Layman's report

Climate – Forests – Vulnerability - Carbon sink – Pest damages – Climate change – Water

With the contribution of the LIFE+ financial instrument of the European Union
LIFE09 ENV/FI/000571
Climate change induced drought effects on forest growth and vulnerability (Climforisk)

www.luke.fi/projektit/climforisk

PROJECT OBJECTIVES

Forests are the most important natural resource in Finland, sequestering 30-60% of annual national CO_2 emissions. In addition to raw material provided by forests, forests are also significant carbon storages and essential reserves of biodiversity.

Climate change will influence forest growth, the rate of carbon sequestration by forests, and the vulnerability of forests to damage. Prediction of these changes is already timely, as the forest practices of today will be reflected in the structure and function of forests for decades to come.

Finnish forests have been intensively and extensively studied and monitored. Climforisk Life+ project (2011-2014) utilized the data created by previous studies, creating more comprehensive knowledge about the impacts of annual climatic variability and long-term climate change on carbon exchange and vulnerability of Finnish forests.

We used this knowledge to derive maps and indicators that support the decisions of officials and forest managers when future silvicultural methods and options are considered.

The most important questions the project aimed to answer were:

- *To create comprehensive understanding of spatial distribution of forest biomass and leaf area index by compiling available field data of Finnish forest environment with satellite images.*
- *To provide predictions of forest carbon and water balances with the compilation of available forest data, climatological data and forest growth models.*
- *To recognize the features that increase or decrease the probability of different types of forest damages, and to estimate how these features might change in the future.*
- *To identify areas most sensitive to changes in carbon sinks and in the occurrence of forest damage.*

By doing so, the project demonstrated the usefulness of national forest inventory (NFI) data, forest monitoring data (under the ICP, ForestFocus and FutMon programmes), and other data sources, such as production- and soil carbon models in building the knowledge about climate change impacts on forests.

- *Project period: 1.1.2011-31.12.2014.*
- *Beneficiaries: Finnish Forest Research Institute and Department of Forest Sciences, University of Helsinki.*

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POLICY FRAMEWORK

EU white paper Adapting to climate change: Towards a European framework for action (COM(2009) 147) presented an EU level framework for adaptation to climate change. The first phase planned for years 2009-2012 called upon essential ground work to prepare a comprehensive adaptation strategy commencing in the 2nd phase starting in 2013. This white paper urged that a solid knowledge base on the impacts and consequences of climate change in the EU should be formed.

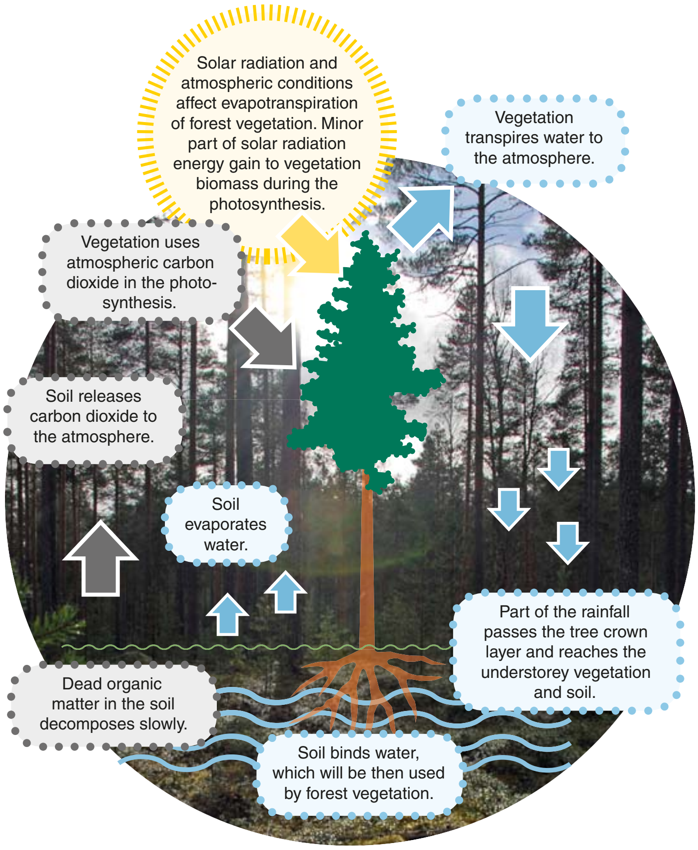
As regards forests, the white paper called upon an updated EU forest strategy with climate-change aspects, which was recently published (EU Forest Strategy, COM(2013) 659 final). Relatedly, a proposal for the EU parliament decisions on accounting rules and action plans on greenhouse gas emissions and removals resulting from activities related to land use, land use change and forestry, LULUCF, (COM(2012) 93 final) highlighted the need for using forests and bio-economy in climate change mitigation. This proposal is conditional on accurate emission and sink estimates for the LULUCF sector. Our project contributed to forming a more solid knowledge base supporting the accurate estimation of carbon sinks in forests by utilizing existing data to generate new input data products needed for such estimations. We further developed a carbon balance model that can be used to make these predictions. The methods and tools also allow spatial carbon stock change estimates, thus moving to a higher level of detail from national level greenhouse gas, GHG, inventory. Using these data and models we estimated carbon sinks in forests in the past, currently and in the future. We further assessed future scenarios of forest growth in order to support bio-economic scenarios of forest resource use and design of cost-efficient and sustainable forest management strategies for the future that allow simultaneous wood production and climate change mitigation. In order to fulfil and implement national forest policies that link forest management practices with climate change targets it is important to have spatial information about carbon sinks and sources of our forests.

