# COST action FP0703 – ECHOES

# Country report

# Finland

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# Contents

# 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. Local provenances and natural regeneration should be favoured by forest regenerations and mixed forest structures by harvesting. 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 -25 million tons of $CO_2$ during 2007. 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.

# 1. Finnish forests and forest management[1]

Jari Parviainen[2], Sinikka Västilä and Silja Suominen[3]

## 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

[1] This chapter is a shortened and modified version from the parallel article in the report: State of Finland’s Forests 2007- based on the criteria and indicators of sustainable forest management, written and edited by Jari Parviainen, Sinikka Västilä and Silja Suominen. Source: www.metla.fi/julkaisut/muut/state-of-finlands-forests-2007.pdf and www.mmm.fi/attachments/mmm/julkaisut/julkaisusarja/2007/5t1pZspXX/state_of_finlands_forests.pdf

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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 $m^3ha^{-1}yr^{-1}$, is twice as much as in northern Finland.

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 majority of forests in Finland are predominantly coniferous, with broadleaves often growing in mixed stands.

The timberline in northern Lapland is a hemiboreal 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.

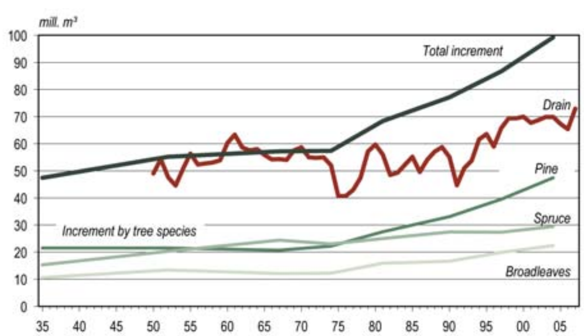


Figure 2: Annual increment of growing stock (1935–2007) and drain (1949–2007). Source: Finnish Statistical Yearbook of Forestry 2008.

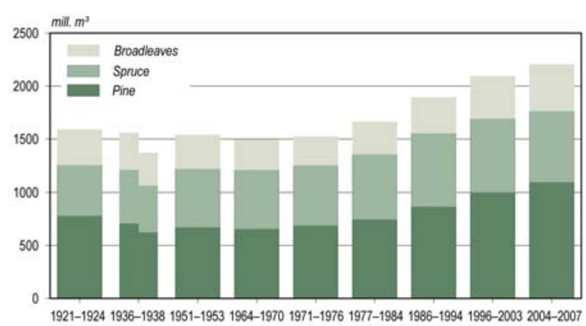


Figure 3: Growing stock volumes on forest and scrub land 1921–2005. Areas ceded to the Soviet Union in 1944. Source: Finnish Statistical Yearbook of Forestry 2008.

### 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 16$^{th}$ century onwards. In the 18$^{th}$ and 19$^{th}$ 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.

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.

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 20$^{th}$ 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.

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.

Figure 4: 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. Photo: Metla/Erkki Oksanen

Figure 5: 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. Photo: Metla/Erkki Oksanen

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.

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 (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.

# 2. Climate Change Impact "hot-spots" in Finland: Impacts and most susceptible regions of severe impact

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## *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 6). According to the last national forest inverntory 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 can be attributed to various factors: intensified silvicultural practices, nitrogen deposition (that improves growth) and age distribution of the forests. The age distribution of forests has shifted towards younger stands. Much of the increased growth can be attributed to the faster growth in young stands in comparison to older stands. It is still an open question whether part of the observed increase in forest growth is due to climate change.

Recent predictions of future forest growth in Finland, using the forestry growth and planning model MELA (http://mela2.metla.fi/mela/), suggest increasing forest growth even for the present type of climatic conditions in the future (Sievänen et al. 2007). There are several reasons for this change: e.g. increased stocking, changes in tree species dominance and age structure of the forests (more younger stands with higher average annual growth rate due to shorter rotations), if the current forest management guidelines continue to be followed. Since growth of boreal forests in the Northern Europe is limited by nitrogen, temperature and atmospheric carbon dioxide concentration [$CO_2$] in the current climate, it means that in a warming climate in future (see Figure 6) forest growth will increase (e.g. Kellomäki & Väisänen 1997, Kellomäki et al. 2005) unless various abiotic and biotic factors restrict growth. Model based calculations also predict changes in tree species dominance due to changing climate, with decreasing proportion of Norway spruce in Southern Finland due to drought (Kellomäki et al. 2005, Figure 7). Growth is expected to increase 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: 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

