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Finland's Forests in Changing Climate

Jari Parviainen, Elina Vapaavuori and Annikki Mäkelä (eds.)

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Abstract

This issue of Metla’s Working Papers is based on the Finnish COST Action FP 0707 Expected Climate Change and Options for European Silviculture (ECHOES) country report published in 2009 compiled with updated information. The main goal was to review the state-of-the-art of climate change issues related to Finland’s forests.

The main effects of expected climate change in Finland’s boreal vegetation zone are: The growing season in the northern coniferous zone is likely to lengthen; forest growth may increase; wind damage will become more prevalent; and in the temperate zone insect pests are expected to spread northwards, possible causing damage on a massive scale. A consequence of climate change could be a northwards shift in the tree-line zone and the gradual extinction of certain species in forests in tree-line areas in the northern polar region.

Good and timely forest management is the main way of improving the ability of forests to adapt to climate change. In forest regeneration, depending on stand conditions, both natural regeneration as well as planting and seeding with improved genetic breeding material are recommended. Safeguarding environmental conditions on the site by wooden biomass extraction need more attention and research, while the soil nutrient loss and water protection have been considered as environmental threats by the increased extraction of wooden biomass. Awareness of the importance of forest management in adapting to climate change must be increased among members of the public, forest owners and those responsible for forest management.

In Finland strong emphasis has been put on the mitigation issues by promoting the use of wood. These actions include the increased use of wood-based bioenergy (including biofuels) and wooden construction. In the land use, land-use change and forestry (LULUCF) sector Finland has a sink of carbon that amounted to -35 million tons of CO2 during 2008. That sink originated mainly from a sink in the tree biomass, which is driven by the amount of annual fellings – i.e. the sink is greater when annual fellings are less.

Keywords
Climate change, forests, impacts, adaptation, mitigation

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Preface

This issue of Metla's Working Papers is based on the Finnish COST Action FP 0707 ECHOES (Expected Climate Change and Options for European Silviculture) country report published in 2009 compiled with the latest updated information. The main goal was to review the state-of-the-art of climate change issues related to Finland's forests. The report compiles the latest scientific information, research results as well as practical measures and actions regarding impacts and adaptation of forests to changing climate and the role of forests in mitigating climate change.

Research on the relation between climate change and forests has a long tradition in Finland. Since the first large scale research programme SILMU (Finnish Research Programme for Climate Change, 1990–1995), numerous climate change programmes and research projects funded by the Academy of Finland, the Ministry of Agriculture and Forestry, the Ministry of the Environment, the Ministry of Employment and the Economy and the Finnish Funding Agency for Technology and Innovation (TEKES) have been carried out.

In the name of the Finnish country delegates of the COST Action FP 0707 ECHOES I would like to take the opportunity to thank all scientists from the Finnish Forest Research Institute (Metla), the Universities of Helsinki and Eastern Finland who have contributed to this publication. We wish that this publication can give a balanced and analytic overview on the timely important issue of forests and climate change.

Acknowledgements: Many thanks to Prof. Pasi Puttonen, Research Director Metla, who has carefully reviewed the texts and has made several suggestions and notes for improving the content of this Working Paper.

Prof. Dr. Jari Parviainen
Regional Director
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Summary

The long-term climate and energy strategies have been set by the Government in Finland for 2001, 2005 and 2008. The latest strategy was accepted by the Government on 6 November 2008. This strategy covers climate and energy policy measures in great detail up to 2020, and in brief thereafter, up to 2050. The main goal is to decrease energy consumption and stimulate intense growth in the share of renewable energy sources. Meeting the obligation of renewable energy requires an intense increase in the use of wood-based energy, waste fuels, heat pumps, biogas and wind energy. The Climate Change Adaptation Strategy and Strategy for Invasive Alien Species are examples for the detailed precautionary actions against the expected climate change.

The main instrument for implementation of the forestry issues concerning also the climate change commitments is the National Forest Programme. The Finnish Government approved on 27 March 2008 the two major programmes that guide the use of Finnish forests into the future: a major update of the National Forest Programme, extending now to 2015, and its 'sister programme' Forest Biodiversity Programme for Southern Finland (METSO) 2008–2016. The purpose of simultaneous approval was to ensure that more effective commercial use of forests under changing climate will be balanced with enhanced biodiversity in the Finnish forests. Together they are expected to promote the widest range of different livelihood and income opportunities that Finnish forests can provide to the people.

The main effects of expected climate change in Finland's boreal vegetation zone are: The growing season in the northern coniferous zone is likely to lengthen; forest growth may increase; wind damage will become more prevalent; and in the temperate zone insect pests are expected to spread northwards, possible causing damage on a massive scale. A consequence of climate change could be a northwards shift in the tree-line zone and the gradual extinction of certain species in forests in tree-line areas in the northern polar region.

Good and timely forest management is the main way of **improving the ability of forests to adapt** to climate change. In forest regeneration, depending on stand conditions, both natural regeneration as well as planting and seeding with improved genetic breeding material are recommended. Safeguarding environmental conditions on the site by wooden biomass extraction need more attention and research, while the soil nutrient loss and water protection have been considered as environmental threats by the increased extraction of wooden biomass. Awareness of the importance of forest management in adapting to climate change must be increased among members of the public, forest owners and those responsible for forest management.

In Finland strong emphasis has been put **on the mitigation** issues by promoting the use of wood. These actions include the increased use of wood-based bioenergy (including biofuels) and wooden construction. In the land use, land-use change and forestry (LULUCF) sector Finland has a sink of carbon that amounted to -35 million tons of CO_2 during 2008. That sink originated mainly from a sink in the tree biomass, which is driven by the amount of annual fellings – i.e. the sink is greater when annual fellings are less.

Key messages

Climate change impacts on Finland‘s forests

The annual mean temperature is predicted to increase by 2–6 degrees by the end of 2100; increase in winter months (3–9 degrees) and summer months (1–5 degrees). Scientifically sound data of climate change effects on forest growth is obtained from phenological observations. Expected impacts of climate change are:

1. Longer growing season having a positive effect on forest growth in particularly in northern Finland and on peatland forests. The forest growth increase up to 20–50% depending of species.

2. Increasing risk of wind damages, although overall predicted increase of wind speed is smaller than in Central Europe, southern Sweden or Denmark due to Finland's sheltered geographical location to prevailing southwestern stormy winds in northern Europe; older Norway spruce stands are especially vulnerable when compared to Scots pine and Birch.

3. Risks of biotic damages due to forest pathogens (Heterobasidion) and pest insects (i.e. Ips typographus) are expected to increase; the spread of new invading species from the South will inevitably increase.

4. The northern timberline is assumed to shift northward in the long run

Adaptive silvicultural measures

Good and timely forest management is the main way of improving the ability of forests to adapt to climate change.

1. Preventative measures such as the timely recognition and removal of dying trees and keeping material that could cause forest fires or insect pests down to a minimum are part of forest management.

2. In forest regeneration, depending on stand conditions, both natural regeneration as well as planting and seeding are recommended. Natural regeneration should be favored if the soil and site conditions are suitable, while local native tree species are expected to be most suited to adapting to local climate change because of their genetic make-up. The use of seeds and seedlings of forest breeding materials could be favored on sites where the phenotypic plasticity, genetic diversity and genetic gains associated with wood production and quality are foreseen.

3. Mixed tree species structures should be favoured by management of young stands, as the presence of various tree species with different characteristics reduces the risks to forests.

4. Forest management contingency plans should be developed with funding options for covering any damage and operational models so that the wood working industry is prepared for the detrimental effects of sudden and extreme weather caused by climate change and the damage it causes to forests.

Contribution of Finland‘s forests to mitigation
Finland’s forests (including peatlands) sequestrated in 2008 35 million tons of CO_2.

1. Finland’s forests will remain a clear carbon sink during the next 30 years if annual cuttings do not exceed 50–60% of annual increment. The increase of overall use of wood-based energy and the volume of forest chips used for energy production to 8–12 million m^3 per year will diminish the carbon sink of forests less than 10%. In 2008 renewable energy sources provided 28% (387 PJ) of Finland’s total energy consumption of which wood-based fuels accounted for 21% of which 49% was covered by waste liquors from the forest industries and 51% by solid wood fuels, mainly heat and power plants and the use of firewood in small-sized dwellings.

2. Harvested wood products make up a considerable carbon store that has gradually increased since the 1990s, thus making up a carbon sink. Recycling of solid wood products is important from the CO_2 emission point of view.

3. Finland produces approximately 2 cubic metres of wood products (mostly long term carbon storage), and approximately 5 tons of pulp and paper products (mostly short time carbon storage) per capita per year.

4. The Finnish Government has promoted both domestic use and export on timber products, and timber construction through various campaigns and programmes over the last 20 years. The implementation of the governmental programmes have provided several imposing examples of timber construction and several multi storey residential house timber frame construction projects.

1. Finnish forests and forest management

Jari Parviainen[1], Sinikka Västilä and Silja Suominen[2]

1.1 Geographical conditions for forest growth

The forest cover in Finland is more extensive than in any other European country. Three fourths of the land area, some 23 million hectares, is under forests. In addition, there are land areas under management where there are only few trees, such as open peatland and areas of exposed bedrock, over 3 million hectares altogether.

Owing to conditions in the north, forest management in Finland takes place in climatically exceptional conditions. Geographically Finland lies in an intermediate zone between maritime and continental climates, belonging for the most part to the boreal vegetation zone (see Fig. 1).

Figure 1: Vegetation zones in Northern Europe. Source: Ahti, 1968

Because of the warming effect of the Gulf Stream, however, the climate of Finland is in many respects more favourable than in corresponding areas in Russia and Canada. Because Finland is over 1,100 km long on the north-south axis, conditions for growth vary considerably between the southern and northern parts of the country. Towards the north, the climate gets increasingly colder and more humid. The growth period in southern Finland is about five months, and in the north it is three months. The average increment of growing stock in southern Finland, 6.1 m^3ha-1yr-1, is twice as much as in northern Finland.

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The number of plant species in Finnish forests is small compared to the boreal zone in North America, for example, or the temperate zone in Central Europe. This is because of the high European mountain ranges running east-west, which prevented the return of plants to the north after the last Ice Age. There are only four coniferous tree species native to Finland, and fewer than 30 deciduous trees and arborescent shrubs. The major-ity of forests in Finland are predominantly coniferous, with broadleaves often growing in mixed stands.

The timberline in northern Lapland is as northern boreal zone often several dozen kilometres wide. To the north of the timberline, the land is a mosaic of exposed ground, shrub and struggling trees or trees less than two metres tall. On the southern edge of the zone, the timberline is reached, where the height of trees exceeds two metres. To prevent the timberline from receding further south, an Act on Protective Forests was adopted as far back as 1922 to prevent unplanned use of forests and consequent shifting of the timberline. Now these provisions are incorporated in the Forest Act.

Access to and recreational use of forests is free for all in Finland. The so-called Everyman's Right (right of public access) bestows on all people a free right to use land owned by others to travel on foot, skis, bicycle or horseback, provided that they do not cause any damage. Other activities freely permitted on other people's land are temporary camping as well as picking wild non-protected flowers, berries and mushrooms. The use of motor vehicles and making fire in forests, however, always require permission from the landowner. Everyman's Right may not be exercised in such a way as to cause any disturbance or damage to the landowner.

The most common forms of recreation in forests are hiking, camping, orienteering and cross-country skiing. Forests also provide a setting for relaxation, meditation and communing with nature. The most important non-wood products which have an economic value are game, berries, mushrooms and lichen. The greatest value in economic terms is game, particularly moose.

1.2 Forest ownership structure and wood resources

In the principal growth area, southern and central Finland, about 3/4 of all forests are in private ownership. In some areas, the share is over 90%. State forests are for the most part situated in northern and eastern Finland. The percentage of growing stock volume, annual increment and fellings in private forests accounts for between 64 and 86% of the total. Private forests produce over 80% of roundwood purchased annually by the forest industry in Finland. Private forestry is a key issue for the entire forest sector in Finland.

In Finland private forest holdings are mostly in the hands of families. The holdings are quite small. There are only about 17,000 private forest holdings of over 100 hectares. The number of farms whose forest holdings are less than two hectares is 443,000. The average size of holdings is 36 hectares.

There are more forest owners than there are holdings, because spouses often have joint ownership of the holding. As estates and pools have an average of four stakeholders, the number of people owning at least two hectares of forest is estimated to be about 920,000.

The fact that forests remain in the hands of families, passed on in inheritance from one generation to the next, is an indication of the predominance of rural habitation. With sweeping structural changes in society, however, the composition of forest owners is also changing. The number of forest owners grows when holdings are split up in conjunction with the distribution of estates. About 63% of forest owners live in areas of scattered settlement, 18% in built-up areas and small towns, and 19% in towns with more than 20,000 inhabitants.

Long-term sustainable wood production in private forests has been secured by forest legislation since 1886. The obligation to regenerate the forest after final fellings has been and remains to this day the basic principle of the law.

Government actions, legislation, national and regional forest programmes, and changes in silvicultural operations as well as the actions of and co-operation amongst private forest owners have all supported the attainment of the goal of sustainability. The annual increment of growing stock (99 mill. m³) has over the last 30 years exceeded the drain by about one quarter. The standing timber stock (2201 mill. m³) in Finland today is greater than it has ever been during the time Finland has been an independent country, i.e. since 1917.