Forest Strategy also stressed that forests are vulnerable under climate change. It urges member states to maintain and enhance resilience and adaptive capacity of forests. Disturbances, both biotic and abiotic are seen as a major threat to forest ecosystems. In line with this, the proposal for the EU parliament (COM(2012) 93 final) also underlined the role of disturbances and their special role as "force major" emission source. Therefore it is important to have solid methodology for damage probability estimation. Enhanced information about the risks to forest growth under climate change is important for forest managers and owners trying to minimize their economic losses. Climforisk collected past forest inventory and forest health records together and evaluated the possibilities to draw such predictions to the future. These efforts are also in line with Finland's National Strategy for Adaptation to Climate Change (Ministry of Agriculture and Forestry, 2005) that called for more accurate means to identify and anticipate climate-change-induced risks for forests.

Based on our work, we concluded that carbon sinks are expected to increase but uncertainties remain large. Although, the changes in future damage regimes are even more uncertain, there are possibilities to anticipate and minimize damages by rapid action. Therefore, we created a novel web service, which provides information about the spring development of important insect species. This service facilitates forest managers' work as it provides a priori information about the beginning of the maturation of damage causing insects, which is the time before which winter harvests and windfalls should be removed from forests. Anticipatory possibilities still do not preclude the fact that more empirical data on damage-climate and also on growth-climate relationships are required.

TOOLS TO ESTIMATE CLIMATE CHANGE EFFECTS ON FORESTS

Climate is changing faster than ever. Trees cannot avoid it, but they carry the potential to mitigate these changes. This potential, however, is hard to assess because there is not much data about how trees respond under elevated CO_2 and in natural-like conditions. Will we see denser and larger forests sequestering more carbon from the atmosphere, and providing ever more resources for the society, or will we see trees suffering from the climate change?



Modelling forest carbon and growth under climate change

In order to generate predictions of forest carbon balances we developed methodologies for these purposes. For forest growth estimation these carbon balance methods were combined with existing models. These methods were then use to draw scenarios of carbon balances and growth under climate change.

- *Modelling approaches to describe the forest carbon and water dynamics were developed in the project*[1].
- *The validity of model predictions was checked by comparing model predictions to other models (model by affiliated Snowcarbo Life+ project and MODIS satellite product)*[2]*. We concluded that the model well predicts current day productivity of forests.*
- *Climate change induced changes in carbon-nitrogen balance and allocation were studied with an existing model*[3,4].

Trees are recyclers of carbon and water

Trees love CO_2. When trees grow, they use atmospheric CO_2 to build biomass.

They photosynthesize and grow faster when it is warm.

More CO_2 in air means trees transpire less water to the atmosphere, but increasing temperatures can counterbalance this effect due to the increases of evaporation.

Dead plant material decomposes in the soil and is released back to the atmosphere as CO_2.

Changes in forest carbon stocks are controlled largely by temperature which tends to increase the growth of biomass, while simultaneously increasing soil carbon emissions.

[1] Peltoniemi M., Pulkkinen M., Aurela M., Pumpanen J., Kolari P., Mäkelä A., 2015. A semi-empirical model of boreal forest gross primary production, evapotranspiration, and soil water-calibration and sensitivity analysis. Boreal Environment Research. 20: 151-171.

[2] Peltoniemi M., Markkanen T., Härkönen S., Muukkonen P., Aalto T., Mäkelä A., 2015. Consistent estimates of gross primary production of Finnish Forests - comparison of estimates of two process models. Boreal Environment Research. 20: 196-212.

[3] Valentine H.T. and Mäkelä A., 2012. Modeling forest stand dynamics from optimal balances of carbon and nitrogen. New Phytol. 194, 961-971.

[4] Mäkelä A., Kalliokoski T. and Peltoniemi M. 2014. Future forest production under optimal C:N balance. Poster presented in 2014 AGU Fall Meeting, San Francisco, USA.

MODELS NEED GOOD INPUT DATA

We created a model-data platform for our models of carbon cycle and growth. We created maps of leaf area index (LAI), which were needed to quantify fraction of absorbed sun light by the forests of Finland (Figure 1)[1].

