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THE IMPACT OF DIFFERENT FACTORS ON THE INCREMENT OF *VACCINIUM*-TYPE PINE STANDS IN TALLINN

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Abstract. The impact of climatic, edaphic, and anthropogenic factors and stand parameters on the additional volume increment (AVI) of *Vaccinium*-type pine stands in Tallinn was studied. A significant negative impact of low current year winter temperatures on the radial increment and on AVI was detected. Among the soil parameters only the thickness of the forest litter horizon had a significant positive impact on the formation of AVI. Of anthropogenic factors, the recreational pressure, expressed as the relative size of trampled area, reduces the AVI of stands of all age classes. Besides this, in age class III the pH of snow water and in age class IV the sulphur content of needles proved to be factors substantially diminishing AVI. A significant impact of stand parameters on the formation of AVI was apparent only in the case of stands of age class IV. A negative effect of stand age and a favourable effect of a thick understorey were detected. An analysis of the coeffect of all the investigated factors showed recreational pressure to be the most essential factor.

Key words: urban forests, *Vaccinium*-type pine stand, radial increment, additional volume increment, climatic factors, soil properties, anthropogenic factors, stand parameters.

INTRODUCTION

The state of *Pinus sylvestris* stands on permanent sample plots in Tallinn was investigated earlier (Pärn, 1990, 1994) on the basis of the additional volume increment (AVI) of *Vaccinium*-type pine stands of quality classes III and IV. AVI is the volume of wood that a stand produces under the impact of some factors (forestry activities, environmental pollution, etc.) in the course of a certain period of time. A negative value of AVI at the end of the observation period (1960–79) was detected for most of the investigated 27 stands. The growth was better than expected in the case of one stand in age class III, two stands in age class IV, and three stands in age class V. The impact of various natural and anthropogenic factors on the formation of AVI of the investigated stands was not yet under observation in those studies. In the course of further research work the impact of climatic factors, soil properties, anthropogenic factors, and different stand parameters on the formation of AVI expressed as RAI – reduced additional increment – (see Pärn, 1994) was studied. The results of this study are presented below.

MATERIALS AND METHODS

The methodology of the selection of sample plots and the location of sample plots are given in Pärn, 1994.

Climatic factors. As initial climatic data the average monthly temperatures and total monthly precipitation were used. With the help of correlation and multiple regression analyses a set of climatic variables controlling the growth of trees to a great extent was selected.

Soil properties. On all sample plots samples of forest litter and the mineral part of soil at a depth of 40 cm were collected for chemical and physical analyses. The thickness of the forest litter layer was measured on 20 regularly located points of sample plots. In the laboratory the soil samples were analysed for pH (0.1N KCl extraction), N (the Kjelldahl method), P (1N HCl extraction, colorimetry), and K (1N HCl extraction, flame photometry). The moisture content and the density of the mineral part of the soils were measured as well.

Anthropogenic factors. The recreational pressure was determined on each sample plot as the relative size of the trampled area of sample plots. The percentage of trees with mechanical injuries (cuts, burns, etc.) on sample plots was determined. Samples of second year pine needles were collected for estimating the sulphur content. The total sulphur content in pine needles was analysed with a coulombmetric detector KDS-41. Samples of snow were collected on all sample plots and electrical conductivity, pH, and concentrations of SO_4^{2-} and Cl^- ions of snow water were determined.

Stand parameters. The mean height, basal area, density, and age of stands were measured. The number of upperstorey trees and the number of understorey trees and shrubs were counted on sample plots.

The effects of different factors (climatic, edaphic, anthropogenic) on AVI were studied by stepwise multiple regression. As the first step of analysis, the relationships between AVI and different factors were studied using the data of all permanent sample plots. In the second step the data for separate age classes were used. To perform the regression analysis the different variables were marked with X and an order index.

RESULTS AND DISCUSSION

The impact of climate on radial growth and AVI. As the first step of the analysis the values of correlation coefficients expressing the relationships existing between climatic factors (average monthly temperature and total monthly precipitation) and radial increment of the investigated stands were calculated for the period 1948–79. No significant correlation between the radial increment and total monthly precipitation was found during any time interval of any year. Therefore, the growth of the investigated stands is not limited by precipitation. This result agrees with Raid (1968), who reported the water supply in soils to be sufficient for the growth of *Vaccinium*-type pine stands during the whole vegetation period in Estonia. On the grounds of the significant ($p \leq 0.05$) correlation coefficients a set of meteorological variables was designed involving a variety of monthly intervals throughout the year over which the values of climatic factors (average monthly temperatures, average yearly temperatures, total monthly precipitation, etc.) were summed or averaged.