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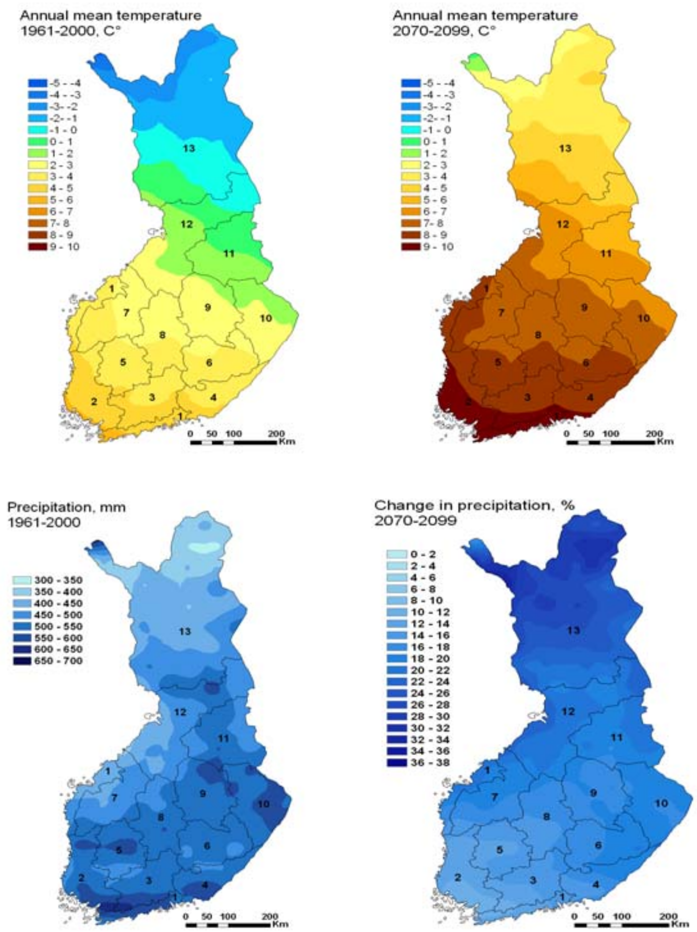
followed) in order to utilise the increased growth of tree stands (Briceño-Elizondo et al. 2006). These predictions are based on data from short-term impact studies and model simulations done based on ecosystem models that may lead to over-optimistic estimates of future forest growth, since multiple stress factors that affect forest growth in nature have not been considered.




<u>Figure 6:</u> Expected changes in annual mean temperature and precipitation under changing climate (FINADAPT A2 scenario, Kellomäki et al. 2005).

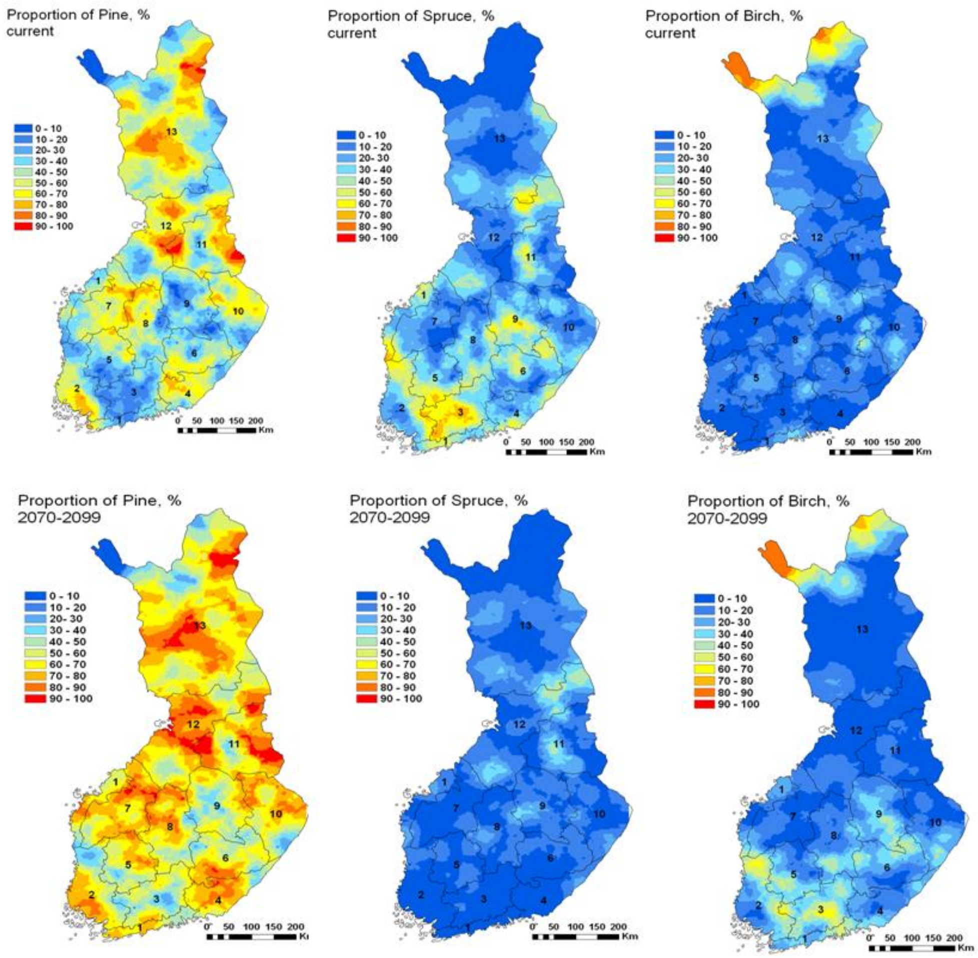



Figure 7: Expected changes in tree species dominance under current and changing climate (FINADAPT A2 scenario, Ruosteenoja et al. 2005) in different periods throughout Finland. In these model based calculations, no tree species has been favoured in thinning (from below), but timing and intensity of thinnings and rotation length has followed the currently recommended forest management guidelines in private forests throughout Finland (Kellomäki et al. 2005).

## 2.2 Current signs and expected impacts of climate change on forests

*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 (~2$^o$C) and less in summer, autumn (~0.5$^o$C) and winter (~1$^o$C) (*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 60°N and 66°33’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 1.8°C (Linkosalo et al. 2009).