- *According to the results for Finland[1] it was found that MODIS LAI product overestimated LAI in Northern Finland but MODIS underestimated LAI in Lake District area. MODIS product is based on satellite images and therefore it also includes reflectance from understorey vegetation that only partially explains this discrepancy between MODIS and NFI-Landsat LAI in Northern Finland. It is essential to have precise input data for models, e.g. LAI, so we advocate using inventory-based LAI for regional model analyses.*
- *We distribute our LAI and fAPAR (fraction of photosynthetically active radiation) products through the Value tool developed at the Finnish Environment Institute in LIFEDATA EU Life+ project at high resolution (Figure 2). Tool supports environmental administrators and will also be launched publicly in future.*

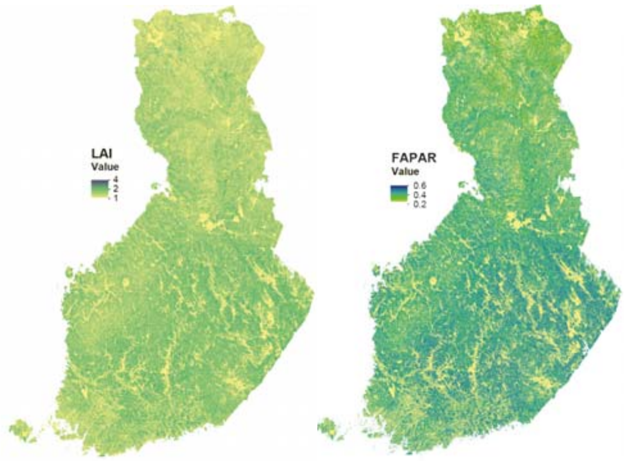


Figure 1. NFI-Landsat LAI (left) and fAPAR map (right). LAI values range from 0 to 10 (mostly 0 to 4), while fAPAR ranges from 0 to 1.

- *We collected information about soil factors to estimate how they influence drought faced by the main tree species2*
- *We combined weather data and climate change predictions, and integrated it to drought observations (Figure 3)2.*
- *We created consistent pest damage data sets based on ICP I network data and past national forest inventories (NFIs)3.*
- *We compiled NFI information from 50s to present day to create the best estimates of soil carbon in Finland for ecosystem carbon stock simulations that were carried out for the last ten years.*

[1] Härkönen S., Lehtonen A., Manninen T., Tuominen S., Peltoniemi M., 2015. Estimating forest leaf area index using satellite images: comparison of k-NN based Landsat-NFI LAI with MODIS-RSR based LAI product for Finland Boreal Environment Research 20: 181-195.

[2] Muukkonen P., Nevalainen S., Lindgren M., Peltoniemi M., 2015. Spatial occurrence of drought associated damage in Finnish boreal forests: results from forest condition monitoring and GIS analysis. Boreal Environment Research 20: 172-180.

[3] Nevalainen S., Sirkiä S., Peltoniemi M., Neuvonen S., 2014. Vulnerability to pine sawfly damage decreases with site fertility but the opposite is true with Scleroderris canker damage; results from Finnish ICP Forests and NFI data. Ann. For. Sci., DOI 10.1007/s13595-014-0435-8.

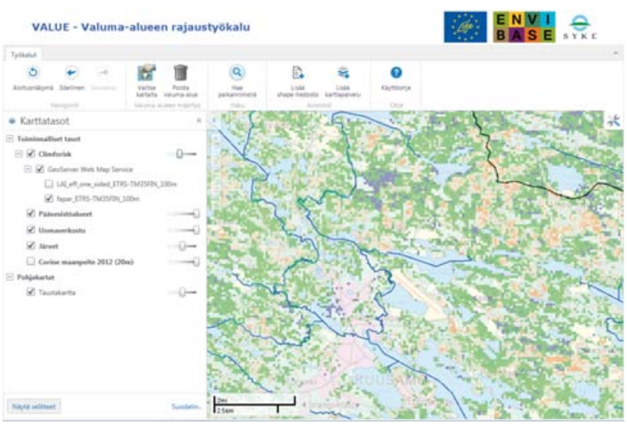


Figure 2. Climforisk LAI and fAPAR products in Value tool.

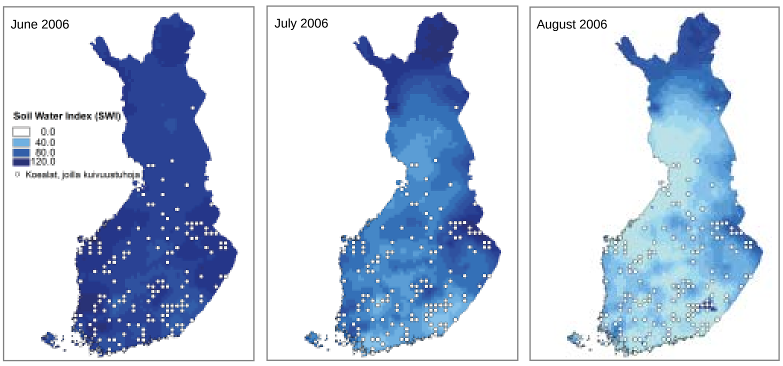
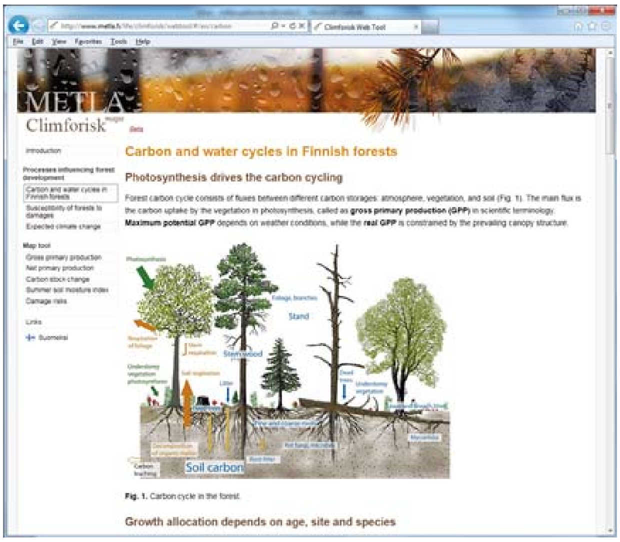