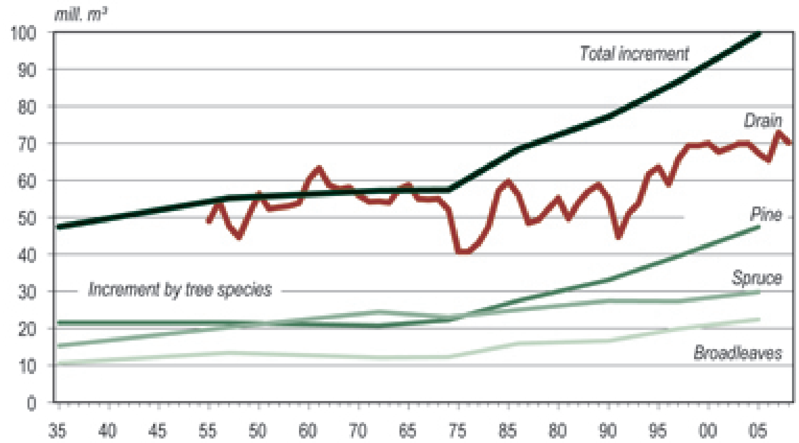

Figure 2: Annual increment of growing stock (1935–2008) and drain (1949–2008). Source: Finnish Statistical Yearbook of Forestry 2009.

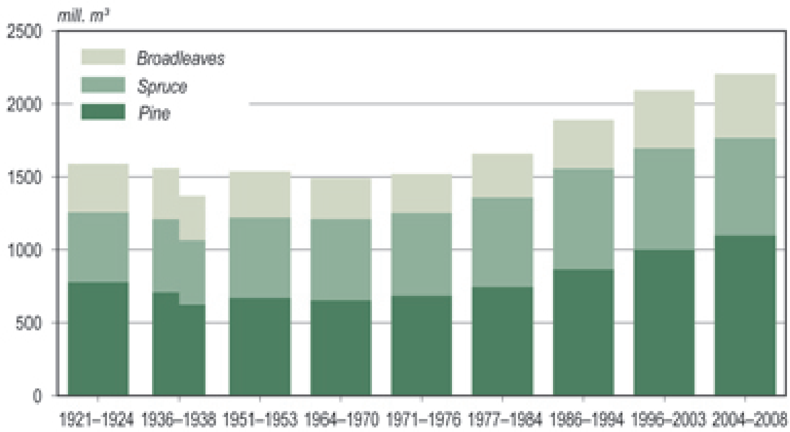

Figure 3: Growing stock volumes on forest and scrub land 1921–2008. Areas ceded to the Soviet Union in 1944. Source: Finnish Statistical Yearbook of Forestry 2009.

1.3 Forest management development and methods

Hunting and the barter of furs were the main livelihoods in the area for thousands of years. Agriculture was first introduced in the form of slash-and-burn cultivation 4000 years ago, and developed into permanent agriculture 3500 years ago. Along with the spread of slash-and-burn cultivation, human settlements spread to central and eastern Finland, especially from the 16th century onwards. In the 18th and 19th centuries, forests in Finland were also used for tar production, the needs of the mining and shipbuilding industries, for home use and construction, as well as for agriculture and grazing within the slash-and-burn culture.
Depending on the area, 50–75% of forests in southern Finland had been treated for slash-and-burn cultivation by the beginning of the 20th century. Since then, the greatest factor affecting the structure of forests has been the use of wood as raw material for the forest industry.

Owing to the various uses of forests, there are no completely untouched natural forests in Finland. Remnants of natural forests are only encountered in certain protected areas in Lapland and eastern Finland. However, there are no intensively managed tree plantations, because forest management in commercial forests makes use only of native tree species, and the development of mixed stands is actively promoted in management and harvesting.

The aim of forest management is to safeguard the production of high-quality roundwood, the biodiversity of forests and the preconditions for the multiple functions of forests.

Forest stands in Finland are classified according to their naturally occurring plant communities, based on a forest site type classification developed by A.K. Cajander in the early 20th century. The surface vegetation at each individual site indicates the properties of the site and also the growth potential of trees. There are six main site types in southern Finland, and management and fellings are directed according to their properties. The average size of managed stands in southern Finland is about 1.2 hectares, which is parallel to the average regeneration stand size in Germany, Austria and France.

Forestry in Finland is based on the management of even-aged stands. Management is clearly divided into two phases, growth and regeneration. Depending on the tree species, geographical location and site characteristics, the recommended growth period varies from 50 to 120 years. In special sites, such as landscape areas and forest parks, cultural sites or forests dedicated for recreational use, uneven-aged management systems is also used. In an uneven-aged system of management, different growth stages are concurrent, and stands are managed with single-tree selection.

In silvicultural management the young and seedling stands are managed by cleaning and thinning. Young and advanced thinning stands are managed by intermediate fellings, which are carried out 1–3 times during the growth cycle of the stand. Each time 25–30% of the trees in the stand are removed. The purpose of intermediate fellings is to direct the growth of the stand in favour of the best trees, to encourage their growth and thereby produce harvesting income already prior to regeneration felling.

By natural regeneration, seed or shelterwood trees are left standing to seed the site. Sometimes natural seeding may take place by trees on the forest edge surrounding the regeneration area. Artificial regeneration by seeding or planting is preceded by final felling. The success of regeneration is ensured by clearing the site and exposing mineral soil with mechanical soil preparation prior to regeneration, and ensuring that grasses will not endanger the early development of seedlings.


Natural regeneration is most successful in sites where a layer of humus over a mineral soil and surface vegetation do not prevent germination and later development of saplings (left). Berry collecting in Finland is allowed under the principle of Everyman's Right. Collecting berries is also an important bond to forests and nature, particularly for people living in population centres (right). Photos: Metla/Erkki Oksanen

The goal is to create a fully productive stand with a suitable species composition in a reasonable period of time. The majority of forests in Finland are regenerated naturally, with about 30% planted or artificially seeded. However, even such artificially regenerated stands have great numbers of naturally regenerated trees as well.

Trees are for the most part harvested using the Nordic cut-to-length system (CTL): logs are debranched and cut to appropriate length according to their use on site. Branches and crowns are left in the forest to maintain an even nutrient cycle. There is a new trend to harvest branches and crowns in spruce stands to be used as fuel. The CTL system of cutting is particularly suited to conditions in Finland as the land is fairly level. Cuttings are carried out mostly in winter, when the ground is frozen and covered by snow to minimise any detrimental effects of cutting on the soil and trees left standing.

1.4 Safeguarding and protecting forest biodiversity

The protection of most valuable forests and ensuring the biological diversity in commercial forests are issues which have attracted special attention in recent decades. Owing to many protection programmes and decisions, the area of protected forests has increased three-fold in Finland over the past 30 years. The total area of protected forests is currently 2.1 million hectares, or 9.0% of all forest land (2005). The total area of protected forests and forests under restricted use is 2.9 million hectares, or 12.6% of all forest land.

The share of strictly protected forests in Finland is among the largest in Europe. Most of the protected areas are in northern Finland. In order to promote voluntary protection measures in privately owned forests Forest Biodiversity Programme for Southern Finland (METSO) in 2002–2007 was created. The goal of the programme was to discover new and cost-effective alternatives for safeguarding the biodiversity of forests. Such alternative measures include co-operation networks of forest owners, natural values trading in and competitive tendering for ecologically valuable features in forests. Results of the METSO programme have encouraged to extend the programme until 2011. The METSO programme also incorporates the restoration management measures in already established conservation areas to enhance their biodiversity.

The Natura 2000 network in Finland comprises 1,860 protected sites whose total area is 4.9 million hectares, of which 3.6 million hectares, or three fourths, are land areas. The European Commission approved the Natura 2000 areas of Finland in 2003 (polar and alpine zone) and in 2005 (boreal zone).

Biological diversity in commercial forests is promoted by means of forest legislation, recommendations and instructions for best practices in forest management, as well as conservation agreements and forest certification. The Nature Conservation Act lists nine protected habitat types, three of which are found in forests. The Forest Act contains definitions of habitats of special importance (key biotopes) whose natural features must be conserved. According to surveys conducted by the Forestry Centres, key biotopes account for 77,000 hectares, or 0.5%, of forestry land in private forests. In commercial forests owned by the forest industries, such habitats account for 0.7% of the area; the percentage in State-owned forests administered by Metsähallitus is 1.0%.

Following recommendations, old broadleaved trees are left standing in the forest in fellings, and decayed trees or other trees that have special biological value are also preserved. Following forest certification requirements, a certified site must have as minimum of 5–10 such trees per hectare. Certification also involves many other measures designed to increase biodiversity, such as increasing prescribed burnings and maintaining water systems.

About one half of the approximately 43,000 species known in Finland live in forests. The occurrence of endangered species is monitored regularly. According to the most recent survey (2000), there are 1505 endangered plant and animal species in Finland, of which 37% are forest species. While the majority of forest species remain viable also in commercial forests, some species depend on natural habitats or decayed or burnt wood for their survival.

1.5 Economic and social importance of forests and forest industries

Forestry and forest industries account for approximately 6% of the GDP. Relative to its size, Finland is more dependent on forests and the forest industry than any other country in the world. As a consequence, Finland has accumulated an expertise in forestry and industrial manufacturing of forest products that is unique in Europe. For instance, 80% of paper industry engineers in Europe are trained in Finland, as are a considerable number of harvester drivers proficient in the Nordic CTL harvesting system.

A couple of decades ago the number of forest industry companies was still fairly large in Finland. The pressures of internationalisation, a reorientation of production in paper industry and extensive need for new investments triggered an intense process of change in the field of forest industry in the early 1980s. Through acquisitions and mergers, this has led to the creation of international forest industry corporations, some of these among the largest in the world. The three largest corporations account for more than 90% of all production in the paper and pulp industry, while the corresponding figure two decades ago was about 30%.

Most of the products of the Finnish forest industries are exported. The most important market is the European Union. Exports there account for nearly 70% of the total exports of the sector. The major export countries are Germany, Great Britain, the United States, France and Spain.

The share of forest industry products in the value of all Finnish export of goods is about 20%. Products of the pulp and paper industry account for about three fourths of the exports of all products of the forest industry, and the share of paperboard and sawn timber is about 25%.

Owing to new technology and advanced production processes, emissions of the forest industry to both water and air have been reduced considerably in the last 20 years, even though the volume of production has increased many times over during this period. Although the reduction of emissions into water systems continues to be important, the emphasis on environmental factors has gradually shifted towards the lifecycle of products, efficient use of natural resources, recycling and use of renewable energy.

70% of paper used in Finland is recycled, which is a considerable achievement considering the low population density in the country. Globally, the recycling percentage for paper is an average of 40%.

The forest industry is energy intensive. It uses about one third of all electricity produced in Finland. The main source of energy for the forest industry is bark and sawdust, and black liquor produced in the pulp industry. Of the total consumption of energy by the forest industries, 73% comes from wood-based fuels.

The number of jobs provided by the forest sector has diminished in the past few decades. Forestry and forest industry employ about 4% of all employed people in the Finnish national economy, or about 89,000 persons, three-fourths of whom work for the forest industry. Forestry provides jobs for about 23,000 people, in addition to which a considerable part of silvicultural work in particular is done by private forest owners and their families.

Acknowledgements

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2. Climate change impacts and most susceptible regions of severe impact in Finland

Elina Vapaavuori[1], Helena M. Henttonen[2], Heli Peltola[3], Kari Mielikäinen[4], Seppo Neuvonen[5], Jarkko Hantula and Michael Müller[6]

Key messages

The annual mean temperature is predicted to increase by 2–6 degrees by the end of 2100; increase in winter months (3–9 degrees) and summer months (1–5 degrees). Scientifically sound data of climate change effects on forest growth is obtained from phenological observations. Expected impacts of climate change are:

1. Longer growing season having a positive effect on forest growth in particularly in northern Finland and on peatland forests. The forest growth increase up to 20–50% depending of species.

2. Increasing risk of wind damages, although overall predicted increase of wind speed is smaller than in Central Europe, southern Sweden or Denmark due to Finland's sheltered geographical location to prevailing southwestern stormy winds in northern Europe; older Norway spruce stands are especially vulnerable when compared to Scots pine and Birch.

3. Risks of biotic damages due to forest pathogens (Heterobasidion) and pest insects (i.e. Ips typographus) are expected to increase; the spread of new invading species from the South will inevitably increase.

4. The northern timberline is assumed to shift northward in the long run.

2.1 Future predictions of forest resources for Finland

Since 1970's forest growth and forest volume have increased markedly in Finland (see Figures 2 and 3, page 12). According to the last national forest inventory in 2008 the growing stock volume was 2201 mill. m^3 and annual growth 99.2 mill. m^3. The reasons for the 30% increase of stock volume since 1970's can be attributed to various factors: 1) shift of age distribution of forests towards younger stands, 2) intensified silvicultural practices and 3) increased nitrogen deposition (improving growth). Much of the increased growth can be attributed to the faster growth of younger stands compared to older ones. It is still an open question whether part of the observed increase in forest growth is due to climate change.