*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 (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 (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 decreases 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 7) 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). On the other hand, forest ecosystem vulnerability can be reduced e.g. by proper selection of drought tolerant provenances and/or tree species for regeneration material.

*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 $m^3$ of timber was damaged by storms). Recently, in 2005 about 70 million $m^3$ 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, 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 greatest 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 thinnings. Older Norway spruce stands are 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 longer 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. Despite any change in windiness in the future (not expected based on number of climate model simulations), forests will be more vulnerable to autumn/early spring storm damage due to expected decrease in 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). Further, milder winters are expected to increase the incidence of heavy snowfall leading to a greater risk of snow damage (MMM 2003, Kilpeläinen et al. 2009a). 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 increase the susceptibility of trees to wind damage also indirectly by increasing the incidence of *Heterobasidion* root and but rot.

*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 6) 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).

*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 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 *H. 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 mountain 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 forest 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 North 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 dieing.

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.

## 2.3 Climate change impact research in Finland of forest trees: past and ongoing studies

The impact studies in Finland are based on a long tradition of ecological and environmental studies on forest trees and forest ecosystems, with expertise in the universities of Helsinki, Joensuu, Kuopio, Turku and Oulu, and the Finnish Forest Research Institute Metla. The following programmes and research projects have close links to the adaption research, it means that, for example, the ISTO- Climate Change Adaptation Research Programme includes both aspects: impact and adaption research.

Instruments of climate change impact studies:

1. Finnish Research Programme on Climate Change (SILMU) by Academy of Finland: 1990-1995:
    - a multi-disciplinary programme (80 projects, 200 scientists), quantification of the greenhouse effect and the magnitude of anticipated climate changes, assessment of the effects of changing climate on terrestrial and aquatic ecosystems, development of mitigation and adaptation strategies;
    - consisted of individual projects in universities/research institutes.
2. Research Programme ‘Understanding the global system – the Finnish perspective (FIGARE)’ by Academy of Finland, TEKES, five ministries: 1999-2002:
    - 36 research groups/multidisciplinary research consortia;
    - mainly national approach;
    - covering various fields: biogeochemical cycle, ecosystems, human systems (policy, economics, societal change, etc.).
  - Participation in EU projects: ECOCRAFT, EUROFLUX, FOREST, LTEEF-II, MOTIVE (ongoing, see below description).
3. Individual projects / EU projects:
    - SILVISTRAT (2003-2005, coordinated by Seppo Kellomäki)

4. Research programme 'Functioning of forest ecosystems and use of forest resources in changing climate (MIL)' by Metla 2007-2011 (http://www.metla.fi/tutkimus/index-en.htm).
    - The aim of the research programme is to produce information on the impacts of climate change on forest ecosystems. Further, studies will be conducted to understand the forest and environmental policy actions and means that help in mitigating and adapting to climate change. The programme also produces information in support of the greenhouse gas reporting dealing with forests.
    - MIL programme consists of 18 research projects. The projects cover phenology, growth and yield studies, basic biological studies of climate change impacts on forestry, adaptation means in forestry, as well as economics and policy studies of the forest policy means in climate change mitigation.
5. Climate Change Adaptation Research Programme (ISTO), 2006-2010. Multidisciplinary programme funded by different ministries. Six research projects of altogether 28 projects deal with forestry and are funded by Ministry of Agriculture and Forestry.
6. Individual projects funded by Academy of Finland, Ministry of Agriculture and Forestry, Ministry of Environment

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# 3. Adaptation

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## 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.

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, 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.

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*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. Furthermore, harvesting during spring and summer causes risk of increasing the insect populations at a landscape scale. 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 it has been discussed also in Finland on the new alternatives for forest management in order to increase heterogeneity of forests for adaptation. Those new options are 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 tree species towards to the north.

The decomposing of soil organic material may also change by warming climate, and then have an influence on the forest management options such as proportion of tree species or size of the regeneration areas. With various measures by management the light conditions falling on the soil surface of the stands can be regulated, and then 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***

Native species should be favoured as tree species that are native to a particular locality are better suited to adapting to local climate change because of their genetic make-up. Natural regeneration is always favoured if the soil and site conditions are suitable for that. Especially in the regeneration of pine natural regeneration or sowing has priority. Tree species and provenances best suited to a certain locality must be planted there. In the future, mixing somewhat more southern origins with local regeneration material should be considered, to allow for a wider adaptive capacity for the established crop (e.g. MMM 2005). Mixed forests should also be favoured, as the presence of various types of trees with different characteristics reduces the risks to forests.

***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.

*Summer droughts may cause tree mortality* especially on soils with low soil water holding capacity. 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).

***Management planning***
*More efficient planning* of harvests is required to solve the problem of *shorter winter time harvest periods*. The first solution could be to use all possible winter time harvesting capacity in 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* will 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 care of 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. 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 felling and for ensuring the smooth functioning of timber markets.

Managing forests for adaption should not contradict *biodiversity aims*. Biodiversity should be taken into account in the management of semi-natural commercial forests by leaving decayed wood and undisturbed micro-biotopes in commercial stands in order to preserve a diverse flora and fauna. Several EU Member States give financial support to private owners of woods who voluntarily undertake to protect them, as a measure to promote biodiversity. Forest certification schemes also require that forest biodiversity criteria are taken into account in forest management.

