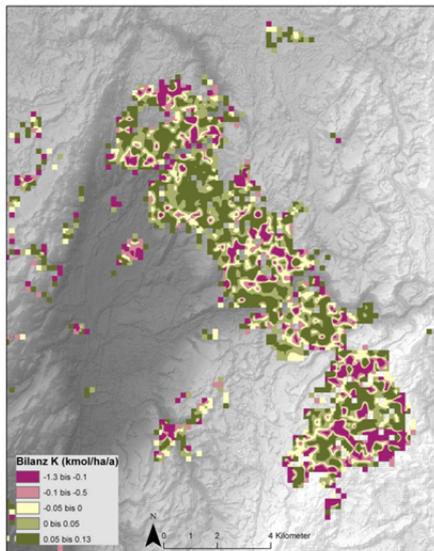


Figure 3. Spatially discrete assessment of the nutrient balances for Calcium (left) and Potassium (right), for an 8200 ha wide test stand. Data have been transferred from NFI grid points to the whole area by multiple linear regression technique. The technical resolution in space is 25x25m.

### Technique of nutrient recycling through wood – ash recycling

Wood – ash is predominantly suited for supplementing the buffer capacity of forest soils because of its high base content. Relevant components for forest nutrition are the macro – nutrients calcium and magnesium and the trace – elements potassium, which is predominantly relevant in loamy soils and phosphorous, being of high relevance at sites with biologically inactive raw – humus sites. The latter can replace the relatively expensive addition of raw phosphate which was usual at these sites in the past. However, heavy metal contaminations are also accumulated in wood ashes as well as the other, useful mineral components.

Critical elements are cadmium, chrome and lead. Heavy metal concentrations are decisively influenced by the kind of burning material. Span plates, impregnated wood and wood with a coloured paint cover lead to orders of magnitude higher heavy metal loads compared with untreated natural timber. But even with the exclusive use of untreated wood biomass high heavy metal contents must be expected if e.g. wood biomass from street plantings are used, in which cadmium and lead contents are often increased. Cadmium is a problem element because of its high toxicity and its relatively high concentrations.

A precondition for the use of wood – ashes for nutrient recycling in the forest is a clear organizational regulation of wood ash – recycling and secure quality assurance rules. The following rules were fixed in Baden - Württemberg (v.Wilpert 2002):

- Only wood –ashes from natural, untreated wood biomass is allowed for recycling in the forest.
- No filter dusts may be used, because they are highly contaminated with heavy metals and must be treated as dangerous waste.
- The heavy metal thresholds of fertilizer regulation laws must be adhered to, controlled and the controls documented.
- Wood – ash recycling should normally be combined with soil protective liming and the proportion of wood – ash should not exceed 30 % in the mixture with Dolomite lime.

An important aim of the project was to identify the technical options for wood – ash recycling. Together with two limestone works the technical process of mixing dolomite rock powder with wood – ash has been optimized. Physical homogenization of wood – ash was the most critical task in this work. Thus Dolomite / wood ash mixture was developed as a new, well standardized product for soil protective liming. This product was distributed during the two project years 2008 and 2009 over about 1561 ha with a dosage of 4 t/ha. The results of the quality checks made during the program showed that the thresholds prescribed in environmental regulations and laws can be met without problems. The following issues of product properties have been demonstrated to be realistic: 75 weight% total carbonate; 12 weight% MgO-equivalents; 1.5 weight% K<sub>2</sub>O-equivalents; and 0.5 weight% P<sub>2</sub>O<sub>5</sub>-equivalents.

Costs for production of the new product are about 10% higher than conventional Dolomite rock powder. This is mainly due to the technical effort for physical homogenization of wood – ash, which tends to form clods because of its hygroscopic properties (Fig. 4). Thus mean realistic costs for recycling the nutrients exported by harvest have been identified for the project region at about 4 €/ha/a. With that measure Ca and Mg deficits will be totally replenished but for the trace elements K and P only about 80 – 90% of the exported nutrient amount will be replaced since the contents of these trace elements in the Dolomite / wood – ash mixture are low. However, full recycling of the trace elements is not necessary, since their effect on forest nutrition is dominated more by plant availability than by their stock amount, and plant availability in acidified forest soils is enhanced by soil protective liming.



Figure 4. Tendency of wood – ash to generate clods because of its hydraulic properties (left), mechanical homogenization and mixing with Dolomite rock powder in limestone – works (centre), distribution of the mixture with helicopter (right)

## Conclusions

Finally we can state that conventional, fully mechanized timber harvest is the most incriminating option for nutrient sustainability since the actual technical solutions foresee the accumulation of the whole crown material on skid trails in order to maintain their viability for heavy machines. This is equivalent to a full-tree harvest since no technical option is given to re-distribute the predominantly nutrient – rich crown biomass on the stand area. Thus we have to state that this technical harvesting strategy, being very common especially in spruce management, will be not sustainable at many sites in the long run. Mechanization was introduced in forest management during the last 15 – 20 years. This took place simultaneously with the phase of highest acid deposition in Central Europe, resulting in heavy soil acidification with subsequent nutrient leaching. Setting aside and ignoring this latent load for nutrient sustainability in Central European forests, a „business as usual“ scenario which is based mainly on economic prosperity will contradict the postulate for resource sustainability in forest management. Harvesting strategies must be identified and judged in a trans-disciplinary way, which combines sustainability in terms of forest products nutrient resources and economic suitability in the sense of an optimized compromise. Thus maximization of the energy – politically sensible fuel wood harvest will be pursued and soil quality maintained and/or developed at the same time. The pilot project could demonstrate that the assessment of fuel wood potentials and compensation needs at the basis of routine forest monitoring data is possible in a statistically reliable way, and can be transferred to small- scale forest enterprises and forest stands. Thus a reliable instrument for sustainability management as well as for supporting economic management decisions is available, which meets the demand of Meiwes et al. (2008) for “good practice guidance of the use of residual wood biomass in the forest“.

The concept presented is open for different strategic approaches and normative settings. It can serve to define the nutrient compensation demand as well as a quantitative data base for the definition of a harvesting threshold above which nutrient sustainability will be endangered, as Göttelein et al. (2007), and Kölling et al. (2007) proposed to be observed through harvesting renounce. In that case it must be clarified that harvesting renounce cannot be restricted to fuel wood harvesting but rather must be applied to all timber harvesting.

