Proc. Estonian Acad. Sci. Ecol., 1994, 4, 2, 64—78
https://doi.org/10.3176/ecol.1994.2.03

THE STATE OF *VACCINIUM*-TYPE PINE STANDS IN TALLINN ON THE BASIS OF INCREMENT

Henn PÄRN

International Plant and Pollution Research Laboratory, Estonian Academy of Sciences, Kloostrimetsa Rd. 44, EE-0019 Tallinn, Estonia

Presented by J. Martin

Received October 27, 1993; accepted November 19, 1993

Abstract. The state of *Vaccinium*-type pine stands affected by air pollution and recreation pressure was studied in Tallinn using sample plots established in Lahemaa National Park as control. Parameters of radial increment and additional volume increment were used for characterizing the state of the stands. The radial increment of urban pine stands was greater than that of control stands during the whole research period (1961—79). In age class III it became smaller than that of control stands at the end of the observation period. The additional increment of the volume of stands was negative in the case of most stands by the end of the research period. The average loss of increment amounted to 10.4 $m^3 \cdot ha^{-1}$ in age class III, 4.5 $m^3 \cdot ha^{-1}$ in age class IV, and 4.2 $m^3 \cdot ha^{-1}$ in age class V.

Key words: urban forests, *Vaccinium*-type pine stand, radial increment, additional volume increment.

INTRODUCTION

Urban scenery—forests, parks, green areas—is one of the important components of the environment in towns helping improve the living environment of human beings. Being part of the urban ecosystem, they affect the other components of the same system: air, soil, water regime, etc. At the same time, they are under the pressure of the urban environment. Pollutants emitted by factories, motor vehicles, and power stations have a devastating impact on natural communities, especially conifer stands (both in cities and in the green zone around them). On the other hand, urban forests have become recreation areas and therefore they suffer an increasing recreative pressure. In Tallinn, air pollution has been relatively high in the 1980s and 1990s; the amount of pollutants emitted into the air increased continuously in 1970—80 (Калласте, 1980). The highest value of air pollution was detected in 1979 and 1980 when it exceeded the maximum permissible concentration respectively 3.9 and 5.1 times. By 1990, the level of air pollution in Tallinn had decreased but it still exceeded considerably the allowed limits (Kallaste, 1992).

In order to estimate the intensity of recreative pressure, the area of forest per urban inhabitant could be used as a conditional index. This value has decreased continuously after World War II. In 1940, the area of forest per inhabitant in Tallinn was 134 m^2, but in 1984 only 78 m^2 (Pärn, 1990).

EARLIER INVESTIGATIONS

Research into the relationship of forests and the industrially polluted environment started in the 19th century. In 1850 and 1871, Stockhardt published his works on the impact of coal smoke on plants, including trees. In 1883, Schroeder and von Reuss published a paper on plant damage caused by the impact of metallurgic industry; there were also other papers dealing with similar problems (cited in Scurfield, 1960; Гудериан, 1979). Today, many scientists of different specialities work in this field. Research methodology is continuously improved and the number of publications on pollution research is increasing (Guderian, 1977; Smith, 1981; McLaughlin, 1985). Yet, the impact of urban conditions on forest ecosystems has been rather poorly investigated. In Russia, a complex research on the state of Moscow forests in 1961—63 was one of the first steps in this field. The results of the work were published in a separate book (Состояние..., 1966). Spiridonov and Taran investigated how the state of stands in Novosibirsk was affected by the thickening of soil due to trampling (Спиридонов, 1975; Таран & Спиридонов, 1977). The state of two large industrial cities of the Urals, Verkhni Tagil and Kirovgrad, has been studied by Lukyanets (Лукянец, 1979). The same problem has been investigated by Grigoryev and Moisseyeva in Minsk (Григорьев & Моисеева, 1979).

As a result of a prolonged human impact, stands which are intensively used as recreation areas may degrade until they perish completely. Several authors have made up deterioration-stage graduations for various types of forests on the basis of the state of canopy layer, natural regeneration of dominant species, shrub layer, the floristic composition and the covering of the herbaceous layer, the grade of trampling, and other indices. In these researches only recreative pressure has been taken into account as an essential factor. Such graduations have been drawn up for the stands of certain cities, for example Moscow (Казанская & Ланина, 1975; Полякова, 1980; Полякова et al., 1981), St. Petersburg (Савицкая, 1979), and Yekaterinburg (Николин, 1975), but there also exist more general ones (Рысин, 1983). Most of these graduations have five stages, but they all have one major drawback: the state of the tree story itself has been almost neglected when differentiating deterioration stages.

In Finland, Jokinen (1972, 1978, 1979) has studied the state of urban forests in Helsinki, Espoo, and Lahti. He differentiated zones of different pollution stress on the basis of visible tree injuries and sulphur content in pine and spruce needles on the territories of these towns. Wuorenrinne (1978) investigated the state of Espoo forests in order to give the town planners an ecological basis for finding the optimal size of forest sites between buildings which would guarantee ecological balance (Wuorenrinne, 1978).

The Estonian State Hydrometeorological Department has observed the state of air in Tallinn and other larger towns in respect of the content of pollutants (Kallaste, 1992). In addition, the state of the environment in Tallinn has been investigated using lichenindication and mathematical modelling (Мартин, 1978; Мартин & Ээнсаар, 1983). However, the state of the forests in Tallinn and their response to environmental changes has not yet been studied.

MATERIALS AND METHODS

The reaction of stands to unfavourable environmental conditions may be revealed by:

(a) changes in the intensity of physiological processes;
(b) accumulation of toxic substances in tree tissues;

(c) visible injuries of trees;
(d) decrease in increment;
(e) changes in the structure of the ecosystem.

