VYTAUTAS MAGNUS UNIVERSITY

Dr. Vida Stravinskienė

DENDROCHRONOLOGICAL INDICATION OF CLIMATIC FACTORS AND ANTHROPOGENIC ENVIRONMENTAL TRENDS IN LITHUANIA

Summary of
Dr. Habilitation Dissertation

Biomedical sciences (000B)
Ecology and Environmental sciences (03B)

Kaunas, 2000

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Dr. Habilitation right was granted to Vytautas Magnus University together with Lithuanian Forest Research Institute on 20th of July 1998, by the order of the Lithuanian Government No. 900.

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Public meeting of the Habilitation Committee will take place at the Small Assembly hall of Vytautas Magnus University at 10 on 31st August 2000.
Address: K.Daukanto st. 28, 3000 Kaunas, Lithuania.
Tel.: +370 7 32 36 02, Fax: +370 7 203858

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The dr. habilitation dissertation is available at the libraries of Vytautas Magnus University, Lithuanian Forest Research Institute and Lithuanian Martynas Mažvydas National Library.

GENERAL CHARACTERISTICS OF THE WORK

Actuality. Studies on tree condition changes due to the impact of environmental factors provide information on the stability of biological systems, peculiarities of their functioning and allow to forecast changes of the natural environment. Stability of ecosystems and changes in environmental quality are given much attention in Europe. This is testified by the most urgent research trends on European environment and health, adopted at the 3rd Environment and Health Conference (London, 1999). Assessment of the condition of trees and significance of trees as bioindicators studying the impact of natural and anthropogenic factors on ecosystems are given priority among the topics of the Fifth Program "Environment and Health" of the European Commission.

Under increasing environmental pollution and its impact on nature, biological tests for the assessment of environmental state are applied even wider. Trees are considered to be sensitive indicators of climatic changes and anthropogenic activity, resembling environmental variations in their growth and condition (Kairiūkštis et al., 1991).

Radial increment of trees is a dynamic dendroindicational index, quickly reacting to the changes of growth conditions. Other important biological test-tree crown defoliation degree, indicating the loss of foliage as compared to a standard tree, revealing the state and ecological sustainability of natural environment (Manual on methods…, 1994).

An exceptional role as indicators play coniferous trees – pine and spruce. Most studies of researches in our country and abroad have proved that conifers are much more sensitive to environmental pollution than broadleaves, thus, they are better indicators. On the other hand, worsening of the condition of less sensitive broadleaves indicates the impact of adverse to biota factors of urban environment.

Having assessed the condition of trees growing in forest ecosystems, one can judge on the state of natural environment and its suitability for different forms of life.

The work was done participating in international program "ICP-Forests" (European Forest Monitoring Program), Lithuanian State research program "Historical aspect of ecological sustainability in Lithuania", common project with the Institute of Tree Biology at Hamburg University "Crown transparency and radial growth of trees", Kaunas "Healthy town" project, as well as in certain research projects, devoted to the studies of forest drainage efficiency and biological productivity, indication of forest state changes and elaboration of scientific background for regional monitoring, the impact of environmental pollution on the state of coniferous forests and dendrochronological indication of environmental state.

Aim and objectives. The work was aimed to assess the impact of climatic factors and anthropogenic changes of environment on the state and growth of trees in Lithuania according to annual radial increment of trees and their crown defoliation indices, and to work out standards for dendrochronological indication.

Main tasks of research:

1) study long-term annual radial increment dynamics of Lithuanian conifers – Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) - based on the analysis of abundant experimental material;
2) study long-term annual radial increment dynamics of Lithuanian broadleaves – Black alder (*Alnus glutinosa* (L.) Gaertn.) and Downy birch (*Betula pubescens* Ehrh.);
3) to create standard dendroscales of the main habitats of Lithuanian conifers and broadleaves – a standard to assess and forecast the changes of natural environment;
4) to create annual radial increment forecasts for conifers and broadleaves of the main Lithuanian habitats;
5) assess the condition and growth of conifers in urban environment;
6) elaborate zonation principles for pine annual radial increment losses and work out maps of increment losses for pines in Kaunas city;
7) assess the condition and growth of broadleaves in urban environment;
8) assess radial increment changes of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten) growing in the environment of industrial pollution;
9) assess the impact of pine and spruce crown defoliation on their radial increment;
10) assess the effect of forest drainage and fertilization on radial increment of trees;
11) foresee favourable climatic periods for efficient forest drainage and fertilization.

