

Global Warming Effects on the Cambial Growth of *Larix leptolepis* in Central Korea : Predictions from Simulation Modeling

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지구온난화에 따른 중부 한국 낙엽송의 형성층 성장 예측: 시뮬레이션 모델링

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ABSTRACT

A simulation model was used to examine the effects of climate variation on the tree-ring structure of *Larix leptolepis* trees growing at a plantation plot in Worak National Park in central Korea. The model uses mathematical equations to simulate processes affecting cell(tracheid) size variations for individual rings using daily precipitation and temperature measurements. Limiting conditions are estimated from temperature, day length and a calculated water balance. The results indicate that the seasonal growth is mostly limited by the soil moisture content and precipitation income during April and May. The April-May temperature also inversely influences the growth by increasing water losses from soil. The global climate-change scenario which includes regional warming(increasing temperature in spring-summer periods) appears to decrease the duration of optimal growths. Consequently, the model estimated that *Larix leptolepis* would lose the total production of xylem by 25%.

요 약

월악산에 자라는 낙엽송의 연륜세포의 성장에 미치는 온난화의 영향을 시뮬레이션 모델로 예측하였다. 이 모델은 각 연륜의 세포(가도관) 폭 변이를 일 강수량과 기온으로 모사하는 수학적식을 사용한다. 세포생장을 제한하는 조건을 기온, 일장, 그리고 계산된 수분수지로 추정한다. 이 모델을 적용한 결과 낙엽송의 계절생장에 가장 큰 영향을 주는 것은 4월과 5월의 토양수분조건과 강수량인 것으로 나타났다. 4~5월 기온 상승은 토양으로부터 수분 증발을 증가시켜 성장을 감소시켰다. 지구온난화(기온 2°C 상승)을 모델에 산정하였을 때 성장기간이 짧아졌고 전체 연륜 성장량을 25% 정도 감소시켰다.

INTRODUCTION

Cell size variability is closely related with climate (Park, 1990; Vaganov, 1990; Vaganov et al., 1985; Sass, 1993; Wilpert, 1993). Several studies suggest that radial tracheid diameter variation in tree ring indicated the seasonal variation of tree growth, for the evaluation of changes in soil water regime (Vaganov et al., 1975; Park, 1990; Wilpert, 1993) and for the analysis of tree growth during and after insect damage (Vaganov and Terskov, 1977). Measurements of anatomical features of the tree-rings help to look for the seasonal information, where the tree responds mainly to climatic (weather) conditions. Intra-seasonal growth changes are first the integration of biochemical and physiological process of the influence of climate to tree growth.

In the contrary to boreal zone with the high amplitude of winter-summer temperature differences, the climate of Korea peninsula is more mild, the period with negative temperatures less than 2 months, average temperature in summer (usually in July and August) reached up to 25 °C, and precipitation has a specific intraannual distribution: very rarely in spring and last autumn, and abundant in short period since last June to beginning of September. We expect that this climatic peculiarities determine the seasonal growth dynamics of trees, and are reflected in anatomical tree-ring structure.

Variations in tree ring structure are successfully simulated with a mechanistic model using daily climatic data as growth limiting conditions for various species: Siberian species of cold climate (Vaganov, 1990), Arizona species of arid climate (Fritts et al., 1991) and Korea species of

temperate climate (Vaganov and Park, 1994). The latter study (Vaganov and Park, 1994) examined climatic influence on the radial variations in the tracheids of *Pinus densiflora* and *P. rigida* trees growing near Seoul. We extend this study for *Larix leptolepis*, a major plantation species in central Korea.

METHODS

Site Description

The study site is located at Worak National Park, University Forest of Chungbuk National University Plantation "Geolgol" site (500 m a.s.l.). The site is on the south slope (aspect: 15 degree) on the shallow (20~30 cm) sandy soil. At lower slope about 1000 square meter *Larix leptolepis* plantation (30 years old) locates and at upper slope about 1500 square meter *Pinus rigida* (25 years old) locates. A few *Pinus densiflora* trees (natural) grow among these plantations.