These processes and phenomena are closely interrelated with each other and the surrounding environment. Stands, especially under urban conditions, are exposed to various environmental factors and, therefore, practically all the above-mentioned phenomena can be observed. The choice among them in investigating the state of a stand depends on the purpose of the investigation as well as possibilities for conducting it.

The measured values of the above-mentioned phenomena characterize the state of a stand in the case of a single observation only at the observation moment or at the end of the observation period. In addition, the informational value of these parameters is not the same and is therefore not sufficient for estimating the state of stands.

Many scientists dealing with the present problem (Vinš & Pollanschütz, 1977; Нестеров & Ишин, 1969; Лиепа, 1980a) believe increment to be the best parameter characterizing the state of stands as it reflects the organic life of a tree most adequately. Changes in the width of tree rings carry information about changes in the environment and its impact over long time periods. Increment can be expressed quite exactly on the basis of a single collection of quantitatively empirical data. From biological and economic aspects, the reaction of stands to both the changes in natural conditions and the impact of human activities can be estimated on the basis of the changes in the increment.

The present paper gives an estimation of the state of coniferous stands in Tallinn. The state and changes of other elements of the subject forest ecosystems—natural regeneration of dominant species, shrub layer, and herbaceous layer—have been discussed in a previous work (Pärn, 1991).

Methods. When investigating the impact of a factor or a group of factors on increment, it is often useful to determine the so-called additional volume increment (AVI) alongside with radial increment (Pollanschütz, 1971; Лиепа, 1980a). AVI is the volume of wood that a stand produces due to the impact of some factor (forestry activities, environmental pollution, etc.) in the course of a certain period of time. The larger the increment, the greater the positive influence of the subject factor on stand growth. A negative value of additional increment shows a decline in the stand growth potential.

In order to determine the AVI of stands, a method worked out at Riga University (Лиепа, 1980a) was used. AVI is determined as a difference between the actual volume of the subject stand at the observation moment and the prognosticated volume of the same stand. The prognosticated volume is the volume that the stand would have had if there had been no impact of the subject factor during the observation period. The prognostication is carried out on the basis of the similarity of the subject stands and control stands, which, in their turn, are checked statistically.

The mathematical algorithm of the method is realized with the help of the computer program FLOWER (Лиепа, 1980b). On the basis of measured tree ring widths tree ring indices are found. In dendrochronology tree ring indices are used instead of the absolute values of tree rings (mm) in order to achieve comparability of stands of different ages. These indices are standardized parameters which show the ratio between the measured actual tree ring width and the standard width. The standard width is obtained by smoothing the time series of tree ring widths by a suitable method (slipping average, exponential or some other function). In this study, the method of regression straight line was applied. After that, the correspondence of the control plots to the subject plot was checked.

In order to achieve comparability between increments of stands, reduced additional increment (RAI; $m^3 \cdot m^{-2}$) is used. RAI is obtained by dividing the summary or cumulative additional increment (CAI; m^3) accumulated during the research period by the size of breast height cross-section of the stand. The difference between the RAIs of two successive years is the reduced additional current increment (RAC; $m^3 \cdot m^{-2} \cdot yr^{-1}$), which is a suitable parameter for studying the dynamics of the additional increment.

Collection of empirical data. The state of *Pinus sylvestris* stands in Tallinn was investigated on the basis of *Vaccinium*-type pine forests of quality classes III and IV. These are the most widely spread stands in Tallinn (Pärn, 1990). The observation period lasted from 1960 to 1979. In 1980—82, temporary sample plots of an area of 0.02—0.05 ha were selected in the stands of age classes III, IV, and V, each of which had at least 20—25 trees. The number of sample plots in age class III was 8, in age class IV—9, and in age class V—10. Control sample plots were selected in similar stands of Lahemaa National Park, approximately 70 km east of Tallinn; four sample plots for each age class.

Table 1

General data on the studied sample plots

No.*	Forest district	Age class	Area, ha	Number of trees	Stand's mean height, m	Stand's mean diameter, cm	Stand's density
12	Harku	III	0.05	36	16.3	20.7	0.8
13	Harku	III	0.05	42	15.9	20.5	0.9
17	Harku	III	0.05	32	15.7	21.4	0.7
32	Municipal	III	0.02	30	14.1	16.0	0.9
35	Iru	III	0.03	33	16.1	16.9	0.8
36	Harku	III	0.02	33	13.8	13.1	0.8
37	Municipal	III	0.03	35	15.2	17.3	0.8
40	Municipal	III	0.05	46	15.7	17.8	0.7
5	Municipal	IV	0.05	37	20.1	22.1	0.8
10	Municipal	IV	0.05	29	18.9	23.4	0.7
14	Harku	IV	0.05	39	17.1	21.1	0.8
15	Harku	IV	0.05	53	15.1	18.4	1.0
29	Iru	IV	0.05	29	21.2	24.3	0.8
30	Iru	IV	0.05	38	16.4	19.0	0.6
38	Municipal	IV	0.05	32	17.9	24.1	0.9
42	Municipal	IV	0.05	29	18.4	24.8	0.8
44	Harku	IV	0.05	33	16.5	23.7	0.8
8	Harku	V	0.05	29	19.0	23.0	0.6
19	Harku	V	0.05	30	19.5	23.4	0.7
31	Municipal	V	0.05	32	19.1	23.0	0.7
33	Iru	V	0.05	27	22.6	26.0	0.8
34	Iru	V	0.05	36	21.1	23.5	0.9
41	Municipal	V	0.05	39	20.8	23.9	1.0
45	Harku	V	0.05	32	19.7	24.7	0.9
46	Municipal	V	0.05	31	19.1	24.9	0.8
47	Iru	V	0.05	20	20.5	28.2	0.7
48	Iru	V	0.05	30	20.1	28.0	0.9

* See Fig. 1 for the location of the sample plots.

