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Influence of Temperature and Moisture on the Radial Growth of Scots Pine and Norway Spruce in Kaunas, Lithuania

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Lithuania의 Kaunas지역 구주소나무와 독일가문비의 연륜생장에 대한 기온과 수분의 영향

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ABSTRACT

Ring-width chronologies of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) from two experimental forest plots in Kaunas, Lithuania were developed to study tree growth-climate relationship in different geohydrological conditions using response function analysis. The tree ring-width chronologies of Scots pine ranged from 1883~1987 A.D. and 1864~1989 A.D., and Norway spruce 1838~1987 A.D. and 1870~1989 A.D., respectively. The response function analysis has vividly demonstrated that the growth of Scots pine is favoured by warm summer and Norway spruce by cool and moist summer. Spring temperature has shown direct relationship with tree growth of both the species. There also exists notable intraspecies analogies in growth responses except some minor differences.

Key words: Growth-climate relationship, Lithuania, Norway spruce, Scots pine, Tree ring analysis

INTRODUCTION

Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) are very widely distributed in the Lithuanian forests. Tree ring studies of these species (Karpavichus 1978, 1984, Stupneva and Bitvinskas 1978, Budriunas and Bitvinskas 1987, Karpavichus *et al.* 1996) have indicated the presence of strong climatic signals in ring width chronologies. However, the applicability of these species in dendroclimatic studies becomes very limited due to their short life span, usually 200~300 years. The old tree ring materials of different tree species with discernible growth rings are found in plenty in bog deposits and archaeological sites. These materials could be utilized to prepare long tree ring chronologies by linking the tree ring sequences of living trees with that of the ancient woods. But this could be possible only when there exists dominant macroclimatic signal in the tree ring sequences of species in question which enables the establishment of reliable crossdating.

The archaeological tree ring materials could not only be the assemblage of different timbers but even from varied ecological provenances too. The species showing similar growth behaviour and response to climate should be scrupulously screened for chronology preparation. This requires thorough understanding of the growth behaviour of various tree species growing in varied ecological conditions. Keeping this problem in mind we investigated the tree growth - climate relationship in Scots pine and Norway spruce from two experimental forest plots with different geohydrological conditions in Kaunas, Lithuania. The present study provides an insight on the influence of monthly climate variables on Scots pine and Norway spruce growth in the region.

MATERIAL AND METHODS

Tree ring samples for the present study were collected from two experimental forest plots; named three and four in Kaunas, Lithuania. The third plot in Kazlu Rudos Forest Division (54° 44′ N, 23° 32′ E) situated on flat terrain is comprised of 50% Scots pine, 40% Norway spruce (30% old and 10% young) and 10% birch(*Betula pendula* Roth). The soil horizons are featured by top 10cm peat with poorly rotten litter, 21~40cm brown grey elluvial layer with white spots and 40~50cm hard, dark brown illuvial layer. The ground water level is at 1.2m depth.

The fourth plot situated on the top of the Nyamunas valley in Chilenu Forest Division (54° 49′ N, 27° 12′ E) in Kaunas has 70% Scots pine and 30% Norway spruce. The soil of this plot is characterized by clay layer at 2m depth which is non-porous and inhibits the downward percolation of water. The soil horizons are characterized by grey elluvial layer with brown spots at 68~82cm depth and grey illuvial with frequent brown spots at 83~130cm depth.

For present tree ring analysis, reconnaissance sampling was done from ten mature canopy trees of each species from both of the plots using increment borer at breast height. Crossmatching by using the pointer year rings in samples was used to date the growth ring sequences to the calendar year of their formation. The ring widths of dated sequences were measured with the accuracy of 0.05mm. To remove the biological growth trend, ring width measurements were standardized with 20 year moving average at 5 year step (Bitvinskas 1974) and ring-width indices derived by dividing the actual measurement values with the smoothed values of the corresponding years. Separate mean ring width chronologies of each species from both the plots were prepared.