Novelty and originality. By this work for the first time in Lithuania have been studied and elaborated:

- long-term annual radial increment dynamics of Lithuanian conifers: Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), as well as broadleaves: Black alder (*Alnus glutinosa* (L.) Gaerth.) and Downy birch (*Betula pubescens* Ehrh.), based on the analysis of abundant experimental material;

- masterchronologies of annual radial increment of Lithuanian conifers and broadleaves of the main habitats, indicating fluctuations of annual radial increment due to climatic factors over the last 100-170 years;
- annual radial increment approximation and forecast for conifers and broadleaves of the main forest habitats of Lithuania;
- condition and growth of pines in urban environment;
- maps of annual radial increment losses for pines in urban environment, illustrating long-term changes of environmental state;
- state and growth of lime trees (*Tilia sp.*) in city;
- changes in radial increment size and structure of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten), growing in the environment of industrial pollution;
- pine and spruce crown defoliation impact on radial increment;
- forest drainage effect on radial increment of pine, spruce and black alder;
- favourable climatic periods for higher forest drainage efficiency.

Approval. All 21 scientific article generalized by habilitation dissertation were published in prestigious publications, corresponding to the requirements of "Regulations on conferring scientific and pedagogical titles" (adopted on 10 July, 1997).

Results of the habilitation work were preliminarily presented and discussed during international scientific conferences in Switzerland, Denmark, Germany, Finland, Italy, Poland, Lithuania and various scientific institutions of the former USSR.

Theoretical significance. Obtained data on annual radial increment of trees and their crown morphological tests and peculiarities for Lithuanian forests, urbanized territories and zones of industrial pollution impact comprise a new input into the science of Lithuanian ecology, environmental studies, dendroindication and dendrochronology.

Practical significance. Masterchronologies of annual radial increment for the main Lithuanian tree species: Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), Black alder (*Alnus glutinosa* (L.) Gaertn.) and Downy birch (*Betula pubescens* Ehrh.) on the main habitats were worked out, resembling changes in climatic fluctuations over the last 100-170 years and are suitable to use for the assessment and forecast of environmental changes.

Forecasts of annual radial increment of Lithuanian conifers and broadleaves indicate changes in future forest yield and environmental quality.

They are applicable in planning forest drainage, fertilization and other silvicultural measures.

Zonation of Kaunas town according to standardized pine annual radial increment losses over recent 30 years allows to evaluate retrospectively and forecast the change of urban environment and its suitability to biota. Analogous zonation principles may be applied for dendrochronological indication also of other coniferous plantations in the town.

Peculiarities of crown defoliation and radial increment variation of conifers will lead to an easier and more reliable indication of environmental state by retrospective annual tree ring analysis methods.

Peculiarities of tree annual radial increment changes due to forest drainage and fertilization conducted in different climatic periods may serve to increase efficiency of these silvicultural measure.

Material of the work may be used for the studies of environment, ecology, biological methods of environment investigation, theoretical essentials of dendrochronology in higher educational establishments.

Practical application of results. Data generalized in the work is used at the Department of Environmental Sciences of Vytautas Magnus University to lecture on “Biological methods of environment investigation”, “Basic ecology”, “Introduction into environmental science”, at the Faculty of Forestry of Lithuanian Agricultural University to lecture on “Theoretical essentials of dendrochronology” for post-graduate students. Masterchronologies for pine, spruce and black alder were applied to evaluate forest drainage results and to work out regulations on forest management.

Extent and structure. The work consists of 7 chapters, 30 tables, 29 figures, conclusions, summary in English, references and a list of scientific publications generalized by habilitation work.

