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Formation of crown structure in Scots pine trees

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Highlights: The ecosystem model MicroForest describes the development of trees, ground vegetation and forest soil in a Scots pine stand based on coupling carbon and nitrogen fluxes in the system. Here, we simulated the crown development in a mature Scots pine stand assuming the semi-autonomous behaviour of the branches with optimizing C and N allocation simultaneously.

Keywords: Carbon balance, nitrogen allocation, SMEAR II, MicroForest, structural regularities

INTRODUCTION

Scots pine forms a whorl of branches each year at the top of the tree. Thereafter the branches grow annually, new needles are formed and the length and diameter of the branches increase. The growth is strong in a young branch, it slows down and finally the branch dies. The needles in the branch are, however, unable to photosynthesize without water that is taken up by roots and transported in the woody structures from roots to needles. At the same time proteins are needed for photosynthesis since pigment complexes, enzymes and membrane pumps carry out the synthesis of sugar. The high nitrogen concentration of proteins (15 – 17 %) explains the crucial role of nitrogen in the metabolism of trees where carbon and nitrogen uptake are connected with each other

We consider that whorls are the functional units of Scots pine trees; the needles, water transport system and fine roots for water and nitrogen uptake form the whorl. The sugars synthesized in the needles and the nitrogen taken up from the soil and obtained from the senescent needles are used for the growth and maintenance of the whorl and for the growth of the treetop. The sugars are used mainly for the synthesis of cellulose, lignin, lipids and starch while the nitrogen is crucial for the synthesis of proteins.

The allocation of sugars and nitrogen for needles, water pipes and fine roots is a very demanding task for the biochemical regulation system of the tree. We assume that the regulation system is powerful and it is able to utilize the resources in an efficient way. There must exist a balance between the transpiration from needles and the water transport capacity in the branches, stem and in transport roots. The commonly observed linear relationship between needle mass and sap wood area (Hari *et al.*, 1986, Nikinmaa, 1992 and Perttunen *et al.*, 1996) is a result of the action of the biochemical regulation system and it makes the balance between the transpiration from needles and water transport in the stem.

The relationship between the sapwood area and needle mass determines the amount of new water pipes needed for a gram of needle growth in a whorl. Thus we can obtain the amount of sugars used for water pipes from the needle growth in the whorl. The tissues have characteristic nitrogen concentrations, high in needles and fine roots and low in woody structures. The amount of fine roots must be such that the fine roots can provide the nitrogen needed for the synthesis of proteins in the needles, fine roots and water pipes. We formulate the above ideas as carbon and nitrogen balance equations. We assume that the action of the biochemical regulation system produces such structures that they fulfil the carbon and nitrogen balance equations.

The carbon and nitrogen balance equations include two unknowns; needle and fine root growth. We solve these unknowns and thereafter we determine the growth of the woody structures. We obtain branch elongation from the requirement that needle density is constant. The whorls form the crown of a pine tree and we obtain the crown development from the growth of the whorls in the tree.

The ecosystem model MicroForest (Hari *et al.*, 2008; Hari *et al.*, 2013) describes the development of trees, ground vegetation and forest soil in a Scots pine stand. Here, we introduce MicroForest as an ecosystem model which can predict the development of stand from an early initial state of stand establishment. Our aim is to present a theoretical framework for structural regularities in crown development in Scots pine and test it. The crown development is based on carbon and nitrogen balance both as a function of needle mass. Thus we can simulate the crown development with MicroForest from an initial state. Then the reduction of photosynthesis per needle mass caused by shading is introduced into the simulations through stand development.

SIMULATIONS

We selected the stand around SMEAR II (Hari and Kulmala, 2005) measuring station for demonstration of the behaviour of our crown model. The needle growth in a branch have a clear pattern, first rapid growth following a stabilization phase and finally a slow decline (Fig.1). The pattern of branch elongation is also clear as a saturating function where a slow declining trend is dominating (Fig.2). The crowns in dominating and suppressed trees are rather different (Fig.3). Based on the simulated needle mass profile and branch elongation model we are able to predict crown size development for Scots pine trees. We will test the simulations with measurements done in the spring 2013.

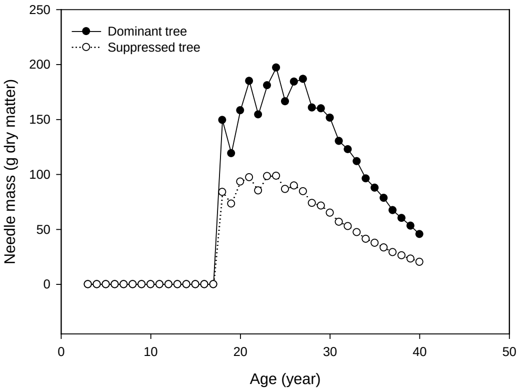

Fig.1. Needle mass growth in a whorl formed at age 18 in a dominant and suppressed tree.

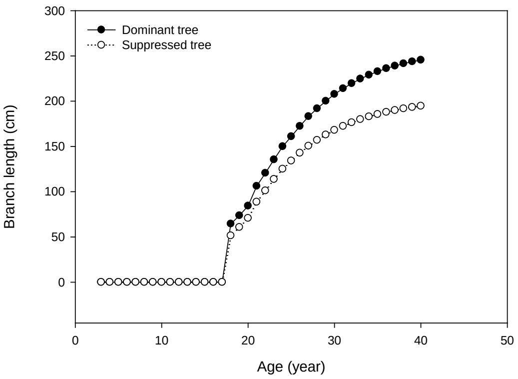

Fig.2. Branch elongation onset at age 18 years in a dominant and suppressed tree.

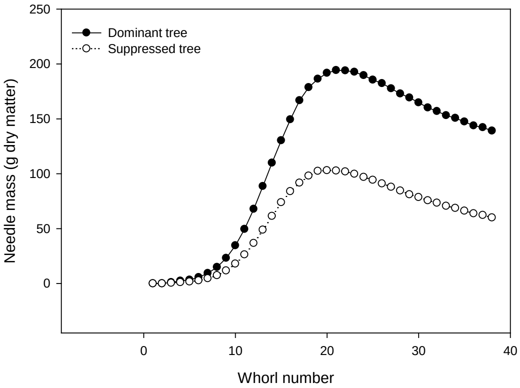

Fig.3. Needle mass distribution in a crown profile at age 40 in a dominant and suppressed tree.

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