Table 2

General data on the control sample plots

No.*	Forest district	Age class	Area, ha	Number of trees	Stand's mean height, m	mean diameter, cm	density
21	Palmse	III	0.05	37	19.6	19.8	0.8
49	Palmse	III	0.03	47	18.3	15.7	1.1
53	Sagadi	III	0.03	47	13.7	13.3	0.7
22	Valgejõe	IV	0.05	28	20.1	24.6	0.8
25	Käsmu	IV	0.05	43	20.4	19.8	0.8
28	Sagadi	IV	0.05	56	18.6	17.2	0.8
50	Palmse	IV	0.05	50	19.3	18.1	0.8
23	Sagadi	V	0.05	43	21.4	21.7	0.9
24	Palmse	V	0.05	53	22.1	20.0	0.9
26	Käsmu	V	0.05	35	20.4	23.3	0.8
51	Sagadi	V	0.05	38	22.5	24.3	1.0

* See Fig. 1 for the location of the sample plots.

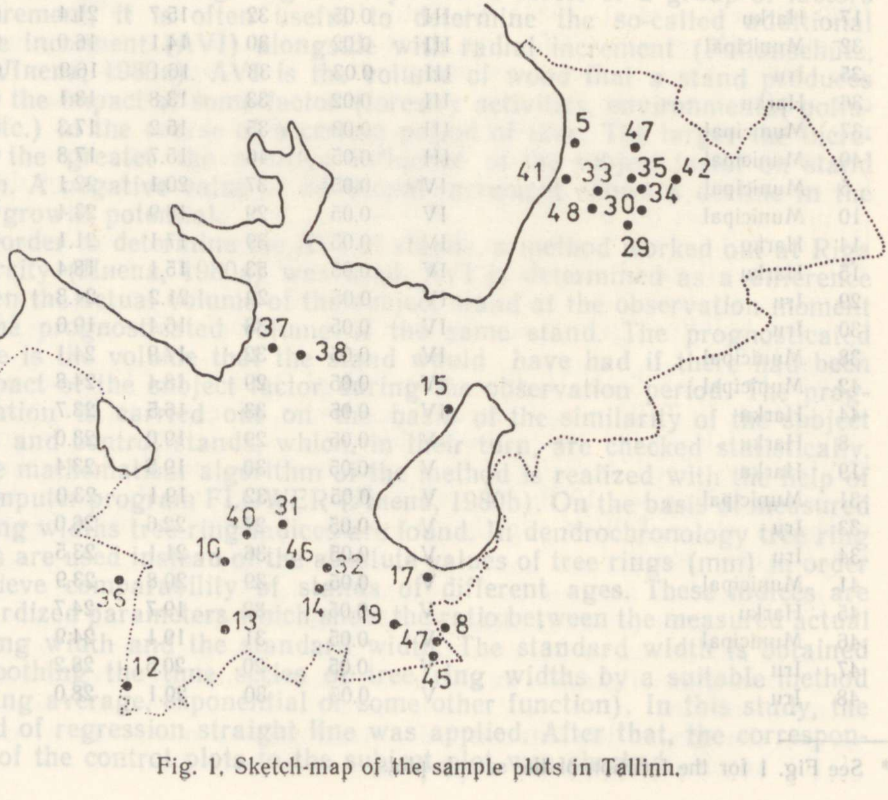

Fig. 1. Sketch-map of the sample plots in Tallinn.

In order to reduce side effects, the sample plots were established in such stands or parts of stands where no forestry works had been carried out. The heights of all trees on the sample plots were measured by height meter ЭВ-1 with a precision of 0.5 m; the breast height diameters in the north—south and east—west directions were measured with a precision of 0.1 cm. The final diameter of the tree was the arithmetical mean of those two values.

In order to measure the radial increment and to estimate the tree age, cores were collected from all trees from their northern and southern sides with an increment borer. The widths of tree rings on cores were measured by a binocular microscope МБС-9 with the precision of measurement of 0.05 mm. The summarized data of sample plots are shown in Tables 1 and 2 and the location of Tallinn sample plots in Fig. 1.

RESULTS AND DISCUSSION

The mean radial increments, both as absolute values and tree ring indices, of sample plots by age classes are shown in Table 3. Calculated mean additional increments of stands by age classes for all the years of the observation period are given in Table 4. The same results, except for indices, arranged graphically as dendrograms are presented in Figs. 2 and 3.

Dynamics of the radial increment of stands. In dendrograms (Fig. 2), a continuous decrease of the radial increment is quite noticeable in all age classes. The quickest fall can be observed in the case of urban stands of age class III. The growth of urban and control stands of age classes IV and V is similar and the increment decreases at the same rate in both groups (regressional straight lines are almost parallel). The increment decreases probably mostly due to the natural ageing of the stands. Both urban and control stands of these age classes react to the changes of natural conditions in the same way.

In age class III, the increment trend of urban stands declines much more rapidly than in the case of older stands. The increment trend of control stands of the same age class declines more slowly, similarly to the decrease of the increment of the control stands of age class IV.

In 1976, the increment of urban stands of age class III becomes smaller than that of the control stands, but the increment of urban stands of age classes IV and V exceeds that of the control stands during the whole period under observation.

During the general decline in increment there are certain periods when the changes are especially rapid and steep.