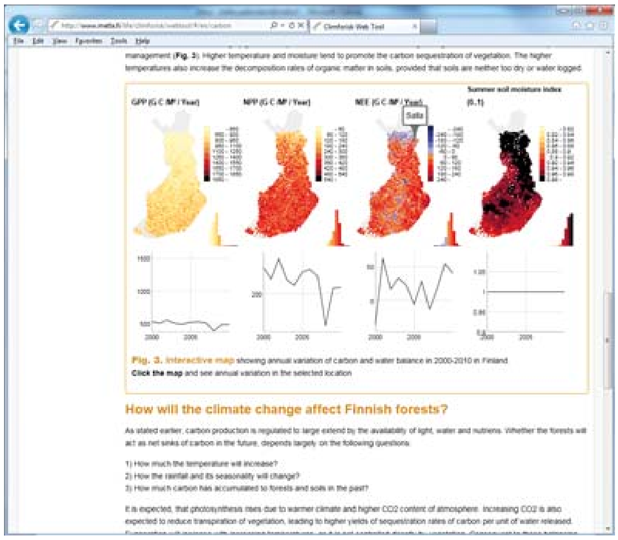
Figure 3. Summer 2006 was extremely dry for trees in Finland. Still in June soil water content was at normal level, by in August that was only 25% from normal. White bullets show sites with observed drought damages in 2006.

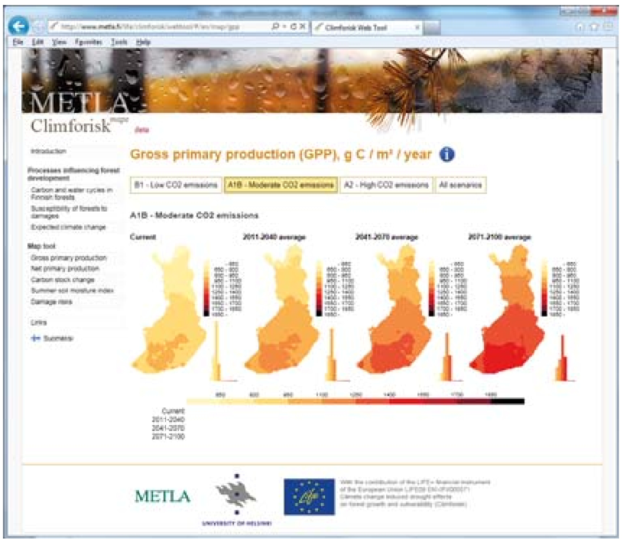
MAP TOOL PRESENTS FOREST RESPONSES TO CLIMATE CHANGE

We established an educational web portal that describes the basic flows of carbon through forest ecosystems. The contents presented in the form of short text chapters and interactive wall-to-wall maps covering Finland (see example figures below) draw from data and models collected and developed in Climforisk. The text chapters discuss forest carbon and water cycles, vulnerability of forests to climate-induced changes and expected climate change, as well as links to other relevant sources, e.g. Finnish Climate-Guide portal. Interactive, user-friendly maps show the development of forest carbon production as well as their predicted water and carbon balances in the past, and in the future (from now until year 2100) in three alternative emission scenarios (low, intermediate and high increase in CO_2 emissions), and eight selected climate model forcings. The web portal also contains maps showing expected risk for pine sawfly damages and drought in Finland. Estimates of forest carbon balances at current weather conditions are presented to provide interpretation for the effects presented in the map tool section. The web portal can be found here:
http://www.luke.fi/projektit/climforisk/webtool/

The service can be later extended to show other responses of forests to climate change.







Maptool shows how Finnish forests were predicted to response to climate change

FOREST UNDER CHANGE

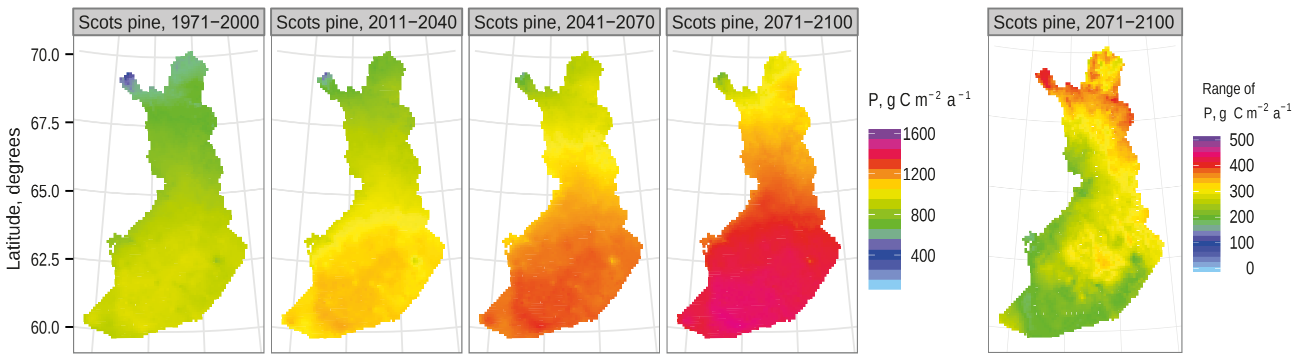
Climate change scenarios have a profound influence on the gross primary productivity (GPP) of Finnish forests. The species specific mean productivity increased in all scenarios and with all climate model forcings. Average increases of GPP in Finland were 25-36%, depending on emission scenario. Uncertainties of the mean productivity increases are notable in each emission scenario, but still nearly all scenario-climate model combinations predicted increases of GPP.