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Recent predictions of future forest growth in Finland, using the forest growth, yield and planning model MELA (http://mela2.metla.fi/mela/) suggest increasing growth and yield even if the present climatic conditions are expected in the future (Sievänen et al. 2007). There are several reasons for this, e.g. increasing growing stock (if annual cuttings are less than growth of forests) and changes in tree species dominance and age structure of the forests (more young stands with higher annual growth and yield due to shorter rotations) if the current forest management guidelines are followed.

The growth of boreal forests in the Northern Europe is currently limited mainly by low temperature during the growing season and nitrogen availability. Thus, a warming climate with concurrent increase in atmospheric carbon dioxide concentration [CO_2] (see Figures 4a and 4b, Jylhä et al. 2009) could be expected to increase forest growth in the future.

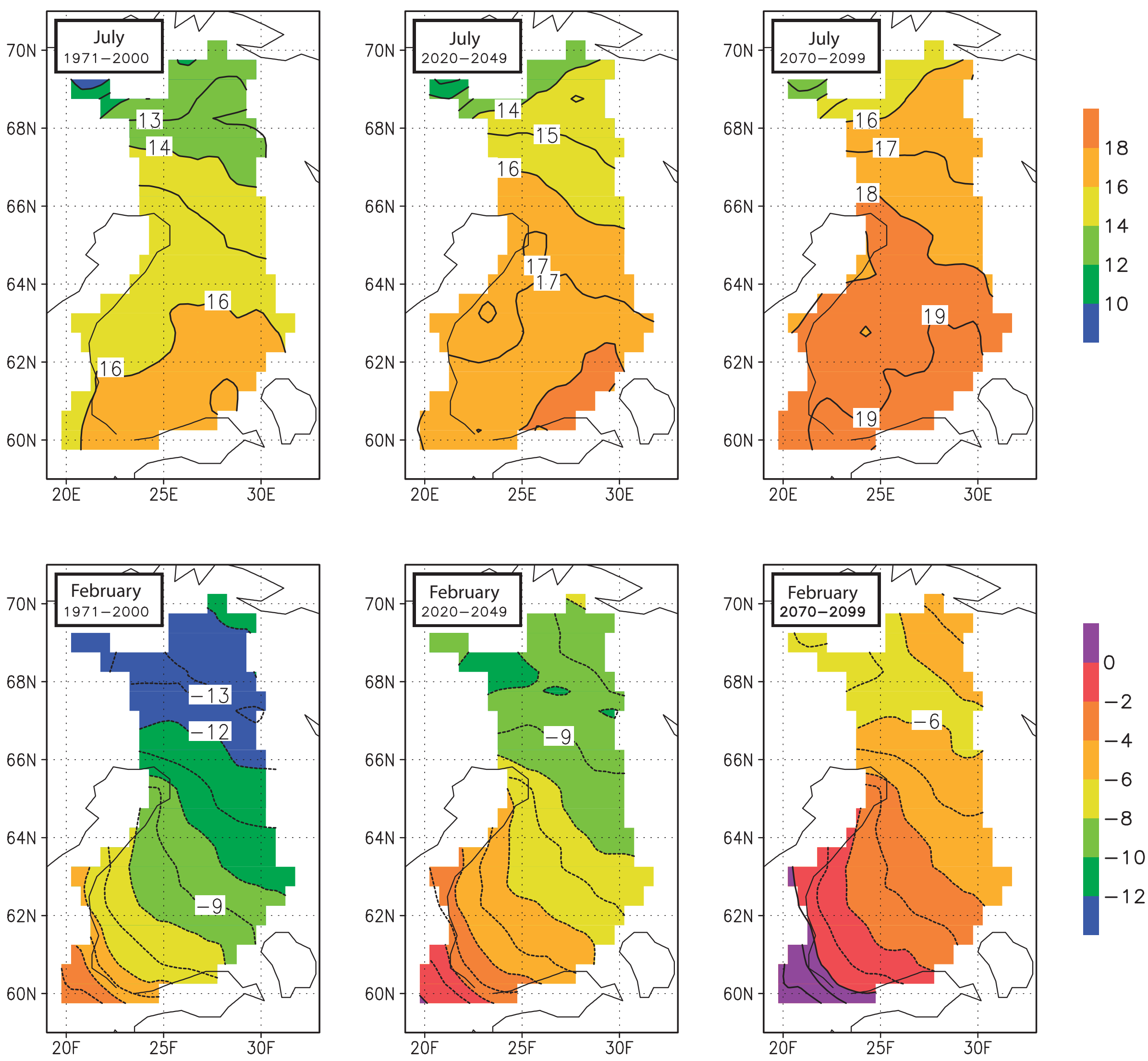

Figure 4 a: Mean temperatures (in ºC) for July (upper panels) and February (lower panels) in Finland for the periods 1971–2000 (left column), 2020–2049 (middle column) and 2070–2099 (right column). For 1971–2000, mean temperatures are derived purely from observations. For the future periods, the model-based best estimate of temperature increase is added to the observational temperatures. Equal weight is given for every one of the 19 global climate models, and the A1B, A2 and B1 greenhouse gas scenarios are considered equally likely. Source: Jylhä et al. 2009. With permission: Kimmo Ruosteenoja (Finnish Meteorological Institute).

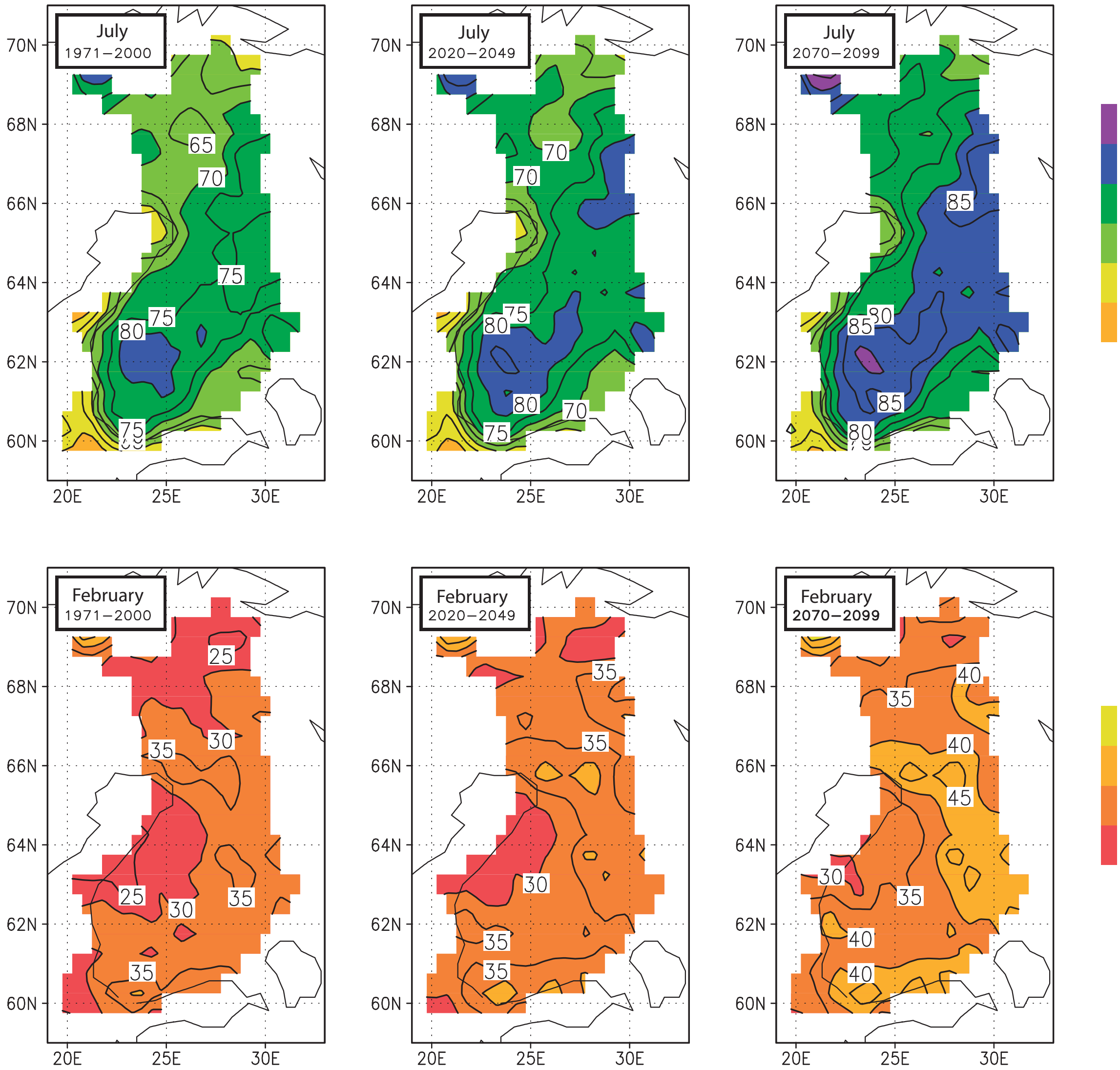

Figure 4 b: Mean precipitations (in mm/month) for July (upper panels) and February (lower panels) in Finland for the periods 1971–2000 (left column), 2020–2049 (middle column) and 2070–2099 (right column). For 1971–2000, mean precipitation is derived from observations. For the future periods, observational precipitation is multiplied by the model-based best estimate of relative precipitation change. For further information, see caption for Figure 6 a. Source: Jylhä et al. 2009. With permission: Kimmo Ruosteenoja (Finnish Meteorological Institute).

Based on process-based model simulations (e.g. Kellomäki & Väisänen 1997, Kellomäki et al. 2005) changes in tree species dominance could also be expected under warming climate. Especially the proportion of Norway spruce could decrease significantly in Southern Finland on sites with low soil water holding capacity if the drought periods will increase in summer time (Kellomäki et al. 2005, see Figure 5).

These findings are based on use of previous FINADAPT climate predictions (Ruosteenoja et al. 2005), in which the mean monthly precipitation in summer time was somewhat lower than in the most recent ACCLIM scenarios (Jylhä et al. 2009). In the previous growth simulations, the occurrence of broadleaves was not controlled in Norway spruce (or Scots pine) stands which favoured the presence of birch. The most recent model based simulations with ACCLIM scenarios show less pessimistic results for Norway spruce in Southern Finland especially if the presence of broadleaves is actively controlled in forest management of coniferous stands (Peltola, unpublished).

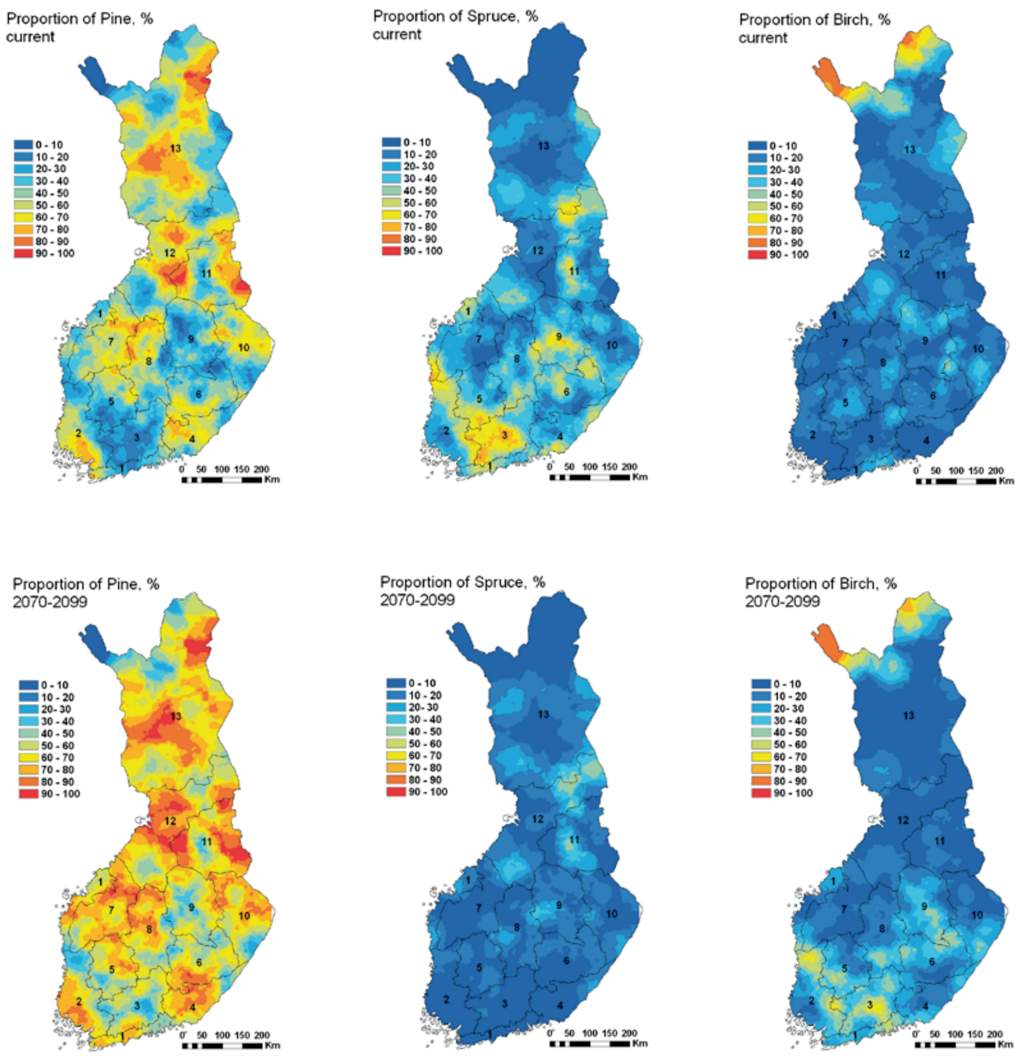

Figure 5: Expected changes in tree species dominance under current and changing climate (FINADAPT A2 scenario, Ruosteenoja et al. 2005) in different periods throughout Finland. In these model based calculations, no tree species has been favoured in thinning (from below), but timing and intensity of thinnings and rotation length has followed the currently recommended forest management guidelines in private forests throughout Finland (Kellomäki et al. 2005).