### 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, Innes et al. 2009).

Alternative 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 develop 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 Metsätalouden kehittämiskeskus Tapio, in cooperation with forest researchers. In parallel other forest owners such as companies and the state forest authority Metsähallitus have also developed their forest management recommendations. Currently, the 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 the 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.

### 3.3.3 Research studies of forest adaptation

The first national study on adaptation to climate change in Finland was the FINADAPT project funded by the Finnish Environment Cluster in 2004-2005 (Carter 2007). It was a scoping study that covered widely the different aspects of adaptation (Kankaanpää et al. 2005), including adaptation in forestry (Kellomäki et al. 2005). This study provided background information for the national strategy of climate change adaptation mentioned above (MMM 2005).

The Ministry of Agriculture and Forestry launched a national programme on climate change adaptation, ISTO, in 2006. The forestry studies in this programme include, e.g., analysing the impacts of climate change on pest damage, forest management under risk, forest production and harvests, and an analysis of the possibilities to utilise tree breeding and different provenances for planting material. Currently, the Academy of Finland is planning a cross-disciplinary programme on climate change adaptation, covering ecological and socio-economic aspects. The Ministry of Agriculture and Forestry is also preparing a strategy for management of alien species, which will be published in 2010.

The Finnish Forest Research Institute started its own programme on climate change in 2008, including projects on adaptation.

In addition to these national studies and programmes, Finnish researchers have participated in many international projects focusing on climate change adaptation. The SILVISTRAT project (2002-2004) outlined adaptation strategies in Europe in general (Kellomäki and Leinonen 2005). Currently, the MOTIVE (Models for Adaptive Management) project is underway within the Seventh Framework Programme (theme 6) led by the Forest Research Institute of Baden-Württemberg, Germany (Participant University of Joensuu led by Prof. Seppo Kellomäki). It will evaluate the consequences of the intensified competition for forest resources given by climate and land-use change, seeking to develop and evaluate strategies that can adapt forest management practices to balance multiple objectives under changing environmental conditions.

Other ongoing projects include the assessment of short- and long-term risks of wind and snow induced damage in forest stands related to current forest management practices (Dr Heli Peltola, University of Joensuu). This work could help foresters to identify the forested areas under risk of damage and take this into account when planning site-specific forest management.

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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 CO2) 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).

## *4.1. Carbon accounts*

Aleksi Lehtonen[14]

In the land use, land-use change and forestry (LULUCF) sector Finland has a sink of carbon that amounted -25 million tons of $CO_2$ during 2007. That sink originated mainly from 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 soils is currently compensated for by the sink of tree biomass on those lands.

During 2007 mineral soils were a sink for -3.6 million tons of $CO_2$, while the drained organic soils were a source for 6.7 million tons of $CO_2$. At the same time the emissions from peat extraction sites were 1.4 million tons of $CO_2$, while the sink of harvested wood products was -1.3 million tons of $CO_2$. Both cropland and grassland were sources of carbon, resulting in annual emissions of 3–4 million tons of $CO_2$ during recent years.

There is a high degree of annual variation for all sinks and sources of the LULUCF sector. For example, during the period 1990-2007 forest biomass varied between -20 and -40, mineral soils between -2.6 and -3.6, organic soils between 10 and 6.7, and harvested wood products between source 0.3 and sink -2.1 of carbon, million tons of $CO_2$.

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

| Year | Forest land | Cropland | Grassland | Peat extraction | Harvested wood products | Total |
|---|---|---|---|---|---|---|
| 1990 | -23.19 | 7.41 | -2.13 | 1.08 | -0.95 | -17.77 |
| 1991 | -37.68 | 5.61 | -0.83 | 1.1 | 0.31 | -31.50 |
| 1992 | -31.5 | 5.44 | -1.07 | 1.14 | -0.22 | -26.22 |
| 1993 | -30.04 | 5.43 | -0.6 | 1.16 | -0.09 | -24.15 |
| 1994 | -22.82 | 5.24 | -0.13 | 1.2 | -0.76 | -17.27 |
| 1995 | -23.12 | 6.9 | -0.68 | 1.21 | -0.87 | -16.56 |
| 1996 | -32.16 | 7.13 | -0.88 | 1.25 | -1.05 | -25.71 |
| 1997 | -24.99 | 6.7 | -0.57 | 1.29 | -2.12 | -19.69 |
| 1998 | -22.37 | 6.13 | 0.09 | 1.32 | -1.77 | -16.59 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| 1999 | -24.59 | 5.8 | 0.96 | 1.34 | -2.04 | -18.53 |
| 2000 | -25.71 | 5.28 | 1.92 | 1.37 | -1.27 | -18.42 |
| 2001 | -30.06 | 5.09 | 2.42 | 1.37 | -0.31 | -21.5 |
| 2002 | -30.18 | 4.62 | 2.15 | 1.35 | -0.44 | -22.5 |
| 2003 | -29.8 | 4.17 | 2.66 | 1.35 | -0.89 | -22.51 |
| 2004 | -30.77 | 3.86 | 3.01 | 1.43 | -0.83 | -23.3 |
| 2005 | -36.36 | 3.55 | 3.44 | 1.41 | -0.34 | -28.31 |
| 2006 | -40.69 | 3.24 | 4.24 | 1.4 | -0.39 | -32.21 |
| 2007 | -32.81 | 3.33 | 4.06 | 1.38 | -1.22 | -25.27 |

## *4.2 Harvested wood products*

Henrik Heräjärvi[15]

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. Different kinds of wood products, including both ground and aquatic constructions, stored almost 19 million tons of carbon in 2005. Thus, 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 by sources in the land use and forestry sectors (Table 1), the harvested wood products include both mechanically (sawn timber, wood-based panels, utility poles, furnishings/solid structure cabinetry) and chemically (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. Solid wood products typically store carbon for longer periods of time in comparison to the paper or paperboard products, such as newsprint or packages. Decreased production of goods representing 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, their computational removal still remaining at a higher level.