Material Preparation

Two cores for two radii have been taken for each tree. In plantation of Japanese larch 10 trees were sampled. Each core was placed and reinforced with glue on wood support and oriented of their fibers to be perpendicular to the surface. Then for all samples we cut a surface using a very sharp knife to obtain a cross-sectional surface. The clear manifestation of cell structure on surface was achieved after applying chalk on the surface which contrasts cell wall from cell lumen.

Measurements of Tracheids

For the period from 1980 to 1995 (16-years), 5 trees were selected for cell measurement. The quality of surface allows to provide the accurate

measurement of radial tracheid dimension with resolution in $0.5 \mu\text{m}$ using the measuring microscope "Olympus" with 400x magnification. For each year the tracheids in 5 randomly chosen radial rows were measured. To compare the measurements of different radial rows as well as different tree-ring we used the standardization procedure described earlier (Vaganov, 1990). Because the number of cells in row varies from 80 to 300 cells, standardization value we used 50 cells, which allow to keep more details in tracheid size variation within tree rings. The tracheidograms (tracheid size variation) were then used for comparative analysis with seasonal climatic data as well as with model calculations.

Simulation Modeling

The model uses mathematical equations to simulate processes affecting cell(tracheid) size variations for individual rings using daily precipitation and temperature measurements. Limiting conditions are estimated from temperature, day length and a calculated water balance. The main approach and algorithms of model were published earlier (Vaganov et al., 1989; Fritts et al., 1991). Although the main approach and algorithms of model were published earlier (Vaganov et al., 1989; Fritts et al., 1991), here it will be repeated briefly for the main model assumptions for description of seasonal growth and tree-ring formation.

For the growth initiating the minimum sum of positive temperatures is necessary. Growth rate equals zero until this sum will be accumulated in the beginning of a season. The dependence of growth rate on temperature is described in following way: it equals zero, if the temperature is below minimum (5 degree), then it increases linearly with the temperature increase

and reach 1.0 at the optimal temperature (for example, 19 degrees), it remains stable in optimum and then decreases to zero with further temperature increase. As a result the simple linear approximation of typical experimental curve is obtained, which are known from the tree physiology.

The dependence of growth rate on soil moisture is similar. Moisture content is calculated according to balance equation taking into account the thawing out of soil and moisture, existing in this layer (stored since the last year at the soil freezing). Such a balance equation is the main modification of a model for permafrost soils. Moisture calculation is following:

$$W_{t+1} = W_t * l_t * (1 - a) + b * P_t - c * Tr_t(T, W)$$

where W_t - water balance on the previous day; l_t - the depth of soil thawing out; P_t - precipitation on day t ; $Tr_t(T, W)$ - a function that describes the water losses by evapotranspiration and depends upon temperature and current water storage; a - coefficient of characterized rate of soil thawing, b - coefficient of available precipitation (the portion of total daily precipitation that enters into the soil), c - coefficient of water loss. a , b , c - are constant coefficients for the whole calculated period of growth (several years).

Transpiration depends on temperature exponentially (if there is no data on air moisture deficit). The depth of thawing out depends also on air temperature and the rate of increasing of thawing layer falls with the increase of this layer itself. For temperate zone without permafrost the first component of the balance equation is simply equal W_t , because the rate of thawing out is high and not necessary to take

into account the dynamics of thawing layer (except mountain regions). The third important component for the calculation of seasonal growth rate is the light. Since the direct photometric observations are not carried out on the most of meteorological stations then we take into account only of insolation flux which are calculated accordingly equation from monograph (Gates, 1980):

$$Et = E_0 * (hs * \sin v * \sin q + \cos v * \cos q * \sin hs)$$

where the insolation flux depends on time of a season t , site latitude(v), day length(hs) and the angle of sun shine(q).