In general, forest growth is also expected to increase in relative terms more in Northern Finland compared to Southern Finland since in the north tree growth is currently mainly limited by the short growing season due to relatively low temperatures during summer time (Briceño-Elizondo et al. 2006, Briceño-Elizondo et al. 2008). The enhanced growth implies also an increase in timber yield regardless of tree species: for Scots pine, up to 26% in the south and 50% in the north; for Norway spruce, up to 23% in the south and 40% in the north; and for silver birch, up to 20% in the south and up to 33% in the north (Briceño-Elizondo et al. 2006).

Because of increased growth, also thinnings should be more frequent and/or intensified and the rotation length could be shortened (if current limits for average diameter at breast height in final harvest are followed) in order to utilise the increased growth of tree stands (Briceño-Elizondo et al. 2006). These stand level predictions are, however, based on data from short-term impact studies and model simulations done based on ecosystem models that may lead to over-optimistic estimates of future forest growth, since multiple stress factors that affect forest growth in nature have not been considered.

2.2 Current signs and expected impacts of climate change on forests

2.2.1 Phenological data prove springtime warming

According to the climatic data recorded since 1840s, air temperature has increased in Finland, being most marked during spring months (~2ºC) and less in summer, autumn (~0.5ºC) and winter (~1ºC) (http://www.fmi.fi/ilmastonmuutos/suomessa_17.html). At the same time the atmospheric concentration of CO_2 has increased by 100 ppm, with an increase from 325 ppm in 1970 to about 380 ppm at present during the last 40 years. Despite these changes in the growth environment of the boreal forests it has been difficult to deduce their influence from the currently observed growth increment in Finnish forests.

Currently, scientifically sound data of climate change effects on forest growth come from phenological observations. Such observations have been gathered in the Finnish Museum of Natural History since the 1840s. In a recent study, long-term phenological records (onset of bud burst and flowering time) collected from eight woody deciduous species from southern and Central Finland (latitudes between 60ºN and 66º33'N) show advancement in the bud burst and flowering time by 3.3 to 11.0 days during a century, corresponding a temperature increase of 1.8ºC (Linkosalo et al. 2009). Further, in western Finnish Lapland, the Scots pine species line has advanced towards North, on average 140 m/year during the last 200 years (Juntunen et al. 2006). Although the summers have been warm enough for sufficiently regular reproduction during the last century, high seedling mortality slows down the rate of forest line advancement (Juntunen & Neuvonen 2006).

2.2.2 Drought – a problem for forest growth in Finland?

Incidence of drought in Finland: In a recent climatic survey using data from 12 stations all over Finland Venäläinen et al. (Venäläinen et al. 2009) show that in the southwestern part of Finland periods of low precipitation (<10 mm), which last for at least 40 days during May–August, occur once in ten years. Further, it was reported that once in ten summers there is likely to be a period of 74 days with precipitation of only 50 mm and a period of 100 days with not more than 65-105 mm of rain.

Drought and forest growth: In northern Finland forest growth is mainly determined by July temperature, while in southern Finland it is not possible to attribute one single factor to the determination of annual growth. Drought effects on growth of Norway spruce have been addressed in several previous studies. Data by Henttonen (1990), examining growth variation between 1967 and 1987, show that air temperature and precipitation during June-July have the strongest effects on annual increment in spruce. During this study period a 6% increase in annual growth per decade was observed and in this case most of this trend could be explained by the increase in precipitation during the study period. This suggests that precipitation has an important role in the annual growth variation of Norway spruce.

The finding is also supported by results of Mäkinen et al. (2001). In this study the growth and vitality of Norway spruce was dependent on the June precipitation especially in stands growing on rocky or stony soils. The results also suggested big differences in the susceptibility of individual trees to drought. An ongoing study (Henttonen, unpublished) with Scots pine using NFI data (National Forest Inventory 1971–2008) shows that the precipitation effects with this species are site-specific. On dry sites rainfall during the first half of the growing season has a decisive role in tree growth, and the drought effects are further amplified with increasing number of warm days (>25°C). On good and intermediate sites soil moisture is generally not a problem and growth is mainly affected by temperature. On sub-dry sites, a high number of very warm days during early summer will decrease tree growth. On wet peatlands, long drought periods increase tree growth, particularly if the peat layer is thick.

These experimental findings are also supported by the ecosystem model based simulations which predict that climate change creates a sub-optimal environment for Norway spruce especially on less fertile sites (with low soil water holding capacity) currently occupied by Norway spruce in southern Finland (Kellomäki et al. 2007). As a result, the dominance of Scots pine and silver birch may increase on these sites (see Figure 5) especially if the tree species composition is not actively controlled in managed stands by tending of seedling stands and/or thinning (Kellomäki et al. 2007).

2.2.3 Wind and snow induced damage in Finnish forests

Forest damage caused by high wind speeds and storms has, in the past 20 years, caused significant economic loss in forestry in Central and Northern Europe (e.g. in 1990 and 1999 about 100 and 175 million m3 of timber was damaged by storms). Recently, in 2005 about 70 million m3 of timber was also damaged in southern Sweden, but Finland was still spared from this storm due to its sheltered location in regard to the prevailing southwestern winds. Moreover, relatively low wind speeds (average speeds of 8–19 m $^{s-1}$ over 10 min, but with gusts up to 30 m $^{s-1}$) have recently caused significant damage in Finnish forests (Talkkari et al. 2000) leading to great economic losses to forest owners (e.g. 7.3 mill. m^3 of timber was damaged in 2001 by the Pyry and Janika storms coupled with a heavy snow load) (MMM 2003). As is typical for this kind of damage the soil was unfrozen at the time of the storm.

In Finnish conditions, the risk of wind damage is largest at newly created stand edges (Zeng et al. 2006), such as around new clear-cut areas (Venäläinen et al. 2004) and in old stands especially after heavy thinning. Older Norway spruce stands are also especially vulnerable when compared to Scots pine and birch stands (Peltola et al. 1999a). The shortening of the duration of frozen soil period (since 1960s) has meant that period when forest stands are exposed to wind becomes longer, which increases the risk of wind damage in Finnish conditions (Peltola et al. 1999b).

On bases of long-term weather records the incidence of severe storms (10 minute averages >21 m s-1) or strong wind speeds (>11–14 m s-1) in Finland has not increased. Occurrence of strong winds are not expected to increase either in the future based on number of climate model simulations (Gregow et al. 2009). Despite of this, forests will be more vulnerable to autumn/early spring storm damage due to expected decrease in the length of period of frozen soil which still nowadays improves tree anchorage from late autumn to early spring, i.e. in the windiest time of year (e.g. Peltola et al 1999b, Kellomäki et al. 2010, Peltola et al. 2010). Further, milder winters are expected to increase the incidence of heavy snowfall leading to a greater risk of snow damage in next few decades, especially in young Scots pine and birch dominated stands (MMM 2003, Kilpeläinen et al. 2010a). The risk of wind and snow induced damage to forests will also be affected in the future by the forest growth and dynamics (including change in tree species dominance) as controlled by forest management and climate climate (see Peltola et al. 2010).

Increased wind and snow damage may also lead to associated outbreaks of insect pests, e.g. due to *Ips typographus*. Currently the risk of *Ips* damage seems to be low in Finland, probably due to good forest hygiene (Eriksson et al. 2007, Nevalainen et al. 2009). Milder winters will in the long run increase the susceptibility of trees to wind damage also indirectly by increasing the incidence of *Heterobasidion* root and but rot.

2.2.4 Fire damage in Finnish forests

According to the recent model based analyses carried out by Kilpeläinen et al. (Kilpeläinen et al. 2009b) it has been predicted that the forest fire risk will increase in the changing climate (based on FINADAPT climate A2 scenario). This is due to the increased evaporative demand, which will increase more than the rise in precipitation (see Figure 4 b) and especially in southern Finland. Furthermore, it is expected that the annual frequency of forest fires over the whole Finland may increase by about 20% by the end of this century compared to the current situation (and most in the southernmost part of Finland).

2.2.5 Climate change and biotic damage

Currently, there are no indications of forest pathogen and insect outbreaks in Finland that can be directly attributed to climate change. However, in the gradually changing climate the risks of outbreaks and damages are expected to increase, both due to present pest species and to invading pests that may be suited to the changing climatic conditions. Further risks are due to the free global trade market, increasingly introducing new pests in our ecosystem, and changing silvicultural practices and biodiversity demands that may cause unexpected changes in pest populations.

Future risks by forest pathogens: Presently the most serious forest pathogens in Finland are *Heterobasidion parviporum* and *Heterobasidion annosum*, which cause root and but rot on Norway spruce and Scots pine, respectively. In future climate scenarios for Finland the abundance and distribution of these pathogens will increase since the root systems of these species will be more prone to injuries during forest felling due to the shorter periods of frozen soil. Spore production by these fungi will also increase as winters become shorter. If storm damages increase, then root and but rot fungi will spread even more. The increasing frequency of mild winters and increasing precipitation during autumn and winter will also promote a number of other forest pathogens. On the other hand, an increasing frequency of long summer droughts may repress some pathogens. The number of new invading species has increased and is expected to increase in the future. Recent new pathogens include *Phytophthora inflata* on deciduous trees, *Chalara fraxinea* causing dieback of ash and *Dothistroma septosporum* causing needle damages in Scots pine seedlings.

Possible new invading species, already found in Baltic countries, include three pathogens on Scots pine (*Mycosphaerella dearnessii*, *Sphaeropsis sapinea*, *Cyclaneusma minus*).
The most susceptible forests for damage by shoot and foliage pathogens are young dense stands especially on depressed sites due to moist microclimate. Presently root and but rot pathogens prevail in most spruce and pine stands in South and Central Finland, and along with warmer climate these are expected to become serious pathogens also in Northern part of Finland.

Future risks by pest insects: Amongst the existing pest insects European pine sawfly (*Neodiprion sertifer*), autumnal and winter moth on birch (*Epirrita autumnata* and *Operophtera brumata*) and spruce bark beetle (*Ips typographus*) are species that will benefit from a warming climate. In European pine sawfly and the moth species, warmer winter temperatures decrease mortality of the eggs and thus increase the population size during the following growing season (Neuvonen et al. 2007, Soubeyrand et al. 2009). Winter moth outbreaks have recently been observed in Finnish Lapland, outside the area where outbreaks had previously occurred (Jepsen et al. 2008). For spruce bark beetle the number of generations increases due to warmer summers and increase the risks of outbreaks particularly if connected with other climatic hazards, e.g. storms or drought.

Pine web-spinning sawfly (*Acantholyda posticalis*) is an example of a native, earlier harmless species that may become a serious pest in Northern Europe. This species is known to cause damage in Central and Eastern Europe. During the extremely dry summer 2006 this insect caused an outbreak on an area of about 200 ha of mature Scots pine forest in western Finland, with about 30 ha being severely damaged. According to summer 2009 observations the affected area has even increased, with up to 100 ha of forest dying.

The spread of new insects from the South will inevitably increase with warming climate. The nun moth (*Lymantria monacha*) and gypsy moth (*Lymantria dispar*) are examples of such species that cause damage to forests in Central Europe (Vanhanen et al. 2007). In recent years the abundance of nun moths has increased markedly in southern Finland and thus the risk of future outbreaks is greater.

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3. Adaptation

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Key messages

Good and timely forest management is the main way of improving the ability of forests to adapt to climate change.

1. Preventative measures such as the timely recognition and removal of dying trees and keeping material that could cause forest fires or insect pests down to a minimum are part of forest management.

2. In forest regeneration, depending on stand conditions, both natural regeneration as well as planting and seeding are recommended.
   - natural regeneration should be favored if the soil and site conditions are suitable, while local native tree species are expected to be most suited to adapting to local climate change because of their genetic make-up
   - the use of seeds and seedlings of forest breeding materials could be favored on sites where the phenotypic plasticity, genetic diversity and genetic gains associated with wood production and quality are foreseen

3. Mixed tree species structures should be favoured by management of young stands, as the presence of various tree species with different characteristics reduces the risks to forests.