Recycling of 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).

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## *4.3 Forestry as a source of bioenergy*

Markus Lier[16]

### 4.3.1 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.

Renewable energy sources[17] provide 28.5% of Finland's total energy consumption and account for more than one-fourth of its power generation. The targets set by the European Commission to raise Finland's share of renewable energy sources to 38% by the year 2020 is 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 and wind energy. Forest biomass is currently the most important renewable energy source in Finland. In 2007, wood-based fuels[18] accounted for 20% (295 PJ) of the total energy consumption (see Figure 8 and Figure 9) (Finnish Statistical Yearbook of Forestry 2008).

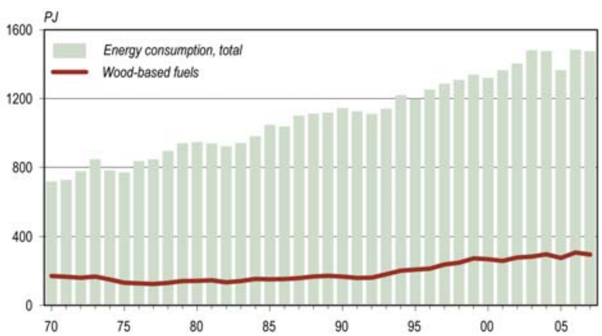


Figure 8: Total energy consumption and consumption of wood-based fuels 1970–2007. Source: Finnish Statistical Yearbook of Forestry 2008.

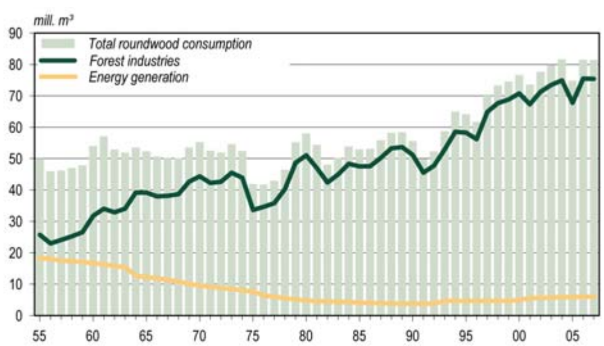


Figure 9: Roundwood consumption by category of use 1955–2007. Source: Finnish Statistical Yearbook of Forestry 2008.

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[17] include bioenergy – wood and wood-based fuels in particular, hydropower, wind power, ground heat and solar energy

[18] 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)

In 2007 the total consumption of roundwood in Finland was 81.40 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 75.43 million m³ of roundwood. (see Figure 9)

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 2007, more than half of wood-based fuel consumption (153 PJ) was covered by waste liquors. Solid wood fuels were consumed to the total of 137 PJ (19.2 million m³), of which the heat and power plants accounted for 89 PJ or 13 million m³. The combustion of bark, accounted for a volume of 7.5 million m³. The use of traditional firewood is an important source of bioenergy in small-sized dwellings in Finland; in 2007 about 6.1 million m³ (48 PJ). The smallest share is straight industrial harvesting of wood material for energy production (logging and thinning residues) to heating and power plants; in 2007 about 2.7 million m³ wood. That part of harvesting was decreasing compared to 2006 (about 13%). (see Figure 10) (Finnish Statistical Yearbook of Forestry 2008)

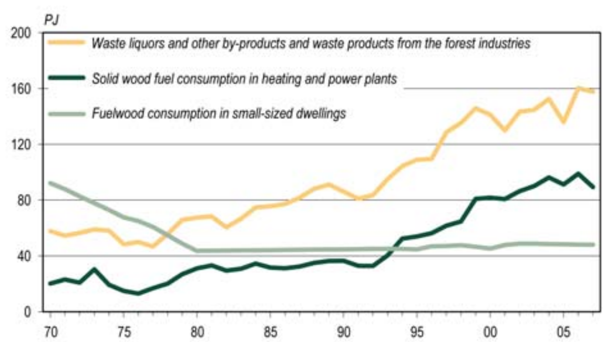


Figure 10: Consumption of wood-based fuels 1970–2007. Source: Finnish Statistical Yearbook of Forestry 2008.

The wood pellet production in Finland accounted in 2007 to 326 000 tonnes. In 2010, the production is estimated to be about one million tonnes. At the same time, the domestic consumption is estimated to grow up to several hundreds of thousands of tonnes (Finnish Statistical Yearbook 2008, Röser et al. 2008).

However, the amounts of available industrial by-products are highly dependent on the production amounts in the forest industry. The prospects do not look promising at the moment. Due to the fall in the global economy the Finnish forest industry production continued to decrease in 2009 i.e. production of sawn timber over the full first half of 2009 was about 30% smaller compared to the corresponding period of 2008. The same trend can be seen in the demand for printing and writing papers which decreased in the Finnish forest industry's main European markets (Forest Industry Review 2009).

