8th International Scientific Conference
RURAL DEVELOPMENT 2017
Bioeconomy challenges
23–24 November, 2017, Aleksandras Stulginskis University

Proceedings of the 8th International Scientific Conference Rural Development 2017

Edited by prof. Asta Raupelienė

ISSN 1822-3230 / eISSN 2345-0916
eISBN 978-609-449-128-3

Article DOI: http://doi.org/10.15544/RD.2017.104

SIGNIFICANCE OF THINNING DEGRADED SWAMPS FOREST STANDS IN SUSTAINABLE ECOSYSTEM`S DEVELOPMENT

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In scope of biodiversity and sustainable ecosystem development swamps ecosystem restoration is important, because by eradicating the effect of drainage in swamps, negative impact on adjacent intact or relatively intact raised swamps and hydrological regime of other wetlands is lowered. Tree cutting in degraded swamps forest stands would speed up restoration of ecosystems disturbed hydrological regime. Habitat conservation value in long-term is the same as for habitat 7110* *Intact raised swamps*, as in case of hydrological regime restoration, within time it will transform into 7110*. Several specially protected plant species can be found only in raised swamps.

Tree stand transpiration volume varies depending on air temperature and solar radiation. Since in reality it is impossible to change air temperature or solar radiation in order to increase the groundwater level in a swamp, we can reduce the leaf area index (LAI) which is the most significant value influencing transpiration by cutting down trees.

Aim of this paper is to examine how LAI interacts with groundwater level by using system dynamics swamps ecosystem model. Swamps ecosystem model shows correlation between LAI and groundwater level.

As a result of this research author observes, that LAI interacts groundwater level and system dynamics modelling could be useful to calculate degraded swamps forest stands thinning intensity through mathematical relationships.

Keywords: *groundwater level, leaf area index, swamp, system dynamics*

INTRODUCTION

After construction of drainage ditches, thus changing its natural hydrologic regime, swamps have been degraded, leaving a negative impact also on the adjacent unaffected and slightly affected hydrological regime of raised swamps and other wetlands. Since after drainage of swamps and its adjacent forest areas swamps became overgrown with trees, density of tree stands increased in the swamps territories and its adjacent forest stands. The large volume of tree crown by interception limits rainwater from reaching the ground, because it evaporates from crowns back into the atmosphere, as well as trees favor water absorption from the soil trough the roots that further enhance the drainage effect.

In a good quality swamp, the level of groundwater should be close to the soil surface, but filling of drainage ditches alone cannot ensure restoration of hydrological regime of degraded swamps, because evapotranspiration can form up to 70% (Butts, 2005) from the total amount of annual precipitation, therefore it is necessary to establish the optimal scale of intervention into the ecosystem – intensity of the thinning out in order to reach the desired result by cutting down as few trees as possible – to increase saturation of soil with water that would contribute to resurgence of the swamp and swampy forest biotopes.

Restoration of hydrological regime will simultaneously improve swamps ecosystem functions, it will delay fast growing of trees and will ensure formation of peat soil – processes that are characteristic to habitat and have been partly or completely stopped due to changes in hydrological regime (Vides risinājumu institūts, 2014).

By restoring the natural level of groundwater, it will be possible to prevent an intense overgrowing of areas with dwarf shrubs - favourable conditions will be created for development and existing of berries, mushrooms, various moss, lichens and other moisture loving populations and preservation of gathering places of human favourite nature goods – cloudberries, cranberries and mushrooms (Kampuse, 2014)

Experimentation with forest thinning intensity in real life would take years to establish the optimal scale of intervention into the ecosystem – intensity of thinning out in order to reach the desired result by cutting down as few trees as possible – to increase saturation of soil with water that would contribute to resurgence of the swamp and swampy forest biotopes. That is why system dynamics modelling was chosen to solve this problem, because it allow to predict tree cutting influence on ecosystem without expensive and time consuming experiments in real life.

In previous studies researching scientific literature the author has not gained any evidence that there is a system dynamics model developed in order to simulate tree cutting intensity in degraded swamps after filling up drainage ditches with the aim to speed up restoration of hydrological regime, thereby this approach is a innovative and sustainable way of solving this problem.