Response function analysis was carried out to evaluate the climatic information in each chronology. This procedure provides an efficient method of comparing tree growth with a large number of meteorological parameters in order to identify those which appear to be most important for growth (Fritts 1976). Mean ring width chronologies and meteorological data (mean monthly temperature and total monthly precipitation) for the hydrological year (September-August) available from Kaunas Meteorological Station (1922~1977) were used for response function analysis. Antecedent year's growth was also included in the response function analysis to account the influence of persistence on ensuing year's growth. Twelve months mean monthly temperature and total precipitation each along with one antecedent year's growth altogether provide 25 time series in the analysis. Since many of the monthly climate variables are inter-correlated, in order to conserve the degrees of freedom, variables used were reduced to a small number of orthogonal series. These orthogonal series were then related by multiple regression to each chronology. The stepwise multiple regression is terminated when the F-quotient for the entering variable becomes less than 1.0. The F-test is used as a measure of the quotient of the variance reduced by a new variable and the error variance. As long as the explained variance added by regressing a new variable is greater than the remaining error variance ($F>1.0$), the residual variance could be reduced by including the variables in the regression. Once the regression coefficients are calculated, the orthogonal variables are transferred to the original set of climate variables. The new set of coefficients are known as the elements of response function. The error bars of each element are controlled by the F-level of explained variance over error variance, where the number of degrees of freedom is given by the number of records (years) in the series minus the number of coefficients in the equation. If the error bars on any element do not touch the zero horizontal axis, the element is considered to be significant.

RESULTS AND DISCUSSION

The present tree ring study has shown that the trees in the two selected forest plots are not old. Scots pine chronology spanned from 1883~1987 A.D. and 1838~1989 A.D. in plot 3 and 4, respectively, whereas Norway spruce from 1838~1987 A.D. and 1870~1989 A.D. respectively (Fig. 1). The chronology statistics (Table 1) show that mean sensitivity which describes the variability of high frequency component of the ring-widths due to cli-

Table 1. Chronology statistics

Chronology	Interval	Years	Mean	Median	Mean sensitivity	Standard deviation	Skewness	Kurtosis	Autocorr. order I
PISY 3	1883~1987	105	0.998	1.004	0.165	0.179	−1.065	4.660	0.29
PISY 4	1864~1989	126	0.999	0.993	0.146	0.147	−0.023	0.041	0.25
PIAB 3	1838~1987	150	0.994	1.000	0.154	0.214	0.156	0.598	0.58
PIAB 4	1870~1989	120	0.993	0.969	0.237	0.261	0.092	−0.283	0.44