Habilitation work has been carried out in 1980-1999 at the Lithuanian Forest Research Institute and Vytautas Magnus University. Part of the material was analyzed at the Institute of Tree Biology at Hamburg University during probation devoted to check tree ring analysis methods and assimilate new methodics (leader Prof. Dr. Dieter Eckstein).

Analyzing data and evaluating their statistical validity, great support was provided by a colleague and friend, doctor of mathematical sciences Jonė Venclovienė from Vytautas Magnus University Department of Environmental Sciences. Habilitation dissertation was prepared by willing advice’s and technical support from colleagues of the Department of Forest Ecology and Forestry at the Lithuanian Forest Research Institute and Vytautas Magnus University Department of Environmental Sciences. The author expresses her heartfelt thanks to all of them.

1.Dendroindication of ecoclimatic and anthropogenic environmental changes (literature overwiev)

Dendrochronological and dendroindicational studies have ascertained, that the width and structure of tree annual rings much depend on environmental phenomena – climatic and anthropogenical (Eckstein, 1989; Fritts, 1987; Bitvinskas, 1974, 1984 etc.). Thus, tree ring width and structure integrally reflect the impact of ecological factors (Ozolinčius, 1994) and serve as perfect indications of natural environment condition (Schweingruber, 1989, 1996). In recent years anthropogenic pollution has to be accounted of more frequently, for its effect on the state and growth of trees becomes even dominating in some cases (Vins, Mrkva, 1973; Philips et. al., 1977; Cook, 1987; Eckstein, 1985; Innes, Cook, 1989; Schulce, 1989; Juknys, 1990, 1994; Lovelius, 1997; Kairiūkštis, 1999 etc.).

1.1.Climatic factors and dendrochronological indication of their impact

In recent decades anthropogenic activity has impact on global climatic changes, especially air temperature (Sneyers, 1998). Growth of the impact is related to almost all models of climatic variations, which help to find out if air temperature rise is an anthropogenic or cosmic phenomenon, depending on atmosphere circulation changes affected by solar activity and helping to forecast regional as well as global climatic variations (Monin, Shishkov, 1979; Tarry, Carter, 1998). If the fear that anthropogenic activity causes climatic warming up comes true, this activity and droughts will inevitably affect environment, therefore, it is necessary to observe climatic, environmental and forest increment peculiarities, foresee their possible changes (Bitvinskas, 1997).

Most authors fluctuations of tree annual radial increment attribute to long-term climatic changes. N.Lovelius (Ловелиус, 1979; Lovelius, 1997) in the result of Arctic warming up of the 20th century has ascertained an increased radial increment in the whole northern forest belt of Eurasia, S.Shiyatov and V.Mazepa (Шиятов, Мазепа, 1986) tree increment reduction in the middle of 19th century along northern forest belt relate to unfavorable growth conditions and fall of temperature. Distinct tree radial increment minimums were observed in the 12-13th, and 19th centuries (Максимов, Гребенюк, 1972), 17th and in the first half of 19th century, while in the second half of 19th and first half of 20th centuries, in respect to global climatic warming, increment maximums are registered (Ловелиус, 1979). Great tree radial increment deviations from the mean of many years were defined during Wolf's, Shpero's and Mounder's climatic minimums (Kocharov, 1989).

Synchronic fluctuations of Lithuanian climate are related to Solar activity cycles and their impact on atmospheric circulation (Ščemeliovas, 1964), anthropogenic activity influence on changes in atmospheric structure and related climatic variations is stressed (Bukantis, 1994), as well as the impact of climate on fluctuations in water abundance of rivers (Jablonskis, 1992; Tilickis, 1994) and water level in lakes and marshes (Kilkus, 1998).

Under most unfavorable growth conditions reaction of trees to climatic changes is strongest, improvement of climate leads to increased annual ring width; however, under favorable conditions trees growing closer to the optimum of their aerial slightly react to climatic fluctuations (Fritts, 1987; Fritts et. al., 1991; Eckstein, 1985, 1989; Kaenel, Schweingruber, 1996; Schweingruber, 1989, 1996; Läänelaid, 1994; Lovelius, 1997 etc.). This feature of trees enables dendrochronological past climate reconstruction, by reliably restoring past climatic changes (Fritts, 1987; Eronen, Zetterberg, 1996; Kalela-Brundin, 1999 et. al.). The effect of precipitation is crucial on tree growth in geographical latitudes with high mean annual temperature, while in northern latitudes and higher altitudes dominate the impact of temperatures over vegetation period (Шиятов, Полозова, 1978; Шиятов, Мазепа, 1986, 1987).