4. Forest management contingency plans should be developed with funding options for covering any damage and operational models so that the wood working industry is prepared for the detrimental effects of sudden and extreme weather caused by climate change and the damage it causes to forests.

3.1 Vulnerability of forests and forestry in Finland

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change. It is a function of the character, magnitude and rate of climate change and variation to which the system is exposed, its sensitivity and its adaptive capacity (IPCC 2007).

In the boreal zone expected climate change will generally increase the growth potential of forests by lengthening the growing season, increasing the atmospheric CO_2 concentration and increasing total precipitation.

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If existing forests do not adapt sufficiently to a gradual change in climate, the results will be among other things a weakening in the vitality of trees, a decrease in productivity, death of individual trees, reduced ability of trees to compete and a consequent increase in the occurrence of diseases and pests, as well as a change in the distribution of tree species occurring in forests. There is also a risk that trees will not adapt in northern regions, because their rate of growth is changing as a result of the increasing length of the growing season and the fact that they are not adjusting sufficiently to the dormant or winter season. In the event of extreme weather phenomena such as drought, forest fires, storms or snow damage, trees may die across wide areas, natural reforestation may be prevented and dead tree matter may cause mass propagation of forest pests, also in surrounding healthy forests.

As a consequence of the favourable climatic conditions, the northern timberline is assumed to shift northward, increasing the total forest area (Juntunen et al. 2002). In addition, the hemiboreal zone will likely also move northward, allowing for rare species such as some valuable broadleaves to thrive in a wider area than today. The risk of droughts may simultaneously increase because of increased evapotranspiration, especially for forests growing on shallow soils (Kellomäki et al. 2008).

Despite these generally advantageous trends for boreal forests under climate change, adverse effects have been predicted and observed that may lead to severe vulnerability of the forest ecosystem and the socio-economic processes related to forestry, especially if no adaptive measures are taken. Because of wide coverage of forests and its strong dependence on the forest sector, the Finnish society as a whole is potentially very vulnerable to adverse changes in forest ecosystems and forestry.

Immediate vulnerability to forestry is largest when extreme climatic events that suddenly produce large amounts of wood that cannot be harvested and used before its quality declines. Such large-scale disasters can be caused by storms, severe droughts or forest fires.

The climate change influences also indirectly to forestry operations by making the wood harvesting period more difficult in winter time when the soil is unfrozen. Up to now, harvests have usually been carried out in the winter and have relied on the frozen soil to support heavy vehicles and machinery without causing damage to the forest soil or to the machines. Problems have already presented themselves in the last decade when mild winters occurred and damage to both machinery and forest floor were reported. In order to reduce vulnerability, it is highly relevant to both develop technologies and improve the planning of harvest operations.

In the longer term, socio-economic vulnerability will increase if biodiversity is increasingly being lost from forest ecosystems. This can be caused by (1) failure in the adaptive measures to maintain sufficient biodiversity or (2) failure in (global) mitigation strategies. It is therefore important to develop the operational forest management towards accommodating wider goals that explicitly account for (a) maintaining biodiversity and (b) managing for mitigation measures, such as carbon sequestration and bioenergy production.

3.2 General adaptation strategy or policy

Finland was the first country in the world to publish a National Adaptation Strategy to climate change in 2004. It was compiled by the Ministry of Agriculture and Forestry in collaboration with other ministries, researchers and stakeholders (MMM 2005, www.mmm.fi/eng/index/frontpage/ymparisto/ilmastopolitiikka/ilmastomuutos.html).

The report concluded that many climate change impacts are still uncertain, and that further research is needed. Nevertheless, it recommended that adaptation measures should be integrated as part of sectoral long-term planning in combination with continuous monitoring and evaluation. The report stressed that the early start of designated activities could help achieve a win-win situation even if the scientific evidence was still circumstantial. The adaptation strategy will be reviewed within 6–8 years.

Adaptation in forestry is included in the National Adaptation Strategy. It draws attention to adaptive measures related to (1) maintaining and securing the natural gene pool as a source of adaptive capacity of the ecosystem, (2) forest management under climate change, (3) forest operations and use, especially, the organisation of harvests during shorter winters and in relation to increased tree mortality during extreme events, and (4) the need for further research into adaptive management and the related needs for advance warning and monitoring systems within forestry.

The national strategy also considers adaptative measures required to maintain biodiversity in forested areas. These include, e.g., facilitating the migration of species along climate gradients through designated ecological corridors, maintenance and development of conservation forests, and the control and prevention of the spread of invasive alien species. Research needs have been identified, e.g., in the development of early warning and monitoring systems and in the increased cooperation between different administrative sectors.

Other areas found in the national strategy and related to forestry include reindeer husbandry, game management, management of water resources and tourism and the recreational use of nature. The report also addresses cross-sectoral issues and the need to adapt to changes taking place in other parts of the world. As a whole, the report provides a sound basis for the further development of an adaptation strategy for Finnish forestry in the national context and interlinked with other sectors of the economy.

The compilation of the National strategy and programme to combat invasive alien species including forest species is under way in Finland and will be finalised before the end of 2010.

3.3 Forest adaptation measures

3.3.1 Immediate and near-term adaptive silvicultural measures

Good and timely forest management is the main way of improving the ability of forests to adapt to climate change. Preventative measures such as the timely recognition and removal of dying trees and keeping material that could cause forest fires or insect pests down to a minimum are part of forest management. In Finland a strict legislation for summer storage of harvested wood in forests and for rapid transportation of felled wood from forests has been created since 1995 in order to prevent the spread of pests. This legislation has been proven to be very effective.

Due to the expected climate warming new alternatives for forest management have been discussed in order to increase heterogeneity of forests for adaptation. Those new options include short-rotation coppice forestry by birch species or other broadleaved trees, continuous forest cover management (uneven aged stands), and extension of the forest regeneration by noble broadleaved tree species towards the north.

The decomposition of soil organic material may also change by warming climate, and then have an influence on various forest stand management options such as proportion of tree species or size of the regeneration areas. By various management measures the light conditions in the forest stands can be regulated, and have an influence on the carbon uptake or release.

The following recommendations are based on the newest silvicultural recommendations for practical forest operation in private, company and state forests (e.g. Tapio 2006), the national adaptation strategy (MMM 2005), and on suggestions made by researchers and specialists in view of climate change impacts (e.g. Kellomäki et al. 2007, Lindner et al. 2008, Seppälä et al. 2009).

Forest regeneration

Plants and seeds used in forest regeneration need to be well adapted both to the climate of the growing locality and express adequate phenotypic plasticity, which enables plants to survive and grow if exposed to a rapid change in environment. Since adaptive traits of forest trees are under strong genetic control, they can be effectively altered by sustained directional selection. In Finland, advanced tree improvement program has put specific emphasis on improving of the overall adaptive performance and making forest regeneration materials more fit to all kinds of climatic fluctuations.

In forest regeneration, depending on stand conditions, both natural regeneration as well as planting and seeding are recommended. Natural regeneration should be favored if the soil and site conditions are suitable, while local native tree species are expected to be most suited to adapting to local climate change because of their genetic make-up. The use of seeds and seedlings of forest breeding materials could be favored on sites where the phenotypic plasticity, genetic diversity and genetic gains associated with wood production and quality are foreseen. Mixed tree species structures should be favoured by management of young stands, as the presence of various tree species with different characteristics reduces the risks to forests.

Possibilities of forest tree breeding

The tree breeding materials undergo genetic testing (10–15 years) at multiple divergent environments. This reveals the reaction norms of genotypes across a wide range of light and temperature regimes and soil characteristics, and provides invaluable information for the Finnish tree improvement program that also addresses prospects of climate change. In general, the genotypes expressing the most stable performance across the environments are deployed as parents in production populations. The measures applied to supply desired genetic include early screening for phenology traits, such as early flushing or late season growth flush, and subsequent removal of maladaptations from the breeding material.

From an evolutionary viewpoint, genetic changes can be accomplished at much faster intervals in breeding populations than in wild forest stands exposed to natural selection. The length of the generation interval in tree breeding (comprising testing, selection and recombination) is commonly 20–25 years. In the long-term, tree improvement programs applying systematic genetic testing procedures are well positioned to keep pace with foreseeable climatic changes. Compared with unimproved material, seed orchard seed offers substantial advantages in terms of phenotypic plasticity, absence of inbreeding depression, genetic diversity and genetic gains in economic traits associated with wood production and quality. Genetic diversity of seed orchard seed is abundant, genetically just as or more variable as seed of natural stands, enabling a large potential for further evolutionary change.

Tending and thinning of stands

The first *pre-commercial thinnings* should be *timely* to allow healthy stands to develop that are more resistant to insect damage and damage from pathogens, and also snow- and wind-induced damage. Natural *mixtures of various tree species* should be favoured when possible so as to increase the biodiversity and general resistance of the stand.

In order to increase resistance to wind and snow induced damage, *too late and/or heavy thinnings* should be avoided, especially along downwind stand edges, where the trees are the most vulnerable to damage in Finnish conditions due to increased wind loading on trees (Peltola et al. 1999a; Zeng et al. 2007). Furthermore, the risk of damage is expected to increase in the future regardless of any change in windiness, due to decrease of frozen soil duration under changing climate (Peltola et al. 1999b). Thus, also avoiding thinnings in older stands (e.g. in the most vulnerable species such as Norway spruce) and reduction of rotation length should be considered as adaptive measures in this sense.

Forest protection

Planning and implementing a new *insect/pest monitoring system* is important in order to avoid large-scale forest damages due to invasive species. (Parviainen 2007, MMM 2008).

As the frequency of droughts is predicted to increase especially in sites with low soil water holding capacity, it becomes more important to detect areas susceptible to fire, as well as to detect and extinguish fires immediately if they occur. An effective monitoring system already exists, but it is important to increase the awareness of the problem among all stakeholders and agents.

Management practices are needed to *detect such situations* in advance and remove the dying trees which could be expected to cause consequent damages e.g. by insect attacks. GIS-based methods for indicating areas at risk are under development (Lindner 2008, Tapio 2002, Holopainen 2009).

Planning of silvicultural operations

More efficient planning of harvests is required to solve the problem of *shorter winter time harvest period*s. The solution could be to use all possible winter time harvesting capacity on the most vulnerable places. These include organic soils, such as pine-spruce dominated swamps, and forests on fine silt soils, typically mixtures of spruce and birch. Less vulnerable sites could be treated in the summer and autumn.

Shorter rotation cycles can follow from current harvest recommendations combined with faster growth. The consequent need for shorter return periods for forest operations and wood supply have to be considered in forest planning (spatial and temporal patterns of harvest operations).

The increased use of forest biomass requires *more consideration for environmental aspects on the harvesting sites*. Several guidelines are already given for harvesting biomass. For example, whole-tree extraction is forbidden on nutrient poor sites. Where stump extraction is permitted – e.g. on fertile spruce forest sites – at least 30% on stumps shall not be harvested. One third of the needle biomass should be left on the site in order to maintain better nutrient balance of the soil. For ensuring the biodiversity in boreal rich soil forest at least 5 m^3ha-1 of deadwood shall be left on the regeneration site.

Forest management contingency plans should be developed with funding options for covering any damage and operational models so that the industry is prepared for the detrimental effects of sudden and extreme weather caused by climate change and the damage it causes to forests. Areas that are particularly at risk from such extreme weather conditions must be mapped. Operational models also need to be drawn up for dealing with sudden increases in timber availability and for ensuring the smooth functioning of timber markets.

3.3.2 Long-term strategic measures to increase adaptive capacity

In the long term, the main concern in forestry is the sustainability of forest functions and ecosystem services under the predicted climate change. At the same time, ongoing and expected changes in economical, political and social working environment have to be considered, both globally and nationally. These will affect not only the management practices, but also the objectives of forest management in the long run.

An important part of long-term adaptation to climate change is the design and implementation of management regimes and silvicultural systems that are most resilient under the changes of forest ecosystem functioning and risks predicted to accompany climate change. Although some general principles can already be outlined and agreed upon, the future planning and implementation of such strategies efficiently will require further research into several aspects of forest ecosystems and their functioning and management.

Measures to maintain the biodiversity of forests

Forest biodiversity is essential to maintain the adaptive capacity of forests to climate change (Innes et al. 2009). The more adaptive gene reserves that a forest has, the more likely it will adapt to new growing conditions and growth-driving factors. For example, in the case of a pest attack a large variation in the gene reserve will allow for the tree population to evolve into a more resistant population in the future. Well managed and healthy forests will adapt best to environmental changes (MMM 2005, Savolainen et al. 2007).

Diverse management methods may help to enhance biodiversity and thus reduce the risk of damage by extreme events, such as pests. These methods include, e.g., mixed and possibly uneven-aged stands, management of stand structure to cope with extreme events, and introduction of provenances corresponding to the expected change of climate. Maintaining biodiversity will allow for more variability and therefore a wider gene pool to respond favourably to expected changes in the climate (MMM 2005, Tapio 2006, Itkonen 2006, MMM 2008)

Wood-based bioenergy

Wood-based energy is already in extensive use in the forest industries which produce a large part of their energy requirement using waste wood. Recent changes in forest management include the utilisation of stumps for energy, and whole-tree harvesting is being intensively studied as a possible source of bioenergy. More research is needed to support national forest management recommendations that include measures related to bioenergy production and energy harvests as a part of timber production (MMM 2005, Parviainen 2007, MMM 2008)

Infrastructure and transport

New and more site-adaptive harvesting technologies and transportation machinery should be developed in order to improve of harvest operations. This is necessary to avoid the forest stand damage that occurs when harvesting in milder winter and unfrozen conditions on peatlands and soils with a high content of organic material.