## References

- Bösch, B. Fachkonzept WEHAM II, Modelle und Algorithmen. Forest Research Institute Baden-Württemberg: Internal research report, 77pp.
- Bündnis90/DieGrünen und SPD Baden-Württemberg 2011. Koalitionsvertrag zwischen Bündnis90/Die Grünen und SPD Baden-Württemberg. 92 s.
- Ebermayer, E. 1882. Naturgesetzliche Grundlagen des Wald- und Ackerbaus.
- Göttlein, A., Weis, W. & Ettl, R., 2007. Energieholznutzung und nachhaltige Waldbewirtschaftung – ein Zielkonflikt? In: Rundgespräche der Kommission für Ökologie, Bd. 33 „Energie aus Biomasse“, 87 – 95.
- Kölling, C.H., Göttlein, A. & Rothe, A. 2007. Energieholz nachhaltig nutzen – Biomassnutzung und Nährstoffentzug. LWF aktuell, 61: 32-37
- Meiwes, K.J., Asche, N., Block, J., Kallweit, R., Kölling, C.H., Raben, G., von Wilpert, K. 2008. Potentiale und Restriktionen der Biomassenutzung im Wald, AFZ-DerWald, 10-11: 598-603.
- von Wilpert, K., Bösch, B., Bastian, P., Zirlewagen, D., Hepperle, F., Holzmann, S., Puhmann, H., Schäfer, J., Kändler, G., Sauter, U.H. 2011. A. Biomasse-Aufkommensprognose und Kreislaufkonzept für den Einsatz von Holzaschen in der Bodenschutzkalkung in Oberschwaben. Freiburger Forstliche Forschung, Berichte, Heft 87.155 S.
- v. Wilpert, K. (Hrsg.) 2002. Holzascheausbringung im Wald – ein Kreislaufkonzept. FVA Kolloquium in Freiburg vom 5.-6. März 2002 Freiburger Forstliche Forschung, H. 43: 166 S.
- Zirlewagen, D. & von Wilpert, K. 2010. Upscaling of environmental information - support of land-use management decisions by spatio-temporal regionalization approaches. Environmental Management, . <http://dx.doi.org/10.1007/s00267-010-9468-4>.

## Impact of short and very short rotation coppices of *Populus* and *Salix* species on soil C, N and P cycling

René Guénon, Jean-Charles Bastien, Pascal Thiébeau, Guillaume Bodineau and Isabelle Bertrand

INRA, CREA, 2, Esplanade Roland Garros, 51686 Reims, France ([rene.guenon@reims.inra.fr](mailto:rene.guenon@reims.inra.fr))

### Introduction

Increased concern for the negative impact of fossil fuels on the environment has put pressure to find new and more diversified renewable energy sources (Boehmel et al. 2008, Sathaye et al. 2011). Lignocellulosic biomass could be used to produce energy, and more specifically with the so-called second generation of biofuels (Menon and Rao, 2012). To do so, the most appropriate agricultural or forest management systems must be selected to meet both industrial and environmental constraints. However, the frequent removal of plants or residue from fields for industrial uses is open to criticism from an environmental point of view. Indeed, several studies have arrived at a negative impact of such practices on soil carbon (Lal 2005, Amougou 2012) and nitrogen (Jug et al. 1999) stocks.

Among possible bio-energy crops, the use of short rotation coppices (SRC) with fast growing species such as poplar and willow which remain implanted for 20 years appears to be a promising alternative. These are rustic species adapted to diverse pedoclimatic conditions. However, these agricultural or forest systems incorporate removal of whole trees and potentially high nutrient exports that need to be quantified in order to avoid soil quality depletion, which has been shown to be species-dependent (Guo et al. 2002). Some studies have shown that fertilization could greatly improve SRC productivity (Djomo et al. 2011). However, it was recognized that SRC should preferably not be fertilized in order to be economically attractive and sustainable (Marron et al. 2012).

The use of SRC to produce bio-ethanol requires a high efficiency of enzymes to hydrolyze the lignocelluloses (Menon and Rao 2012). This efficiency depends on sugar accessibility, plant species and maturity. This application also requires a continuous biomass supply chain, as storage may not always be possible. To meet these requirements, one option would be to increase the frequency of harvesting by cutting trees every two or three years (i.e. very short rotation coppices: VSRC) instead of every 8 to 10 years (i.e. SRC). However, this practice could impact soil nutrient status and thus hamper overall sustainability.

In this context, the aim of this study was to quantify the potential impact of SRC and VSRC of poplar and willow on soil C, N and P cycling. To do so, the balance between inputs (i.e. litterfall and fine roots) and outputs (i.e. aboveground biomass) of soil nutrient was measured. We hypothesized that this balance would depend on i) the species by comparing two fast growing species (one of the genus *Populus* and one of the genus *Salix*) and ii) intensification of management (i.e. density of plantation and frequency of harvest).

### Material and Methods

#### *Study site and experimental design*

The field experiment was located in the centre of France (Saint-Cyr-en-Val). The study site has an oceanic climate with mild and rainy winters and cool and wet summers. Mean annual temperature and rainfall are 10.5 °C and 699 mm respectively (13.8°C and 399 mm between March and September). This experiment was conducted on a fallow that resulted from land abandonment for 12 years. The soil consists of alluvial deposits with a significant content of stony gravels (>2mm) and a stony layer at 45 cm depth. Tillage (0-20cm) was performed on the site before planting.

Two species were planted: i) poplar with the clone Dorskamp, which is a euramericana hybrid (*Populus deltoides* x *Populus nigra*) and ii) willow with the clone Olof, which is a Swedish hybrid (*Salix viminalis* x *S.*

schewerinii x *S. viminalis*). The design of this experiment was divided into 3 treatments: short rotation coppice of poplar (SRC<sub>poplar</sub>), very short rotation coppice of poplar (VSRC<sub>poplar</sub>) and very short rotation coppice of willow (VSRC<sub>willow</sub>). In April 2010, trees of SRC<sub>poplar</sub> were planted at a density of 1428 stems per hectare in simple line (1.02 ha). The trees of VSRC<sub>poplar</sub> and VSRC<sub>willow</sub> were planted in double line at a density of 7272 and 9697 stems per hectare respectively (0.27 ha and 0.65 ha respectively). For each treatment, 4 repeated plots of 252 m<sup>2</sup> for SRC<sub>poplar</sub>, 165 m<sup>2</sup> for VSRC<sub>poplar</sub> and 100 m<sup>2</sup> for VSRC<sub>willow</sub>, respectively, were delimited. An area with no trees (3000 m<sup>2</sup>) was conserved as control plot (without plantation).

### Sampling and analyses

To characterize the study site, two layers of soils (0-20 cm and 20-45 cm) were sampled at the beginning of the experiment. Sixteen samples for each layer ( $n=4$  by treatment) were analyzed for total organic carbon (TOC) and nitrogen (TN) by total elemental analysis (NA 2000, Fisons Instruments, Milan, Italy). Total phosphorus (TP) extracted by fluorhydric and perchlorite acids (NF X 31 147) and exchangeable base cations (Ca, Mg, Na, K) extracted with cobaltihexamine chloride solution (NF X 31 130), were analyzed by ICP-AES. Water pH (1/2.5) was also assessed.