Studies of other author experience have helped to determine elements which shape swamps ecosystem and interact with each other. Based on exploration of elements forming the swamps ecosystem system dynamics model in STELLA® environment have been constructed.

Previous studies also have shown that leaf area index (LAI) is one of the most important key vegetation structural variables for quantitative analysis of many physical and biological processes related to vegetation dynamics (Chen et al., 2006).

RESEARCH METHODS

As wetland modelling specialist Jørgensen mentioned in his previous work, to administer swamp ecosystems decently and to optimize their role in the landscape, it is crucial to understand how these systems act and what to await when we intervene or change the way they are. We must clearly understand how by changing one part of a swamp we influence the other parts of ecosystem (Jørgensen et al., 1988). That is why the author in his previous studies have mostly used theoretical methods, using case study and content analysis methods to understand complexity of swamps ecosystem and to build swamps ecosystem conceptual model. After building the conceptual model the author made a study to find the most appropriate equations to reflect each component of ecosystem mathematically. Those mathematical equations are calculating each step in water path through ecosystem: from precipitation to tree canopy, lakes and surface water; intercepted water from canopy back to the atmosphere; from surface water to peat layer or back to atmosphere through sublimation; from peat layer to shale layer, roots or back to atmosphere through evaporation; from shale layer to till layer or back to peat layer; from till layer and shale layer to other ecosystems through lateral flow; from roots to trunk; from trunk to leaves and bark; from leaves and bark to the atmosphere trough transpiration; from lakes back into the atmosphere through evaporation or to other ecosystems through channel flow.

Very valuable scientific publication that helped to understand the complexity of the swamps hydrological system, was "Simulation of hydrological processes on reconstructed watersheds using system dynamics". It clearly explains how the water held in the pores of the soil moves downwards to the till and the shale layers (Elshorbagy et al., 2007). Other significant research where Amin Elshorbagy have took place is "A generic system dynamics model for simulating and evaluating the hydrological performance of reconstructed watersheds" (Carey et al., 2009). The two documents include appropriate mathematical equations that helped the author to continue research and to create a system dynamics model.

Research "Different views on tree interception process and its determinants" interpret how tree crown structure and size determines the amount of the total precipitation that stays in the tree crown and does not reach the ground. This case study allows to better understand hydrological processes in trees and in a forest in general (Klamerus-Iwan, 2014).

In the context of Latvia modelling hydrological regime is not anything new, for example project "Restoring the hydrological regime of Kemeri National Park LIFE10 NAT\00016\ HYDROPLAN" can be mentioned. It was implemented by Nature Conservation Agency of Latvia and was implemented from September year 2011 until August year 2013. The main aim of this hydrological model was to provide reasonable forecasts on the impact of restoration of hydrological regime of wetland territories and its significance (PAIC, 2013).

While constructing STELLA® model the author have used also data acquisition method – direct observation in Gulbjusala swamp, Latvia. Direct observation have furnished significant information regarding groundwater level and forest tree stand. Direct observation also shows that filling of drainage ditches already shows signs of swamp restoration and biodiversity increase – in year 2017, two years after ending of the project FOR-REST, LIFE10 NAT/LV/000159 cloudberries and some species of moss and lichens have already returned to ecosystem, but the large volume of trees obstruct hydrological regime restoration by precipitation interception and soil-water absorption by roots.

Based on theoretical knowledge and information gained during direct observation STELLA® model was build. STELLA® system dynamics model runs on Gulbjusala swamps data such as: peat layer, till layer and shale layer physical and hydrological properties (humus depth and bulk density, depth of soil layers, soil texture of each layer and other); meteorological data (air temperature, solar radiation, precipitation, relative humidity and wind speed) and tree stand physiological data (leaf area index, canopy resistance, percent cover by conifers and deciduous trees). Combining empirical data regarding tree anatomical and physiological properties with remote sensing data (reflectiveness of red and near infrared bands), it was possible to determine accurate leaf area index (LAI).

Validation can be defined as verification of the parameters obtained through calibration. Calibration was carried out mostly based on groundwater level measurements taken at Gulbjusala swamp every month since year 2014 and comparing them with simulated soil water level.