Fuel economy of forest management vehicles should be improved; independence from fossil fuel would be a major benefit to forest businesses that could be achieved with relatively small effort. Public awareness of the use of renewable energy sources should be increased. Increasing the use of renewable energy would contribute to current technological progress and illustrate more ecologically valued production methods used by national industries. This might also stimulate more environmentally healthy ways to maintain the national fuel supply (Parviainen 2007).

Development of new management recommendations

In Finland, national recommendations for forest management have been produced since 1996 by forest researchers in cooperation with Metsätalouden Kehittämiskeskus Tapio. In parallel other forest owners such as companies and the state forest authority Metsähallitus have also developed their forest management recommendations. Current recommendations are based on a number of detailed growth models and economical analyses of how to manage different forest stands so as to maximise the profits under certain socio-economic and ecological constraints (Tapio 2006). It is of high importance to develop these management recommendations further to cover a wider variety of objectives and to take into account the impacts of climate change on the forest ecosystems. The objectives should include, e.g., management for fuelwood and carbon sequestration, but also other socio-economic goals, such as recreation and forest protection. The role of even-aged vs. continuous cover management in achieving various goals should also be analysed in detail.

Implementation of adaptive strategies

On the basis of the above review, many changes will be required in forest management strategies at different levels in order to allow for both the ecosystem and forestry as a whole to adapt to the expected climate change and related socio-economic changes. When developing an adaptation strategy it is important to examine which parts of these adaptations could occur autonomously, i.e., by the activity of the relevant stakeholders, and which would require governmental regulation and/or legislation.

Autonomous adaptations in different parts of the forestry sector are already taking place. For example, industries are developing harvest machinery that could be suitable for harvests outside the frost period even on soft terrain. However, these kinds of reactive measures will not be effective unless they can keep up with the rate of occurrence of adverse effects of climate change.

Awareness of the importance of forest management in adapting to climate change must be increased among members of the public, forest owners and those responsible for forest management (Kankaanpää et al. 2005). It is crucial to *increase the awareness* about the expected impacts of climate change, and to facilitate networks of information exchange across the whole forest sector.

Forest management recommendations need to be developed for a wider set of management regimes and situations than currently available. This requires further research that combines ecosystem functioning with economic and societal issues.

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4. Mitigation

As a signatory to the Kyoto Protocol, Finland has committed to reducing greenhouse gas emissions to 1990 level (according to the EU burden sharing). During 2007 the total greenhouse gas emissions of Finland (78.5 million tons of CO_2) exceeded the 1990 emission levels that are used as the baseline in Kyoto reporting. In order to fulfill these commitments, Finland chose to use article 3.4. ‘Forest management’ to offset emissions originating from deforestation (reported under the article 3.3 of Kyoto Protocol).

Key messages

1. In 2008 Finland’s forests (including peatlands) sequestrated 35 million tons of CO_2.

2. Finland’s forests will remain a substantial carbon sink during the next 30 years if annual cuttings do not exceed 50–60% of annual increment. The increase of overall use of wood-based energy and the volume of forest chips used for energy production to 8–12 million m^3 per year will diminish the carbon sink of forests less than 10%. In 2008 renewable energy sources provided 28% (387 PJ) of Finland’s total energy consumption of which wood-based fuels accounted for 21% of which 49% was covered by waste liquors from the forest industries and 51% by solid wood fuels, mainly heat and power plants and the use of firewood in small-sized dwellings.

3. Harvested wood products make up a considerable carbon store that has gradually increased since the 1990s, thus making up a carbon sink. Recycling of solid wood products is important from the CO_2 emission point of view.

4. Finland produces approximately 2 cubic metres of wood products (mostly long term carbon storage), and approximately 5 tons of pulp and paper products (mostly short time carbon storage) per capita per year.

5. The Finnish Government has promoted both domestic use and export on timber products, and timber construction through various campaigns and programmes over the last 20 years. The implementation of the governmental programmes have provided several imposing examples of timber construction (Sibelius Hall in Lahti, Savonlinna Hall in Savonlinna, Viikki Church in Helsinki, Pohjola Stadion in Vantaa, Metla House and Joensuu Arena in Joensuu)) and several multi storey residential house timber frame construction projects.

4.1 Carbon accounts

Aleksi Lehtonen[1]

In the land use, land-use change and forestry (LULUCF) sector Finland has a sink of carbon that amounted to -35 million tons of CO_2 during 2008 (Table 1). That sink originated mainly from the sink in the tree biomass, which is driven by the annual fellings – implying that higher fellings result in smaller sinks and lower fellings result in greater sinks. The mineral forest soils of Finland are also a sink, while drained organic forest soils are a source of carbon. This source of emissions from drained organic forest soils is currently compensated by the sink of tree biomass on those lands.

During 2008 mineral soils and dead organic matter (DOM) were a sink for -9.4 million tons of CO_2, while the drained organic soils and dead organic matter were a source for 6.2 million tons of CO_2. At the same time the emissions from peat extraction sites were 1.3 million tons of CO_2, while the sink of harvested wood products was -0.1 million tons of CO_2 (Table 1). Cropland has been a source of carbon, resulting in annual emissions of 4–6 million tons of CO_2 during recent years, while according to the latest estimates grasslands were close to steady state (not a sink / not a source).

Table 1. Emissions and removals (million t CO_2 eq.) of the land use, land-use change and forestry sector in Finland (emissions are positive figures, while removals are negative). Source: unfccc.in
During the 2010 parties of Kyoto Protocol reported emissions and sinks according to the sc. Marrakech accords. Finland also estimated emissions and sinks under articles 3.3 (afforestation, reforestation and deforestaton) and 3.4 (forest management) of 2008. According to the reporting; the emissions of CO_2 due to deforestation were 2.8 million tons, while the sink due to afforestation and reforestation was 1 million tons of CO_2 during 2008. The sink of forest management was close to 40 million tons of CO_2 during 2008.

Year	Forest land	Cropland	Grassland	Peat extraction	Harvested wood products	Total
1990	-21.57	5.70	-0.26	1.01	-0.95	-15.05
1991	-35.77	5.07	-0.25	1.03	0.31	-28.59
1992	-28.21	4.85	-0.24	1.07	-0.23	-21.68
1993	-26.13	5.08	-0.23	1.09	-0.09	-19.20
1994	-18.01	5.04	-0.22	1.12	-0.76	-11.70
1995	-19.49	5.31	-0.22	1.14	-0.87	-13.00
1996	-29.28	5.31	-0.21	1.17	-1.05	-22.89
1997	-24.60	5.38	-0.21	1.20	-2.12	-19.14
1998	-23.06	5.28	-0.21	1.24	-1.77	-17.28
1999	-25.66	5.18	-0.19	1.26	-2.04	-20.19
2000	-27.67	5.11	-0.17	1.28	-1.27	-21.45
2001	-32.38	5.13	-0.16	1.28	-0.32	-25.16
2002	-32.89	5.12	-0.13	1.26	-0.44	-25.81
2003	-32.87	4.91	-0.11	1.27	-0.89	-26.43
2004	-34.55	4.92	-0.08	1.33	-0.83	-27.88
2005	-39.02	4.94	-0.05	1.31	-0.34	-31.84
2006	-44.08	5.01	-0.03	1.31	-0.39	-36.92
2007	-36.10	4.97	0.00	1.31	-1.22	-29.73
2008	-41.93	4.94	0.00	1.31	-0.10	-34.47

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There is a high degree of annual variation for all sinks and sources of the LULUCF sector. For example, during the period 1990–2008 the sink of forest biomass varied between -20 and -40, while the sink of mineral soils and DOM varied between -5 and -12 million tons of CO_2. Since 1990 emissions of drained organic soils varied between 12 and 6, and harvested wood products between source 0.3 and sink -2.1 of carbon, million tons of CO_2.

The high annual variation in the LULUCF sector is mainly due to annual variation of harvesting that results from wood demand driven by the market situation.

4.2 Scenarios of greenhouse gases

Risto Sievänen[2]

Scenarios of carbon stocks and/or budgets of greenhouse gases (GHGs) of forests have been produced as a part of National Communications (Finland's Fifth National Communication under the United Nations Framework 2009), in preparation of National Forest Programes (Ministry of Agriculture and Forestry 2008), and in the scientific literature (Matala et al. 2009).

The Fifth National Communcation considered two scenarios: with measures (WM) and with additional measures (WAM). The WM scenario describes a development in which measures already implemented and adopted affecting different sectors are continued with. The WAM scenario includes a number of additional actions that are planned for future. In the forestry sector it was assumed for the WAM scenario that the annual use of forest chips increases from 8 million cubic metres to 12 million cubic metres in 2015. This is also in the planned range of use of forest chips of the National Forest programme (Ministry of Agriculture and Forestry 2008).

The Fifth National Communcation does not display any scenarios in figures of forest GHG balances but states that Finnish forests will probably continue to act as a net sink in the future.

Sievänen et al. (2007) produced scenarios of GHG balances of forests from 2005 to 2034 to back up the decision making about Kyoto protocol artcle 3.4 and the National Forest programme. The calculations of GHG balances were made on the basis of data of stocking and drain and natural mortality produced with a Finnish large-scale forest management planning system (MELA; Redsven et al. 2009). The MELA system calculates the development of forest resources with different utilization strategies and rates of cuttings. Three alternative utilization strategies were considered: I) The net present value (NPV) of forest production was maximized using a 5% interest rate with no other constraints, II) NPV of wood production was maximized with a 4% interest rate and with a non-decreasing flow of wood and sawlogs, and III) annual cuttings as they were on average in 2001–2005. The data on stocking, drain and natural mortality were input for the calculation of carbon balance of forests. The method was the same as in the National Greenhouse Gas Inventory (Greenhouse gas emissions in Finland 1990–2004) that uses the data of trees from the national forest inventory as input. The calculations covered biomass of trees as well as soil carbon (dead wood, litter and soil organic matter) both in upland and peatland forests. The emissions of other greenhouse gases (methane, nitrous oxide) were taken from published literature.

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The forests are a GHG sink in all utilization alternatives except during the period 2005–2014 in heavy utilization alternative (I), Fig. 6. This is because of the large amount of cuttings during that period producing a large input of harvesting residues to soil that is a sink in 2005–2014 but which turns to a source in the next period because this large volume of litter is decomposing. If the fellings remain at the level of years 2001–2005 (alternative II) the forest sink increases markedly because the growth is much larger than drain for a prolonged period. In addition, a calculation was made in which the use of forest chips increased from 4 million cubic metres in 2005 to 15 million cubic metres in 2030 in utilization alternative III. The forest sink decreased at maximum 11 per cent indicating that energy use of trees does not markedly change the GHG balance.

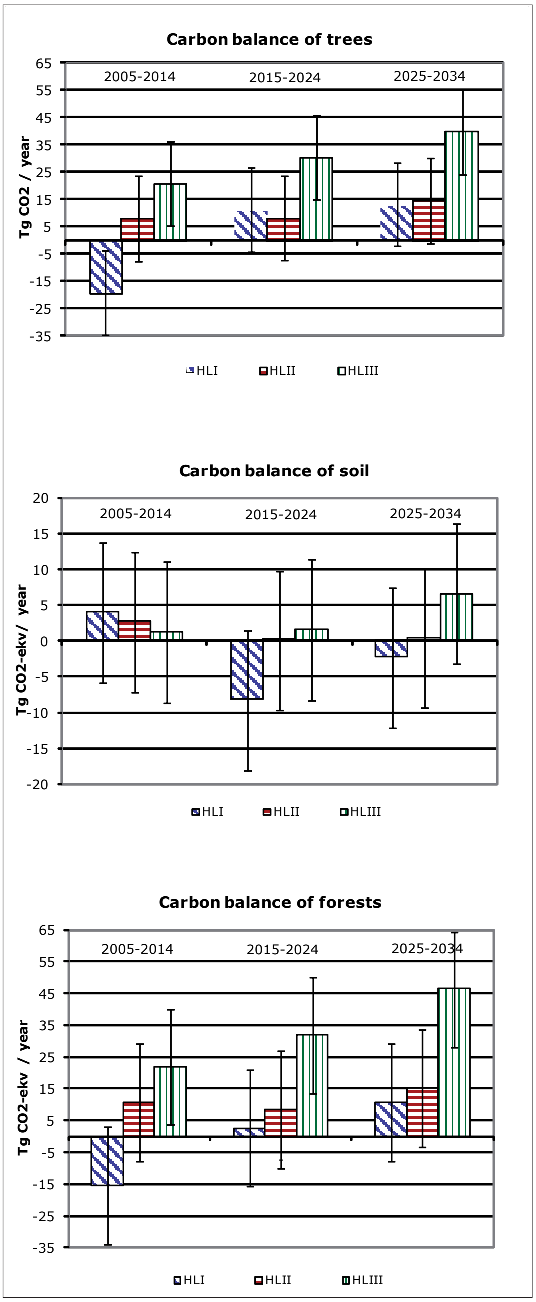

Figure 6 GHG balance (positive values = sink) of Finnish forests from Sievänen et al. (2007) (trees, soil and total) in different utilization alternatives (HLI = I, HLII = II, HLIII = III) during 2005–2034. Error bars are 95% confidence limits from the Finnish Greenhouse Gas Inventory (Greenhouse gas emissions in Finland 1990–2004).