As a result of these particular calculations of growth rate depending on current climatic conditions is the tree seasonal growth rate calculated to the formula:

$$Gr_t = Gr_t(E) * \min(Gr_t(T), Gr_t(W))$$

where $Gr_t(E)$ -growth rate, determined on each day according flux of insolation, $Gr_t(T)$ -according to temperature, $Gr_t(W)$ - according to current soil moisture. Common Gr_t calculated is used as input parameter for cambial activity block of the model in calculations of tracheid production during a season and in calculations of cell size variation within tree-ring. The algorithm of tracheidogram calculation according to curve of a seasonal growth rate was described earlier(Vaganov et al., 1985, 1989; Fritts et al., 1991). The mechanism of functioning of cambial block in model was already published(Fritts et al., 1991).

RESULTS AND DISCUSSION

As an example of modeling work, we present the process for the 1988 year. This year was unusually dry and ring width decreased very much. The standardized tracheidograms(Fig. 1D) show the continued decreasing of tracheid diameter from the beginning of a season, small fluctuation to increase in diameter in early wood zone due to small rain fall at the first days of June and abruptly decreasing in tracheid diameter until the first third of July when the abundant rainfall occurred. In this year about 60% of cells in tree-ring produced until the first third of July.

The calculations according to the model for 1988 were presented on Fig. 1. First graph shows the climatic dynamic and integral growth rate calculation(A), second one the partial (dependent on temperature or soil moisture content) growth rates calculations(B), third one the seasonal dynamics of total cell production and number of cells in cambial zone(C) and forth one the comparison of actual tracheidogram and estimated one(D). In 1988, low soil moisture at the beginning decreases very fast since beginning of May due to low precipitation and growth rate was limited mainly by moisture. From second part of June to the end of August, the growth rate was limited by high temperature in spite of the optimal content of water in soil. Such limits occur most effectively in 1988, and in combination with water limit in first part of a season it leads to large suppression of growth rate and finally to narrow tree-rings. Fig. 1C clearly show that new cells in formed tree-ring appear with some delay in time according to the first division in cambial zone. The cambial cells start to divide at second or last third of April, but new cells in tree-ring appear in the beginning of May. The result of