RESEARCH RESULTS

As theoretical study shows components affecting swamps hydrological regime are: interception, sublimation, evaporation, leaf area index, lakes evaporation, peat layer, till layer, shale layer, overland flow and lakes outflow. Swamps ecosystem is influenced also by external factors such as: rain, snow, solar radiation, temperature, wind speed, relative humidity. Based on this information the author have constructed a system dynamics model in STELLA® environment.

Evaporation is determined not only by the meteorological conditions and climate factors, but also by tree biological factors, influencing tree crown irradiance and shading. That is why while constructing swamps ecosystem model it is important to collect empirical data regarding tree species and their anatomical and physiological properties. Transpiration from forest is higher than from intact swamp, because trees have several times higher LAI compared to sphagnum. LAI is one of the most important parameters influencing tree stand evaporation, rainfall and snow interception.

To examine how LAI interacts with groundwater level by using system dynamics swamps ecosystem model the author used two values of LAI: 2.21 and 1.1.

The first value 2.21 is determined during research and is actual Gulbjusala swamp`s LAI. To calculate LAI the author used remote sensing data from airborne surveillance and environmental monitoring system (ARSENAL). There was LIDAR laser scanner data used, to acquire information regarding tree species, height and density per unit ground are, and VIS-NIR sensor (380-1050 nm) data used to calculate LAI using near-red (711-842 nm 8 band median) and red (718-754 nm 4 band median) bands reflection from tree canopy. ARSENAL data was compared with on-site situation in test area.

To show how tree cutting in Gulbjusala swamp would affect groundwater level as second LAI value the author have chosen to use 1.1, because STELLA® model declare it as desired LAI value to achieve the optimal increase in soil saturation with water that would contribute resurgence of the swamp and swampy forest biotopes.

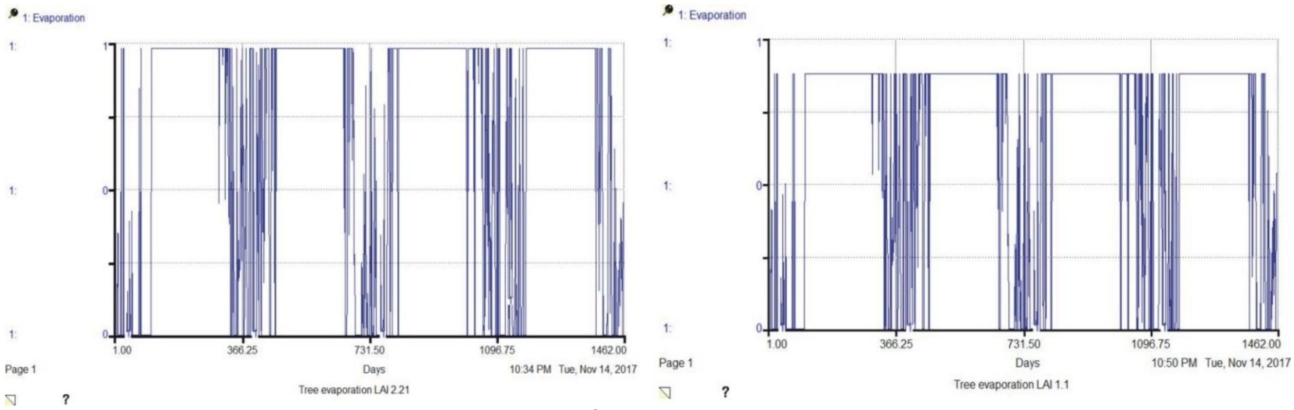

Figure 1. Tree evaporation with LAI 2.21 (on the left side) versus tree evaporation with LAI 1.1 (on the right side)

By looking at tree evaporation simulation data figures with LAI 2.21 and LAI 1.1 (Figure 1.) the difference in evaporation seems insignificant. It is possible to observe actual changes in tree evaporation extent only by comparing data output with different LAI. Simulation output data with LAI 2.21 represent sum of tree evaporation of 930.05 mm in four year time with maximum diurnal tree evaporation in hot sunny day of 0.884 mm. By reducing LAI to 1.1 tree evaporation is reduced to 472.19 mm in four year time and maximum diurnal tree evaporation in hot sunny day decreases to 0.440 mm.