We estimated that nearly two thirds of the productivity increase is stimulated by increasing CO_2 fertilization, while the rest is mostly due to temperature. Different climate model forcings, however, suggested somewhat different ratios, because different climate models predict different temperature increases with the same CO_2 increases. Temperature effects are relatively larger in the north in all climate scenarios.

CO_2 has a decreasing effect on transpiration, with the consequence that stands use approximately as much water as they use today. Large uncertainties govern changes of stand water use under changed climate, and without transpiration changes we found more drought vulnerable forests because increasing temperatures suggest higher evaporation.

Nutrients play a significant role in the future predictions of biomass production.

Our results indicated that net primary production (NPP) and woody growth will increase under climate change throughout Finland, but only if nutrient availability is also increasing. Soil model analyses suggested that the release of N from soil supports large part of the potential and enhanced biomass production under future climate, especially on fertile sites. Still, the uncertainty of the growth projections due to the nitrogen assumptions was greater than that due to the climate scenarios applied.



Gross primary productivity of forests increases by the end of the century (left) but uncertainties due to climate models were high (right). Maps present simulation results for Scots pine stands.

Definitions used above:

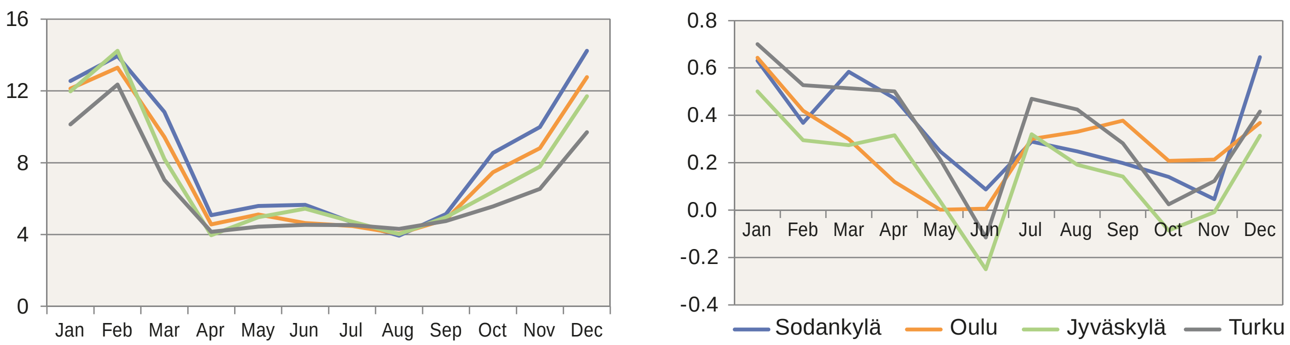
- *Gross primary productivity - GPP describes the photosynthetic carbon sequestration of a forest.*
- *Net primary productivity - NPP describes the biomass growth of a forests, it is calculated as GPP minus respiration losses due to metabolic activity of trees.*
- *Climate model forcings – Climate predictions from eigth climate models to force our impact model*

THE VULNERABILITY OF FINNISH FORESTS TO BIOTIC DAMAGES

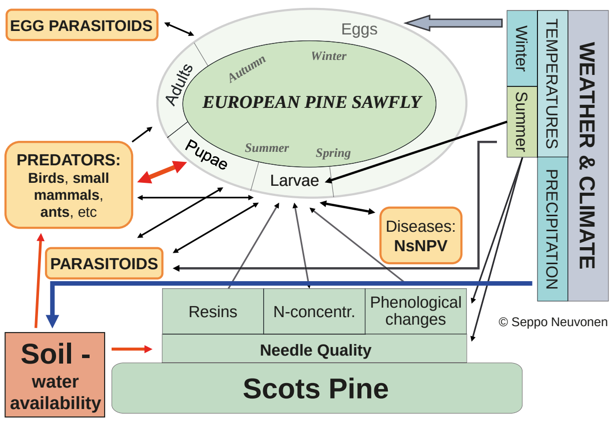
Factors affecting risks to biotic damage

Recent reviews show that forest pest insects and diseases respond individualistically to changing climatic conditions. Furthermore, clear and well documented examples of climate change induced range expansion or increases in the abundance of pest insects are surprisingly few given the high number of insect species living on trees. There are probably two main reasons for this: (1) trophic interactions play a crucial role in the population dynamics of insects and these may counteract the direct effects of climatic factors; (2) the high variation in climatic conditions between years may obscure the effects of changing climate; insects are well adapted to average climatic conditions during different parts of their life-cycles and the range of variation in e.g. mean monthly temperatures within a decade is at least an order of magnitude larger than the observed or predicted rates measured as temperature change per decade (see Fig. below).