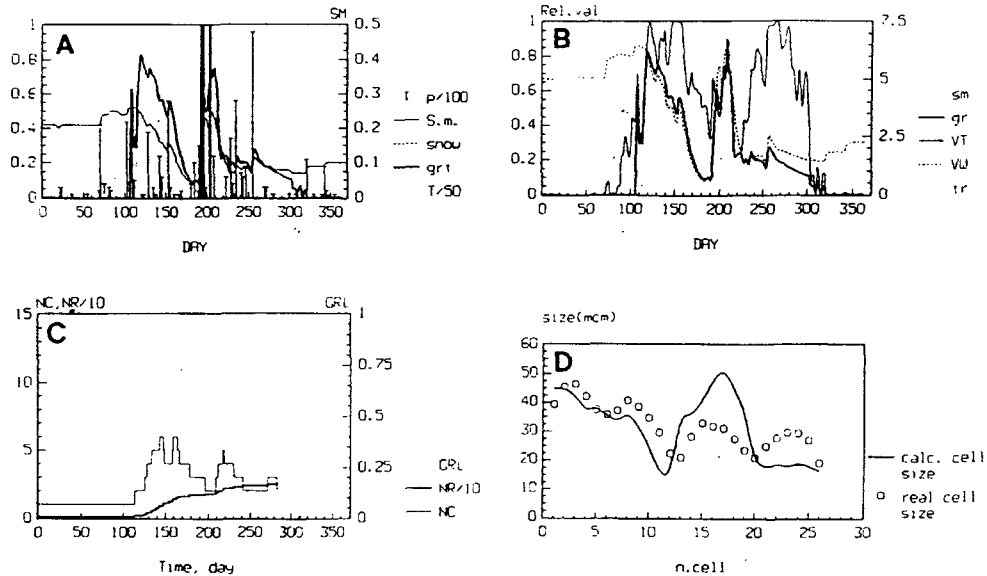


Fig. 1. Seasonal growth rate and tracheidogram calculation for 1988. (A) growth rate (grt) estimated from climate data. P: precipitation, T: temperature, S.m.: soil moisture, (B) growth rate estimated by temperature factor (VT) and water factor (VW); tr: transpiration, (C) cumulated number of cells (NR) calculated by the model; GRL: growth rate of cell, NC: number of cells in cambium zone, and (D) Real cell size and calculated cell size in annual ring of 1988.

modeling fully agrees with our experimental data obtained using the dendrometer and anatomical measurements (Park et al., 1999). Coincidence between calculated and measured tracheidograms (Fig. 1D) seems rather low than other calculations, but calculated tracheidograms matches the main change observed in the measured one.

The sum of radial diameters of all tracheids produced in a year. Using the parameters used in the model, we simulated the ring widths for the years of 1980 to 1995. The results of simulation indicated good agreements (correlation coefficient $r=0.85$) between actual ring widths and simulated ones (Fig. 2). It demonstrated the reliability of the simulation model we applied to.

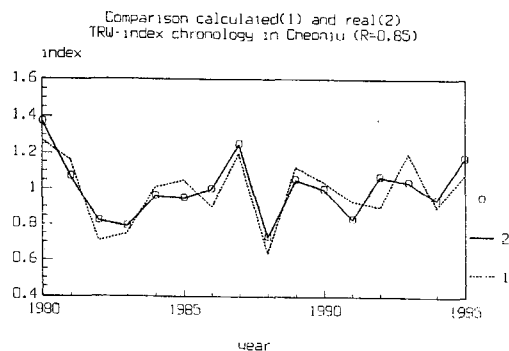


Fig. 2. Comparison of calculated (simulated) (1) and measured (actual) (2) tree-ring width index chronology for *Larix leptolepis* growing in Worak Mt.

We applied our results to estimate the influence of expected warming on the seasonal

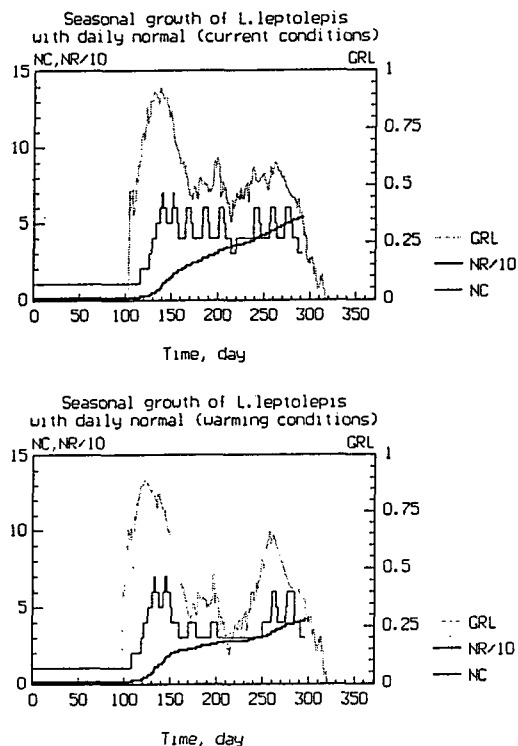


Fig. 3. Cumulated number of cells produced per year (NR) which were calculated by the model with the global warming scenario (upper: normal temperature, lower: 2°C warming); GRL-growth rate of cell, NC-number of cells in cambium zone, NR-cumulated number of cells produced.

growth of *L. leptolepis* in studied area. We obtained it from model calculations which are based on two theoretical years using daily normal: one is average for current changes, another has the temperature on 2°C higher than previous one. The warming effects reduce the intervals with favorable climatic conditions for growth and increases the duration of interval with unfavorable climatic conditions. According to this scheme we expect for *Larix leptolepis* in the research area to lose the 25% of production of new cells due to 2°C warming (Fig. 3).