Tree annual radial increment and climatic extremes in Lithuanian forests appear in certain stages of 22-year solar activity cycles, therefore, they cannot be considered accidental. The greater solar activity amplitudes in 22-year cycles, the greater amplitudes of fluctuations in tree radial increment of conifers (Bitvinskas, 1989, 1994; Stravinskienė, 1980 etc.). Formation of annual rings on sites of normal humidity in Lithuanian forests is influenced by air temperature in autumn and winter months, precipitation and vegetation start temperature (Битвинскас, 1984). Meanwhile, higher mean air temperature in May-June and less than the norm precipitation quantity on surplus humidity and marshy soils stimulates growth of trees, while precipitation surplus limits it (Стравинскене, 1981; Kairiūkštis, Stravinskienė, 1987).

Studies have been shown (Fritts, 1987; Шиятов, Мазепа, 1987; Kairiūkštis, Dubinskaitė, 1990; Stravinskienė, Vencloviene, 1998 etc.), that fluctuations of tree annual radial increment are cyclic, while the length of their variation cycles reflect certain processes on the earth and in space, indicating the impact of climatic factors on trees.

1.2. Anthropogenic environmental factors and dendroindication of their effect

Air pollution and predetermining it factors. Air pollution is defined as a certain state of the atmosphere, under which concentrations of some substances are higher than in uncontaminated environment (Zwozdiak et. al., 1990). Air pollution is accumulation of different chemical substances of anthropogenic origin (SO_2, NO_2, NO, CO etc.), which may be harmful to plants, animals and man. Tassing pollution sources (industrial regions and towns), air masses "enrich" in pollutants (Žukauskas et. al., 1996). Transfer of pollutants, dispersion, time of presence in the atmosphere follow movement and turbulent diffusion regularities depending on many factors, first of all, meteorological conditions. In the atmosphere takes place gravitational sedimentation of large-size particles, chemical and photochemical reactions among many substances, their long-distance transfer and leaching out with precipitation. Even under constant pollution emissions, contamination of above - ground air pollution may vary considerably (Perkauskas, 1997).

Regional air pollution. At present Lithuania is distinguished among Western and Central European countries by small amount of pollutants (1.7 t/km^{-2} SO_2 and 0.8 t/km^{-2} NO_2) per area unit. Rise in the concentrations of nitrogen oxides during transitional period is attributed to rapid traffic development (Kairiūkštis, 1999). Air condition in Lithuania is now preconditioned by long – range transboundary pollutants and transformation of air admixtures during their transfer (Žukauskas et. al., 1998). Prevailing southwestern winds bring most pollutants from Central and Western Europe. Local emissions of all anthropogenic pollution sources in Lithuania comprise 20-25%, 75-80% of them arrives from neighbouring countries (Girgždys et. al., 1998; Kairiūkštis, 1999). In annual emissions dry sulphur stream makes up 40-50%, while that of nitrogen – 30%. Further away from stationary pollution sources the portion of dry streams decreases, while that of wet ones – increases. In forested areas of Lithuania pollutants emitted with precipitation are decreasing now (Girgždys et. al., 1999).

Local air pollution. Lithuanian local (mobile and stationary) pollution sources emit only 25% of the whole amount of pollutants falling per Lithuania's territory; their emissions form local air pollution. Three main air pollution regions are singled out: Vilnius-Elektrėnai, Kaunas-Jonava-Kėdainiai and Mažeikiai-Naujoji Akmenė-Šiauliai. On the rest part (70%) of the territory dominate long – range transboundary emissions (Ozolinčius, 1999).