There are anyway some cases (pest species) where extreme climatic conditions have strong effects on insect population dynamics, and in these cases the causal links between climatic variables or site conditions and damage risks are strong enough to make the assessing of risks feasible. The European pine sawfly is the most important pine defoliator in Finland. The main abiotic factors affecting the risk of European pine sawfly outbreaks are cold winter temperatures killing the overwintering eggs, and soil moisture conditions modulating spatial and temporal variation in the efficacy of natural enemies. The figure below shows the life cycle of the European pine sawfly, and its interactions with host plant, natural enemies, and abiotic factors.



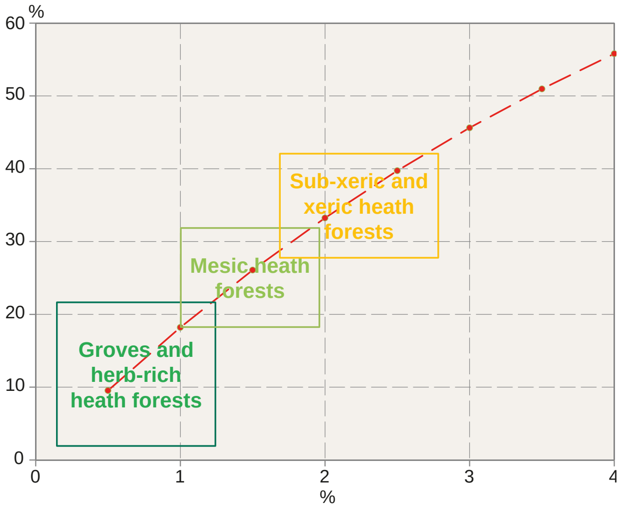
Left panel: the range (=max-min; °C) of monthly mean temperatures within decades (averaged for the period 1961-2010) in different places in Finland; the latitudes (N) are: Sodankylä 67.4, Oulu 65, Jyväskylä 62.2, Turku 60.5. Right panel: the slope (°C/decade) of the linear trend in mean monthly temperatures in different places during the period 1961-2010. (Data source: Finnish Meteorological Institute).



Life cycle of European pine sawfly.

We used extensive monitoring data (ICP Forest & NFIs; 1986-2008) to quantify the effects of environmental factors on the vulnerability of forests to damages caused by two most important pests/pathogens in Finnish pine forests: European pine sawfly and Scleroderris canker. The damage risks were modelled as functions of environmental factors to see how the risk probabilities change under different conditions, such as different forest site types and minimum winter temperatures. There was a general agreement between ICP Forest Level 1 and the more extensive NFI data in the patterns in the incidence of pine sawfly damages.

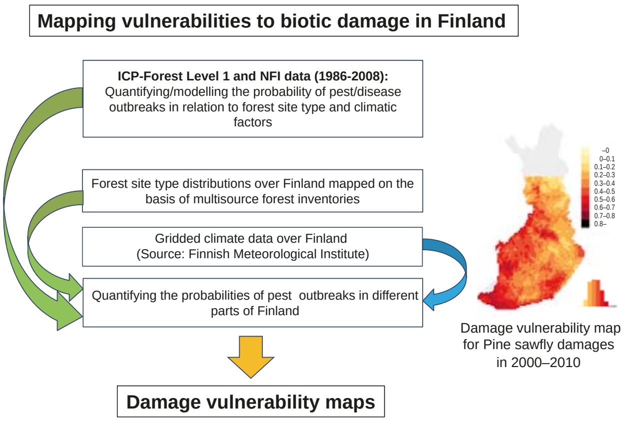
The probability of pine sawfly outbreak starting is affected by site type[1]: this probability was about four-fold higher in the driest forest site types compared to the freshest types on mineral soils. Minimum winter temperatures limited the occurrence of pine sawfly outbreaks in eastern and northern Finland[1]. To help forest owners to comprehend the risks, the annual probabilities used in the analyses were transformed to the probability of at least one pine sawfly outbreak occurring in a 20 year period (the commonly used time frame in forest management planning) as shown below. In general, the pine sawfly outbreak probabilities are rather low in the most productive pine stands. Increasing winter temperatures (see Fig. on page 8) are expected to increase European pine sawfly outbreak risks especially in eastern and northern Finland. The relationship of Scleroderris canker to forest site types was opposite to that of pine sawfly outbreaks: Scleroderris canker damages were most abundant in the most productive and moist site types[1].