CONCLUSION

The results show that seasonal and year-to-year growths of Japanese larch are very sensitive to climate changes. The most specific response of studied species to climate may be the optimal climatic conditions for growth occurred in short period from starting at the end of April-beginning of May to the end of June. Seasonal growth is mostly limited by soil moisture content and precipitation regime during April-May. The April-May temperature also inversely influences the growth in first sub-period by increasing of water losses from soil. Therefore, every scenario of climatic changes which include the regional warming (increasing the temperature in spring-summer periods) leads to decreasing of duration in two sub-periods of seasonal growth with optimal conditions. The common seasonal interval with optimal climatic conditions for growth decreases, then it will be expected that trees have to lose the total production of xylem. According to calculations with daily normals the reduction of growth of *Larix leptolepis* will be 25%.

Our study shows the perspectives of combine dendrochronological, anatomical and seasonal growth monitoring approach to answer on question: what can we expect in conifer trees growth under global and regional climate changes? The forecasting based on the present studied material is not optimistic because of more evidences to suppress the seasonal growth under warming trend.

The next experiments have to be made on more widely distributed material from different climatic zones of Korea as well as on more species. The knowledge about seasonal climatic response of trees in plantation gives the basis for

inspection of pollution impact on seasonal tree growth. Such inspection has to be made using the tree-ring material as well as modeling approach.

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REFERENCES

- Fritts, H. C., Vaganov, E. A., Sviderskaya, I. V. and Shashkin, A. V. 1991. Climatic variation and tree-ring structure in conifers: empirical and mechanistic models of tree-ring width, number of cells, cell size, cell-wall thickness and wood density. *Climate Research* 1: 97-116.
- Gates, D. M. 1980. *Biophysical Ecology*. Springer-Verlag, New York, 611pp.
- Park, W. K. 1990. Development of anatomical tree-ring chronologies from southern Arizona conifers using image analysis. Ph.D. thesis, Univ. of Arizona, Tucson, 234pp.
- Park, W. K., Kwon, Y. R., Choi, J. K. and Seo, J. W. 1999. Radial growths and electrochemical monitoring of cambium activity of *Pinus densiflora* from Worak Mt. Proceeding of the Korean Society of Wood Science and Technology 1999 Autumn Meeting, Cheongju, Korea. 307-312.
- Sass, U. 1993. Die Gefasse der Buche als okologische Variable. Bildanalytische Erfassung, dendroklimatologische Prufung, okologische Bewertung. Ph.D. thesis, Univ. Hamburg, 172pp.
- Vaganov, E. A. 1990. The tracheidogram method in tree-ring analysis and its applications. In: Cook E.R., Kairiukstis L.A.(eds.): *Methods of Dendrochronology-Applications in the Environmental Sciences*, Kluwer Acad. Pub., Dordrecht, 63-76.
- Vaganov, E. A. and Park, W. K. 1994. Dynamics of seasonal growth of *Pinus densiflora* and *Pinus rigida* annual rings in the Korean peninsula. *Lesovedenie* 2: 31-41.
- Vaganov, E. A., Shashkin, A. V., Sviderskaya, I. V. and Vysotskaya, L. G. 1985. Histometric analysis of woody plant growth. Nauka, Novosibirsk, 121pp.
- Vaganov, E. A., Sviderskaya, I. V. and Kondrat'eva, E. N. 1989. Weather conditions and tree-ring structure: the simulation model of tracheidogram. *Lesovedenie*, n2: 37-45.
- Vaganov, E. A., Smirnov, V. V. and Terskov, I. A. 1975. Determination of the tree water regime changes using tree-ring reflectograms. *Sov. J. Ecology*, n. 2: 45-53.
- Wilpert, K. 1993. Intraannual variation of radial tracheid diameters as monitor of site specific water stress. *Dendrochronologia*, 9: 95-113.

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