The dendrograms of all age classes vividly show a decline of the increment starting from 1958 (in the case of age class III, from 1962) until 1972. The reason for a decrease in the increment during that period may be the worsening of climatic conditions. Still, a possibility of an increased anthropogenic impact should not be excluded as Tallinn witnessed a rapid growth of the engineering industry, the pulp and paper and construction materials industries, and transport in the 1960s. As known, the wastes of these industries pollute the air to a great extent. In addition, housing began to develop very intensively at that time, resulting in the existence of large new districts at border zones of the city. In connection with this, the recreative stress on the surrounding forests increased considerably. Which of these factors was of the greatest importance in the retarded increment needs further research.

Table 3

Mean radial increment by age classes

Year	Age class III				Age class IV				Age class V			
	Urban		Control		Urban		Control		Urban		Control	
	Radial increment, mm	Tree ring indices	Radial increment, mm	Tree ring indices	Radial increment, mm	Tree ring indices	Radial increment, mm	Tree ring indices	Radial increment, mm	Tree ring indices	Radial increment, mm	Tree ring indices
1	2	3	4	5	6	7	8	9	10	11	12	13
1979	1.53	110.9	1.84	128.6	1.49	109.7	1.64	122.4	1.48	118.2	1.23	121.8
1978	1.38	97.2	1.55	107.0	1.35	97.3	1.41	103.4	1.38	108.8	1.14	111.0
1977	1.40	95.9	1.55	105.8	1.36	95.9	1.41	101.6	1.29	100.5	1.11	106.3
1976	1.49	99.9	1.66	112.0	1.54	107.1	1.50	106.2	1.50	115.4	1.28	120.6
1975	1.91	124.8	1.69	112.7	1.99	135.5	1.69	117.7	1.93	146.6	1.26	116.9
1974	2.01	128.0	1.63	107.5	1.99	133.8	1.46	100.0	1.82	136.5	1.15	105.0
1973	1.76	109.3	1.51	98.5	1.65	108.7	1.38	93.0	1.42	105.4	1.08	97.1
1972	1.53	92.6	1.53	98.7	1.36	87.9	1.41	93.5	1.12	82.2	1.04	92.1
1971	1.28	76.2	1.34	85.5	1.12	71.4	1.35	88.1	0.94	68.2	0.98	85.5
1970	1.64	95.3	1.57	99.1	1.41	88.3	1.50	96.4	1.12	80.2	1.04	89.4
1969	1.46	82.9	1.28	80.0	1.25	77.3	1.25	79.1	0.88	62.4	0.87	73.7
1968	1.80	99.9	1.74	107.5	1.63	99.0	1.68	104.7	1.17	82.0	1.12	93.6
1967	1.73	94.0	1.78	108.9	1.74	103.7	1.89	116.1	1.45	100.5	1.36	112.0
1966	1.61	86.1	1.47	89.0	1.63	96.1	1.63	98.7	1.31	89.7	1.14	92.6
1965	1.90	99.5	1.62	97.1	1.84	106.5	1.76	105.0	1.49	101.0	1.34	107.4
1964	1.84	94.3	1.42	84.2	1.76	100.8	1.54	90.6	1.39	93.2	1.13	89.3
1963	1.73	86.9	1.45	85.1	1.57	88.3	1.65	95.7	1.29	85.6	1.19	92.8
1962	2.01	99.0	1.54	89.5	1.79	99.1	1.76	100.7	1.47	96.4	1.19	91.6
1961	2.35	114.1	1.67	96.1	1.95	106.7	1.70	96.0	1.58	102.7	1.20	91.2
1960	2.01	95.6	1.43	81.5	1.51	81.4	1.42	79.1	1.34	86.2	1.07	80.3
1959	2.42	113.1	1.66	93.7	1.85	98.5	1.79	98.3	1.56	99.3	1.29	95.6
1958	1.95	89.4	1.50	83.9	1.63	85.5	1.72	93.3	1.42	89.4	1.27	92.9

1	2	3	4	5	6	7	8	9	10	11	12	13
1957	2.62	118.0	1.30	105.3	2.06	106.3	2.19	117.2	1.88	117.3	1.53	110.5
1956	2.07	91.9	1.47	80.7	1.58	80.8	1.65	87.2	1.40	86.5	1.04	74.2
1955	2.27	99.1	1.73	94.1	1.88	94.6	1.81	94.5	1.58	96.7	1.28	90.3
1954	2.43	104.3	2.06	111.0	2.23	111.1	2.07	106.7	1.85	111.9	1.64	114.3
1953	2.53	106.8	2.09	111.6	2.26	110.9	2.14	109.0	1.97	118.1	1.57	108.1
1952	2.32	96.2	1.96	103.7	1.93	93.4	1.96	98.6	1.64	97.5	1.55	105.5
1951	2.02	82.8	1.92	100.7	1.87	89.6	2.09	103.9	1.56	91.9	1.53	103.0
1950	2.42	97.6	1.87	97.2	2.14	101.1	1.82	89.4	1.74	101.4	1.40	93.1