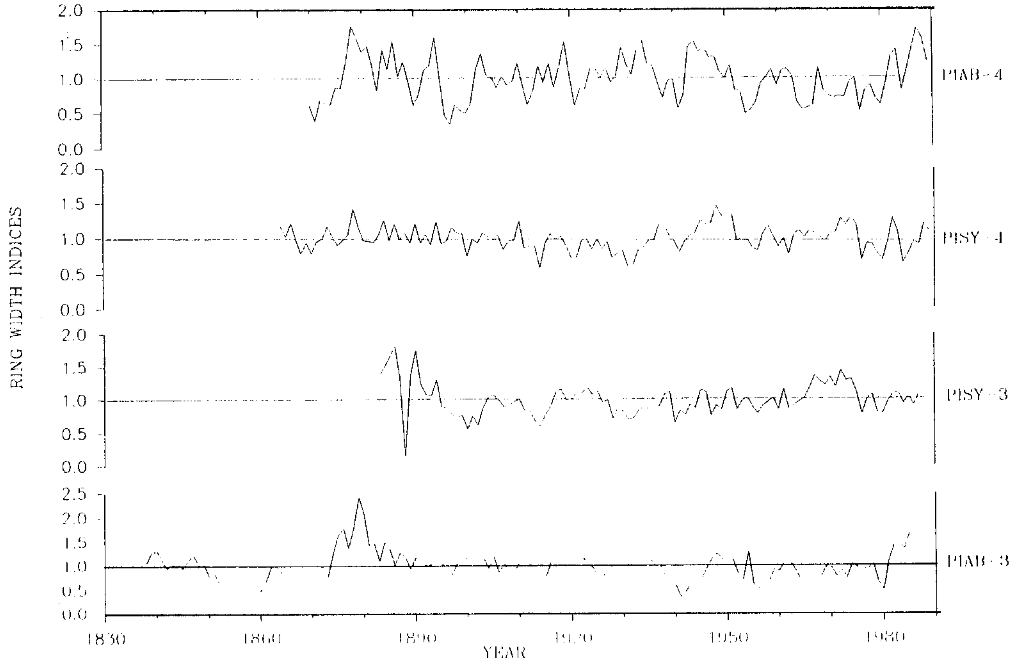

Fig. 1. Ring width chronologies: PISY3 - *Pinus sylvestris* (1883~1987 A.D.) from plot 3, PISY4 - *P. sylvestris* (1864~1989 A.D.) from plot 4, PIAB3 - *Picea abies* (1838~1987 A.D.) from plot 3, PIAB4 - *P. abies* (1870~1989 A.D.) from plot 4.

mate fluctuations is very low for both the species in two plots. This indicates the complacent nature of the sites. The high first order autocorrelation in the chronologies of both the species is indicative of the importance of antecedent year's growth on ensuing year's growth which is also reflected in the respone function plots (Figs. 2~5). Norway spruce chronologies are found to possess higher first order autocorrelation in comparison to Scots pine. The inter-correlation between the chronologies (Table 2) shows that pine chronologies from the two plots are more closely related in comparison to that of Norway spruce. Norway spruce growth seems to be much sensitive to site specific geohydrological conditions. Intercorrelation between the two chronologies of different species from the same plot is also lower in comparison to that of the pine chronologies from two different plots. This could be due to their differing growth habit and climatic requirements. High cross correlation between the two chronologies of Scots pine from the two plots could indicate higher common variance due to climate in com-