Matala et al. (2009) made calculations of carbon in the growing stock of the trees in Finland during 2003–2053 under different cutting and climate scenarios. They considered maximum and sustainable utilization schemes with or without climate change. In all their calculations the carbon stock of trees increased over the simulation period. In the maximum utilization scheme the carbon stock decreased first due to heavy cuttings but recovered later when the regenerated forests started to grow rapidly. This similar to utilization alternative II of Sievänen et al. (2007).

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4.3 Finnish carbon account

Henrik Heräjärvi[3]

Until recently, harvested wood products have not been included in the carbon accounting, due to insufficient statistical information and the lack of international agreement about calculation methods. Finland included the harvested wood products in the official carbon balance statistics for the first time in 2008. Harvested wood products make up a considerable carbon store that has gradually increased since the 1990s, thus making up a carbon sink.

In the calculation of CO_2 emissions and sinks in the land use and forestry sectors (see Table 1), the harvested wood products include both mechanically (sawn timber, wood-based panels, utility poles, furnishings/solid structure cabinetry) and chemically (pulp, paper and paperboards) produced goods used in Finland. Changes in storage of roundwood, wood products in landfills, furniture, or wooden package materials are not included. Finland produces approximately 2 cubic metres of wood products (mostly long term carbon storage), and approximately 5 tons of pulp and paper products (mostly short time carbon storage) per capita per year.

Decreased production of goods with short life cycle leads to a situation where more goods are, at least computationally, removed from the consumption compared to the production of new ones. The statistics show 1991 as an exceptional year, when the harvested wood products actually appeared to be a source of carbon emission. At that time the economic recession decreased the production and consumption of papers, paperboards and other wood products, but their computational removal still remaining at a higher level.

Recycling of solid wood products is important from the CO_2 emission point of view. It has two implications: (1) it increases the service life of wood products, thus also increasing the time of carbon sequestration; and (2) recycled wood also substitutes for fossil fuels when used in energy production. COST Action E 31 reported that the use of recycled wood products as energy source reduces the CO_2 emissions in Europe by ca. 11 million tons per year, due to substitution of fossil fuels (see: COST Action E 31, Management of recovered wood). Paper or paperboard recycling is perhaps not as advantageous as the solid wood product recycling from the climate point of view, since the mills utilising recycled paper products are sparse. Therefore, the emissions caused by collection and transportation are considerable.

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4.4 Forestry as a source of bioenergy

Markus Lier[4]

Use of wooden bioenergy in Finland

The European Union has agreed to reduce the effects of climate change and to establish a common energy policy. As part of this policy, the European Heads of State or Government agreed in 2007 on binding targets to increase the share of renewable energy. By 2020 renewable energy should account for 20% of the EU's final energy consumption (8.5% in 2005). In order to meet this common target, each EU Member State needs to increase its production and use of renewable energy in electricity, heating and cooling, and transport. Renewable energies are an integral part of mitigating climate change and contribute to economic growth, job creation and increase energy security.

In 2008[5] renewable energy sources[6] provided 28% (387 PJ) of Finland's total energy consumption and account for more than one-fourth of its power generation (Statistics Finland 2009). The targets set by the European Commission to raise Finland's share of renewable energy sources to 38% by the year 2020 are challenging and its achievement depends on finding ways to reduce the total energy consumption and ways to increase the use of wood-based energy, waste fuels, heat pumps, biogas, hydro power and wind energy. Forest biomass is being an important renewable energy source in Finland. In 2008, wood-based fuels[7] accounted for 21% (302 PJ)[8] of the total energy consumption (see Figure 7) (Finnish Statistical Yearbook of Forestry 2009).

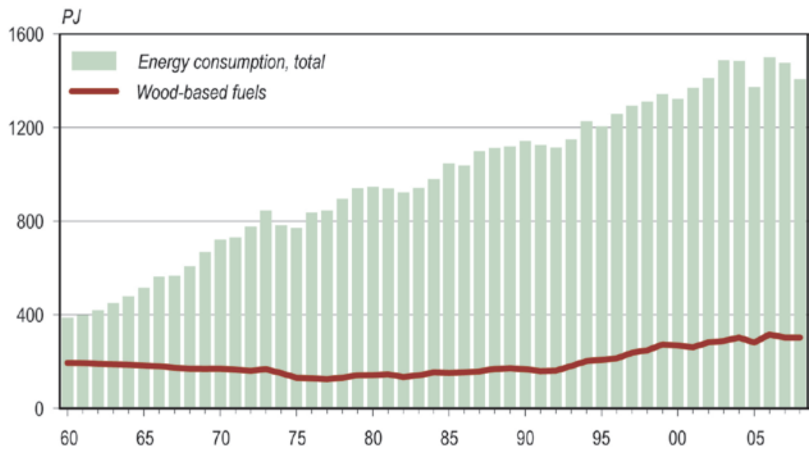

Figure 7: Total energy consumption and consumption of wood-based fuels 1970–2008. Source: Finnish Statistical Yearbook of Forestry 2009. Preliminary data for 2008.

In 2008 the total consumption of roundwood in Finland was 72.8 million m³. Of that total, 59.44 million m³ were of Finnish origin and 15.98 million m³ roundwood were imported. In total, the forest industries utilised 66.3 million m³ of roundwood. About 6,5 million m³ was used for energy generation in heating and power plants and small-sized dwellings. (see Figure 8) (Statistical Yearbook of Forestry 2009)

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5 data for 2009 will be published by Statistics Finland in December 2010.
6 include bioenergy – wood and wood-based fuels in particular, hydropower, wind power, ground heat and solar energy
7 wood-based fuels divided into industrial waste liquors (mainly black liquor produced by pulp industries) and solid wood fuels. Solid wood fuels further divided into wood fuels consumed by heating and power plants and fuelwood consumed by small-sized dwellings (i.e., private houses, farms and recreational dwellings)
8 preliminary data (November 2009)

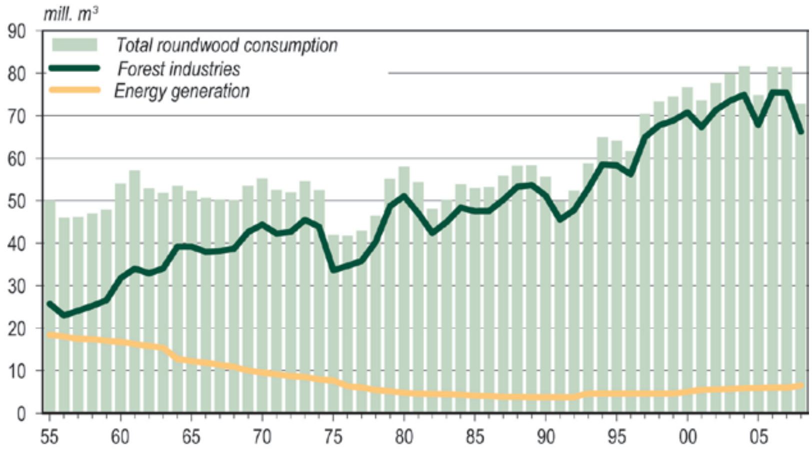

Figure 8: Roundwood consumption by category of use 1955–2008. Source: Finnish Statistical Yearbook of Forestry 2009.

The main provider of wood-based energy is the Finnish forest industry, which gets the wood fuels in connection with raw material procurement or as a by-product of wood processing. Pulp waste liquors are the largest single source of bioenergy in Finland. In 2008, wood-based fuel consumption was 302 PJ and about half of it (149 PJ) was covered by waste liquors and other by-products from the forest industry (decreased compared to 2007 due to the reduction in forest industry production). Solid wood fuels were consumed to the total of 153 PJ (21 million m³), of which the heat and power plants accounted for 99 PJ or 14.3 million m³. The combustion of bark, accounted for a volume of 7.1 million m³ (46 PJ). The use of traditional firewood is an important source of bioenergy in small-sized dwellings in Finland; in 2008 about 6.7 million m³ (55 PJ). Industrial harvesting of wood material for energy production (logging and thinning residues) accounted in 2008 about 4.0 million m³ wood. (Finnish Statistical Yearbook of Forestry 2009) (see Figure 9)

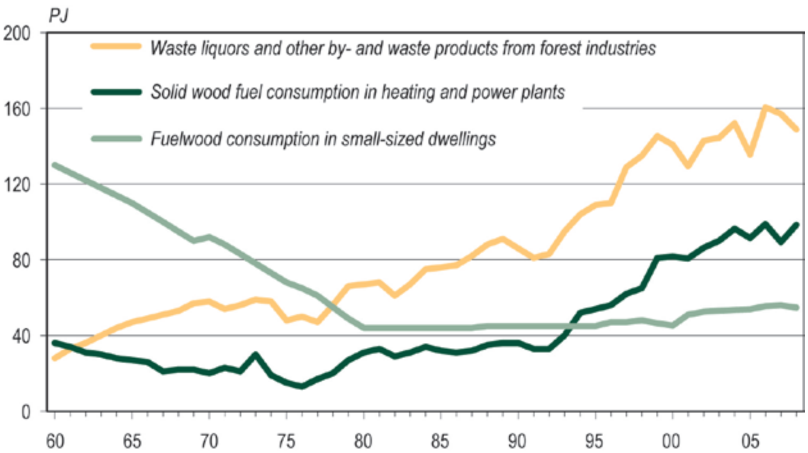

Figure 9 Consumption of wood-based fuels 1970–2008. Source: Finnish Statistical Yearbook of Forestry 2009. Preliminary data for 2008

New developments

Due to the current worldwide economic market depression, the weakening of Finland's main exports markets for wood-based products due to the decreasing demand for printing and writing papers, the oversupply of pulp and paper products in Europe, and also from the weakening competitiveness of the Finnish production relative to major competing countries the Finnish forest industry production continued to decrease also in 2009. (Forest Industry Review 2009, Metla Bulletin 2010). Therefore also the amounts of available industrial by-products of wood processing, highly dependent on the production amounts in the forest industry, have been decreasing in 2009.

The goal of the Finnish national energy policy is to support economic and labour policy and guarantee the availability and competitive price of energy and ensure that environmental emissions are within the limits set by international agreements. An objective is also to accelerate the use of energy saving, to increase the use of renewable sources of energy and their share of energy consumption and promote the development of renewable energy technology and its commercialisation. The final success in meeting the objectives depends on the development of the international economic market, the international energy market and especially prices of imported fuels (Röser et al. 2008, Finnish Ministry of Employment and the Economy 2009).

The role of forests in energy production and the mitigation of climate change is seen as important in the Finnish National Forest Programme 2015. The programme sets ambitious targets for the use of forest chips for energy: the basic scenario suggests an increase overall use of wood-based energy and the volume of forest chips used for energy production to 8–12 million m^3 per year. (MMM 2008, Röser et. al 2008)

In spring 2010, the Finnish Government's ministerial working group for climate and energy policy agreed on the contents of an package of obligations concerning renewable energy, aiming an increase of energy production based on renewable forms of energy by a total of 38 TWh of total energy consumption by 2020. This energy package promotes inter alia to increase the use of forest chips to 13.5 million m^3 per year by 2020. (MEE 2010) The use of forest chips in heating and power plants has already increased from 2.7 million m^3 in 2007 to 6.0 million m^3 in 2009.

The establishment of a joint venture between the pulp and paper manufacturer Stora Enso and the state oil company Neste Oil is another indication of the high interest in biomass for energy. The two companies inaugurated a trial plant first to develop technology and later to produce in commercial-scale biocrude for renewable diesel from forest biomass, mostly logging residues and stumps in summer 2009. This large-scale project, which plans to utilise 1 million solid cubic meters of forest biomass annually, is the first of its kind in Finland (Röser et al. 2008, Stora Enso 2009).

Increasing production of wood-based energy and the emergence of markets for energy wood will tighten the competition for wood. The challenge is to establish a balance between the use of wood for pulp and paper production, for mechanical wood products and for energy (MMM 2008).

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4.4 Timber frame house construction in Finland

Pekka Ollonqvist[9]

Promotion of timber construction on the basis of ecological and climate change benifits is undisputable. Timber is a low-energy, renewable and carbon-neutral construction material throughout its life cycle. Using one cubic metre of timber as a substitute for other building materials reduces CO_2 emissions in the atmosphere by an average of 1.1 tonnes. The heating and cooling of buildings is responsible for 8% of CO_2 emissions (see EESC opinion 2009). A significant proportion of such emissions can be avoided through professional construction and new techniques as well as by increasing the share of wood used in construction.

