Influence of Climatic Factors on Annual Rings of Conifers

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Relationships of the width of annual rings of 75–85-year old *Pinus sylvestris* L. and *Picea abies* (L.) Karst. with average monthly temperature, amount of precipitation and a complex climatic indicator developed on their basis was studied against the background of pollution load in the zone influenced by a cement plant and in a control area. Multiple regression analysis (equations with two and three independent variables) showed a significant correlation between precipitation and temperatures with increment, especially for pine; however, the prediction capability of the models is modest, describing usually 35–40% of the variation in radial increment. The calculations suggest that precipitation amounts are more important and temperature parameters less important and can be replaced by one another in the models. A direct correlation with the pollution load can be observed: at probability (P) near zero the coefficients for precipitation were the highest (0.45–0.51) in the area strongly affected by the cement plant and the lowest (0.31–0.35) in the weakly affected and control areas. In case of spruce shortage of air humidity during summer months was important for increment, especially so in the heavily polluted area.

Introduction

Information on environmental conditions important for the growth of trees and on their changes over long periods of time is documented in a visible and measurable form in the structure of the annual rings, making thus analysis of the effect of environmental factors possible (Fritts, 1976). Many factors influence the formation of the width of annual rings which may vary greatly depending on the species, geographical location and the conditions of the given site. Research into the effect of climatic factors is especially fruitful in areas where the growth of trees is subject to the effect of the so-called limiting factors. In areas where the production of trees depends significantly on some climatic factor (in arid and arctic areas and in mountains at the tree line in North America, northern Urals, etc.) the variation in the width of annual rings correlates well with changes in microclimate (Cropper and Fritts, 1981; Graybill and Shiyatov, 1992). Lindholm (1996) proved that midsummer temperature influences significantly the growth of pine at the northern boundary of their growth in Fennoscandia. Temperature regime affects the radial increment of conifers also in areas with moderate and humid climate in Germany (Huber and Griertz, 1970), Sweden (Bartholin, 1975), Norway (Thun, 1987) and Finland (Zetterberg and Meriläinen, 1987). The growth of spruce in Finland depends on early summer temperatures, but that of pine on mid- and late summer temperatures (Mikola, 1978). Summer temperatures affect significantly the radial increment also in Lithuania (Bitvinskas, 1974). In Estonia a strong correlation was established between the radial increment of bog pines and the ratio of precipitation amount and average temperature in June (Läänelaid, 1978). The radial increment of pines growing on mineral soils depends significantly on winter temperatures. A negative effect of low winter temperatures on the radial increment of conifers has been observed also in Latvia, Lithuania, Belarus and elsewhere (Lõhmus, 1992).

The present paper discusses the effect of climatic conditions on the radial increment of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) in an area heavily polluted by the cement industry and in a control area. Attention was focused on correlation between average monthly temperatures, amount of monthly precipitation and a comprehensive climatic indica-

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tor developed on their basis, which were combined with data on pollution loads.

Material and Methods

Growth conditions in stands

The study area belongs to the mixed-forest subregion of the Atlantic continental region of the temperate zone, which is strongly affected by the vicinity of the Baltic Sea (Raukas, 1993). The duration of sunshine at the coast is 1700–1750 h per year; the number of days without any sunshine is 110 per year. The average yearly temperature in the area is 4.9 °C, minimum 3.2 °C and maximum 7.3 °C. January is the month with the lowest average temperature (–5.7 °C), while July is the warmest (16.2 °C) month. Temperature fluctuations within a month vary greatly; the difference between the minimum and maximum over years is the biggest in February (18.0 °C) and the smallest in August (4.7 °C). The average duration of air temperatures above zero is 150 days. As an average, 11 December is the beginning of the period when the temperature stays below zero. This period lasts for 80 days with average absolute minimum temperature of –22.7 °C. In the vicinity of Kunda the average annual amount of precipitation is 550 mm. July and August are the months with the biggest amount of precipitation (respectively 13.0 and 13.4% of the total annual amount) and February and March have the smallest amount (3.8 and 3.9% of the total annual amount, respectively). The predominating winds are southerlies and southwesterlies (41%); during the winter season southerlies prevail while in summer northerlies gain predominance. The average annual wind speed is 5.2 m/s. Since 1975 the average air temperature and precipitation amount have had rising trends with the average annual air temperature by 0.3 °C and winter temperature by 0.7 °C higher and annual precipitation amount by 41 mm higher over the period 1975–1993 than over a long-term period (1954–1993).