Litterfall was evaluated with metal structures ( $n=3$  by treatment) with the following dimensions: length, width, height= 6 x 3 x 4.5m and covered with a nylon mesh size (1cm<sup>2</sup>). Fallen leaves were collected every week, from September to December 2011, then dried (80°C, 48h) and weighed. In February 2012, all the trees for VSRC<sub>poplar</sub> and VSRC<sub>willow</sub> were cut (corresponding to two years old), weighed to assess above-ground biomass and dried at (103°C, 48h). For SRC<sub>poplar</sub>, four trees were removed to assess above-ground biomass, because the optimal time for harvesting this treatment, i.e. 8 to 10 years, was not reached. Root biomass was assessed by completely removing 4 poplars in SRC, 4 poplars in VSRC and 8 willows in VSRC treatments. Fine (diameter <2mm) and coarse (>2mm) roots were assessed and separated. Total C, N and P in leaves, fine roots and above-ground biomass were assessed as described above.

## Results and Discussion

### Soil properties

Soil has a sandy loam texture (64-78 % of sand and 6-13% of clay) for both soil layers (0-20 cm and 20-45 cm) (Figure 1).

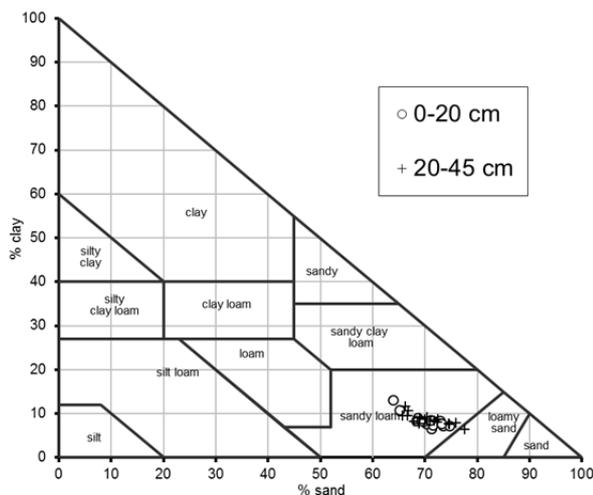


Figure 1. Soil texture of the study site.

There were no significant differences between treatments for all soil physico-chemical properties (Table 1) and for both soil layers. Total C, N and P in the 20-45 cm layer decreased significantly compared to the 0-20

cm depth layer regardless of the treatment (data not shown). Results on soil properties confirmed that the study site presented homogeneous properties.

Table 1. Soil physico-chemical properties of the study sites.

	Layer	SRC <sub>poplar</sub>	VSRC <sub>poplar</sub>	VSRC <sub>willow</sub>	Control (unplanted)
TOC (g/kg)	0-20cm	6.8 ±0.7	7.4 ±0.7	8.6 ±0.6	6.2 ±0.1
	20-45cm	3.4 ±0.3	4.4 ±0.4	4.7 ±0.4	5.0 ±0.2
TN (g/kg)	0-20cm	0.70 ±0.05	0.75 ±0.06	0.82 ±0.05	0.61 ±0.04
	20-45cm	0.39 ±0.03	0.47 ±0.03	0.49 ±0.15	0.51 ±0.02
TP (g/kg)	0-20cm	0.25 ±0.01	0.27 ±0.01	0.27 ±0.02	0.26 ±0.01
	20-45cm	0.20 ±0.01	0.24 ±0.01	0.22 ±0.02	0.25 ±0.01
pH	0-20cm	5.3 ±0.0	5.2 ±0.1	5.0 ±0.1	5.1 ±0.2
	20-45cm	5.7 ±0.0	5.6 ±0.1	5.3 ±0.3	5.4 ±0.3
Base cations (cmol+/kg)	0-20cm	2.9 ±0.4	2.5 ±0.2	3.8 ±1.9	3.2 ±0.0
	20-45cm	2.9 ±0.6	2.5 ±0.5	2.2 ±0.7	1.7 ±0.5

#### *Contribution of above-ground biomass and litterfall to C, N and P balances*

Above-ground biomass was significantly (2.6-3.0 times) higher in VSRC treatments in comparison with SRC poplar. Transposing this biomass into C, N and P stocks in plant tissues (i.e. above-ground and litterfall), the same increase was found. Concerning the biomass of leaves, our results indicated that the VSRC<sub>poplar</sub> increased 2.5 times more than the content of litterfall in comparison with SRC<sub>poplar</sub>, whereas litterfall in VSRC<sub>willow</sub> was not significantly different from the two other treatments. Otherwise, no significant changes in C, N and P concentrations were found between treatments for both components (i.e. above-ground and litterfall), indicating that differences in exportations were mainly attributed to the differences in biomass (kg) produced per ha. Therefore, exportations by above-ground biomass and inputs by litterfall depend mainly on the density of plantation.

#### *Contribution of fine roots to C, N and P balances*

Our results indicated no significant difference of total root biomass between the three treatments (data not shown). However, we found that the stocks of C, N and P in fine root biomass were significantly (2.5-fold) higher in VSRC<sub>poplar</sub> than in SRC<sub>poplar</sub> treatment, whereas the stocks of C, N and P in fine roots of VSRC<sub>willow</sub> were not significantly different from the two other treatments. As in the case of litterfall, we attributed these differences to the significant differences in fine root biomass (kg) produced per ha.

#### *Balances of C, N and P*

The C-input in soil (kg/ha) was calculated as the sum of C-stock in litterfall and fine roots and the N-and P-balance (kg/ha) for each element as the sum of litterfall and fine root stocks minus above-ground stocks. Results for each treatment and for each element are shown in Table 2.

Table 2. Balances of total C, N and P (kg/ha) of inputs and outputs

(kg/ha)	SRC <sub>poplar</sub>	VSRC <sub>poplar</sub>	VSRC <sub>willow</sub>
C	+225	+551	+414
N	-3.9	-12.1	-15.4
P	-0.3	-0.9	-3.6

The treatment VSRC poplar and willow increased the C-input in soil in comparison to SRC<sub>poplar</sub>. Conversely, all the treatments had a negative balance for nitrogen and phosphorus. The key effect was for the negative N-balance, which increased with VSRC treatment, and especially for willow that also presented the most negative balance for P.

### Conclusions and perspectives

After only two years of growth, differences due to management could be quantified, demonstrating the tremendous effect of the frequency of harvest on soil fertility. Indeed, the intensification of rotation coppices increases the impact on soil fertility especially by decreasing the N budget that generally limits plant productivity. These first results also demonstrate a species effect, with the balance of inputs and outputs in VSRC willows having a higher impact on soil nutrients than that of poplar after 2 years of growth.