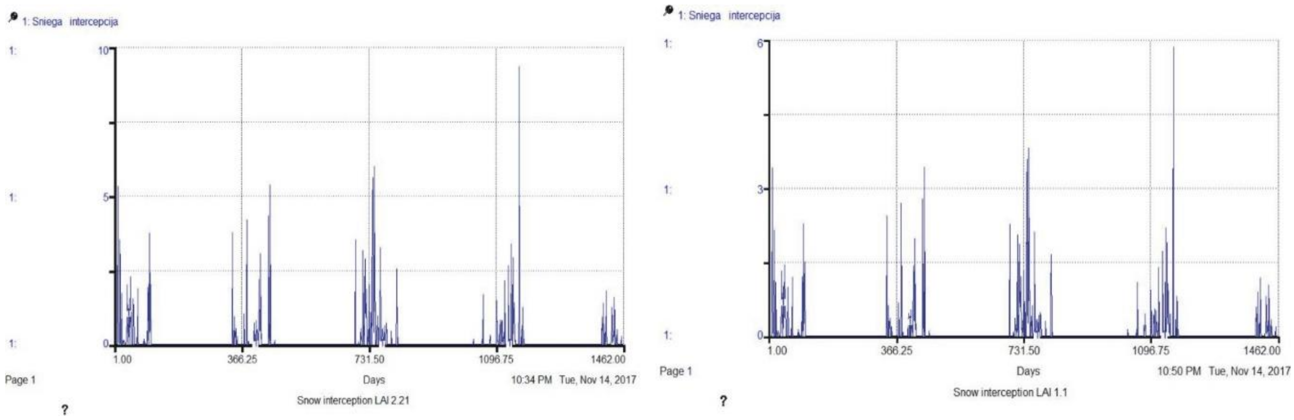

Figure 2. Snow interception with LAI 2.21 (on the left side) versus snow interception with LAI 1.1 (on the right side)

By looking at snow interception simulation data figures you can observe that by reducing LAI from 2.21 to 1.1 snow interception proportion stays the same, but changes values on the y axis which indicates changes in snow interception. Simulation output data with LAI 2.21 represent sum of intercepted snow 200.89 mm in four year time. By reducing LAI to 1.1 tree snow interception is reduced to 132.30 mm in four year time.

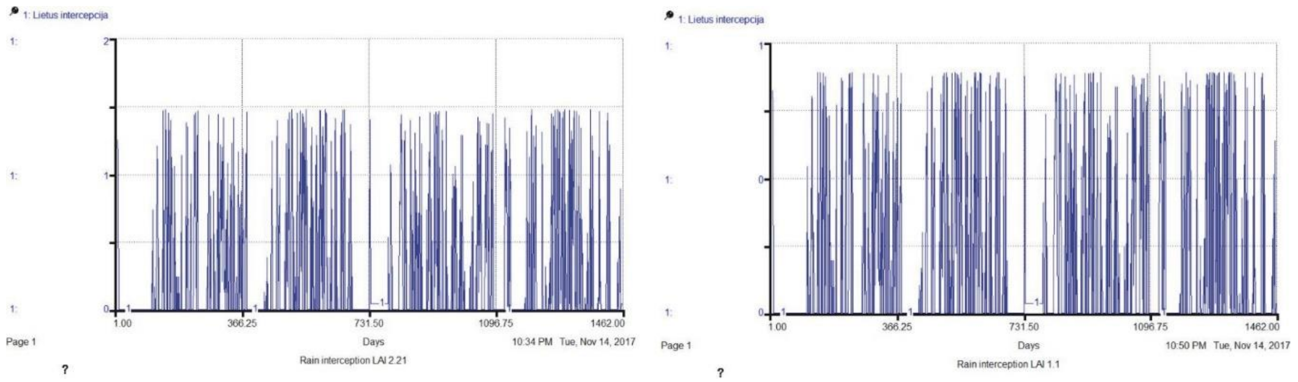

Figure 3. Rain interception with LAI 2.21 (on the left side) versus rain interception with LAI 1.1 (on the right side)