Traffic input into environmental pollution from local anthropogenic sources. Burning fuel emits into the environment carbon monoxide (80%), carbohydrates (15%), nitrogen oxides (5%), small amounts of lead, benzapyrene and other harmful substances. In Lithuania the largest part of annual traffic emissions comprise carbon monoxide – 258 thou. tons, carbohydrates – 60 thou. tons, nitrogen oxides – 36 thou. tons and sulphur dioxide – 5.5 thou. tons. According to forecast, traffic pollution in Lithuania will increase (Baltrėnas et. al., 1996).

In big cities emissions from mobile pollution sources are prevailing. Due to emissions of intensive traffic, energetics and industrial enterprises, the air of towns is polluted by nitrogen oxide and sulphur dioxide. They stay in the atmosphere for a shortwbile, which causes their seasonal variation – in summer their concentrations usually are 3-5 times less than in winter (Perkauskas, 1997). The main stationary pollution sources of the air in towns are energetics (27.4%), chemistry (23.9%) and construction (23.8%) industry. Air quality in urbanized Lithuania's territories depends on emissions from local transport and industrial sources. Unstable meteorological conditions in Lithuania are favorable for the dispersion of pollutants. One of the greatest problems in Lithuanian towns – air pollution with benzapyrene due to traffic emissions. Air pollution in Kaunas is greater than that in other Lithuanian towns. In Kaunas air pollution is heaviest in the Central, Petrašiūnai, Kalniečiai districts, where dust, carbon monoxide and nitrogen dioxide exceed GAC.

At present amounts of local emissions in all Lithuanian towns and industrial regions are reduced. Local emissions of sulphur dioxide decrease since 1990 due to reduced production volumes of industry and energetics. Assessing emissions of sulphur, nitrogen, benzapyrene and heavy metals on Lithuanian territory, it must be said, that somewhat more of these pollutants are found in bigger towns, impact zones of industrial objects and nearby highways. Pollution was greatly reduced by the development of nuclear energetics (Kairiūkštis, 1999).

Air pollution impact on trees. Air pollution is ascribed to predisposing and tree condition worsening factors (Manion, Lachance, 1992). Some authors point out, that air pollution impact on forests appears only under very high concentrations of pollutants and are revealed only locally (Kandler, 1992; Landmann, Bonner, 1995), others (Evans, 1984; Bruch, 1985 etc.) long-term pollution point as tree viability and resistance weakening factor. Under polluted air almost ceases the growth of conifers, deciduous trees grow slightly better (Dagys, 1980; Sporek, 1981 etc.). Ever more researchers think, that forest defoliation and early decline is caused not by soil acidification and increase of aluminium ions in rhizosphere, but by greater stream of dry pollutants (Pollanschutz, 1987; Schulze, 1989; Lindberg et. al., 1990).

As far as annual radial tree increment and crown morphological indices, especially defoliation, are the indicators of environmental condition seeking to indicate more reliably the state of environment by tree ring analysis methods, it is very important to ascertain correlation's among these indices. There is no unanimous opinion on tree increment changes under increasing crown defoliation. Some authors think, that trees with needle losses up to 25% have insignificant increment losses (Soderberg, 1991; Murri, Schaleepfer, 1987) or none at all (Юкнис, 1990), while rapid increment decrease starts, when defoliation exceeds 40% (Petraš et. al., 1993). According to other opinions, increment decrease is caused even by slightly higher defoliation (Schmidt-Haas et. al., 1986; Kramer, 1986; Huber, 1987 et. al.), while under greater defoliation its relation to increment losses becomes closer (Pretzisch, Utschig, 1989). Under the same defoliation, increment losses are higher in older stands (Rohle, 1986).

Information provided by tree annual rings, crown defoliation and other morphological indices helps to assess more objectively ecoclimatic and anthropogenical changes in the environment and their impact on trees. Morphological tree crown indices (crown defoliation, foliage dechromation, amount of dry branches, state of crown tops, age of needles, etc.) reflect the condition of trees in certain calendar years and complement information provided by tree rings, especially for the assessment of urban environment.

2. Object, extent and methods of studies

2.1. Object and extent of studies

Native tree species, comprising stands within forest ecosystems, near industrial centers, in urban plantations were chosen as study object.