### 4.3.2 Forest energy conversion plants

In 2006 the total number of plants using forest chips was already 580. Of that total 532 were heating plants providing hot water heating for municipalities or steam for industrial processes. The remaining 48 plants produced heat and electricity (Ylitalo 2007) (see Figure 11).

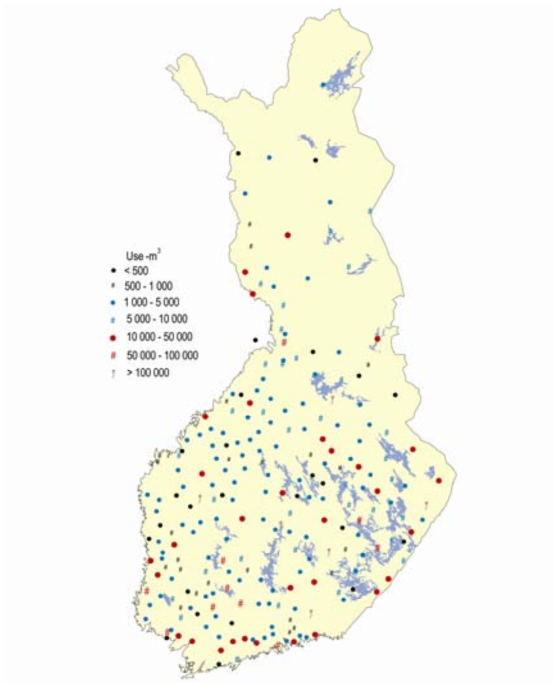


Figure 11: Use of wood-based fuels in heat and power plants on municipality level in Finland in 2007.
Sources: Boundaries © National Land Survey of Finland, license MYY/179/06-V; Waters: Corine Land Cover 2000 (© Finnish Environment Institute, partly Ministry of Agriculture and Forestry, National Land Survey, Population Register Centre).

Over the past decade the forest industry in Finland has increasingly become aware of the positive impacts of the increased use of wood energy. With the already existing wood procurement organisations the forest industry is able to utilise the available energy wood potential. The forest industry also has high conversion capacity, which they are already updating at many of the bigger plants to accommodate the increased use of energy wood in the future. With increasing energy prices the use of e.g. logging residues and stumps for energy generation has increased considerably over the last years (Röser et al. 2008).

Small to medium sized heating plants of urban and rural communities are typically between 1 and 50 MW and provide heat and hot water for public buildings, terraced houses, schools or retirement homes. The main source of fuel for these heating plants is normally wood chips coming either from logging residues or precommercial thinnings. The establishment of these local heating plants using local fuels has created benefits in terms of fuel security, lower energy prices for consumer and creation of new employment possibilities (Röser et al. 2008).

### 4.3.3 Policy, legislation and new developments

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 use of renewable energy technology development and commercialisation. The final success in meeting the objectives depends on the development of 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 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 (heating and power plants used 2.7 million $m^3$ of forest chips in 2007). The scenarios are roughly doubling (basic) and even tripling (ambitious) the current use of forest biomass (MMM 2008, Röser et. al 2008).

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 fuel 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 controlled balance between the use of wood for manufacture and for energy (MMM 2008).

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## *4.4. Timber frame house construction in Finland*

Pekka Ollonqvist[19]

The Finnish Government has promoted the use of domestic timber products and their export through various campaigns and programmes over the last 20 years. The programmes have aimed to increase the added value of timber vwlue chains and enhance more versatile use. The enhanced use of timber in the real estate & building sector has been in the policy agenda along with other ecological impacts from timber use,. The obstacles of multi-storey timber buildings were removed in 1997, when the reformed planning, fire and building regulations made more versatile timber construction possible. As the result of the various programmes, new timber products, new enterprise, and several imposing examples of timber construction, such as Sibelius Hall and Metla House, have been created in Finland.

Figure 12 and 13: The carbon sequestration capacity and the substitution effects were calculated for the Metla House. The amount of used wood was 2000 m³, which corresponds to 1460 tons $CO_2$ eq.. In comparison to a similar building made from concrete the construction of Metla House has saved 620 tons of CO2. Photos: Metla/Erkki Oksanen and Scanfoto.

*New Generation National Innovation System towards Sustainable Low Tech Industries*

Public financing of industrial R&D activities, delivered through a single institution TEKES - Finnish Funding Agency for Technology and Innovation, has gradually been diversified and expanded to cover the innovation support portfolio to low tech industry value chains during the early 1990s. New policy, promoting extensive programmes towards implementation of new technical solutions in traditional industries, opened up financing from TEKES to R&D projects in timber-based value chains. The programmes related to wood product industries covered: (a) first degree production (sawmills and wooden panel industries); and (b) wood construction technology.

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- *Mechanical Wood Processing and Wood-Based Panels Industry technology programmes 1992-1996;*
- *Wood Construction Technology Programme 1995-1998*[20]*;*
- *The Value Added Wood Chain Programme 1998-2003*[21]*;*
- *Construction cluster technology 2003-2007.*

These programmes provided (a) research financing to public universities and research institutes for open access research, and (b) PP joint interest projects for single research projects of individual companies for radical or incremental technological innovations. The national innovation policy expansions were in good coordination with the international sawmill industry joint interests to radically increase the percentage of wood used in construction (CEI-Bois)
(www.forestindustries.fi/Infokortit/roadmap/Documents/roadmap.presentation.pdf).