Table 4

Mean additional increments of urban stands by age classes in 1960—79

Year	Age class III			Age class IV			Age class V		
	CAI, m³ · ha⁻¹	RAI, m³ · m⁻²	RAC, m³ · m⁻² · yr⁻¹	CAI, m³ · ha⁻¹	RAI, m³ · m⁻²	RAC, m³ · m⁻² · yr⁻¹	CAI, m³ · ha⁻¹	RAI, m³ · m⁻²	RAC, m³ · m⁻² · yr⁻¹
1979	—10.402	—0.378	—0.082	—4.502	—0.164	—0.033	—4.208	—0.135	—0.006
1978	—7.975	—0.296	—0.063	—3.555	—0.131	—0.017	—3.990	—0.131	—0.007
1977	—6.160	—0.233	—0.054	—3.077	—0.116	—0.020	—3.785	—0.125	—0.011
1976	—4.639	—0.179	—0.063	—2.523	—0.097	—0.009	—3.463	—0.117	—0.013
1975	—2.965	—0.116	—0.015	—2.393	—0.089	0.019	—3.055	—0.106	0.044
1974	—2.527	—0.101	0.010	—2.751	—0.113	0.043	—4.248	—0.151	0.034
1973	—2.658	—0.111	—0.010	—3.843	—0.155	0.016	—5.155	—0.188	0.006
1972	—2.404	—0.102	—0.037	—4.256	—0.174	—0.021	—5.279	—0.198	—0.020
1971	—1.522	—0.065	—0.048	—3.730	—0.155	—0.040	—4.705	—0.178	—0.030
1970	—0.497	—0.034	—0.032	—2.763	—0.116	—0.024	—3.884	—0.150	—0.018
1969	0.173	0.015	—0.015	—2.178	—0.094	—0.018	—3.388	—0.137	—0.028
1968	0.455	0.029	—0.035	—1.780	—0.077	—0.021	—2.529	—0.106	—0.031
1967	1.207	0.065	—0.046	—1.269	—0.057	—0.040	—1.774	—0.075	—0.026
1966	2.129	0.111	—0.024	—0.362	—0.017	—0.010	—1.132	—0.050	—0.006
1965	2.557	0.135	0.007	—0.148	—0.007	0.000	—1.028	—0.044	—0.028
1964	2.401	0.127	0.043	—0.144	—0.006	0.014	—0.385	—0.016	—0.002
1963	1.595	0.084	0.007	—0.426	—0.020	—0.027	—0.346	—0.014	—0.024
1962	1.445	0.077	0.024	0.127	0.007	—0.009	0.229	0.009	—0.007
1961	0.952	0.053	0.026	0.322	0.016	0.015	0.375	0.017	0.015
1960	0.462	0.027	—	0.009	0.001	—	0.059	0.002	—

CAI—cumulative additional increment; RAI—reduced additional increment; RAC—reduced additional current increment.

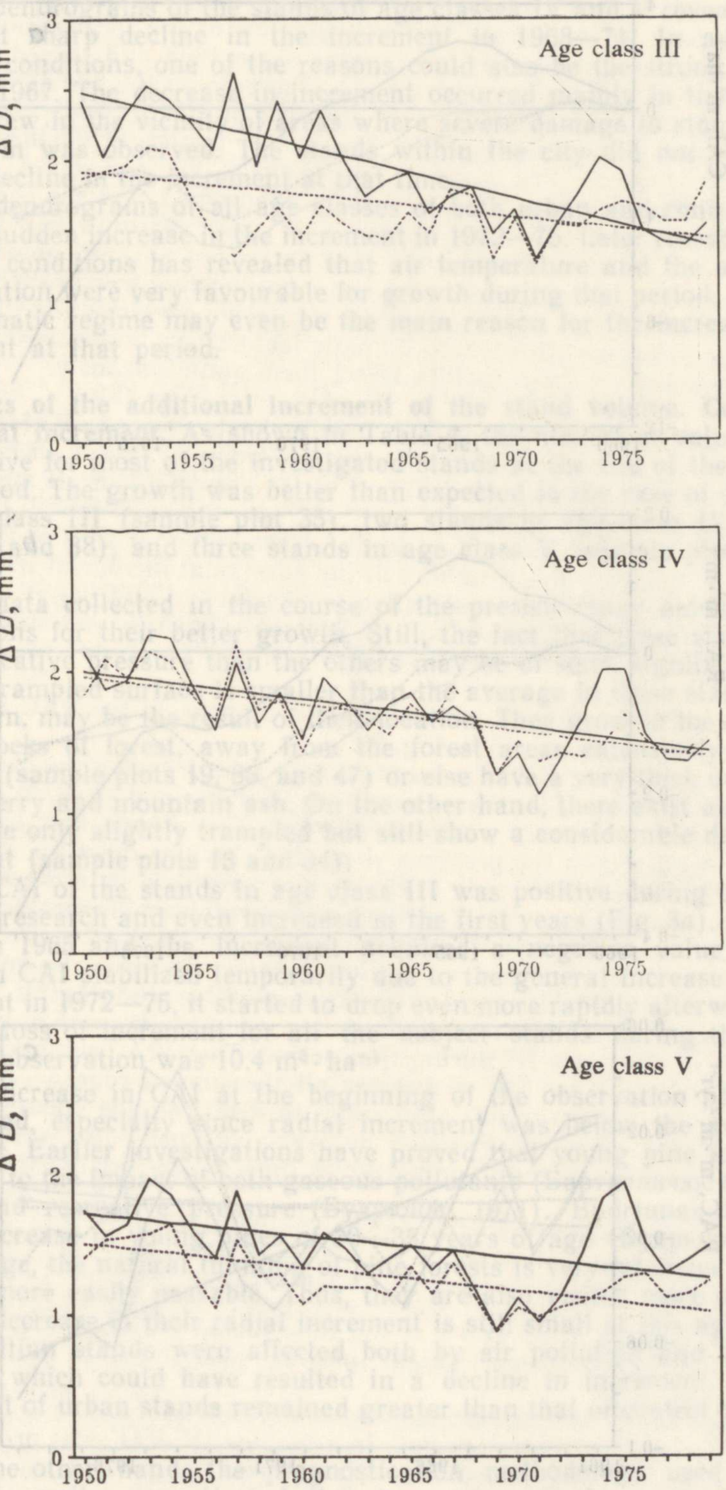

Fig. 2. Radial increment of the investigated stands.
1 radial increment on the urban sample plots; *2* radial increment on the control sample plots; *3* the trend of the radial increment of the stands on the urban sample plots; *4* the trend of the radial increment of the stands on the control sample plots.