However, one of the limits of our approach to calculate nutrient balance was that we did not take into consideration the rate of decomposition of leaves and roots. Therefore, the amount of C could have been over-estimated whereas that of nutrient may have been underestimated due to mineralization, leaching and uptake by plants. There is a need to measure decomposition of leaves and roots to verify these balances and soil C, N and P impacts.

### Acknowledgements

This study was part of the Futurol project (<http://projet-futurol.com/>) partly funded by Oseo. The authors are grateful to C. Corbeaux for her technical assistance.

### References

- Amougou, N., Bertrand, I., Cadoux, S. & Recous, S. 2012. *Miscanthus x giganteus* leaf senescence, decomposition and C and N inputs to soil. *Global Change Biology Bioenergy*, doi: 10.1111/j.1757-1707.2012.01192.x
- Boehmel, C., Lewandowski, I. & Claupein, W. 2008. Comparing annual and perennial energy cropping systems with different management intensities. *Agricultural Systems* 96: 224-236.
- Djomo, S.N., El Kasmoui, O. & Ceulemans, R. 2011. Energy and greenhouse gas balance of bioenergy production from poplar and willow: a review. *Global Change Biology Bioenergy* 3: 181–197.
- Guo, L.B., Sims, R.E.H. & Horne, D.J. 2002. Biomass production and nutrient cycling on *Eucalyptus* short rotation energy forests in New Zealand. I: biomass and nutrient accumulation. *Bioresource Technology* 85: 273-283.
- Jug, A., Makeschin, F., Rehfuess, K.E. & Hofmann-Schielle, C. 1999. Short-rotation plantations of balsam poplars, aspen and willows on former arable land in the Federal Republic of Germany. III. Soil ecological effects. *Forest Ecology and Management* 121: 85-99.
- Lal, R. 2005. Forest soils and carbon sequestration. 10th North American Forest Soils Conference Location, St Marie, CANADA. *Forest Ecology and Management* 220: 242-258.

- Marron et al. 2012. Cost reduction and efficiency improvement of short rotation coppice. CREFF Final report. Project ERA-Net Bioenergy CREFF.
- Menon, V. & Rao, M. 2012. Trends in bioconversion of lignocellulose: Biofuels, platform chemicals & biorefinery concept. *Progress in Energy and Combustion Science* 38: 522-550.
- Sathaye, J., Lucon, O., Rahman, A., Christensen, J., Denton, F., Fujino, J., Heath, G., Kadner, S., Mirza, M., Rudnick, H., Schlaepfer, A., & Shmakin, A. 2011: Renewable Energy in the Context of Sustainable Development. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation In: O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

## Forest bioenergy and soil sustainability in Finland

Heljä-Sisko Helmisaari

University of Helsinki, Dept. of Forest Sciences, P.O.Box 27, FI-00014 University of Helsinki, Finland  
([helja-sisko.helmisaari@helsinki.fi](mailto:helja-sisko.helmisaari@helsinki.fi))

### Forest bioenergy harvesting in Finland

Forest biomass is increasingly being used as an energy source in Europe, following the targets for renewable energy in 2020 for reducing greenhouse gas emissions set by the European Union. In Finland the government has set a target of more than double the annual domestic use of forest chips from 5.4 (in 2009) to 13.5 mill. m<sup>3</sup> by the year 2020, amounting to a large part of the technical harvesting potential of forest chips of 16 million m<sup>3</sup> per year in Finland (Helynen et al. 2007).

Forest bioenergy sources in Finland include logging residues, stumps and small-size or inferior-quality tree stems that are normally not harvested in conventional stemwood harvesting at thinnings and final fellings. Stump uplifting started in Finland in 2000, and in 2006 already 0.5 Mm<sup>3</sup> (million cubic meters) were uplifted. The area of stump harvesting was 9000 ha in 2006 and 20 000 ha in 2010 (Juntunen 2011).

### Research on forest bioenergy and soil sustainability: logging residues

During recent years forest bioenergy harvesting has been studied in a large program at the Finnish Forest Research Institute. An important study field has been the long-term sustainability of residue and stump harvesting. The effects of residue harvesting have been shown to be site, soil and practice-specific (Lattimore et al. 2009). Experiments that follow long-term stand development help in identification of conditions under which negative impacts of biomass harvesting are likely (Thiffault et al. 2011). Although long-term experiments exist in Finland for studying the effects of logging residue harvesting for bioenergy, stump harvesting is a relatively recent practice, and long-term experiments are therefore rare. Furthermore, long-term logging residue removal effects at thinning are much better known (14 long-term experiments) than the effects of final felling (only a few long-term experiments).

Long-term experiments have shown that forest energy harvesting causes changes in the biogeochemical cycles of nutrients, especially when nutrient-rich residues are harvested in addition to conventional stem harvesting. Compared to stem-only harvesting, logging residue harvesting increases the removal of nitrogen and phosphorus, the most limiting nutrients in boreal forests, with possible long-term consequences for biomass production (Jacobson et al. 2000; Helmisaari et al. 2011).

Changes in the availability of forest soil nitrogen due to whole-tree harvesting are more difficult to determine than changes in tree growth. The greatest part of soil organic layer nitrogen consists of older compounds not readily available. Nitrogen is the major growth-limiting nutrient in boreal Scots pine forests, and nitrogen cycling is the basic factor in forest soil nitrogen availability (Helmisaari 1995). A study in four thinned Norway spruce sites, performed over 20 years after the treatment, showed that removal of logging residue tended to decrease both C and N mineralization in the humus layer (Smolander et al., 2010). Thus, even if the soil N stores are relatively less affected than the cation stores (Tamminen et al. 2012), removing logging residues decreases the amount of N released in decomposition, increasing the immobilization of N to microbial biomass in the mineralization process. Therefore, less nitrogen may be available after whole-tree than after stem-only harvest (Smolander et al., 2010). These results indicate that removal of logging residue may have long-term harmful effects on processes important in nutrient cycling, but more information is needed.

A decrease in forest growth could also reduce the capacity of forests to bind carbon. There is a growing concern on this point as carbon neutrality and low carbon footprints are and will be important indicators of the environmental performance of different actors and products. Therefore, research on the feedback effects of carbon cycles of forest bioenergy harvesting on nitrogen cycles is needed, and more research results will be reported on this in near future.

### **Research on forest bioenergy and soil sustainability: Stumps**

After stump harvesting, physical soil disturbance may be the main cause for most of the other soil-related impacts. Forest soil is the basis for renewable forest resources, but the soil itself is practically non-renewable - only organic matter from above- and belowground litter slowly accumulates in forest soil. The formation of forest soil physical structure with distinct soil horizons has taken thousands of years during and after the last glaciation, whereas disturbances may be rapid. Stump removal causes soil compaction and mixing, which may increase soil erosion and decrease site productivity. As stumps left in forests are long-term carbon and nutrient sinks (Palviainen et al. 2010), stump removal may temporarily also increase leaching into groundwater and watercourses. Similar processes may also occur when logging residues are no longer used on forest roads.