Stepwise multiple regression was used to express the effect of each variable on radial growth. Significant ($p \leq 0.05$) regression relationships were discovered between the radial growth of stands of all age classes and the sum of average monthly temperatures of winter months (from December through March) (marked as X30), the average temperature of the current hydrological year (X32), and average temperature of the coldest month of the current year (X34). Correlation analysis indicated a high positive linear correlation between these and some other meteorological variables and AVI (Table).

Correlation coefficients (*r*) and significance levels (*p*) of the correlation coefficients between AVI and meteorological variables

Meteorological variable	Age classes					
	III		IV		V	
	r	*p*	*r*	*p*	*r*	*p*
X29	0.47	0.0003	0.66	0.0000	0.60	0.0000
X30	0.34	0.0344	0.66	0.0000	0.67	0.0000
X32	0.33	0.0402	0.55	0.0000	0.58	0.0000
X34	0.27	0.2243	0.59	0.0000	0.67	0.0000
X35	0.02	1.0000	0.37	0.0000	0.52	0.0000
X37	0.27	0.2319	0.60	0.0000	0.71	0.0000

X29 = the sum of average monthly temperatures from December through February; X30 = the sum of average monthly temperatures from December through March; X32 = average temperature of the current hydrological year (the period from September 1 of the prior year through August 31 of the current year); X34 = the average temperature of the coldest month of the current year; X35 = a combined variable expressing synergetical effect of the average temperature of the coldest month of the current hydrological year and of the total precipitation of the previous hydrological year; X37 = a combined hydrothermal coefficient (O_3; Битвинскас, 1974) which takes into account the effect of the average temperature and the total precipitation of three preceding years on the growth of trees.

It may be inferred from the Table that the AVI of the investigated stands is significantly related to the same meteorological variables as the radial growth (X30, X32, and X34). It may be assumed that compared to the stands of age class III, the AVI of the stands of age classes IV and V depends more significantly on the climate of both the current and the preceding year. The negative synergetical effect of the cold winter of the current year and the droughty summer of the previous year (X37), which diminished significantly the radial growth of stands, especially that of stands of age class III, did not have such an essential impact upon AVI.

The impact of forest litter properties on AVI. Under natural conditions the nutrient stock is formed in forest soils as a result of the decomposition of dead organic matter. Therefore, the fertility of forest soils depends directly upon the reserve of forest litter. The soils of *Vaccinium*-type sites are typical Sod-podzolic soils on sandy and loamy sandy sediments with weakly developed A horizon and a poor humus reserve. The reserve of forest litter is of great importance in such conditions in supplying the trees with nutrients.

The average thickness of the forest litter horizon, O horizon, in *Vaccinium*-type commercial pine stands in Estonia is 3–6 cm (Raid, 1967; Lõhmus, 1974) with an average pH value of 3.0 (Lõhmus, 1974, 1985). The concentrations 1.12% of total nitrogen, 28.4 mg/100 g of lactate-extractable P_2O_5, and 69.8 mg/100 g of lactate-extractable K_2O have been recorded in the O horizon (Lõhmus, 1985).

The average thickness of the O horizon (X45) on permanent sample plots was 4.9 cm and that on the control sample plots in Lahemaa National Park was 5.9 cm.

On most permanent sample plots in Tallinn the pH of forest litter (X41) (average 5.5) considerably exceeded the above-given value (3.0) and the values of control sample plots (average 3.4). Higher pH values of urban soils were reported earlier by several authors (Мамаева,1964; Бганцова et al., 1987). A probable explanation for this phenomenon is the more intensive deposition of alkaline particles (ash, dust, soot, etc.) in towns.

The concentrations of nitrogen in forest litter (X42) varied in the range 0.8–2.4 mg/100 g (average 1.40 mg/100 g) in permanent sample plots and in the range 0.6–2.8 mg/100 g (average 1.25 mg/100 g) in the control samples. The concentrations of potassium (X44) varied in the range 22–356 mg/100 g (average 88.4 mg/100 g) and 20–98 mg/100 g (average 44.2 mg/100 g), respectively. The concentrations of phosphorus (X43) varied respectively in the range 4–84 mg/100 g (average 32.1 mg/100g) and 4–20 mg/100 g (average 8.2 mg/100 g).

Significant ($p \leq 0.05$) regression relationships were discovered between AVI (expressed as RAI) and the thickness of the O horizon (X45) only in the case of stands of age class V. The following regression equation was obtained by selecting only those coefficients that were statistically significant:

$$RAI = -0.563 + 0.304 \times X45 \qquad (R^2 = 0.39).$$

Although the nutrient stock is of great importance in the case of sandy soils, no impact of nutrient concentrations in forest litter on the formation of AVI was revealed in this case. Only the thickness of the O horizon displayed a consistency.

