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Modeling of Tree Crown Development Using L-Systems

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Introduction

This paper suggests a concept of multilevel simulation model of a young dark-conifer tree crown (*Picea jezoensis*). The model predicts crown structure and can be used for the estimation of needles phytomass distribution in the crown.

In the spring time young shoots of the *Picea jezoensis* begin growth using nutrients accumulated during the past vegetation season. These nutrients are stored mainly in the needles and two- and three-years-old shoots. In the spring and early summer young shoots are most powerful acceptors of assimilates. Therefore the spring flow of nutrients in tree crown is inverted. Assimilated nutrients are transported from the old shoots to growing ones and distributed between the young shoots according to their position in the crown.

Methods.

Because the monopodial type of branching is characteristic to the crown of *Picea jezoensis*, it can be described as a system of subdominant axes, where the trunk is the first order axis; the main axes of lateral branches are second order axes and so on. Each axis ends with a dominant apical bud. When a shoot is branching out, the new whorl appears. In this whorl one shoot (top shoot) continues mother axis, other shoots (lateral) begin next order axes. The length of lateral shoots correlates with the length of the top shoot. On the basis of trees observation performed in young stands we can assume that the apical bud can be dominant only in relation to its own axis. When young shoots grow, stored nutrients are transported to the top of each axis. Therefore the longest shoots appear on the top of axes. Thus, we can formulate a common rule for the axes elongation: the longer distance between the base of i-th order axis and top of i-1-th order axis, the shorter new shoot on the top of an i-th order axis. Analysis of the empirical data showed that decrease of a new shoot length is exponential. The best example is elongation of the lateral branches (second order axes). It is the main rule of our model.

The model is based on modified L-systems. Supplying software was written with the Object Pascal programming language (Delphi 5 workspace). For 3D visualization of the tree crowns standard OpenGL library was used.

Results

Thus, if the annual tree height growth is known, it is possible to calculate length of the young shoots in whorl on the tree top. Then using rule of axes elongation we can calculate shoots length on the ends of the all subordinated axes. Similar calculations can be repeated for third and higher order axes. In other words, calculation of axes elongation can be represented as a series of iterations. It makes possible to create the multilevel simulation model of a tree crown development, in which the level of predicting accuracy may vary depending on particular task. The main levels are described below.

First level: tree height growth (elongation of the first order axis). In strict sense, this level neither describes crown development nor involves the described above relationships. In order to simulate tree height growth we can use known growth equations. We only need to rewrite these equations in discrete form. Discrete form is necessary because we need exact information about the tree top shoot length (height increase). The value of top shoot length is needed for calculations on the next accuracy levels. If we simulate height growth during short time period, a simple linear growth equation can be used.

Second level: appearance and elongation of the second order axes (main axes of the lateral branches). At this level we involve data on quantity, spatial distribution, age, length and annual increment of branches. Using these values, we can calculate volume of the tree crown, its effective volume and general needle phytomass distribution in crown.

The accuracy of model reached at level is enough for describing of crown of very young trees of *Picea jezoensis*. The branches of young trees occupy almost all crown volume, and the needles are distributed relatively uniformly. After several years of growth, the branches usually separate from each other and occupy only 60-80% of crown volume (as it was calculated on the basis of the second order axis lengths). Therefore, for more accurate prediction of the crown structure the next level is needed.

***Third level*:** appearance and elongation of the third order axes. When we take into account these axes, we can predict the shape of each branch, their volume and, hence, distribution of the needles phytomass in the crown.

***Fourth and higher levels*:** appearance and elongation of higher level axes (it should be noted, that fifth and higher level axes are relatively rare). This level provides most accurate information about structure of the single branches and the crown as a whole. We can obtain information about needles quantity on each shoot. But, due to high quantity of fourth level axes and shoots, a very powerful computer may be needed for the growth simulation. Thus fourth and higher levels of accuracy can be useful in simulation of single tree growth or growth of small trees groups.

Conclusion

Information about crown (or braches) structure from higher accuracy levels can be used for more precise describing of processes at lower accuracy levels. For example, the information on quantity of second order axes and, consequently, effective crown volume can be used for the more precise description of tree height growth.

L-systems are capable for the model formalization. However, the use of this complicated technology can be replaced by the set of other tools without critical lost of quality. Further development of crown simulation models is seen more expedient with using of a specific programming languages.

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