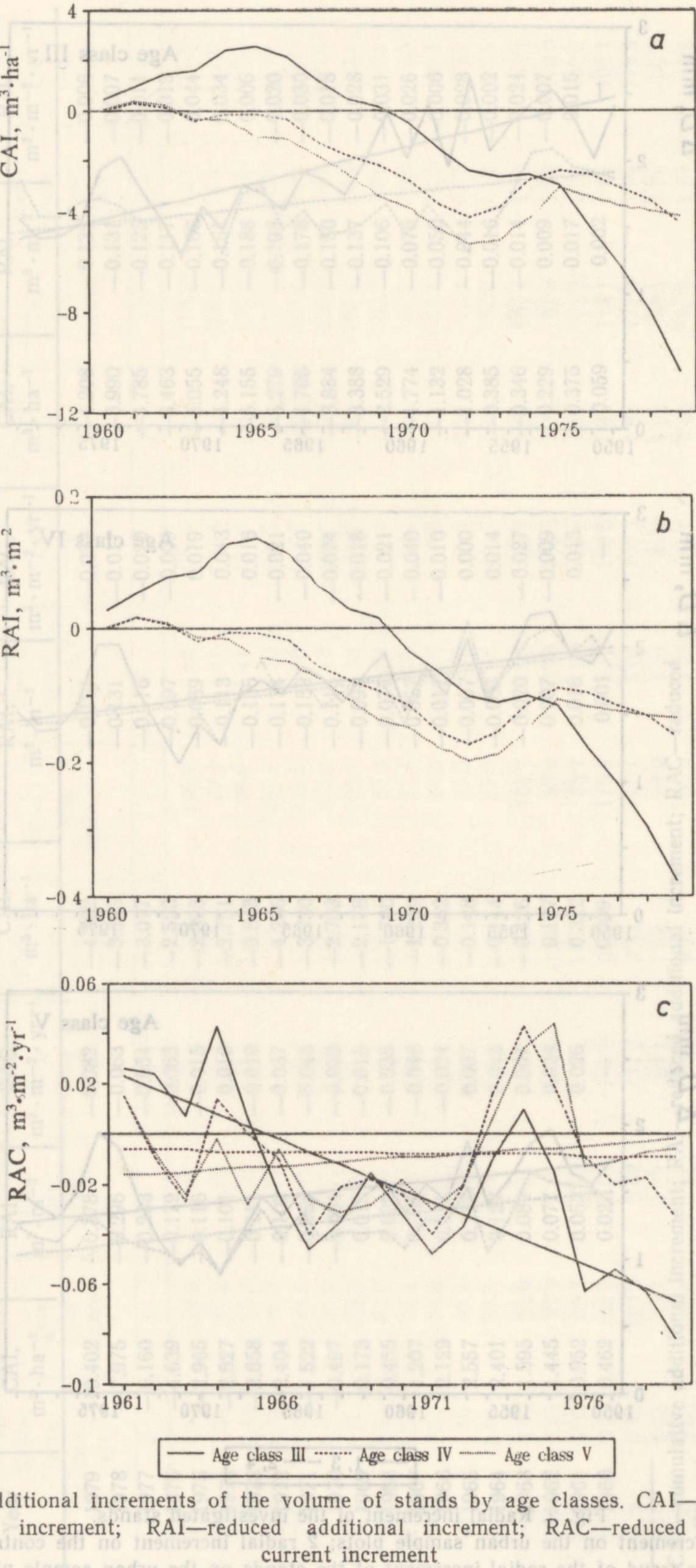

Fig. 3. Additional increments of the volume of stands by age classes. CAI—cumulative additional increment; RAI—reduced additional increment; RAC—reduced additional current increment

The dendrograms of the stands of age classes IV and V reveal a short-term but sharp decline in the increment in 1968—71. In addition to climatic conditions, one of the reasons could also be the strong storm in August 1967. The decrease in increment occurred mainly in those stands which grew in the vicinity of areas where severe damage to stands due to this storm was observed. The stands within the city did not show such abrupt decline in the increment at that time.

The dendrograms of all age classes of both urban and control stands show a sudden increase in the increment in 1972—75. Later research on the climatic conditions has revealed that air temperature and the amount of precipitation were very favourable for growth during that period. A favourable climatic regime may even be the main reason for the increase in the increment at that period.

Dynamics of the additional increment of the stand volume. Cumulative additional increment. As shown in Table 4, the numerical value of CAI is negative for most of the investigated stands at the end of the observation period. The growth was better than expected in the case of one stand in age class III (sample plot 35), two stands in age class IV (sample plots 14 and 38), and three stands in age class V (sample plots 19, 41, and 47).

The data collected in the course of the present study did not reveal the reasons for their better growth. Still, the fact that these stands have less recreative pressure than the others may be of some significance. The area of trampled surface is smaller than the average in these stands. This, in its turn, may be the result of their location. They grow in the middle of large blocks of forest, away from the forest areas extensively used for walking (sample plots 19, 35, and 47) or else have a very thick underwood of raspberry and mountain ash. On the other hand, there exist also stands which are only slightly trampled but still show a considerable decrease in increment (sample plots 13 and 34).

The CAI of the stands in age class III was positive during the initial stage of research and even increased in the first years (Fig. 3*a*). A decline began in 1965 and the increment acquired a negative value in 1970. Although CAI stabilized temporarily due to the general increase of radial increment in 1972—75, it started to drop even more rapidly afterwards. The average loss of increment for all the subject stands during the twenty years of observation was 10.4 $m^3 \cdot ha^{-1}$.