At first sight it could seem that by reducing LAI from 2.21 to 1.1 rain interception simulation figures shows that the amount of intercepted rain is increased, but actually the amount of intercepted rain is decreased and so does the values on y axis. Expressed in numbers rain interception in four year time is reduced from 392.15 mm with LAI 2.21 to 218.23 mm with LAI 1.1. Simulation shows that forest tree stand with LAI 2.21 after can intercept up to 1.474 mm of a diurnal. By reducing LAI to 1.1 maximum diurnal rain interception is reduced to 0.713 mm.

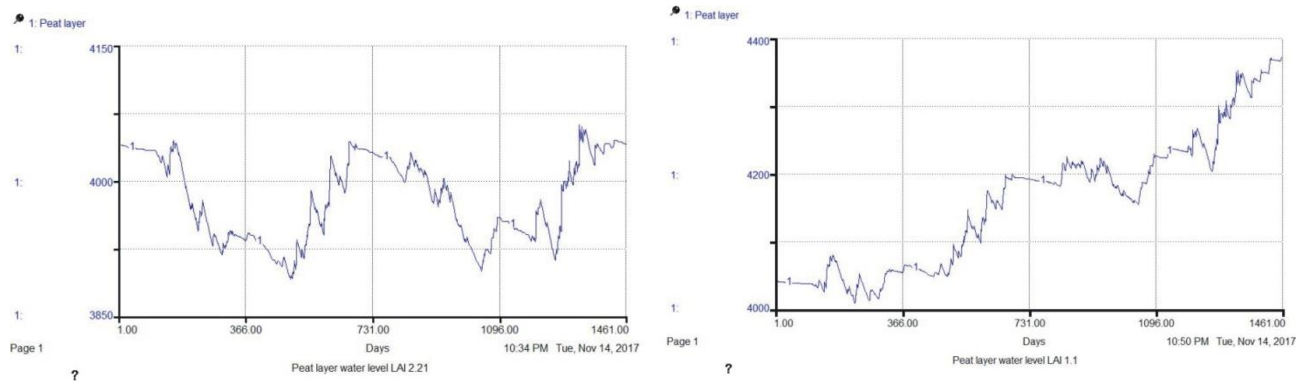

Figure 4. Peat layer water level with LAI 2.21 (on the left side) versus pet layer water level with LAI 1.1 (on the right side).

Figure 4 clearly indicate that by cutting down trees thus reducing LAI it will resolutely increase peat layer water level thus accelerating degraded swamps restoration. Optimum peat layer saturation fluctuation in Gulbjusala swamp is between 4150 and 4500 mm, and it could be reached already in the third year after tree thinning.

Since January 1 year 2013 till December 31 year 2016 total precipitation in Gulbjusala swamp summed 2835.1 mm. In the same period of time transpiration summed 1523.09 mm alias 53.72% of annual precipitation. With LAI 1.1 evaporation would decrease for 50%, rain interception for 45% and snow interception for 35% compared to LAI 2.21 output data, total transpiration would decrease for 53.95% and would form only 29.01% of annual precipitation alias 822.72 mm.

CONCLUSIONS AND DISCUSSION

Transpiration volume mainly varies depending on air temperature and solar radiation. Since in reality it is impossible to change air temperature or solar radiation in order to increase the groundwater level in a swamp, we can reduce leaf area index (LAI) thus reducing transpiration area by cutting down the trees. In order to determine the intensity of cutting down the trees, it is necessary to empirically determine the number of trees per one swamp ground area unit. This number would allow to calculate the number of trees per one LAI unit, which would consequently allow to determine the intensity of thinning out by changing LAI.

Tree thinning intensity determination in degraded swamps using system dynamics is a new innovative approach which would allow to restore ecosystems water level faster and more efficiently, thus increasing natural diversity, improving local people quality of life and promoting swamps recreational ability.

This STELLA® system dynamics model by changing input data would allow to use it in other degraded raised swamps with similar weather conditions and soil properties restoration projects.

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