*Challenge – strong concrete based construction value chains*

The high cost efficiency of concrete based solutions for multi-storey construction has been based on assembling pre-fabricated elements on-site. This value chain mode constituted the base for their dominant position in the market. This high competition challenge implied public innovation support to multi-storey wood frame solutions to be extended to cover national, sectoral and regional innovation policy activities in Finland.

- *National innovation system applied through technology programmes and carried out in wood related context through the programmes listed above.*
- *Sectoral innovation system promoting wood frame house construction value chains through centres of expertise network (PuuOske) thus providing knowledge services especially for SMEs www.puusuomi.com/index.php?anonymous=ptaokeng).*
- *Regional innovation system aimed to mobilise regional developers for networking among wood product business stakeholders (PuuSuomi).*

*Implementation – multi-storey solutions in appartment and office construction 1996-2005*

There has been a ten-year period, 1996-2005, when the outputs of the Wood Construction Technology Programme has been implemented. In total 11 multi-storey apartment building projects in seven cities have been accomplished. There are 517 apartments in those projects covering 2-4 storey buildings. The total output, about 50 000 m$^2$, has provided opportunities to create and accumulate new knowledge in Business to Business (BtoB) construction value chains. Two office building projects have also been completed, providing about 20 000 m$^2$ of office space, providing high quality architectural solutions to innovative wood interior and exterior solutions.

[20] http://www.tekes.fi/english/programmes/woodconst/woodconst.html
[21] ttp://websrv2.tekes.fi/opencms/opencms/OhjelmaPortaali/Paattyneet/Tukista_tuplasti/en/etusivu.html

The construction projects listed above have been experimental and the breakthrough of wood-based multi-storey construction solution has been postponed mainly due to the cost advantages in concrete based value chains. Since the 1990s, innovation policy activities have been targeted to considerably enhance construction industry effectiveness by radically changing the industry's processes: instead of constructing on-site, building elements can be pre-fabricated in factory environments and simply assembled on-site (www.tekes.fi/english/programmes/woodconst/woodconst.html).

There are some factory producers of wood pre-fabricated structural construction elements for BtoB value chains that have been able to create competitive solutions. In addition the re-engineering of construction technologies and processes through recent technology programmes has provided equal opportunities for wood frame construction alternatives to be implemented into BtoB construction value chains as businesses with sustainable competitive advantages. These programmes include:

- *ProBuild - Progressing building process technology programme 1997-2001;*

- *Sara - Value networks in construction 2003-2007 (htttp://akseli.tekes.fi/.../OhjelmaPortaali/ohjelmat/Sara/.../Sara-Arvoverkottunut_rakentaminen.ppt).*

## 4.5 Greenhouse gas balance in peatlands drained for forestry

Jukka Alm[22]

*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). Mire vegetation binds atmospheric carbon dioxide ($CO_2$) in biomass. As the plants die in an undisturbed mire, carbon (and nitrogen) in organic litter gets deposited in waterlogged conditions as peat, thereby removing $CO_2$ from the atmosphere. On the other hand, slow decomposition of peat produces methane ($CH_4$), another greenhouse gas (GHG) warming the atmosphere. Mires thus maintain, in part, the natural atmospheric GHG mixing ratio.

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). In this document, the term 'mire' is used for pristine ecosystems, and 'peatland' for drained ones. Drained peatlands tend to emit more $CO_2$, but less $CH_4$ than undrained mires do (Moore and Knowles 1989, Silvola *et al.* 1996a, Nykänen *et al.* 1998). On the other hand, more biomass can be stored in

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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) and 0.7–1.0 Mha for agriculture (Myllys 1996, Myllys & Sinkkonen 2004), leaving ca. 40% (4.1 Mha, Finnish Forest Research Institute 2005) in pristine condition. Some of the current peat extraction area (0.06 Mha) has been established on peatlands, previously drained for forestry, but pristine mires have also been reclaimed. Cutaway peatlands, abandoned from industrial peat extraction, have mostly been prepared for afforestation, for special agriculture and energy crops, or returned as waterlogged wetlands through restoration measures (Selin 1999).

The majority of the C balance in pristine mires comprises of the exchange of $CO_2$ and $CH_4$ between the ecosystem and the atmosphere. The rates of gas exchange are sensitive to variations in weather, responding immediately to changes in irradiation and with varying lags to those in air and soil temperature and precipitation (Alm *et al.* 1997, 1999a, Saarnio *et al.* 1997, Kettunen *et al.* 2000). The average long-term rate of C accumulation in Finnish minerotrophic fens during the Holocene has been ca. 17 g C $m^{-2}yr^{-1}$, and in ombrotrophic bogs ca. 21 g C $m^{-2}yr^{-1}$, corresponding to 62 g and 77 g $CO_2$ $m^{-2}yr^{-1}$, respectively. Those figures have been obtained using geological cores and $^{14}C$ dating (Turunen *et al.* 2002), and include the possible impact of fires that may locally deplete a considerable part of peat reserves over the millennia (Pitkänen *et al.* 1999).