The total amount of dust emitted into the atmosphere from the Kunda Cement Plant has varied over the investigation period (40 years, for pine 1954–1993, for spruce 1953–1992) depending on the condition of equipment and the intensity of production, reaching according to the data provided by the plant to a maximum of 98 900 tonnes (in 1991). In recent decades dust has made up 87–96% of the total emission. The amount of various exhaust gases (SO_2, NO_x, CO etc.) has been smaller. Analyses made in the laboratory of the plant show that the dust contains 42.5% CaO, 13.5% SiO_3, 7.8% K_2O, 7.5% SO_3, 3.6% Al_2O_3, 2.8% Fe_2O_3, 2.7% MgO, 0.13% Na_2O, 0.04% TiO_2 and 0.03% MnO (Mandre *et al.,* 1995). The amounts of Cl, Ba and Sr are also relatively high. These are followed by Zn, Pb, Cr, Cu and other elements. The large amounts of cement dust emitted by the plant have caused notable alkalisation of precipitation in the town of Kunda and in its surroundings (Mandre *et al.,* 1995). Transect studies carried out in 1993 showed that the pH value of rain in Kunda was 7.9, at a distance of 10–12 km to the east 7.2 and to the west 7.3. These values are notably higher than the values suggested by Austrian scientist Smidt (1984) as normal for precipitation (pH = 5.11–6.10) and than those of our control area (pH = 6.1–6.7). The high concentration of dominating elements (Ca, K etc.) in the dust has brought about also a rise in the pH value of snowmelt, which is usually over 10.0 in the town of Kunda (control 6.8–7.0).

Dust from the cement industry has had a serious impact on soil towards alkalisation (Teras, 1984). In the forest the pH value of the upper horizons of weakly podzolised temporarily overmoist sandy soils has risen by up to 4.5 units. The technogenic influence is the strongest in the litter layer of forest soil and it decreases towards deeper layers being in areas with a higher pollution load observable up to a depth of 70 cm. As compared to the control area the Ca and Mg content in the upper horizons of soil is 15 times higher, that of K 2–4 times, S up to 3 times and Al 5 times higher. The content of several microelements is also elevated. However, the content of total nitrogen and carbon has decreased. The carbon-nitrogen ratio (C/N) is likewise smaller, which indicates to changes in the biological efficiency in the soil (Teras, 1984). In the horizontal direction a strong influence of emissions can be observed in the leeward direction from the prevailing winds (to the east and northeast) up to 5 km from the plant (in the windward direction up to 2 km) while a weak influence can be observed at a distance up to 15 km.

Study sites

Studies were carried out on a transect in the area of the Kunda Cement Plant (established in 1871) in North-East Estonia. Differences in the radial increment of conifers in the influence zone of this emission source and a relatively unpolluted control area were estimated. The transect selected is a 50 km long strip of land in the coastal area stretching 38 km west and 12 km east from the cement plant (longitude 26°30' E, latitude 59°20' N). The selected stands were similar as far as their site type, quality class, composition of trees, age and density was concerned. They were with 0.7–0.8 density II quality class, average density or sparse understorey, 75–85-year old *Myrtillus* site type pine or spruce stands. Thereby the effect of numerous external (climate, phytocoenotic, anthropogenic etc.) and internal (biological age, hereditary properties, etc.) factors could be eliminated affecting radial increment in addition to pollution load.