Table 2. Crosscorrelation between the chronologies

	PISY3	PISY4	PIAB3	PIAB4
PISY 3	1.000	0.793	0.566	0.398
PISY 4		1.000	0.596	0.483
PIAB 3			1.000	0.514
PIAB 4				1.000

PYSY - *Pinus sylvestris* PIAB - *Picea abies*

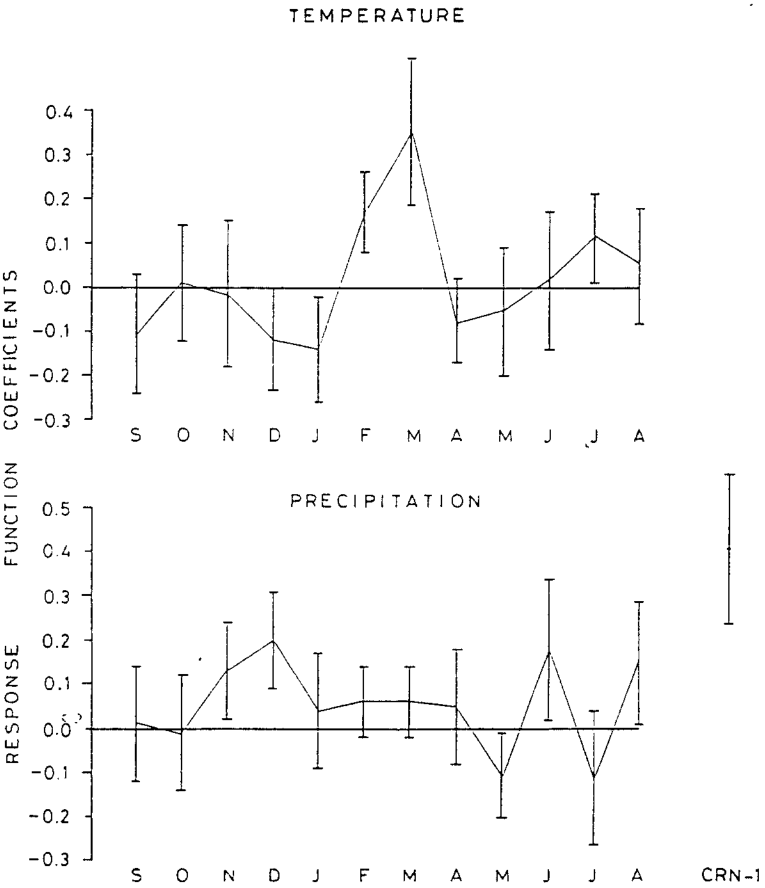

Fig. 2. Response function plots for PISY3. Bars represent the 95% confidence limits. Significant elements are those where both the limits are above or below the zero line. The analysis included mean monthly temperature and monthly precipitation from September to December of the prior growth year and January to August of the current growth year. Prior year's growth was also included in the analysis to account for its effect on ensuing year's growth.

parison to Norway spruce. This feature greatly helps in dating of the tree ring materials of Scots pine originated from distant places. The studies elsewhere have indicated successful crossdating of Scots pine tree ring materials derived from far off distances (Zetterberg 1987, Zeilsky 1982, Zetterberg *et al.* 1994).

The response function plots of Scots pine (Figs. 2, 3) show that the temperature of February, March and current year's summer and precipitation of November, December of antecedent growth year play direct influence on growth. The climatic variance in the chronologies have been found to be 40% and 34%, respectively. As the chronologies are based on very limited samples, it is expected that higher replication of samples could enhance the climatic variance. Such chronologies would be very useful to reconstruct the spatial and temporal climatic variability in Lithuania. Existence of good crossdating and

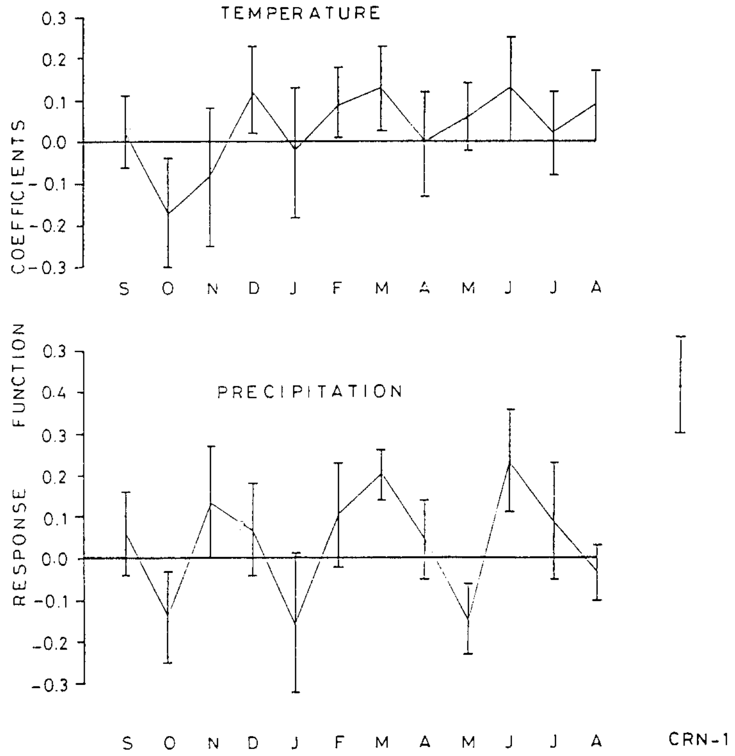

Fig. 3. Response function plots for PISY4. Bars represent the 95% confidence limits. Significant elements are those where both the limits are above or below the zero line. The analysis included mean monthly tmperature and monthly precipitation from September to December of the prior growth year and January to August of the current growth year. Prior year's growth was also included in the analysis to account for its effect on ensuing year's growth.

its climatic sensitivity has made possible one of the longest ever summer temperature reconstruction for the Scandinavian region (Briffa *et al.* 1992) from this species.