Overall, gas exchange measurements can result in annual C accumulation rates comparable to geological methods. However, some very different data have demonstrated that large interannual variability in carbon gas exchange takes place in mires (Alm et al. 1999). The major implication from this variability is that C accumulation rate of mires is sensitive to variations in weather and climate. Consequently, for example during summer droughts or rainy periods, the annual C accumulation rate can be much lower or higher, respectively, than can be expected on the basis of geological measurements (Alm et al. 1999, Saarnio et al. 2007).

Various disturbances have 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 forms of 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, 160–500 g C $m^{-2}yr^{-1}$ of the peat substrate (> 1-year-old organic matter) is oxidised (Minkkinen *et al.* 2007a). These figures exclude the contribution of root associated respiration (e.g. Silvola *et al.* 1996b). 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). According to 30-year weather simulations in Finnish conditions, the average annual soil $CO_2$ release is ca. 880 g $m^{-2}$ for the Vatkg (dwarf-shrub) type, and ca. –1713 g $m^{-2}$ for the Rhtkg (herb-rich) type (Minkkinen *et al.* 2007a) . The simulated averages can be used as best estimates of soil respiration for the respective site quality classes in the Finnish organic forest GHG inventory. Litter from trees and ground vegetation adds new organic litter in the rooting zone and on the soil surface (Laiho *et al.* 2003). Part of this litter is quickly decomposed and returned to the atmosphere as $CO_2$, but a more recalcitrant fraction can remain in the soil for longer periods of time (Minkkinen and Laine 1998).

### *$CH_4$ 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 as small sources of $CH_4$ when emissions from ditches are included.

### *$N_2O$ 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, 1998) 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). According to Martikainen *et al.* (1993), drained mesotrophic peatlands, comparable to *Vaccinium myrtillus* type and herb-rich type, released 0.08 to 0.22 g $N_2O$ $m^{-2}yr^{-1}$, respectively. Klemedtsson *et al.* (2005) showed that the annual release of $N_2O$ from drained Swedish, Finnish and German peatlands has an inverse, non-linear correlation with peat CN ratio. This method would give means for regional estimation of $N_2O$ emissions if peat CN ratios were known. 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 of Klemedtsson *et al.* (2005). Applying the different models and regional distribution of forested peatland site types in Finland from the 10$^{th}$ National Forest Inventory, the emission estimates fell between 8.5–15.3 Gg $N_2Oyr^{-1}$, i.e. 0.17–0.31 g $N_2O$ $m^{-2}yr^{-1}$. 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 $CO_2$ by peatland forest growth exhibits a potential climatic cooling effect, simultaneous release of greenhouse gases from the aerated, decomposing peat may generate 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 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 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 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 by 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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## *4.5 Research studies on mitigation*

There are three large current research programmes by Metla which deal partially with the mitigation issues or directly concentrate on mitigation: (http://www.metla.fi/tutkimus/index-en.htm). Metla is the responsible organisation in Finland for reporting the carbon account for EU and other purposes. Metla produces several reports for Finnish applications on carbon accounts, which can be found on the address http://www.metla.fi.

The mitigation issues related to wood are also studied at the University of Helsinki (Forest Resources). Extensive research on mitigation issues on wood, wood construction and production of wooden energy and biofuel from wooden biomass are under way also by VTT Technical Research Centre of Finland (http://www.vtt.fi). The Finnish Environmental Centre (SYKE) (http://www.environment.fi) has created a Research Programme for Production and Consumption, which includes several projects on wood products in the light of life cycle analysis and mitigation issues.

The three Metla's research programmes related to mitigation are:

**1. Functioning of forest ecosystems and use of forest resources in changing climate (MIL) 2007-2011**

These studies will be conducted to understand the forest and environmental policy actions and means that help in mitigating and adapting to climate change. The programme also produces information in support of the greenhouse gas reporting dealing with forests.

**2. Bioenergy from Forests (BIO) 2007 – 2011**

The goals are:

1. Produce research based information on the principles and impacts of biomass production in forests and peatlands on the forest resources.
2. Develop sustainable silvicultural methods for forest biomass production and study the possibilities to cultivate energy crops also on peat and farm land.
3. Develop inventory and planning methods for forest biomass resources.
4. Promote the innovation and development of technology and logistics for forest biomass procurement.
5. Support new entrepreneurship and creation of new business models in forest energy business.
6. Join the researcher resources within the institute in the field of bioenergy research and support the creation of new researcher networks.
7. Evaluate the impacts of increasing energy use of forests on forest sector including forest owners, forest machine entrepreneurs, forest and energy industry.
8. Research and develop woody biomass and its properties as a raw material for biorefineries

Studies also together with other Metla's research programmes the impacts of forest energy use on greenhouse gas and energy balances of Finland.

**3. Renewing wood product value chains and timber procurement solutions (PUU): 2009-2013**

**The objective** of this research and development programme is to improve the competitiveness and profitability of the wood product companies, timber procurement organisations and timber producers by providing information on:

- the quality potential of available wood supply now and in the future;
- wood raw materials, new wood products as well as their competitiveness and performance;
- technologies, service and business concepts that provide customer value and cost efficiency in timber procurement and timber trade;
- novel customer, service and product solutions as well as company networking solutions based on added value in the wood product industries.

In addition, PUU programme supports the governmental policy and strategy initiatives in the forest cluster from the viewpoint of wood utilisation. The own strategy and development processes of the wood product companies and timber procurement organisations is also collaboratively supported.