Analysis of radial increment and climatic factors

At each site increment cores were taken from 15–20 dominant or codominant trees from their northern and southern sides at a height of 1.3 m and the width of the annual rings was measured. To eliminate the effect of random local factors influencing individual trees average parameters of study sites were used. These were grouped on the basis of sites and distance to the cement plant. To eliminate the effect of age, the initial data were standardised, i.e. on the basis of the actual widths of annual rings increment indices (Fritts, 1976) were calculated, showing the ratio of the actual increment and that regarded as standard increment in per cent. The correlations of radial increment indices as increment parameters with climatic factors were calculated on the basis of various parameters of air temperature and precipitation (average air temperatures and absolute minimum temperatures of the previous hydrological year, current hydrological year, its May, June, April–July, December–February, December–March; precipitation sums of the previous hydrological year, its July–August, current hydrological year, its June, July, August; and the average shortage of air humidity in June–August). Separate analyses were carried out for the period of regular climate observations in the Kunda area (40 years) and for the period that was climatically favourable for increment. The following influence zones of the cement plant were analysed: strongly affected area (up to 2 km west and 3 km east from the plant; pollution load 1800–2700 g m^{-2} per year); significantly affected area (2–3 km west and 3–5 km east; pollution load 1000–1800 g m^{-2} per year); moderately and weakly affected area (3–15 km west and over 5 km east; pollution load 100–1000 g m^{-2} per year); and the control area (30–38 km west) (Mandre *et al.*, 1995). The combined effect of meteorological parameters on increment was determined by multiple regression analysis (Sokal and Rohlf, 1995) with both temperature and precipitation indices used as independent variables for each model. Because different scales were used the initial data were standardised by subtracting from each variable their mean and dividing the result by the standard deviation. Models in case of which the determination multiplier $R^2 \geq 0.33$ were regarded as possible suitable models of radial increment. Initial data for the climate parameters of the Kunda Meteorological Station were obtained from the archives of the Estonian Institute of Meteorology and Hydrology.

For correlation and regression analysis and for finding statistical differences (*t*-test) the programs STATGRAPHICS 5.0 and EXCEL 5.0 were used.

Results and Discussion

The graphs of radial increment indices of Scots pine in Fig. 1 show the impact of climate on the width of annual rings over a period of 40 years. Over shorter periods this impact has been different. An inhibition of increment due to climatic factors is observable in 1958–1972. For all years of this period the values of radial increment indices are below the average (100) for the whole observation period. The inhibition of increment occurred both in the influence zone of the cement plant and in the control area. From 1975 onward the average radial increment indices of conifers are, as a rule, above the average, indicating improving climatic conditions for forest growth. It is well known that the increment of trees is affected not only by the regime during the current vegetation period but the after-effect of the previous year is always involved (Fritts, 1976; Lõhmus, 1992).