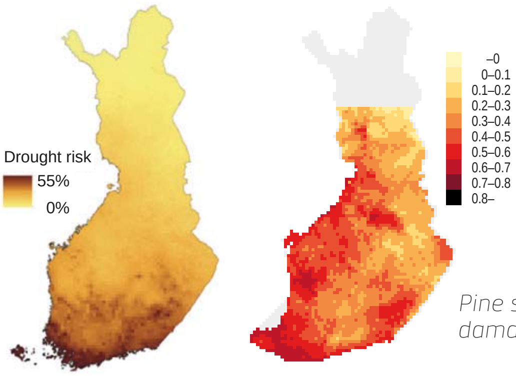


Probabilities of pine sawfly outbreaks occurring at least once in 20 years (y-axis) are shown as a function (red dotted line) of the respective annual probabilities (x-axis). The estimated probabilities for three site types on mineral soils are shown by the boxes. Based on the analysis of ICP Level 1 data (years 1986-2008).

Damage vulnerabilities mapped

- *We found out in which regions of Finland trees have been the most vulnerable to drought[2]*
  - *In combination, we classified soils of Finland to drought vulnerable, typical, and moist based on the information of topographical maps, and used that information in carbon-water balance model*
- *We created a drought vulnerability map based on drought observations in ICP I network[2].*
- *Based on past records, the risks are highest in southern Finland, due higher occurrence of hot and dry summers and because of the nature of terrain. Terrains are typically rocky and good land is in other use. The most drought vulnerable lands are of lesser economic value. Dry spots may, however, act as important starting foci of pine sawfly outbreaks.*
- *Based on the analyses of ICP and NFI data we quantified the effects of forest site type and climatic factors for vulnerability of forest to damages by Pine sawflies and Scleroderris canker, and produced damage vulnerability maps for these species.*





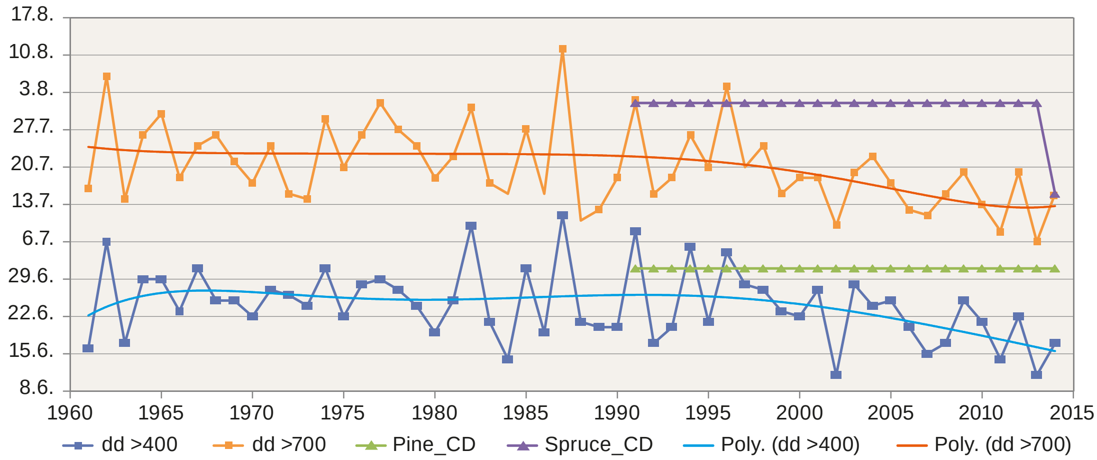
Pine sawfly damage risk.

[1] Nevalainen S., Sirkiä S., Peltoniemi M., Neuvonen S., 2014. Vulnerability to pine sawfly damage decreases with site fertility but the opposite is true with Scleroderris canker damage; results from Finnish ICP Forests and NFI data. Ann. For. Sci., DOI 10.1007/s13595-014-0435-8.

[2] Muukkonen P., Nevalainen S., Lindgren M., Peltoniemi M., 2015. Spatial occurrence of drought associated damage in Finnish boreal forests: results from forest condition monitoring and GIS analysis. Boreal Environment Research. In Press.

Springs get warmer and warmer — pests develop earlier and earlier

Due to the climate change we expect that the risks of some damages may increase. This means that the forest owners should be more aware of the annual course of development of damage agents, and should monitor their forests for attacks. With respect to bark beetles the most efficient ways to minimize future risks is to remove wood damaged by storms (salvage cuttings) as well as already infested wood (sanitation cuttings) from the forest. However, these actions should be done within narrow time windows before the new generation reaches maturity, which may be difficult because of large year to year variation in the accumulation of temperature sums (Fig. below).



The calendar dates (y-axis) when Pine shoot beetles (dd>400) and European spruce bark beetles (dd>700) start maturing show large interannual variation and have become earlier during recent decades (data from Finnish Meteorological Institute for Turku, southern Finland). The triangles and continuous lines show the critical dates (according to the Law for protection of forests from damage, changed in 2014) before which storm damaged pine (light green) and spruce (purple) wood should be removed from the forest in southern Finland.

The new Finnish law to protect forests from damages (1087/2013), in effect from the beginning of 2014, specifies critical/obligatory dates for the removal of damaged pine and spruce wood from the forest. The critical removal date for damaged spruce wood changed in southernmost Finland to two weeks earlier than in the earlier law, but there was no change with pine wood.

As a part of vulnerability assessment, ***we established a web service to monitor spring development of certain important pests.*** This system facilitates monitoring of forests by forest owners. It provides timely information about when dead wood material should be collected out from forests.