The impact of the properties of soils mineral part on AVI. Mineral nutrients formed in the decomposition process of forest litter are removed by percolating water to the lower, mineral horizons of the soil profile. There they absorb selectively at the soil–root surface by an exchange of ions between the root and the soil. The fertility of the upper 60 cm soil layer is of great significance for tree growth because in this layer up to 95% of all root endings may be found (Kochenderfer, 1973; Lõhmus, 1985).

The concentrations of nitrogen in samples of mineral soil (X47) collected on permanent sample plots varied in the range 0.1–0.6 mg/100 g (average 0.28 mg/100 g) and in soil samples from control sample plots in the range 0.3–0.6 mg/100 g (average 0.37 mg/100 g). Thus, no significant differences were detected in nitrogen concentrations in samples from permanent and control sample plots.

The concentrations of potassium did not differ significantly in the mineral soil samples from permanent and control sample plots. The concentrations of K (X49) varied in the range 3–8 mg/100 g (average 5.4 mg/100 g) in the samples collected on permanent sample plots and in the range 4–6 mg/100 g (average 5.1 mg/100 g) in the samples from control sample plots.

However, a great variability was found in the phosphorus concentrations (X48) in the investigated mineral soil samples. In permanent sample plots the P concentrations varied in the range 1–270 mg/100 g (average 41.5 mg/100 g) and in samples from control sample plots in the range 6–580 mg/100 g (average 84.0 mg/100 g).

The performed regression analysis showed that the nutrient reserve in the upper layer of the mineral part of the investigated soils had no significant impact on the formation of AVI.

The impact of the anthropogenic factors on AVI. The impact of the following anthropogenic factors was studied: the content of total sulphur in second year pine needles (X52); deviations of the SO_4^{2-}/SH^- ratio from normal (control) (X53); relative size of trampled area of sample plots (X54); percentage of trees with mechanical injuries (cuts, burns, etc.) (X55); pH (X56) and electrical conductivity (X57) of snow water; concentration of SO_4^{2-} ions (X58) and Cl^- ions (X59) in snow water.

The content of total sulphur in second year pine needles from permanent sample plots varied in the range 0.31–1.19 mg/g (average 0.61 mg/g). A slightly lower content of total sulphur in samples from control sample plots was measured. They ranged in an interval from 0.40 to 0.76 mg/g (average 0.53 mg/g).

The balance of SO_4^{2-}/SH^- ratio, which expresses the stability of sulphur metabolism, is considered an essential biochemical indicator of physiological stresses of plants under air pollution (Мандре & Кангур, 1986).

In studies on the ecological state of urban forests the relative size of trampled area has been used as an indicator of recreational pressure (Таран & Спиридонов, 1977). This parameter varied on permanent sample plots in the range 5–87% (average 33%) and on control sample plots in the range 0–6% (average 0.7%). A close negative correlation ($r = -0.49$) between the relative size of trampled area and AVI was detected. No relationship between the size of trampled area and percentage of trees with mechanical injuries was detected.

Among the chemical parameters of snow that indicate the air pollution load the pH of snow water is considered to be the best as it summarizes the impact of various chemical ingredients (Донцева et al., 1992). No essential difference was detected between the values of pH of snow water of permanent (average 6.2) and control sample plots (average 6.3). The distribution pattern of permanent sample plots by the pH of snow water is quite similar to that of sample plots by the pH of forest litter.

The first step of regression analysis showed a significant relationship between AVI and the relative size of trampled area (X54). The following equation for estimating AVI was obtained:

$$RAI = -0.00683 \times X54 \qquad (R^2 = 0.47).$$

In the case of pine stands of age class III a close relationship between AVI and the pH of snow water (X56) was found. The following equation was obtained:

$$RAI = -0.05902 \times X56 \qquad (R^2 = 0.65).$$

In pine stands of age class IV AVI depended significantly on the content of total sulphur in needles (X52) and on the relative size of trampled area (X54):

$$RAI = 1.23751 - 1.17493 \times X52 - 0.018 \times X54 \qquad (R^2 = 0.55).$$

In the case of pine stands of age class V the relative size of trampled area (X54) appeared to be the only significant variable in the regression equation. The following regression equation was obtained:

$$RAI = -0.00444 \times X54 \qquad (R^2 = 0.36).$$

The analyses showed that the most essential anthrophogenic factor affecting the AVI of the investigated pine stands was the relative size of trampled area.

The impact of stand parameters on AVI. The following stand parameters were used for analyses: the mean height (X60), m; the basal area (X61), m^2/ha; number of upperstorey trees per ha (X62); stand age (X63); number of understorey trees and shrubs per ha (understorey density) (X64); stand density (X65).

A regular increase in the stand height and basal area and a decrease in the number of upperstorey trees in older stands were observed.