Pine stands are the most common in Lithuania, they comprise 37.2% from the total forest cover (Brukas, Kuliešis, Rutkauskas, 1998). Data on annual radial increment of Scots pine (*Pinus sylvestris* L.) growing in *Pinetum vacciniosum* and *Pinetum vaccinio-myrtillosum*, *Pinetum myrtillo-sphagnosum* and *Pinetum carecoso-sphagnosum* forest types were collected in Biržai, Anykščiai, Lazdijai, Marcinkonys, Panevėžys, Radviliškis, Širvintos, Ukmergė, Utena and Varėna forests, in 80-100-year-old pine stands.

Spruce stands account to 23.4% of forest area (Brukas, Kuliešis, Rutkauskas, 1998). Data on annual radial increment of Norway spruce (*Picea abies* (L.) Karsten) were collected in 80-100 -year-old spruce stands growing in *Piceetum oxalidosum* and *myrtillo-oxalidosum* as well as *Piceetum carecoso-calamagrosticosum* forest types in Papilė forest district of Mažeikiai forest enterprise, Sukmedžio forest district of Pakruojis forest enterprise, Giliogirio forest district of Rietavas forest enterprise, Armenos forest district of Jurbarkas forest enterprise, Švenčionių forest district of Švenčionėliai forest enterprise and Pakražantė forest district of Tytuvėnai forest enterprise.

Black alder stands in Lithuania account to 8.2% of forests on overmoistured and marshy soils (Uc, Ud and Pc, Pd habitats); most widespread are *Alnetum carecosum*, *Alnetum carecoso-calamagrosticosum*, *Alnetum urticosum* and *Alnetum philopendulosum* forest types (Kapustinskaitė, 1983). Radial increment of black alder (*Alnus glutinosa* (L.) Gaertn.) due to bad visibility of annual ring contours is less studied (Stravinskienė, 1981, 1998). Dendrochronological information was collected in black alder stands of Biržai, Kazlų Rūda, Marijampolė, Radviliškis, Raseiniai, Šakiai, Jurbarkas, Trakai, Ukmergė and Vilnius regions.

Birch stands in Lithuania comprise 19.9% of forest area (Brukas, Kuliešis, Rutkauskas, 1998). Silver birch (*Betula verucosa* Ehrh.) – is a light – demanding species, adapted to more dry habitats, while Downy birch (*Betula pubescens* Ehrh.) is shade-tolerant, more frequent in wet forests and marshlands, where it may form main forest communities. Both species of birch were not studied yet from dendrochronological viewpoint, studies of downy birch were started quite recently (Stravinskienė, 1998). Masterchronologies of downy birch generalize the data of radial increment from Biržai, Marijampolė, Radviliškis, Raseiniai, Šakiai, Jurbarkas, Ukmergė, Vilnius regions.

Lime trees are the most favorable trees in Lithuanian farmsteads, parks, and urban plantations, grown separately and in groups, in alleys. Radial increment and ecological state of lime trees in urbanised environment were not studied, therefore, linden (*Tilia sp.*) species prevailing in Lithuanian urban plantations were chosen: large-leafed (*T. platyphylla* Scop.), European (*T. europaea* L.), small-leafed (*T. cordata* Mill.) and Crimean (*T. euchlora* K. Koch.) limes.

The studies intended to cover forested areas of Lithuania. Annual radial increment studies of Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karsten), Black alder (*Alnus glutinosa* (L.) Gaertn.) and Downy birch (*Betula pubescens* Ehrh.) were carried out in forest ecosystem (stands of 0.7-0.9 stocking level) objects without local pollution. To ascertain correlations of tree annual radial increment with climatic factors and to elaborate masterchronologies, wood samples from 2126 coniferous trees were taken and 200000 measurements of annual radial increment in conifers were done; for the studies of broadleaves 1700 wood samples were taken and 130000 annual radial increment measurements were conducted.