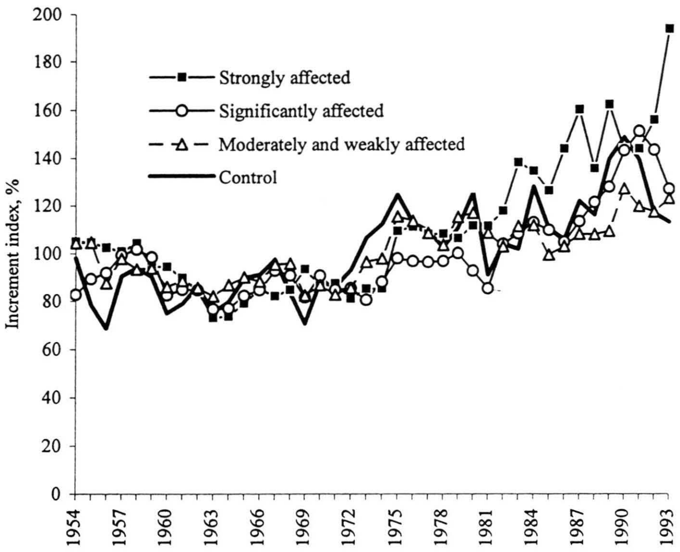

Fig. 1. Indices of radial increment of Scots pine under different impacts of cement dust pollution. To eliminate the effect of age, the initial data were standardised, i.e. on the basis of the actual widths of annual rings increment indices (Fritts, 1976) were calculated, showing the ratio of the actual increment and that regarded as standard increment in per cent. An inhibition of increment due to climatic factors is observable in 1958–1972. For all years of this period the values of radial increment indices are below the average (100) for the whole observation period. The inhibition of increment occurred both in the influence zone of the cement plant and in the control area. From 1975 onward the average radial increment indices of conifers are, as a rule, above the average, indicating improving climatic conditions for forest growth.

For example, an unfavourable previous vegetation year may have reduced the area of assimilating organs and the amount of active roots, as a result of which the increment during a favourable year may be inhibited. Significant changes in the radial increment of conifers under the impact of dust emitted from a cement plant have been established (Mandre *et al.,* 1995; Rauk, 1995). Because of high sensitivity of Norway spruce and Scots pine a strong negative correlation of increment with high concentrations of K and Ca in the environment (air, soil, subsoil water) has been observed. Inhibition of the radial increment of conifers and its dependence on the pollution load were especially obvious in the area strongly affected by the cement plant. From the 1950s to the present the average radial increment of trees growing on observation sites in this area has made up less than 70% of the control (in case of pine even below 50%) (1.79 mm for pine and 1.24 mm for spruce). In remoter areas within the influence zone of the cement plant (weakly affected area) the low concentrations of pollutants do not put enough stress on conifers to change their increment significantly.

Both in the area influenced by the cement plant and in the control area, from the parameters characterising temperature regime the strongest, most stable and unidirectional correlation with the radial increment of Scots pine was established with the average air temperature of winter months (from December through March) (Table I). Next come the average temperature of the current hydrological year (in significantly, moderately and weakly affected and control areas); average temperature of the previous hydrological year (in strongly and significantly affected and control areas) and the absolute minimum temperature (in significantly affected and control areas). It has been suggested that low temperatures cause destruction of the structure of cytoplasm, intensification of depletion of reserves, physiological dryness due to the freezing of the stem and soil (Lõhmus, 1992; Lyr *et al.,* 1974); the effect of the last mechanism is supported by a reliable correlation with the freezing depth of soil. In the area strongly affected by cement dust the dependence of the radial increment of pine on winter and annual temperature parameters was weaker than in less affected areas and the control area; however, a significant correlation with early summer temperatures was ascertained, which was absent elsewhere (Table I). Optimal air temperatures in May usually accelerate the growth of new needles, intensifying photosynthesis (Huttunen *et al.,* 1983), which is disturbed in the strongly polluted areas due to high levels of defoliation and the cement crust covering older needles. In case of Norway spruce the dependence of the radial increment on the average temper-

Table I. Correlations (r) of increment indices of pine and meteorological parameters and the probability of their significance (P) in the influence zone of the cement plant and in the control area. The correlation of radial increment indices as increment parameters with climatic factors were calculated on the basis of various parameters of air temperature and precipitation: x_1 = average air temperature of the current hydrological year (1 Sept.–31 Aug.), x_2 = average air temperature of the previous hydrological year, x_3 = average air temperature of May, x_4 = average air temperature of June, x_5 = average air temperature of April–July, x_6 = average air temperature of December–February, x_7 = average air temperature of December–March, x_8 = absolute minimum air temperature of the current hydrological year, x_9 = precipitation sum of the current hydrological year, x_{10} = precipitation sum of the previous hydrological year, x_{11} = precipitation sum of June, x_{12} = precipitation sum of July, x_{13} = precipitation sum of August, x_{14} = precipitation sum of July–August of the previous hydrological year, x_{15} = average shortage of air humidity in June–August. The following influence zones of the cement plant were analysed: strongly affected area (up to 2 km west and 3 km east from the plant; pollution load 1800–2700 g m^{-2} per year); significantly affected area (2–3 km west and 3–5 km east; pollution load 1000–1800 g m^{-2} per year); moderately and weakly affected area (3–15 km west and over 5 km east; pollution load 100–1000 g m^{-2} per year); and the control area (30–38 km west). Significant (significance level $P < 0.05$) correlations (r) are given in bold.