The variation of understorey density with stand age was irregular. On permanent sample plots the understorey density varied to a great extent ranging from total absence to 19.5 thousand individuals per ha. On control sample plots the understorey was poor in species and sparse, which is characteristic of *Vaccinium*-type pine stands in Estonia. The undergrowth of coniferous species was reported on 8 out of 27 permanent sample plots. The state of the undergrowth was not promising.

The first step of the regression analysis showed the formation of AVI to depend significantly on the number of upperstorey trees (X62) and on understorey density (X64). The following regression equation was obtained:

$$RAI = -0.00041 \times X62 + 0.03191 \times X64 \quad (R^2 = 0.40).$$

The second step of the regression analysis revealed that there existed no stand parameters having a significant impact on the formation of AVI in all age classes.

The AVI of stands of age class III decreased with an increase in the basal area of stands (X61) by the following equation:

$$RAI = -0.01538 \times X61 \quad (R^2 = 0.73).$$

The formation of AVI of stands of age class IV is significantly related to stand age (X63) and to understorey density (X64). The following equation was obtained:

$$RAI = 2.44802 - 0.04087 \times X63 + 0.05423 \times X64 \quad (R^2 = 0.63).$$

In the case of stands of age class V no significant variables were obtained. Apparently the formation of AVI of older (>80 years) pine stands is not directly affected by stand parameters.

The analysis showed a positive impact of understorey density on increment. This is an additional evidence that sufficient water supply in soils during the vegetation period weakens the competition between understorey and upperstorey trees. Besides, a dense understorey promotes the accumulation of humus as a result of the abundant forest litter.

The coeffect of all significant factors on AVI. To carry out this analysis the most significant factors of each group treated above were used supposing that the climatic conditions had a similar impact on the formation of AVI on all the investigated stands. Such variables as the thickness of the O horizon of soils (X45), the relative size of trampled area (X54), the number of upperstorey trees (X62), and the understorey density (X64) were used.

The following regression equations were obtained:

for stands of age class III

$$RAI = -0.00465 \times X54 \quad (R^2 = 0.81);$$

for stands of age class IV

$$RAI = -0.01046 \times X54 + 0.03519 \times X64 \quad (R^2 = 0.70);$$

for stands of age class V

$$\text{RAI} = -0.00444 \times \text{X54} \qquad (R^2 = 0.36);$$

for all stands

$$\text{RAI} = -0.00683 \times \text{X54} \qquad (R^2 = 0.47).$$

The analysis indicated that out of all investigated factors recreational pressure was the most significant factor affecting the formation of AVI.

CONCLUSIONS

The most essential climatic factor having a negative impact on radial increment and AVI of the investigated stands was low winter temperatures. Among the soil parameters only the thickness of the forest litter horizon had a significant positive impact on the formation of AVI. Of anthropogenic factors, the recreational pressure reduces the AVI of stands of all age classes. In age class III the pH of snow water and in age class IV the sulphur content of needles proved to be the factors substantially diminishing AVI. A significant impact of stand parameters on the formation of AVI became apparent only in the case of stands of age class IV, where a negative effect of stand age and a favourable effect of a thicker understorey were detected. The analysis of the coeffect of all significant factors revealed that in urban conditions the recreational pressure was the most essential factor affecting the formation of AVI.

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MITMESUGUSTE TEGURITE MÕJU POHLA KASVUKOHATÜÜBI MÄNNIKUTE JUURDEKASVULE TALLINNAS

Henn PÄRN

On uuritud mitmesuguste tegurite (kliima, mulla, antropogeense toime) ja puistute takseernäitajate mõju Tallinnas kasvavate pohla kasvukohatüübi männikute tagavara täiendavale juurdekasvule. On kindlaks tehtud, et talvine temperatuur mõjutab negatiivselt nii radiaaljuurdekasvu kui ka tagavara täiendavat juurdekasvu. Mulla parameetritest oli ainsana määrav mulla koduhorisondi tüsedus. Antropogeensetest faktoritest oli märgatavaim rekreatiivkoormus, väljendatuna tallatud metsaaluse pinna suurusena. See mõjus negatiivselt kõikide vanuseklasside puistutes. III vanuseklassi puistute puhul avaldus lumevee pH ja IV vanuseklassi puistute puhul okaste väävlisisalduse negatiivne mõju. Puistu tagavara täiendav juurdekasv sõltus puistu takseernäitajatest oluliselt ainult IV vanuseklassi puistute puhul, vähenedes puistu vanuse suurenemisel ja suurenedes tihedama alusmetsa olemasolu korral. Uuritud puistute tagavara täiendavat juurdekasvu mõjutab linnatingimustes kõige tugevamini rekreatiivkoormus.