At stump removal, logging residues are also regularly removed, and the site is prepared. This procedure is likely to cause greater direct effects on forest soil structure and indirect effects on soil processes, e.g. on the biogeochemical cycles, than either of these practices alone. After stump removal and site preparation, the share of undisturbed soil may account for only around 30% of soil surface, whereas site preparation alone may leave twice as large an area untouched. The increased area of exposed mineral soil is beneficial for pioneer plant species but may lead to a lower amount of high quality habitat for most decomposer organisms (Kataja-aho et al. 2011), affecting carbon and nutrient cycling. Few long-term studies in Finland have been designed to separate the effects of different treatments, and therefore there is a great need to carry out research on the oldest stump harvesting sites, even if it is more challenging to find proper control sites, and to detect possible soil changes often masked by high spatial and temporal variation in soil parameters and processes.

### **Good practice guidelines in Finland**

Finnish guidelines on site suitability for logging residue and stump harvesting were renewed in 2010 at Tapio (Äijälä et al. 2010), which provides consulting services and solutions for efficient and sustainable forest management and bioeconomy.

The Finnish guidelines are based on the suitability of Finnish site types of different fertility for additional biomass harvesting in addition to stem-only harvesting, leaving the poorest site types out of residue and stump harvesting. Furthermore, the results on the long-term volume increment decrease after residue harvesting at thinnings especially in spruce stands (Helmisaari et al. 2011) have led to the recommendation that mineral soil stands in which spruce forms over 75% of the stem number before thinning are not suitable for residue harvesting at thinnings.

Recommendations propose leaving 30 % of the residues on the final felling (clear-cutting) sites. Spruce branches should be left to dry if possible, in May-June for two weeks and in late summer for four weeks, in order to allow some of the nutrient-rich needles to dry, fall and remain on the sites. Recommendations also consider deadwood to be important for biodiversity, suggesting that all standing and lying deadwood over 10 cm thick should be left on site.

Stump harvesting criteria leave the poorest mineral soil site types, peatlands, steep and stony sites, important groundwater areas, shelter areas for watercourses and archeologically or historically valuable

sites as well as valuable environments (3 m radius) such as those close to deadwood and ant heaps, outside the sphere of harvesting. Recommendations also propose that stumps from earlier loggings and stumps with diameter less than 15 cm be left on site. More than 25 stumps/ha of the >15 cm thick stumps, on fine-textured soils >50 stumps/ha, should always be left unharvested, while *Heterobasidion*-infected stumps should always be removed. Stump harvesting holes should not be deeper than 30 cm, organic layer should not be unnecessarily removed and the organic layer and mineral soil attached to the stumps should be shaken back into the hole.

## Final words

Although scientific research on residue removal effects on the sustainability of residue harvesting is spatially and temporally challenging, huge progress has been made in recent years. The existing guidelines are under constant renewal, and the results from recently ended and on-going long-term research programs are important for the development and updating of Finnish guidelines for more sustainable residue and stump harvesting.

## References

- Helmisaari, H-S., Holt Hanssen, K., Jacobson, S., Kukkola, M., Luro, J., Saarsalmi, A., Tamminen, P. & Tveite, B. 2011. Logging residue removal after thinning in Nordic boreal forests: Long-term impact on tree growth. *Forest Ecology and Management* 261: 1919-1927.
- Helmisaari, H-S. 1995. Nutrient cycling in *Pinus sylvestris* stands in eastern Finland. *Plant and Soil* 168-169: 327-336.
- Helynen, S., Flyktman, M., Asikainen, A. & Laitila, J. 2007. Metsätalouteen ja metsäteollisuuteen perustuvan energialiiketoiminnan mahdollisuudet. [Scenarios on wood-based bioenergy business in Finland for the forestry and forest industry.] VTT Tiedotteita– Research Notes 2397. 66 p. (In Finnish).
- Jacobson, S., Kukkola, M., Mälkönen, E. & Tveite, B. 2000. Impact of whole-tree harvesting and compensatory fertilization on growth of coniferous thinning stands. *Forest Ecology and Management* 129: 41-51.
- Juntunen, M-L. 2011. Finnish Statistical Yearbook of Forestry 2011.
- Lattimore, B., Smith, C.T., Titus, B.D., Stupak, I. & Egnell, G. 2009. Environmental factors in woodfuel production: Opportunities, risks, and criteria and indicators for sustainable practices. *Biomass and Bioenergy* 33: 1321-1342.
- Palviainen, M., Finér, L., Laiho, R., Shorohova, E., Kapitsa, E. & Vanha-Majamaa, I. 2010. Carbon and nitrogen release from decomposing Scots pine, Norway spruce and silver birch stumps. *Forest Ecology and Management* 259: 390-398.
- Smolander, A., Kitunen, V., Tamminen, P., Kukkola, M., 2010. Removal of logging residue in Norway spruce thinning stands: Long-term changes in organic layer properties. *Soil Biol. Biochem.* 42, 1222-1228.
- Tamminen, P., Saarsalmi, A., Smolander, A., Kukkola, M. & Helmisaari, H. 2012. Effects of logging residue harvest in thinnings on amounts of soil carbon and nutrients in Scots pine and Norway spruce stands. *Forest Ecology and Management.* 263: 31-38.
- Thiffault, E., Hannam, K.D., Paré, D., Titus, B.R., Hazlett, P.W., Maynard, D.G & Brais, S. 2011. Effects of forest biomass harvesting on soil productivity in boreal and temperate forests — A review. *Environmental Reviews* 19: 278-309.
- Äijälä, O., Kuusinen, M. & Koistinen, A. (eds.) 2010. Hyvän metsänhoidon suositukset energiapuun korjuuseen ja kasvatukseen (in Finnish, Good silvicultural practise recommendations for energy wood harvesting and production.) Metsätalouden kehittämiskeskus Tapio (Forestry Development Center Tapio) publications. ISBN 978-952-5694-64-2.