a) Investigation period (1954–1993)

Parameter	Strongly affected area		Significantly affected area		Moderately and weakly affected area		Control area	
	r	P	r	P	r	P	r	P
x_1	0.31	0.06	**0.44**	**0.01**	**0.39**	**0.02**	**0.41**	**0.01**
x_2	**0.34**	**0.03**	**0.35**	**0.03**	0.29	0.07	**0.34**	**0.03**
x_3	**0.39**	**0.02**	0.24	0.14	0.26	0.11	0.20	0.21
x_4	−0.16	0.30	−0.13	0.39	−0.21	0.20	−0.13	0.44
x_5	0.21	0.19	0.21	0.20	0.10	0.56	0.23	0.16
x_6	**0.31**	**0.05**	**0.37**	**0.02**	**0.37**	**0.02**	**0.36**	**0.02**
x_7	**0.37**	**0.02**	**0,47**	**0.01**	**0.46**	**0.01**	**0.47**	**0.01**
x_8	0.28	0.08	**0.37**	**0.02**	0.30	0.06	**0.35**	**0.03**
x_9	**0.53**	**0.01**	**0.46**	**0.01**	**0.42**	**0.01**	**0.41**	**0.01**
x_{10}	**0.45**	**0.001**	**0.54**	**0.001**	**0.44**	**0.01**	**0.45**	**0.01**
x_{11}	0.08	0.64	0.05	0.77	0.11	0.50	0.13	0.44
x_{12}	0.21	0,18	0.13	0.43	0.15	0.34	0.09	0.60
x_{13}	**0.39**	**0.01**	0.22	0.18	0.12	0.46	0.20	0.23
x_{14}	0.21	0.18	0.30	0.06	0.28	0.08	0.30	0.06
x_{15}	−0.31	0.06	−0.16	0.34	−0.25	0.14	−0.21	0.21

b) Climatically favourable growth period (1975–1993)

Parameter	Strongly affected area		Significantly affected area		Moderately and weakly affected area		Control area	
	r	P	r	P	r	P	r	P
x_1	0.38	0.11	**0.53**	**0.02**	**0.49**	**0.03**	0.41	0.08
x_2	0.45	0.06	**0.54**	**0.02**	**0.53**	**0.02**	**0.51**	**0.03**
x_3	0.33	0.16	0.03	0.90	0.10	0.71	−0.11	0.63
x_4	0.01	0.98	0.06	0.84	−0.03	0.89	0.12	0.63
x_5	0.36	0.13	0.30	0.21	0.15	0.53	0.26	0.28
x_6	0.42	0.07	**0.50**	**0.03**	**0.61**	**0.01**	**0.48**	**0.04**
x_7	0.43	0.06	**0.57**	**0.01**	**0.58**	**0.01**	**0.50**	**0.03**
x_8	0.36	0.13	**0.51**	**0.02**	0.43	0.07	0.38	0.11
x_9	0.23	0.35	0.09	0.71	−0.15	0.55	−0.07	0.78
x_{10}	0.05	0.83	0.23	0.35	−0,04	0.86	0.06	0.81
x_{11}	−0.13	0.59	−0.15	0.55	−0.10	0.68	−0.20	0.42
x_{12}	−0.01	0.95	−0.10	0.70	0.09	0.70	−0.08	0.74
x_{13}	0.43	0.07	0.07	0.79	−0.25	0.30	−0.03	0.90
x_{14}	−0.05	0.85	0.10	0.67	−0.03	0,91	0.16	0.52
x_{15}	0.10	0.68	0.26	0.28	0.22	0.36	0.08	0.73

ature of winter months, minimum temperature and the average temperature of the previous and current hydrological years was generally insignificant ($P > 0.05$).

