Extension of a single tree functional-structural model to stand level

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Background

The functional-structural tree model LIGNUM (Perttunen et al., 1996; Perttunen and Sievänen, 2005) has been originally constructed to be applied to single trees. The above ground part of the coniferous and the deciduous trees is modeled with structural units. They are tree segment, branching point and bud. So far the root system is represented with a single variable denoting its mass. LIGNUM combines in one modeling framework a process based model and the architectural development of three-dimensional tree crown. The architectural development is accomplished with the aid of Lindenmayer systems. The time step is one year.

The metabolic processes in a tree are explicitly related to the modeling units in which they are taking place. The main functioning unit is the tree segment. The intercepted solar radiation can be computed for each segment with the aid geometrical and optical properties of conifer segments (shoots) or leaves. Photosynthesis is directly proportional to intercepted radiation. The net (carbon) production of the tree is obtained by subtracting respiration losses of the tree compartments and the root system from the whole tree production. The allocation of the net photosynthates in a tree is used to primary growth based on the growth vigor of the terminal buds scattered in the tree, to the secondary growth by defining pipe model relationships invariant in any branching point, and to the renewal of the root system.

The original formulation of LIGNUM employs about 15 parameters and a few functions. In the single tree applications this parameterization has worked satisfactorily. However, there are ample evidence that many of the parameters of LIGNUM change within the crown and during tree development. We report here an exercise where we have extended LIGNUM to a stand (group of trees). It has required taking into consideration the variability of parameter values and functions, and using the voxel space method to assess the radiation conditions.

LIGNUM forest

We have realized LIGNUM forest as consisting of a group of Scots pine trees on a plot 20 m by 20 m. The locations of trees are random with minimun distance between trees of 0.5 m. We have evaluated the radiation conditions (photosyntheically active radiation, reflection ignored) in the stand using a method based on voxel space (or 3D discretization of the space) approach which nevertheless enables us to calculate radiation conditions of single shoots based on their optical properties as described in Perttunen et al. (1998). Unlike in the normal voxel space methods (e.g. Knyazikhin et al. (1997)) we do not evaluate the mean condition in a voxel but rather use it to store information of shoot locations to speed up calculations. The method is described in detail in contribution Perttunen et al. (2007) of the present meeting.

As the calculation of radiation is computationally demanding, we have simplified the stand simulation by growing one tree in the middle of the plot and assuming all the other trees to be identical to the subject tree. In this way we have saved LIGNUM from calculating radiation conditions of all trees that would have been too complex to determine computationally. These stand simulations thus pertain to an even-aged, single species stand. We did not simulate tree mortality but specified stand density as a function of average tree diameter. The initial density was 9400 trees/ha and declined to 2200 trees/ha when diameter is 15 cm at ages beyond 20 years.

We made an analysis on the basis of studies made at the Department of Forest Ecology, University of Helsinki (e.g. Palmroth (2000); Vanninen (2003)) and literature about how the parameters (pertaining to individual tree segments) of LIGNUM vary with local conditions inside the crown and during tree development. The following main parameters are changing within the tree:

Parameter	Depends on
Foliage-wood relationship in shoot	Light conditions
Needle angle	Light conditions
Effect of branching order on segment length	Light conditions
Density of wood	Branching order, age of segment
Light use efficiency	Shading foliage area
Specific needle area	Shading foliage area
Number of buds	Foliage mass of mother segment, light conditions
Length of new segment	Light conditions, branching order
Pipe model coefficient	Branching order

Results

We have compared simulated tree height and diameter to measured ones and they agree reasonably well with an average Scots pine tree growing in a dense stand (Fig. 1). Figure 2 shows two trees grown with different strategy of foliage expansion (otherwise the parameter values have been the same). This indicates how important the flexible response of foliage and branching habit to local conditions is for tree and forest growth. We will present further results on the effect of local flexibility of organ properties on forest growth.

We will also study how this application of LIGNUM to an even-aged single species stand can be extended to a mixed, inhomogeneous forest without losing details or ending up with computational problems.

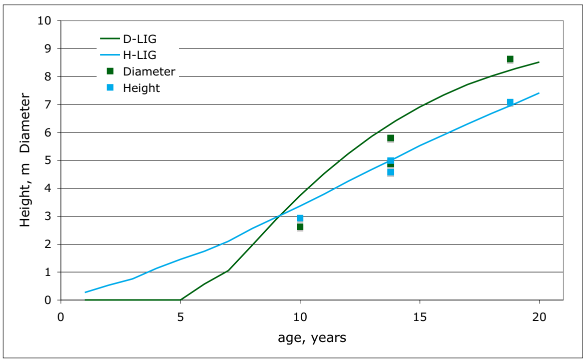

Figure 1: Comparison of simulated (solid line) diameter at breast height (green) and tree height (blue) with measured values (squares).

Figure 2: Effect of distribution of new growth between apical and lateral shoots. Two 20 year old trees; the left one (11.3 m high) has been grown with promotion of apical shoots, in the right one growth has been divided more evenly between apical and lateral shoots.

References

Knyazikhin, Y., Mießen, G., Panfyorov, O., Gravenhorst, G., 1997. Small-scale study of three-dimensional distribution of photosynthetically active radiation in a forest. Agricultural and Forest Meteorology 88, 215 – 239.

Palmroth, S., 2000. Photosynthetic production and resource use efficiency of scots pine: an analysis along environmental gradients. Ph.D. thesis, University of Helsinki Department of Forest Ecology, Publications no. 23.

Perttunen, J., Sievänen, R., 2005. Incorporating lindenmayer systems for architectural development in a functional-structural tree model. Ecological Modelling 181 (4), 479 – 491.

Perttunen, J., Sievänen, R., Nikinmaa, E., 1998. LIGNUM: A model combining the structure and the functioning of trees. Ecological Modelling 108 (1–3), 189–198.

Perttunen, J., Sievänen, R., Nikinmaa, E., 2007. Assessing the light environment for scots pine in the functional-structural tree model LIGNUM. Oral presentation at 5th International Workshop on Functional-Structural Plant Models.

Perttunen, J., Sievänen, R., Nikinmaa, E., Salminen, H., Saarenmaa, H., Väkevä, J., 1996. LIGNUM: A tree model based on simple structural units. Annals of Botany 77 (1), 87–98.

Vanninen, P., 2003. Development of the production and biomass structure of scots pine: effects of competition, tree age and site fertility. Ph.D. thesis, University of Helsinki Department of Forest Ecology, Publications no. 28.