Response function analyses of Norway spruce (Figs. 4, 5) have indicated the direct influence of spring temperature on tree growth in both the forest plots. Precipitation during winter has negative influence whereas positive on growth during summer in both the plots, however, it is more significant in plot 4. Soil features especially the presence of non-porous clay layer in plot four inhibiting the downward percolation of water perhaps leads to the excessive water availability in top soil layers, thereby water is not limiting for the tree growth whereas such is not the case for plot 3. The Norway spruce growth seems to be much favoured by cool and wet summers. This is very much in accordance with the earlier studies on this species (Eckstein and Krause 1989, Eckstein *et al.* 1989, Karpavichus *et al.* 1996). Total climatic variance in the two Norway spruce chronologies from both the plots has been found to be 30% and 31% which are lower than that of pine.

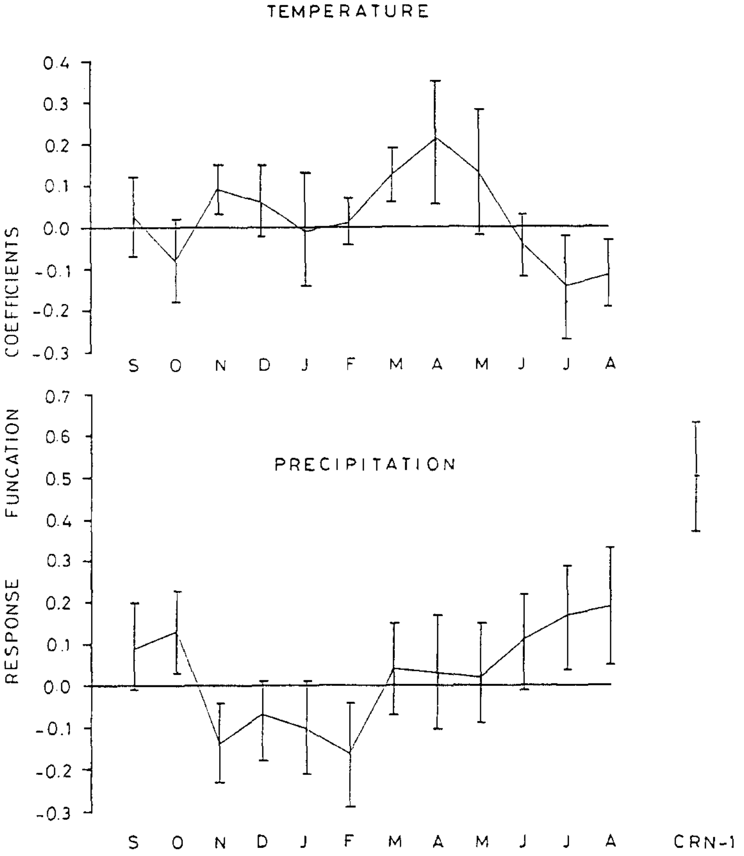

Fig. 4. Response function plots for PIAB3. Bars represent the 95% confidence limits. Significant elements are those where both the limits are above or below the zero line. The analysis included mean monthly temperature and monthly precipitation from September to December of the prior growth year and January to August of the current growth year. Prior year's growth was also included in the analysis to account for its effect on ensuing year's growth.

The present study has displayed interesting intraspecies analogies in the growth response of species growing in differing geohydrological conditions to climatic variables. The growth of both Scots pine and Norway spruce are favoured by warm springs. The warm springs perhaps influence the breaking of dormancy and resumption of physiological activities thus enhancing the growth (Fritts 1976). But this could also accentuate the sensitivity of trees to spring frost damages. Norway spruce is reported to be very sensitive to frost damages (Pukacki and Pukacki 1987). The response functions of two species from the same plot also showed considerable differences which could be attributed to physiological or phenological factors. Scots pine, due to its deeper root system, responds poorly to the moisture supply in the growing season. However, Norway spruce, due to its shallow root system, is much prone to temporary desiccation during the growing season. The