As to the parameters characterising the humidity regime, radial increment was significantly correlated with the precipitation sum of the previous hydrological year. For pine the correlation was the strongest in the strongly affected area, to some extent weaker in significantly, moderately and weakly affected and control areas (Table I). The radial increment of pine is also affected by the total amount of precipitation of the previous hydrological year. Frequent rains wash off part of the pollution deposited on the crowns of trees and carry the dust from upper layers of the soil into deeper layers. For spruce, the correlation with the same parameters was much weaker (for the current hydrological year in the moderately and weakly affected area $r = 0.38$ and $P < 0.02$; for the previous hydrological year in the strongly affected area $r = 0.51$ and $P < 0.001$, in the moderately and weakly affected area $r = 0.43$ and $P < 0.01$ and in the control area $r = 0.37$ and $P < 0.02$); moreover, in some sites no correlation was observed. An important parameter for spruce was the shortage of air humidity in June–August, which affected increment especially in polluted areas (in the strongly affected area $r = -0.45$ and $P < 0.01$, in the moderately and weakly affected area $r = -0.33$ and $P < 0.05$). Under a shortage of air humidity transpiration and photosynthesis are disturbed if water reserves in the soil are insufficient; this, in turn, affects radial increment of trees (Fritts, 1976).

During the period climatically favourable for the growth of trees (from the mid-1970s onward) the air temperature parameters had a somewhat different effect on radial increment. For pine the correlation of the average air temperatures of the winter months (both from December to February and from December to March), of the current hydrological year and the previous year were generally significant but relatively weaker than for the whole study period, which includes also years less favourable for the growth of trees (Table I). The effect of summer temperatures on increment was statistically insignificant. In the strongly affected area no reliable relationships were observed with temperature parameters limiting growth. No reliable correlation was observed between the parameters characterising the humidity regime and increment of Scots pine (Table I). For Norway spruce no significant correlation was established with any temperature and humidity parameters ($P > 0.05$).

The radial increment of conifers was more notably affected if two or more climatic factors affecting growth in the same direction coincided than by individual climatic factors. For example, the significant reduction in the increment due to the previous dry summer and very cold winter of 1939/1940 is clearly observable in all dendrological scales of Estonia and its neighbouring areas (Lõhmus, 1992). Multiple regression analysis revealed a combined effect of the sum of precipitation of the current hydrological year, the average air temperature of winter months, current and previous hydrological year and the absolute minimum temperature on the formation of the increment of conifers both in the influence zone of the cement plant and in the control area (Table II). The combined effect of these factors was more obvious for pine over the whole investigation period (1954–1993) than for the climatically favourable period (1975–1993). The coefficients calculated suggest that for the whole investigation period precipitation amounts played a decisive role, whereas the temperature parameters were of less significance and are interchangeable in models. A significant correlation with the pollution load was observed: at probability of significance (P) near zero the coefficients of precipitation are the highest in the area strongly affected by the cement plant and the smallest in the weakly affected and control areas. During the climatically favourable period when the amount of precipitation was bigger the main factor affecting radial increment was average winter air temperature.