So far there are available only few scientific analyses that compare carbon footprint between wooden and concrete buildings (Sathre & O'Connor 2008, Gustavsson & Sathre 2004). In Finland one of the most important wooden reference buildings is the Metla House in Joensuu. In total about 2000 m³ timber was utilized for the construction of Metla House. In the reinforced concrete construction, the consumption of non-renewable energy would have been 2.4 times greater, and more than four times the quantity of non-renewable raw materials would have been used compared to Metla House (Häkkinen & Wirtanien 2006, Vatanen 2005). Moreover, timber structures store a significant amount of carbon dioxide for the lifetime of the building: in computational terms for at least a hundred years, but in reality for a considerably longer period. Metla House has saved emissions of 620 tons CO_2 when compared with an analogous concrete solution

The Finnish Government has promoted both domestic use and export on timber products, and timber construction through various campaigns and programmes over the last 20 years. These programmes (such as Wood Construction Technology Programme 1995–1998, Wood Construction Promotion Programme 2004–2010, Multi-storey Timbre Frame Construction programme 1995–2006, Modern wooden town programme1997–2013) have provided research and development financing to public universities and research institutes and individual enterprises towards construction technology innovations. The major institutional obstacles on the construction of multi-storey timber houses were removed in 1997, when the reformed planning, fire and building regulations made more versatile timber construction possible. Up to 1997, timber buildings more than two-storey had required exceptional permission procedures (Karjalainen & Koiso-Kanttila 2002, Karjalainen & Patokoski 2009, Paajanen et. al 2007, Parmanen et. al 1998, ProBuild -1997–2001).

Modern Wooden House Concept implementation in Finland has provided new timber frame professional construction by applying row house, single house and detached house construction. Viikki Helsinki, Finland. Photo: Metla/Erkki Oksanen

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The increase of timber use in construction (60 % from 1995 to 2008) has been parallel with the increase in the volumes of new construction. The current market share of timber frames is dominant in single residential house and leisure construction as well as in rural schools, elderly houses and other small scale public construction. The major unused growth potentials are in commercial and industrial construction as well as multi storey residential house construction (Table 2).

Table 2: Annual aggregate volumes and number of units in the initials of new buildings in 2008 and change (%) from 2007. Shares of apartments in house modes from the residual construction aggregate and shares of timber frame in different groups (Sources: Statistics Finland, VTT, RTS)

	1000 m^3	*Number of units*	*Share of res. units*	*Change 2007-2008*	*Timber frame %*
Residential	10 500	23 000		-22 %	35
Single-houses	6 900	11 200	49	-20 %	81
Row	800	2 800	12	-35 %	60
Multi-storey	2 900	8 850	38	-21 %	1
Leisure	1 140			-10 %	80
Other (schools, etc.)	2 550				85
Commercial and industry	16 910				15
Total	41 700	45 850		-19 %	

The implementation of the governmental programmes have provided several imposing examples of timber construction, such as Sibelius Hall (Lahti), Savonlinna Hall (Savonlinna), Viikki Church (Helsinki), Pohjola Stadion (Vantaa), Metla House (Joensuu) and Joensuu Arena (Joensuu). Totally 11 multi storey residential house timber frame construction projects, covering 2–4 storey multi-storey solutions) and 517 apartments have been constructed with the aggregate output of about 50 000 m2, has been completed in seven cities during the period 1999–2005 (Karjalainen & Patokoski 2009). These projects have provided opportunities to create and accumulate new knowledge towards cost efficient Business to Business construction value chains. Several factory producers exist that have been able to create competitive solutions for pre-fabricated structural wooden construction elements (Viljakainen 1998, 2003, Sara 2003–2007).

The total volume of 2000 m³ timber utilized in the construction of Metla House in Joensuu (left), the first largest office building in Finland, provides the carbon sequestration capacity that together with substitution during the life time corresponds to 1460 tons CO_2 eq. Using wood as construction material for the Metla House has saved 620 tons of CO_2 compared to an analogous concrete solution. (Vatanen 2005) Installation of the timber intermediate floor elements at Metla House (right). Photos: left Metla/Erkki Oksanen, right Onni Miettinen

The more widespread use of timber frame in Europe and worldwide and the use of wood in construction are limited by the lack of uniform standards, rules and certification criteria. The construction sector should have at its disposal analyses of the life-cycle and greenhouse gas emissions of products, based on scientific calculations, so that it could compare various materials on an impartial basis.

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4.5 Greenhouse gas balance in peatlands drained for forestry

Jukka Alm[1]

Impacts of forest drainage

In Finland, peat comprises the largest soil carbon (C) store, containing ca. 5.5 Pg (Pg = 10^9 tons) C (Minkkinen et al. 2002) compared to the ca. 1.1–1.3 Pg C in mineral soils (Liski and Westman 1997). Mires have been drained for various land uses, and the consequent lowering of the water tables changes the conditions for plants and soil organisms. The primary change is an increase in the aerated soil volume which changes the decomposition process and hence the greenhouse gas fluxes (Trettin et al. 2006).

Drained peatlands tend to emit more CO_2, but less CH_4 than undrained mires do (Moore and Knowles 1989, Silvola et al. 1996, Nykänen et al. 1998). On the other hand, more biomass can be stored in forestry drained peatlands during the forest succession (e.g. Minkkinen et al. 1999), but the question of whether peatlands are net carbon sinks or sources is more complex (Laiho 2006). Further, mineralisation of organic matter may stimulate emissions of nitrous oxide (N_2O) from drained nutrient rich peatlands as demonstrated by Martikainen et al. (1993).

A major proportion, 5.4–5.7 Mha (Mha = millions of ha) of the original ca. 10.4 Mha, of Finnish mires have been drained for forestry (Päivänen and Paavilainen 1996, Minkkinen 1999), 0.7–1.0 Mha for agriculture (Myllys 1996, Myllys & Sinkkonen 2004), and ca. 0.08 Mha for peat extraction, leaving ca. 40% (4.1 Mha, Finnish Forest Research Institute 2005) in pristine condition. Land use has affected the peat C stores in Finland. According to a recent review by Turunen (2008), the total C storage of Finnish peatlands from 1950 to 2000 was estimated to have increased by 52 Tg because the intensive peatland drainage significantly increased the total C storage of vegetation. However, the actual C storage in peat at the same time decreased by about 73 Tg. The most important anthropogenic C losses have occurred from croplands in peat soils, water reservoirs, extracted peat and dissolved organic carbon output from forestry drained peatlands.

CO_2 emissions from peat drained for forestry

Depending on peatland forest site type, 160–500 g C $m^{-2}yr^{-1}$ of the peat substrate (> 1-year-old organic matter) is oxidised (Minkkinen et al. 2007a). The soil losses of CO_2 are greatest on fertile site types such as the drained herb-rich type, and lowest on less fertile sites, e.g. dwarf-shrub or *Vaccinium vitis-idaea* type (Silvola et al. 1996a, Minkkinen et al. 2007a). Litter from trees and ground vegetation adds new organic materials in the rooting zone and on the soil surface (Laiho et al. 2003). In nutrient poor drainages, total biomass production rate may exceed that of the peat decomposition and lead to at least temporal net carbon accumulation to the system. Unfortunately such net carbon gain is probably more due to litter from increased dwarf shrub biomass rather than trees. The carbon balance in nutrient rich sites where the tree stand grows best can show net loss.

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CH_4 emissions in peatland forests

Methane (CH_4) is formed and oxidised in peatland forest soils, but the net CH_4 release rate is less than 4 g $m^{-2}yr^{-1}$ in high water table conditions on less fertile drained peatlands. In successfully forested peatlands, where effective drainage and evapotranspiration keep the water level low, net CH_4 consumption rates up to 1 g $m^{-2}yr^{-1}$ have been measured (Minkkinen et al. 2007b). However, Minkkinen and Laine (2006) have estimated that the CH_4 emitted from the ditches compensate for or even exceed the observed maximum rate of CH_4 consumption -0.82 g $m^{-2}yr^{-1}$ from within the forested strips. Thus even though drainage greatly diminishes CH_4 emissions, most drained peatlands remain small sources of CH_4 when emissions from the ditches are accounted.

N_2O emissions in peatland forests

Drainage for forestry can stimulate N_2O emissions only on fertile or fertilised sites (Martikainen et al. 1993, Regina et al. 1996), but very little data is available from Finnish conditions. In oligotrophic bogs N_2O effluxes remain very small (Regina et al. 1996, 2004) whereas in the most fertile drained pine fens and spruce mires emissions may rise close to 1 g N_2O $m^{-2}yr^{-1}$ (Kari Minkkinen et al. unpublished data). A regional sampling for peatland sites in Finland was performed in 2001–2002 by the Finnish Forest Research Institute (Laiho et al. 2006). The CN ratios derived from that database, and the actual N_2O measurements available from peatland forests were used in estimating the potential N_2O emissions from forestry drained peatlands (Minkkinen et al. unpublished manuscript). The tested CN ratio –N_2O relationships were comparable to those published earlier by Klemedtsson et al. (2005). Applying the different models and regional distribution of forested peatland site types in Finland from the 10th National Forest Inventory, the emission estimates fell between 8.5–15.3 Gg N_2Oyr-1, i.e. 0.17–0.31 g N_2O m-2yr-1. Half of this amount was emitted from the nutrient rich spruce sites, although the majority of drained peatlands are originally oligotrophic pine mires (Keltikangas et al. 1986).

Mitigation issues for peatland forests

While binding of atmospheric CO_2, peatland forest growth exhibits a potential climatic cooling effect, while the simultaneous release of greenhouse gases from the aerated, decomposing peat generates a counteracting warming effect. At least, heterotrophic decay of the >1-year-old soil organic matter means a considerable reduction in the overall forest C sink for peatland forests. The net balance is complicated, since the emissions of CO_2, CH_4 and N_2O from peat vary in different moisture and nutrient conditions (see e.g. Minkkinen et al. 2007).

Net radiative forcing of the influxes and outfluxes over the long term determines the forest's true mitigation potential. A measure of the atmospheric impact of the gas balance is the Global Warming Potential (GWP, IPCC) that relates the warming effect of the different GHGs with that of CO_2. The GWP coefficient of CO_2 has a value of 1, while specific coefficients are estimated for other gases on the basis of their chemical or physical decay in the atmosphere. The GWP coefficients can be used to convert the fluxes into CO_2 equivalents. The value of a GWP coefficient is estimated on the basis of the life time of the gas molecule due to decay by atmospheric chemistry during the time scale of interest, being higher on short time scales and getting lower as the considered time window increases. The time scale applied to forest related GHG fluxes is usually 100 years, the respective GWP_{100} coefficients for CH_4 being about 20 and about 300 for N_2O.

The latest estimate published in Finnish National Greenhouse Gas Inventory for 1990–2007 (see 4.1. Carbon accounts) shows that the reduction in the whole peatland forest CO_2 equivalent GHG balance by emissions from organic soils is about 40%. The overall reduction in the total annual forest CO_2 sink caused by soil emissions in peatland forests is about 4–7%. According to Finnish NFI data the first generation peatland forests, drained predominantly in the 1950–1980s, are currently in their rapid growth phase. As many of these forests start to mature ready for harvest within the next 10–30 years, the share of soil emissions in the total GHG balance of peatland forests can be expected to increase. Forest regeneration, including soil preparation by mounding and renewed ditch network, will follow the harvest at least in sites with nutrient reserves adequate to support the second tree generation (Laiho and Alm 2005). Not much is known on how the clear-cutting and soil preparation will affect the GHG balances in organic rich soils. Furthermore, a marked proportion of forest drainages have been established on sites where the nutrient regime has proved inadequate or unbalanced, and the management of those perhaps 0.5–1 Mha of unproductive peatland forests is under consideration. Possible rewetting of those sites may have significant mitigation potential through sustained C accumulation in peat in the future.

Organic soils have been afforested after abandonment from cultivation or on residual peat or cutaways after peat extraction. Croplands established on peat, i.e. organic croplands, show most adverse GHG impact due to typically high CO_2 and N_2O emissions that persist even decades after the abandonment (Maljanen et al. 2007). Afforestation of organic croplands is therefore expected to reduce the GHG impact (Maljanen et al. 2007, Laurila et al. 2007). The growing tree stand actually lowers the net GHG emissions, but this effect does not seem large enough to make the net balance in croplands positive, to mitigate the atmospheric GHG content (MMM 2007). Afforestation also reduces the greenhouse impact due to oxidation of residual peat left behind after the cessation of peat extraction. After the first years of net GHG losses the afforested cutaways seem to approach zero or positive GHG balance when the tree stand reaches its rapid growth phase (MMM 2007).

Sequestration of atmospheric CO_2 in forest biomass is one of the few means available to man to mitigate the GHG balance in the short term. It would be crucial that all possible mitigative actions were executed as soon as possible to be able to turn down the present increase in atmospheric GHG content. Although possessing a lower net GHG sequestration ability compared to mineral soil forest ecosystems, peatlands may have a special importance in mitigation. For example in Finland peat harbors a far greater amount of C than can be found in the aboveground parts of all forest biomass. Maintaining the conditions suitable for both litter production and low decomposition of soil organic matter would help to preserve the large peat C store in drained peatlands in the long term. Poor decisions in forest management in the expected warmer and more humid climate could lead to disintegration of this large C store, and result in further warming of the climate by gas emissions from accelerated peat decay. That could greatly void mitigation results achievable in the forest sector.

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