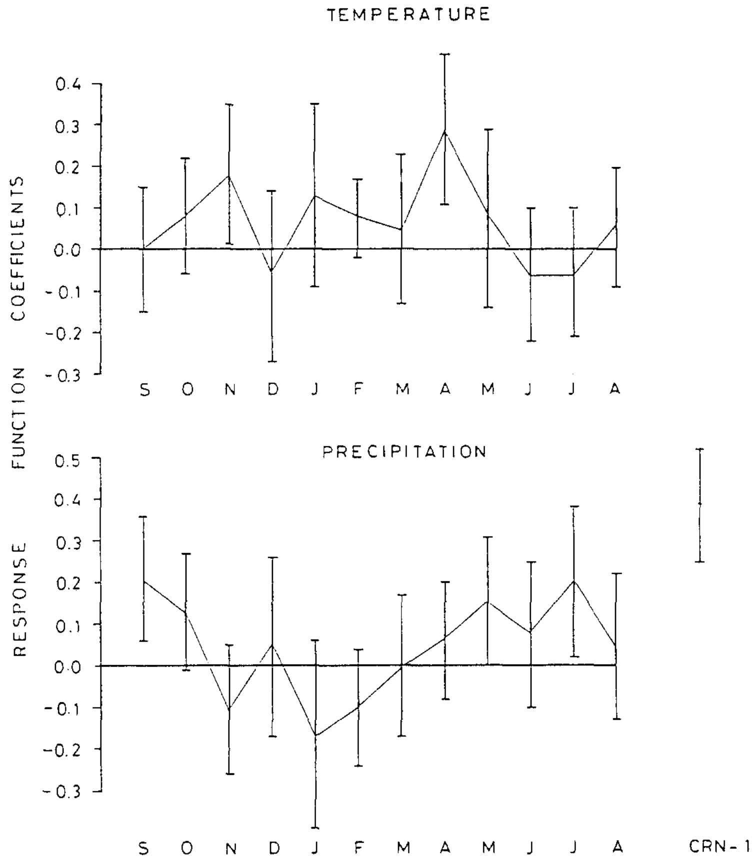

Fig. 5. Response function plots for PIAB4. Bars represent the 95% confidence limits. Significant elements are those where both the limits are above or below the zero line. The analysis included mean monthly temperature and monthly precipitation from September to Dececber of the prior growth year and Janunary to August of the current growth year. Prior year's growth was also included in the analysis to account for its effect on ensuing year's growth.

existence of high cross-correlation between the two chronologies of Scots pine from the two plots of varying geohydrological conditions indicates the possibility of getting good crossdating in tree ring samples of this species from different localities which would greatly help in preparing multicentennial tree ring chronologies by linking growth ring sequences of modern woods with that of the ancient timbers. Such long tree ring chronologies, likely to provide valuable data base in supplementing the meteorological data in time and space, are of utmost need in global change studies.

적 요

Lithuania의 Kanunas지역 두 시험림에 자라고 있는 구주소나무(*Pinus sylvestris* L.)와 독일

가문비(*Picea abies* (L.) Karst.)의 연륜폭연대기를 작성하여, 토양과 수분조건에 따른 수목생장과 기후와의 관계를 반응함수를 이용하여 분석하였다. 두 지역에서 작성된 연륜폭연대기의 기간은 구주소나무가 1883~1987년, 1864년~1989년, 독일가문비는 1838년~1987년, 1870~1987년이었다. 반응함수분석에 의하면 구주소나무의 생장은 하계기후가 온난하였을 때 증가하였으나 독일가문비의 경우는 한랭다습하였을 때 증가하였음을 알 수 있었다. 춘계기온의 경우는 두 수종 모두 온난하였을 때 생장이 증가하였다. 몇가지 차이점을 제외하곤 두 수종의 기후에 대한 반응은 유사하였다.

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