PEATLAND SIMULATOR SUSI – A TOOL FOR ESTIMATING WATER TABLE LEVELS AND GREENHOUSE GAS EMISSIONS IN ORGANIC SOILS

LIFE OrgBalt contributes to improving the national greenhouse gas (GHG) inventories in the project regions by both establishing demonstration sites where GHG emissions are measured and using tools for estimating GHG emissions where actual measurements are not available. The Peatland simulator SUSI created by the Natural Resource Institute Finland (Luke) uses a hydrological model which requires inputs of weather and stand data to estimate water table levels and create projections of GHG emission levels in organic soils. In this technical article, the key principles of the simulator are explained.

Peatland soils and drainage

The peatland simulator SUSI is a software package for modelling the forested peatland ecosystem hydrology, stand growth and nutrient availability under different management, site types and weather conditions. Given input weather and stand data, SUSI calculates various quantities of interest for making projections and comparing management options. The core of SUSI is a strip hydrology model, which simulates the water table level on a linear strip perpendicular to two bordering ditches. Hydrology, along with other components of the software, are in turn used to estimate, for example, greenhouse gas emissions, nutrient flows, and stand growth. Drained peatlands are important for agricultural and forest biomass production in humid boreal, temperate and tropical areas. The utilisation of managed peatlands has been recently questioned due to notable greenhouse gas emissions and nutrient and sediment exports to water courses.

Ditching and drainage of peatlands is a common practice in conventional rotational even-aged peatland forestry where tree stand is clear-cut at the end of rotation. The intent behind drainage is to lower the water table in order give tree roots more oxygenated space and access to nutrients in developing stand, but it also profoundly affects the biogeochemical and microbiological functioning of the soil. Long-term efficacy of drainage measures are often reduced because of organic material accumulation to the ditches and top soil compaction between the ditches, causing the need for maintenance at around 15 to 20 years from the initial effort. However, lower water level after ditch maintenance results in leaching of organic material downstream, and subsequently causes adverse environmental effects, which is why it should not be conducted on sites where stand growth remains economically unviable. Due to interactions between peat, ground vegetation, tree roots, and groundwater, the peatland soil biogeochemistry is complicated, and the outcomes of management options (drainage, maintenance, do nothing), may be far from straightforward. The peatland simulator SUSI models these interactions with the best knowledge currently available, and enables estimation of water table level, and subsequent effects to the soil and tree stand, from the current situation into the following decades. Most importantly, projections of greenhouse gas emissions can be made based on knowledge of the water table and other quantities in the model. The value of the model is in producing these estimates for sites for which actual greenhouse gas measurements are not available. Modelling only requires weather and stand data, which are readily available.

Description of the Model

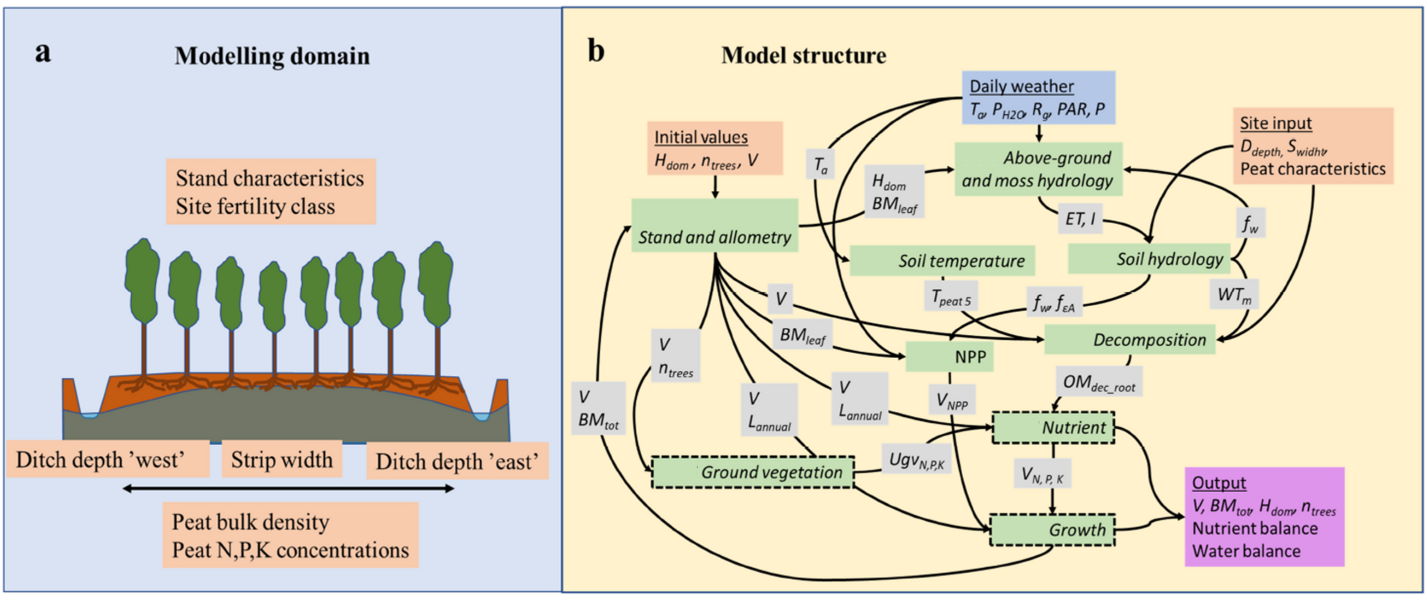
The SUSI model was recently published in Forests (doi: 10.3390/f12030293). The publication describes the structure and equations of the model, as well as validates the model against a wide variety of data from Finland. This recent publication shows how the model can be used for identifying and quantifying different forest growth-limiting factors, such as found caused by oxygen stress in site types where water level tends to be high due to low hydraulic conductivity, chemical growth restriction mostly attributable to availability of K in peat, and stand growth rate change resulted from change in water level (ditch network maintenance impact).