The combined effects of temperature and humidity parameters on the radial increment of spruce (y) was observed over the whole investigation period only in the control area. It can be expressed by the following equation:

$$y = 0.0003 + 0.2121x_2 + 0.1269x_7 + 0.3328x_9$$
$$R^2 = 0.33,\ P = 0.003,$$

which shows dependence on the amount of precipitation during the current hydrological year (x_9) and average air temperatures in winter (x_7) and

Table II. Coefficients of regression equations and determination multipliers (R^2) of radial increment between pine and meteorological parameters and the probability of their significance (P). The combined effect of meteorological parameters on the increment of pine over the whole investigation period and during the climatically favourable period is expressed by formulas for which the probability of significance, P, is almost zero and the determination multiplier $R^2 \geq 0.33$. Out of the parameters of humidity regime the only significant one is the sum of precipitation during the current hydrological year (x_9), among the temperature parameters the average air temperature of the current hydrological year (x_1), winter months (x_6 and x_7) and of the previous hydrological year (x_2) and the absolute minimum temperature of the year (x_8) are significant. In the model with two independent variables the sum of precipitation are combined with different temperature parameters, in the model with independent variables combinations of two temperature parameters (combinations of the average temperature of winter months with the average air temperature of the current and previous hydrological year and with the absolute minimum temperature of the current hydrological year) were used. The prediction capability of the equations is modest: they usually describe 35–40% of the variation of the radial increment.

a) Investigation period (1954–1993)

Influence areas	Intercept	x_1	x_2	x_6	x_7	x_8	x_9	R^2	P
Strongly affected	0.0002	0.1647	–	–	0.1194	–	0.4900	0.36	0.001
	0.0005	–	0.2292	–	0.2269	–	0.4479	0.40	0.0003
	0.0001	–	–	–	0.2005	0.0784	0.4810	0.35	0.001
	0.0002	0.2693	–	–	–	–	0.5071	0.35	0.0003
	−0.0004	–	–	0.2364	–	–	0.4946	0.34	0.0005
	0.0002	–	–	–	0.2697	–	0.4712	0.35	0.0004
	−0.0001	–	–	–	–	0.2483	0.5132	0.34	0.0004
Significantly affected	0.0008	0.3127	–	–	0.1043	–	0.4134	0.38	0.0006
	0.001	–	0.2289	–	0.3471	–	0.3544	0.41	0.0003
	0.0007	–	–	–	0.3448	0.0510	0.3841	0.36	0.001
	0.0008	0.4042	–	–	–	–	0.4283	0.38	0.0002
	0.0007	–	–	–	0.3899	–	0.3777	0.36	0.0003
	0.0004	–	–	–	–	0.3433	0.4394	0.33	0.0006
Moderately and weakly affected	0.0008	–	0.1696	–	0.3534	–	0.3164	0.34	0.002
	0.0008	–	–	–	0.5658	−0.2045	0.3079	0.33	0.003
Control	0.0006	0.1388	–	–	0.269	–	0.3457	0.33	0.003
	0.0008	–	0.2234	–	0.3541	–	0.3071	0.37	0.001

b) Climatically favourable growth period (1975–1993)

Influence areas	Intercept	x_1	x_2	x_6	x_7	x_8	x_9	R^2	P
Strongly affected	–	–	–	–	–	–	–	–	–
Significantly affected	−0.0014	–	0.3811	–	0.4258	–	0.075	0.45	0.03
Moderately and weakly affected	−0.0018	−0.7284	–	–	1.3008	–	−0.2388	0.43	0.03
	−0.0012	–	0.3831	–	0.4656	–	−0.2349	0.51	0.01
	−0.0015	–	–	–	1.0845	−0.5295	−0.2405	0.43	0.03
	−0.0004	–	–	0.6295	–	–	−0.2015	0.42	0.01
	−0.0007	–	–	–	0.6045	–	−0.2226	0.38	0.02
Control	−0.0014	–	0.415	–	0.2865	–	−0.1369	0.34	0.09

during the previous hydrological year (x_2). Analogously to pine, precipitation was the most important factor. For spruce the period climatically favourable for forest growth multiple regression analysis yielded no results.

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