## Poster abstracts

### **Biomass utilization and its consequences for soils - a retrospective view**

Viktor J. Bruckmann & Gerhard Glatzel

Austrian Academy of Sciences, Commission for Interdisciplinary Ecological Studies, Vienna, Austria

Biomass was the major source of energy until the early utilization of fossil energy sources. Its availability is strongly linked to the development, prosperity and extinction of former civilizations. Biomass from forests became scarce as the industry developed, leading to increasing transport distances from biomass sources and vast deforested patches of land along streams. There is good evidence from the past that unsustainable biomass extraction and consequent soil degradation had significant impact on soil properties in specific cases. In central Europe, litter raking and pollarding were common practices until the middle of the last century. Nutrients were directly extracted from forest ecosystems to sustain the human population by setting up forest pastures and harvesting of edible parts of plants. Starting from the Bronze Age, mining and proto-industrialization had significant impacts on forests because of the rising demand for fuel wood, charcoal and even wood-ash. Such historical practices led to significant base cation loss in many forest ecosystems and consequently to soil acidification and reduced growth potential. Consequences of such practices should be kept in mind when evaluating the impact of harvesting residues management (utilization of slash), which is nowadays discussed extensively

### **Impacts of disc trenching on soil water and heat flows in a forest regeneration area in Sweden**

Linnea Hansson<sup>1</sup>, Eva Ring<sup>2</sup>, Annemieke Gärdenäs<sup>1</sup>

<sup>1</sup>Swedish Agricultural University, Soil and Environment, Uppsala, Sweden, <sup>2</sup>Skogforsk, Nature and Environment, Uppsala, Sweden

Site preparation is executed on more than 80 % of the forest regeneration areas in Sweden and disc trenching is the most common method. It is done to stimulate a successful regeneration and thereby to improve the productivity for the whole rotation period. The environmental consequences of disc trenching are poorly understood. The aim of this study was to analyze the impact of disc trenching on the heat and water dynamics both by measurements and by process-oriented modeling. This is of importance for understanding the abiotic conditions for decomposition, soil fauna, nutrient leaching and the re-establishment of vegetation after disc trenching. The study site is situated on a sandy soil in the western part of central Sweden. The Scots pine stand was harvested in 2006 and disc trenching was carried out shortly afterwards. Soil moisture content and temperature were monitored on an hourly basis for five years in disc trenched areas; i.e. below furrows, ridges, between ridges and in undisturbed soil respectively. The dynamic bio-geophysical ecosystem model, Coup Model (Jansson & Karlberg 2010), was used for simulating soil water- and heat fluxes. We present an analysis of the impact of disc-trenching on the daily and seasonal amplitudes of soil temperature and moisture in the furrows, the ridges and the control. We also assess the duration of the impact of disc trenching. Preliminary results indicate that the effects are leveling off after five years. The study was funded by the Swedish Research Council Formas and the Swedish University of Agricultural Sciences.

## Examining whole site productivity when intercropping giant miscanthus (*Miscanthus × Giganteus*) with loblolly pine (*Pinus taeda*) for bioenergy feedstock production in southeastern United States

Ryan Heiderman<sup>1</sup>, Jose Stape<sup>1</sup>, Zakiya Leggett<sup>2</sup>, Eric Sucre<sup>2</sup>, Ron Gehl<sup>3</sup>

<sup>1</sup>North Carolina State University, Forestry and Environmental Resources, Raleigh, United States, <sup>2</sup>Weyerhaeuser Company, Southern Timberlands R&D, New Bern, United States, <sup>3</sup>North Carolina State University, Soil Science, Mills River, United States

There is growing interest in production of dedicated biomass crops to be used as feedstock for bioenergy production. Perennial grasses have been identified as attractive feedstock. Giant miscanthus (*Miscanthus × giganteus*), a perennial, warm season grass related to the sugarcane family is one potential high-yielding bioenergy crop. European experience with miscanthus has shown yields up to 22 Mg ha<sup>-1</sup> and has also revealed its potential to sequester carbon below ground. Although miscanthus is native to the tropics, it has been shown to be tolerant of cooler climates. In the Southeastern United States, forest-based biomass may be able to provide raw materials to help build a biomass-based energy industry. Loblolly pine (*Pinus taeda*) planted on wide row spacing (e.g. for sawtimber production) allows dedicated energy crop intercropping. Intercropping for bioenergy feedstock production may maximize economic and biomass output from the land early in the forest rotation while still maintaining long-term production of traditional forest products. This study examined effects of managing miscanthus as a feedstock for biofuels on crop tree growth and soil sustainability in a loblolly pine plantation. The extent of these potential effects on yield and soil needs detailed investigation, which would facilitate development of sustainable forest management strategies for intercropping. This intercropping system is evaluated in three areas: (1) Productivity of pine and miscanthus, (2) Above- and below ground carbon dynamics and storage, and (3) Soil nitrogen dynamics.

## Whole-tree harvest at final felling: long-term effects on soil properties in a Norway spruce stand

Lilli Kaarakka, University of Helsinki, Department of Forest Sciences, Helsinki, Finland

The objective of this study was to determine and compare differences in soil properties after conventional harvest and whole-tree harvest in a fertile Norway spruce (*Picea abies* (L.) Karst.) stand in southern Finland. Only a limited number of long-term studies have been carried out on this topic in the boreal region.

The site was clear-felled in August 2000 and spruce seedlings were planted in the following summer. Soil sampling in the form of systematic randomized sampling was carried out in May 2011. Changes in base saturation, cation exchange capacity, elemental pools (total and exchangeable) and acidity were studied in both organic and mineral horizons. The results indicate that WTH lowered effective cation exchange capacity and base saturation, particularly in the humus layer. The pools of exchangeable Al and Fe were increased in the humus layer whereas the amount of exchangeable Ca decreased in both layers. WTH also resulted in lower Ca/Al-ratios across the sampled layers. Treatment did not have a significant effect on pH, total pools of elements or on the C/N-ratio of the soil. The results suggest that although the stand possesses significant pools of nutrients at present, WTH, if continued, could have long-term effects on site productivity.

## Effects of forest biomass harvesting on hydrological processes and leaching of nutrients

Eero Kubin<sup>1</sup>, Tanja Murto<sup>1</sup>, Jiri Kremsa<sup>2</sup>

<sup>1</sup>Finnish Forest Research Institute, Muhos Unit, Muhos, Finland

<sup>2</sup>Czech Technical University in Prague, Faculty of Civil Engineering, Department of Hydraulics and Hydrology, Prague, Czech Republic

The use of forest biomass for energy is becoming a more and more prominent part of forest management in Finland. In addition to harvesting logging residues, stumps are also uplifted for energy, the annual area currently reaching up over 10 000 ha. Because of good energy quality and other benefits, the stump harvesting area is rapidly increasing. In order to obtain more understanding about possible risks to water quality, a new project was launched to evaluate hydrological processes, nutrient leaching and other environmental effects.

The study was carried out in three phytogeographical areas in Finland. The treatments, repeated with three replicates on each location, were: 1) Uncut control 2) No logging residue removal, patch mounding and spruce planting 3) Clear-cut, 70 % logging residue removal, patch mounding and spruce planting 4) Clear-cut, 70 % logging residue removal, stump removal retaining 25 stumps/ha, patch mounding, spruce planting 5) All stumps and logging residues harvested. For monitoring groundwater, altogether 249 wells were set before cutting in 2006 after radar scanning of the groundwater table. In 2010 catchment areas from north-eastern Finland were also implemented into the project. Clear-cutting and subsequent stump harvesting result in nitrate leaching to the ground water more than other elements. Increased leaching started a year after harvesting and still continues. In addition to leaching, hydrological processes were evaluated with groundwater and precipitation-runoff models applied to the experiment areas. In the conference the experimental layout and results will be discussed in the context of utilizing boreal forests.