The increase in CAI at the beginning of the observation period was unexpected, especially since radial increment was below the average at that time. Earlier investigations have proved that young pine forests are sensitive to the impact of both gaseous pollutants (Барткявичюс & Тябера, 1982) and recreative pressure (Будрюнас, 1971). Budrjunas detected a sharp decrease in young pines of 30—35 years of age (Будрюнас, 1971). At this age, the natural thinning of pine forests is very intensive and they become more easily passable. Thus, they are also visited more often. The natural decrease in their radial increment is still small at this age. At that time, Tallinn stands were affected both by air pollution and recreative pressure which could have resulted in a decline in increment. Still, the increment of urban stands remained greater than that of control ones until 1966.

On the other hand, the prognostication methodology used gave us relatively small prognosticated diameters, consequently small volumes of stems for the first years of the subject period. Therefore, the actual volumes of the subject stands exceeded their prognosticated volumes until 1969. CAI became negative for the first time in 1970, although a decrease in the increment began much earlier.

The stands of age classes IV and V grew better than expected in the course of three to four years at the beginning of the observation period (Fig. 3*a*). CAI acquired a negative value since 1963 and stayed negative until the end of the research period. The increase in the radial increment in 1972—75 was reflected also in the increase of CAI in that period. Still, CAI continued to decrease later on. The loss of increment during the subject period was on the average 4.5 $m^3 \cdot ha^{-1}$ for age class IV and 4.2 $m^3 \cdot ha^{-1}$ for age class V. It should be mentioned that the increase in CAI in 1972—75 for age class III was very small. Kuzmin and Kuzmina (Кузьмин & Кузьмина, 1986) show that increased anthropogenic impact may decrease the role of climate as a factor influencing tree growth. Young stands are sensitive to technogenic and recreative pressure and, therefore, react to the influence of improved climatic factors less intensely than older stands, provided all these factors affect them simultaneously.

Reduced additional increment. The changes in the average RAI of stands of all age classes during the research period are shown in Fig. 3*b*. A general similarity between the courses of RAI and CAI in all age classes can be observed (Fig. 3*a*).

RAI is found by dividing CAI by the cross-sectional area of the stand. Thus, it characterizes the dynamics of the additional increment irrespective of the stand density. So the objective parameters of additional increment are obtained for comparing stands of different densities and studying the impact of various factors on the growth of stands.

Reduced additional current increment. The changes in the RAC of stands of all age classes are shown in Fig. 3*c*.

In all age classes, RAC varied to a great extent during the observation period. In age class III, the values of RAC remained positive from the beginning of the research period until 1965. This means that every year RAC was bigger than the previous year. RAC became negative after 1965 due to the continuous dropping of RAI and remained so until the end of the observation period. As a result of the above-mentioned favourable climatic conditions, there occurred a slow-down in the decrease of additional increment in 1972—75. This was reflected instantly by a rise in RAC in this period, and in 1974 its value was even positive. Judging by RAC, the stands in age classes IV and V showed even a bigger increase in increment than those of age class III during that period. Their RAC was, contrary to the stands of age class III, positive in all the subject years.

In order to find the trends of changes in RAC (by age classes) during the observation period, regression analysis was used. As a result, the following equations of regression straight lines characterizing trends were obtained:

age class III $y = 0.328 - 0.005\,t$

age class IV $y = 0.0043 - 0.00017\,t$

age class V $y = -0.064 + 0.00078\,t$,

where y stands for RAC and t is the time factor (calendar year).

The obtained regression straight lines are also shown in the diagrams of RAC (Fig. 3*c*).

The regression analysis demonstrates a rapid decrease in RAC in age class III during the research period. In age class IV, RAC was prevailingly negative. The very slight decline of the regression straight line shows a very slow decrease in RAC during the period under observation. The average RAC of age class V was also negative most of the time. Contrary to younger stands, the stands of this age class reveal a general improvement of increment at the end of the investigation period. Thus, their actual increment approached the prognosticated increment.

CONCLUSIONS

The radial increment of urban stands was bigger than that of control stands during the whole research period. In age classes IV and V, the radial increment of both urban and control stands decreased at the same rate. The radial increment of stands of age class III decreased more rapidly than that of control stands and became smaller than at the end of the observation period. Against the background of the general decrease in increment, a depression since 1958 until 1972 and a sharp increase in 1972—75 may be distinguished.

AVI was negative in the case of most stands at the end of the research period. Thus, their increment was smaller than prognosticated. By the end of the observation period, the average loss of increment amounted to 10.4 $m^3 \cdot ha^{-1}$ in age class III, 4.5 $m^3 \cdot ha^{-1}$ in age class IV, and 4.2 $m^3 \cdot ha^{-1}$ in age class V.

The mean additional increment of the stands of age class III showed a tendency of declining during the whole research period. Additional increment decreased also in age class IV, but very slowly. The mean additional increment of age class V is characterized by a general tendency of increase during the whole investigation period due to the improvement of increment at the end of the period.

The extent of the impact of various natural and anthropogenic factors on the formation of radial increment and AVI of stands needs further investigation.

REFERENCES

Guderian, R. 1977. Air Pollution. Phytotoxicity of Acid Gases and Its Significance in Air-pollution Control. Berlin, Heidelberg, New York.

Jokinen, J. 1972. Kaupunkiyhdyskunta puustovaurioiden aiheuttajana. — Työterveyslaitoksen tutkimuksia (Helsinki), 74.

Jokinen, J. 1978. Ilman epäpuhtauksien vaikutustutkimus Lahdessa vuonna 1978. Ilmatieteen laitos, Helsinki.