POLICY BRIEF

FOREST CARBON SINKS AND VULNERABILITIES UNDER CLIMATE CHANGE – WHAT WE KNOW ABOUT FINNISH FORESTS?

Climforisk EU Life+ project (2011-2014, ENV/FI/000571) aimed at generating more comprehensive picture about future of Finnish forests. The project pulled together forest related data sources, climate scenarios and developed methodologies to estimate carbon sinks and growth of Finnish forests in the future. The project further assessed the possibilities of estimating changes of damage vulnerability of forests based on existing information. This policy brief lists main findings of the project.

Finnish forests will continue being a carbon sink

Changing climate benefits photosynthesis, vegetation biomass accumulation, and stem-wood growth in Finland

- *Average changes in photosynthesis, biomass accumulation, and stem-wood growth of forests in Finland were clearly positive in all impact model simulations, which were run with combinations of three climate scenarios and eight climate models.*
- *In the long term, total biomass carbon stocks increase in Finland, but part of the positive increases in vegetation carbon stock are offset by increasing soil carbon emissions. In the short terms, and periods of few decades, harvest regime will continue to be the most important factor influencing carbon sink in forests.*
- *Contrasts between poor and productive sites in stem wood growth will increase in future because high productivity sites have more growth resources to support CO_2 fertilisation. This in turn may influence the relative profitability of forestry at given sites.*
- *Insect pests overwintering in the egg stage are most probable to benefit from warming climate. Large scale outbreaks are rare, but when they occur, they can temporarily have strong effects on forest carbon emissions and nutrient fluxes.*
- *Warming winters also increase the problems from certain pathogens like root rot, and this, in combination with longer frost-free periods increases wind damages. These, in turn, increase the risks of bark beetle outbreaks.*
- *Increasing temperatures speed up the development of pest insects. This means earlier pest development and possibly more generations. Salvage and sanitation cuttings should be done in time to prevent further damages. We launched portal to monitor spring development of serious pest insects that facilitates the protective actions of forests by forest managers and owners.*

Positive but uncertain

- *In spite of the predicted positive changes of forest productivity, the uncertainties of future carbon balance and growth estimates are large, and increase towards future. Uncertainties stem from many sources:*
  - *There is uncertainty about sosio-economic and technical development (scenario uncertainty).*
  - *Predictions of future climate vary largely by climate model.*
  - *Water balance of forests is uncertain due to uncertain rainfall estimates and uncertainties in tree water use under elevated CO2.*
  - *Long-term growth effects of CO_2 fertilization on trees are uncertain, largely due to uncertainties associated with nitrogen availability.*
  - *Changes of soil carbon stocks are uncertain and depend on both decomposition sensitivity and litter inputs that are oppositely affected by climate, and their responses to climate change are not accurately known. Different soil model versions produce different predictions for soil carbon sinks and sources.*
  - *Changes of productivity under climate change seem more pronounced in the north Finland than in the south Finland, but there are considerable uncertainties in spatial resolution of climate models.*
  - *Changes in damage regimes cannot be reliably quantified presently. Qualitative estimates predict increase of damage frequencies and intensities of some pests.*
  - *Climatic extremes (e.g., minimum winter temperatures) are more important for pest population dynamics than mean temperatures, but their interpolation at high resolution is challenging and needs more efforts.*
  - *ICP Forests and rolling Forest Inventory (FI) data have good potential for quantifying patterns in damage occurrence, but region-wise FIs may produce biased results.*

Anticipation of changes requires impact research

- *Proposal "accounting rules and action plans on greenhouse gas emissions and removals resulting from activities related to land use, land use change and forestry (COM(2012) 93 final)" called for mandatory reporting of greenhouse gas balances for lands under forest management. We developed tools to support this goal. We produced a tool that can be used to estimate sinks and sources of lands under forests management at high spatial resolution, so as to support regional decision making and GHG-inventories. Still, we concluded that there are large gaps of knowledge, which hamper accurate estimation of sinks at small spatial scales under climate change.*
- *Predictive tools should be further developed to allow site-specific detailed assessments of forest growth scenarios under climate change. These scenarios would be valuable for individual forest owners in Finland. Enhanced information about the effects of nutrient release from soils on growth under climate change are needed.*
- *Present soil databases do not support local level carbon sink estimation, especially in dry conditions. New LIDAR based measurements of topographical variation at 1 m resolution will open new avenues in research.*
- *Forest damages can lead to large carbon emissions within a short time period. European level forest damage data collection is needed to facilitate the construction of predictive models. Forest inventories should also collect damage information at annual level from forests.*
- *Pest and pathogens can be best controlled by timely preventive actions (salvage and sanitation cuttings to control bark beetles), which could be facilitated by developing online monitoring of pest status and near-future forecasts of pest development. Overall damage risks can be minimized by diversifying forest structure.*

With high probability, Finland will become even more suitable region for forestry than it is nowadays. Risks can be minimized by diversifying management and forest structure. But still, basic research is required to reduce uncertainties of forest growth predictions. Due to the highly complex and variable nature of pest dynamics, actions should be taken to collect coherent and pan-European long-term datasets of forest pest damages and required ancillary data, which would support predictive modelling in future.

http://www.luke.fi/projektit/climforisk

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Jouni Hyvönen, Luke