## Soil biological activity in eucalyptus and poplar SRC

Nicolas Nguyen<sup>1</sup>, Alain Berthelot<sup>2</sup>, Thierry Fauconnier<sup>1</sup>

<sup>1</sup>FCBA Sud-Est, Grenoble, France, <sup>2</sup>FCBA Nord-Est, Charrey-sur-Saône, France

Short Rotation Coppices (SRC) are expected to be developed significantly in order to meet future requirements in renewable energy. The question of the impacts of SRC on soil is regularly addressed. A synchronic soil study was made in 2008 from three different sites in south-west France, gathering two different SRC species (poplar and eucalyptus) aged more than 15 years and cultivated under a typical 10 year rotation pulp scheme, compared to adjacent set-asides and annual crops. The focus was particularly on Soil Organic Matter (SOM) and soil biological activity under these crops. The SOM was higher in set-aside lands and SRC than in annual crop but it was difficult to distinguish the effect of the species on this parameter. The C/N ratio was lowest in the annual crop and highest in the eucalyptus plot. The microbial biomass was strongly linked with the SOM content and the microbial activity correlated best with C/N ratio and pH. The C mineralization was clearly correlated with SOM content, in contrast to N mineralization, which could not be explained by any other variable. Further investigations must be made on the future silvicultural scenarios that will be applied for energy purposes. The agricultural sector is investigating shorter rotation systems than the usual 10-year pulp rotation and it is possible that whole-tree harvesting systems will be developed which would entail increasing nutrient exports, with consequent needs for compensatory fertilization.

## Enzyme activities in soil profile of two beech forests on Campania Apennines

Stefania Papa, Antonella Pellegrino, Antonietta Fioretto

Second University of Naples, Department of Life Science, Caserta, Italy

Soil organic matter (SOM) is a key component of terrestrial ecosystems and it is functionally and structurally integrated into basic ecosystem processes. Therefore, it is very important to understand the mechanisms that determine the decomposition and accumulation rates of SOM in the soil in order to predict responses to climate change. Forest soils in Europe act as sinks of organic C, but it is not clear how much longer this can be maintained. Beech forests cover a wide area of European lowlands but, in Italy, they cover the Alps and Apennines generally above 600 and 1000 m a.s.l., respectively. The focus of this study was to analyse and compare cellulase, xylanase and chitinase activities along the soil profile (organic horizon and mineral soil until 40 cm depth) of two beech forests on the Campania Apennines. The experimental sites were located within the Regional Park of Monte Matese (CE) and on the Raiamagra Mountain (AV), respectively. Both soils arise from a calcareous bedrock covered by pyroclastic material and had deep profiles. The trees were 70-80 years old. The two sites did not show significant differences of SOM content along the profile, but the enzyme activities were generally much higher in the Raiamagra than in the Monte Matese soil, particularly in the decomposition continuum of the organic horizon. Only cellulase activity in the mineral soil did not differ between the forest sites. Some other physical, chemical and climatic characteristics were also compared. In addition, the relationship between enzyme activities and active fungal biomass was investigated.

## Getting quantitative: how much slash should remain on site to sustain tree growth?

<sup>1</sup>David Paré, Annie Desrochers<sup>2</sup>, Christian Messier<sup>3</sup>, Evelyne Thiffault<sup>1</sup>, Nelson Thiffault<sup>4</sup>, Amélie Trottier-Picard<sup>5</sup>

<sup>1</sup>Natural Resource Canada, Canadian Forest Service, Québec, Canada, <sup>2</sup>Université du Québec en Abitibi-Témiscamingue, Centre d'étude de la Forêt, Amos, Canada, <sup>3</sup>UQAM, Centre d'étude de la forêt, Montreal, Canada, <sup>4</sup>Ministère des Ressources naturelles et de la Faune, Direction de la recherche forestière, Quebec, Canada, <sup>5</sup>Université du Québec en Abitibi-Témiscamingue, Centre d'étude de la Forêt, Amos, Canada

An experimental design was set up to test the effects of various levels of slash (forest harvest residues) on soil and tree growth and to elucidate the mechanisms that are operating. It included four sites located under different soil and climatic conditions in the boreal forest. Based on estimates of the average level of biomass that should remain on site when the stand is harvested by stem-only harvesting (1 load), the experimental design included the following gradient of slash loading: no slash, half load, full load, double load. Various combinations of fertilisation, herbicide and plastic mulches were also used as treatments designed to simulate and isolate specific mechanisms by which slash affects plant growth: providing nutrients, shading the soil, and limiting the growth of competing plants. The design included different tree species with contrasting traits, some of the conservative type such as black spruce and others of the acquisitive type such as hybrid poplar. The results indicated slash effects that were linear with dose application, but only on sites where plant competition is important or on very poor soil. The beneficial effect of slash on soil nutrient and on the reduction of plant competition was apparently not as optimal as standard silvicultural techniques such as fertilization and vegetation control. Quantifying the effect of slash on soil conditions and tree development may help to arrive at recommendations on the amount of slash that should be left on site to maintain ecosystem functions, and also on mitigation alternatives.

## Forest bioenergy climate impact can be improved by allocating forest residue removal

Anna Repo<sup>1</sup>, Riina Känkänen<sup>1</sup>, Juha-Pekka Tuovinen<sup>2</sup>, Riina Antikainen<sup>3</sup>, Mikko Tuomi<sup>1</sup>, Pekka Vanhala<sup>1</sup>, Jari Liski<sup>1</sup>

<sup>1</sup>Finnish Environment Institute, Natural Environment Centre, Helsinki, Finland, <sup>2</sup>Finnish Meteorological Institute, Helsinki, Finland, <sup>3</sup>Finnish Environment Institute, Consumption and Production Centre, Helsinki, Finland

Bioenergy from forest residues can be used to avoid fossil carbon emissions, but removing biomass from forest reduces carbon stocks. The magnitude and longevity of these carbon stock changes determine how effective forest bioenergy is in reducing GHG emissions and mitigating climate change. We estimated the variability of GHG emissions and consequent climate impacts resulting from producing bioenergy from stumps, branches and thinning wood in Finland, and the contribution of the variability in key factors, i.e. forest residue diameter, tree species, geographical location of the forest biomass removal site and harvesting method, to the emissions and climate impacts. The GHG emissions and the climate impacts estimated as changes in radiative forcing were comparable to fossil fuels when bioenergy production was initiated. Both decreased over time because forest residues were predicted to decompose, releasing CO<sub>2</sub> even if left in the forest. Both were mainly affected by forest residue diameter and climatic conditions of the collection site. Tree species and the harvest method of thinning wood had a smaller effect on the emissions. The largest reduction in the climate impacts after 20 years, up to 62%, was achieved when coal was replaced by the branches collected from southern Finland; the smallest reduction of only 7% was gained by using stumps from northern Finland instead of natural gas. After 100 years the corresponding values were 77% and 21%. The choice of forest residues collected affects critically the magnitude and the timing of emission reductions and climate benefits that a country can achieve with forest bioenergy.