Jokinen, J. 1979. Ilman epäpuhtauksien vaikutustutkimusraportti. Ilman epäpuhtauksien vaikutukset Espoossa, metsävaikutusselvitys, v. 1978. — Espoon ympäristösuojelulautakunta julkaisu (Helsinki), 1/79.

Kallaste, T. 1992. Õhu saastatuse taseme kompleksne hindamine Põhja-Eesti suuremates linnades. In: Õhu saastatus Eestis 1985—1990. (Environmental Report 3.) Helsinki, 28—47.

McLaughlin, S. B. 1985. Effects of air pollution on forests. A critical review. — J. Air Poll. Contr. Ass., 35, 5, 513—534.

Pollanschütz, J. 1971. Die ertragskundlichen Meßmethoden zur Erkennung und Beurteilung von forstlichen Rauchschäden. — Mitt. Forstl. Bundesversuchsanst., (Wien), 92, 155—206.

Pärn, H. 1990. Tallinna metsad ja nende seisund. Tallinna Botaanikaaed. Preprint TBA—10, Tallinn.

Pärn, H. 1991. Dynamics of the structure of Tallinn urban forests. — Proc. Estonian Acad. Sci. Ecol., 1, 4, 165—172.

Scurfield, G. 1960. Air pollution and tree growth. — Forestry Abstracts, 21, 3, 339—347; 4, 517—518.

Smith, W. H. 1981. Air Pollution and Forests. Springer, New York.

Vinš, B., Pollanschütz, J. 1977. Erkennung und Beurteilung immissionsgeschädigter Wälder anhand von Jahrringanalysen. — Allg. Forstztg., 6.

Wuorenrinne, H. 1978. Metsä urbaanin paineen puristuksessa. Yleiskaavaosasto, Espoo.

Барткявичюс Э. Л., Тябера А. П. 1982. Изменение производительности сосновых древостоев в условиях локального загрязнения окружающей среды. — Лесн. ж., 2, 29—32.

Будрюнас А. Р. 1971. Антропогенная дигрессия лесов в густонаселенных районах. In: Вопросы охраны ботанических объектов. Наука, Ленинград, 48—53.

Григорьев В. П., Моисеева Н. А. 1979. Влияние комплекса городских условий на рост сосновых насаждений. — Лесоведение, 1, 40—44.

Гудериан Р. 1979. Загрязнение воздушной среды. Мир, Москва.

Казанская Н. С., Ланина В. В. 1975. Методика изучения влияния рекреационных нагрузок на древесные насаждения лесопаркового пояса г. Москвы в связи с вопросами организации территорий массового отдыха и туризма. Москва.

Калласте Т. 1980. Экстраполяционное прогнозирование загрязненности воздуха во времени (на примере Таллинна). — Eesti NSV TA Toim. Ühiskonnateadused, 29, 4, 309—323.

Кузьмин А. В., Кузьмина Л. И. 1986. Динамическая оценка техногенного и рекреационного воздействия на древостои Крайнего Севера. — Лесоведение, 5, 45—50.

Лиепа И. Я. 1980a. Динамика древесных запасов. Прогнозирование и экология. Зинатне, Рига.

Лиепа И. Я. 1980b. Единая программа оценки реакции древостоя на влияние факторов воздействия. In: Моделирование и прогнозирование в экологии. Межвузовский сборник научных трудов. Латв. ГУ, Рига, 44—67.

Лукянец А. И. 1979. Состояние загазованных лесов в районе городов Верхнего Тагиля и Кировограда. In: Популяционные биогеоценологические исследования в горных темнохвойных лесах Среднего Урала. Изд-во УФ АН СССР, Свердловск, 147—165.

Мартин Л. Н. 1978. Лихеноиндикационное картирование г. Таллинна. In: Лихеноиндикация состояния окружающей среды. АН ЭССР, Таллинн, 134—139.

Мартин Л. Н., Ээнсаар А. 1983. Лихеноиндикация и математическое моделирование распространения двуокиси серы на территории Таллинна. — Изв. АН ЭССР. Биол., 32, 3, 206—215.

Нестеров В. Г., Ишин Ю. Д. 1969. Влияние антропогенных факторов на прирост сосняков лесопаркового пояса г. Москвы. — Докл. Тимирязевской с.-х. акад. Вып. 154. Москва, 301—306.

Николин А. А. 1975. Изменение лесопарковых ландшафтов под влиянием человека. In: Леса Урала и хозяйство в них. Вып. 8. Свердловск, 227—234.

Полякова Г. А. 1980. Деградация сосняков Подмосковья под влиянием рекреации. — Лесоведение, 5, 62—69.

Полякова Г. А., Малышева Т. В., Флеров А. А. 1981. Антропогенное влияние на сосновые леса Подмосковья. Наука, Москва.

Рысин Л. П. 1983. Рекреационные леса и проблема оптимизации рекреационного лесопользования. In: Рекреационное лесопользование в СССР. Наука, Москва, 5—20.

Савицкая С. Н. 1979. Влияние высоких рекреационных нагрузок на лесную растительность пригородной зоны Ленинграда. Автореф. дис. канд. с.-х. наук, Ленинград.

Состояние насаждений лесопаркового пояса Москвы и меры по их улучшению. 1966. Лесн. пром., Москва.

Спиридонов В. Н. 1975. Влияние уплотнения почвы на прирост деревьев в лесопарках Новосибирского научного центра. — Изв. СО АН СССР. Сер. биол. наук, 2, 10, 3—8.

Таран И. В., Спиридонов В. Н. 1977. Устойчивость рекреационных лесов. Наука, Новосибирск.