Figure 1 illustrates the modelling domain and model structure. The study demonstrates how improved aeration in the rooting zone induces stand growth by increased availability of nutrients released from the organic matter decomposition, but simultaneously the decomposition process results in increased CO2 emissions.

A Python implementation of the model is publicly available at https://github.com/annamarilauren/susi, making the simulator accessible by anyone. The required inputs to the model are a few site-specific parameters, daily weather data, and stand growth curves with biomass partitioning.

The key component of the model is soil hydrology simulation on a strip

Figure 1. (a) The Peatland simulator SUSI describes hydrology, biogeochemical processes and stand growth along a 2D cross-section between two parallel ditches. The variables in orange boxes are used to parameterize the model. (b) Information flow in SUSI. The model is initialized using forest inventory data and site characteristics (orange boxes) and is run using daily meteorology (blue box). Independent modules (green boxes) are linked through state variables and fluxes (grey boxes). The model predicts, for instance, stand growth and yield and nutrient and water balance (purple box) responses to forest management. Figure is modified from Laurén et al., Forests 2021, 12, 293; https://doi.org/10.3390/f12030293.



reaching from one ditch to another.
Effective water inputs to the soil profile are calculated from the input rainfall values, interception by the tree stand and ground vegetation, and surface runoff and evapotranspiration. The soil water profile then approaches an equilibrium with the bordering outputs, which are the ditches on both sides of the strip.
The hydrology values for both above-ground vegetation and soil profile are calculated daily. The other quantities of interest: nutrient biogeochemistry, gas emissions, stand growth, and so on, are calculated using a statistical approach (based on the hydrology values) on either daily or annual resolution. The greenhouse gas emissions are calculated using well studied statistical relationships between water table level, temperature, and soil fertility. Tree stand growth is determined by Liebig's law of the minimum. Potential growth is calculated according to the availabilities of nitrogen, phosphorus, potassium, and net primary production given the root space and solar radiation conditions. The growth limiting factor is then identified and effective growth calculated accordingly.
Ecosystem-level modelling is commonly considered challenging,
due to limitations on our knowledge of the bottom-level processes. However, the SUSI peatland simulator performs formidably within the validation dataset, making it a promising tool for larger-scale predictive modelling in forested peatlands.

Utilisation in the LIFE OrgBalt project

The LIFE OrgBalt project aims to estimate the greenhouse gas emissions from organic soils in the Baltic states and Finland under different and changing land use. One of the alternative management approaches studied in the project in Natural Resource Institute Finland (Luke) is continuous cover forestry (CCF) at nutrient rich peatlands. CCF does not aim at even-aged stand structure, retains a significant proportion of the tree stand after periodical forest cover harvesting by selective cutting, and is based on primarily natural regeneration of tree stand. Reduced need or avoided ditch maintenance is the outcome of maintained transpiration in continuous tree cover and ground vegetation after partial harvests aims at less harmful environmental consequences (e.g. related to water level and decomposition processes) from the forest management. The SUSI peatland simulator is being used as the estimation tool of choice for sites where the required input data are available.
Within the LIFE OrgBalt project, the published model has been expanded to estimate methane and dinitrogen oxide emissions, in addition to the carbon dioxide releases in the original description.
Additionally, improvements have been made to the simulator interface, making it more accessible to the research community. It is planned that the model will be utilised to produce large scale emission projections from organic soils for the involved countries to improve the greenhouse gas inventory in each country. The spatially comprehensive data from organic soil rich countries in the Baltic region forms a considerable contribution for evaluating the importance of c. 21 Mha area of nutrient rich drained organic soils in the EU countries. The use of the Peatland simulator SUSI in demonstration sites and other nutrient rich organic soils in the Baltics, Finland, and Germany, will also closely contribute to one of the key objectives of the LIFE OrgBalt project - to improve the GHG accounting methods and activity data for nutrient-rich organic soils under conventional management condition.

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