## Nurse crops: long term effects on forest soil nutrient and carbon pools

Hendrik Stark<sup>1</sup>, Arne Nothdurft<sup>2</sup>, Jürgen Bauhus<sup>1</sup>

<sup>1</sup>Freiburg University, Institute of Silviculture, Freiburg, Germany

<sup>2</sup>Forest Research Institute Baden-Württemberg, Department of Biometrics and Informatics, Freiburg, Germany

Nurse crops of fast-growing tree species can be a silvicultural approach for forest restoration and provide additional biomass for bioenergy purposes. We hypothesize that the use of early successional tree species with rapid growth rates will benefit soil fertility and carbon storage relative to conventional reforestation practices. In 1990, 16 monoculture plots of birch (*Betula* spp.), aspen (*Populus* spp.), and oak (*Quercus* spp.) were established at two different sites, and in 1996 oak was planted beneath the sheltering nurse crop canopies of birch and aspen to form the long-term future forest stand. In 2010 we determined nutrient and carbon pools in the mineral soil and soil organic layers. During 2011 we assessed nutrient and carbon pools in above-ground harvestable biomass, differentiating between stem wood, stem bark, and branches. Pools of base cations (Ca, K, Mg, Na) in the upper mineral soils (0 - 10 cm and 10 - 30 cm) were significantly (ca. 50%) higher under nurse crops compared to oak monocultures, but there were no significant differences in soil carbon storage. Here we link our data on nutrient and carbon pools from soils with data from above-ground woody biomass to see whether nurse crops may also have influenced the ecosystem pools of nutrients in the biochemical cycle through reduced leaching or uptake from deep soil horizons. In addition, the effects of harvesting at different intensities (whole tree harvest, stem only harvest, debarking) on these ecosystem pools will be assessed.

## Results from intensive harvesting field trials: how does Europe compare with North America?

Brian Titus<sup>1</sup>, Robert Fleming<sup>2</sup>, C.T. (Tat) Smith<sup>3</sup>, Gustaf Egnell<sup>4</sup>, David Morris<sup>5</sup>, Evelyne Thiffault<sup>6</sup>, W.L. (Bill) Mason<sup>7</sup>, Elena Vanguelova<sup>8</sup>, Rona Pitman<sup>8</sup>, Antti Wall<sup>9</sup>, Andy Scott<sup>10</sup>

<sup>1</sup>Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, Canada, <sup>2</sup>Great Lakes Forestry Centre, Canadian Forest Service, Natural Resources Canada, Sault Ste. Marie, Canada, <sup>3</sup>Faculty of Forestry, University of Toronto, Toronto, Canada, <sup>4</sup>Department of Forest Ecology and Management, SLU, Umeå, Sweden, <sup>5</sup>Centre for Northern Forest Ecosystem Research, Ontario, Ministry of Natural Resources, Thunder Bay, Canada, <sup>6</sup>Canadian Forest Service, Laurentian Forestry Centre, Natural Resources Canada, Sainte-Foy, Québec, Canada, <sup>7</sup>Northern Research Station, Forest Research, Midlothian, United Kingdom, <sup>8</sup>Centre for Forestry and Climate Change, Forest Research, Farnham, United Kingdom, <sup>9</sup>The Finnish Forest Research Institute, Silmäjärventie, Kannus, Finland, <sup>10</sup>Southern Research Station, USDA Forest Service, Normal, United States

A range of field trials have been established in various parts of the world to assess the environmental impacts of intensive forest biomass removals. Whereas some trials were designed to address bioenergy-related questions, others have different objectives but include some relevant treatments. Meta-analysis increases the amount of information that can be extracted from a range of field trials. The types of analyses that can be carried out with meta-analysis can be used (within the limits of the data available) to test hypotheses and generate empirical results to feed into our scientific understanding - and from there directly into development of guidelines and standards. Building on their experience with meta-analysis in the LTSP network (Fleming et al. (2006) Can. J. For. Res. 36: 529-550), researchers have recently embarked on a program to apply meta-analysis to intensive harvesting trials in order to test hypotheses that tree growth response to intensity of biomass removals is dependent on factors such as tree species (conifer vs. hardwood, genus and genus groups, fast-growing vs. slow-growing), ecosystem type, climate, site index, soil properties (time since glaciation, texture, soil moisture, major nutrients, base cations, acidity), and surface and bedrock geology. The literature usually only reports site-level mean values, and unpublished plot-level data is also being used to increase the power of the meta-analysis. Preliminary results comparing Europe and North America will be presented.

## Long-term sustainability of forest soil fertility assessed by nutrient input-output budgets and a modeling approach

Gregory van der Heijden<sup>1</sup>, Arnaud Legout<sup>1</sup>, Manuel Nicolas<sup>1</sup>, Jacques Ranger<sup>1</sup>, Etienne Dambrine<sup>3</sup>

<sup>1</sup>INRA ~ BEF ~ Nancy ~ France, <sup>2</sup>ONF, Département recherche, Fontainebleau, France, <sup>3</sup>INRA, Carrel, Chambéry, France

Since the 1980s, atmospheric deposition acidity has generally decreased in European forest ecosystems. However, at many sites, little or no sign of recovery has yet been observed. Concerns are rising about the sustainability of these ecosystems because of reduced nutrient inputs in atmospheric deposition and the increase in biomass harvesting to supply bio-energy. Nutrient input-output budgets are widely used tools to diagnose the forest ecosystem nutrient status and the changes in soil fertility over time. This approach was applied to two different poor forest ecosystems: a 60-year old silver fir stand in the Vosges Mountains (Lorraine, France) and a 30-year old beech stand in the Morvan Mountains (Burgundy, France). The monitoring data of the silver fir stand was used to calibrate a process-orientated biogeochemical model (NuCM) over a 12 year period which was used to simulate the consequences on soil fertility of two main scenarios and their combinations: constant or reduced atmospheric deposition, and traditional or whole-tree harvesting. Although the acid deposition load has been decreasing since the 1990s, input-output

nutrient budgets showed an ongoing acidification. The model NuCM was successfully calibrated and scenarios were implemented. A slight recovery was simulated when deposition was maintained constant but combined acid and nutrient atmospheric deposition reduction delayed recovery. Moreover, whole-tree harvesting drastically decreased soil fertility compared to traditional silviculture. Hence, biomass harvesting in forests on poor soils may hinder recovery in the future.