To study the state and growth of trees in objects of industrial pollution, coniferous stands – pine and spruce stands, growing on Lb and Lc habitats, 8-12 and 13-24 km away from pollution source – Jonava chemical plant "Achema" (former "Azotas") - were chosen. 20 sample plots were singled out in homogeneous or with a small (up to 20%) admixture of other species 0.7-0.9 stocking level pine and spruce forest stands in Ąžuolynė, Jonava, Liepiai, Santaka, Vepriai and Upninkai forest districts of Jonava forest enterprize.

Pine condition monitoring in urban environment (urban forests and forest parks) is conducted since 1993 (432 sample trees in 18 objects), that lime trees growing in city centre (680 sample trees) – since 1998.

Changes in pine, spruce and black alder annual radial increment due to forest drainage were assessed by studying the most widespread within Lithuanian amelioration fund *Pinetum myrtillo-sphognosum*, *Piceetum* *carecosum* and *Piceetum carecoso-calamagrosticosum* forest types as well as Black alder stands in *Alnetum carecosum and Alnetum carecoso-calamagrosticosum* forest types, drained in different climatic conditions – in 1951-1956 (dry period) and 1958-1959 (rainy period). Number of study objects – 50 (1000 wood samples, 80000 annual radial increment measurements).

Pine increment changes due to fertilization by traditional (carbamide – 80 kg/ha of nitrogen and superphosphate – 100 kg/ha of phosphorus) and non-traditional (phosphogypsum doze 5 t/ha and 10 t/ha of acid reaction by Kėdainiai "Lifosa" and 5 t/ha of phosphogypsum mixture with superphosphate) mineral fertilizers were studied in 40-year-old pine stands growing on intermediate type peat soils (Pb habitat) in observation plots on the surroundings of "Akmenės cementas" (200 wood samples, 10000 annual radial increment measurements).

Control stands for the studies of forest drainage and fertilization efficiency were chosen in analogous according to all biometric indices undrained and unfertilized stands.

2.2. Methodics of annual tree ring studies

Collecting of experimental material. Homogeneous or with a small admixture (up to 20%) of other species stands of 0.7-0.9 stocking level growing in areas without local pollution were selected. In each sample plot from 15-20 trees of 1 and 2 class according to Kraft's classification wood samples were taken at 1.3 m height from root collar by Pressler's borer in two directions to eliminate the effect of tree growth eccentricity on radial increment (Битвинскас, 1974).

Preparation of wood samples for annual tree ring measurements. Dry wood samples were soaked in water for 2-4 hours, so that annual rings regain their former width. To make the contours of early and late wood more visible, one side of the sample was cut by a special knife. To reveal the contours of birch, black alder and linden annual rings, wood samples were grinded, grinding quality was checked by a microscope. Well visible are annual rings of pine and spruce, satisfactorily – those of black alder, badly – birch, very badly – annual rings of linden. Contours of badly visible rings after grinding were made distinct by dying: tissues of differing density in early and late wood become dyed with varying intensity (Stravinskienė, 1994).

Measurement of tree annual rings. For annual radial increment (width of annual rings) measurement and ring structure assessment were used LINTAB tree ring measurement system and TSAP set of programs. Measurement accuracy (±0.1 or ±0.01 mm) is chosen depending on the aim of studies. Primary ring measurement data are recorded on a discette to facilitate further processing of the information by mathematical statistics and dendrochronological analysis methods according to special TSAP programs: dating, synchronization, compiling of chronologies, etc.

For the dating of annual rings and tree increment synchronization, methodics used world-wide for dendrochronological studies was applied (Eckstein, 1989; Schweingruber, 1989 et al.), on the basis of which a set of TSAP programs was worked out (TSAP by FRANK RINN and SIEGWARD JAKEL, Heidelberg, Germany).

Calculation of tree annual radial increment indices. To eliminate the impact of tree ageing on radial increment rate and to reveal the cycles of increment dynamics due to climatic background fluctuations, as well as to compare increment series, tree annual radial increment measurement data were standardized elaborating masterchronologies. For the purpose were calculated annual radial increment indices – relative values expressing the ratio between radial increment of a certain calendar year and increment norm of the year. Increment norm was calculated by the formula:

$$Zr_{vid.} = \frac{Z_{r_m} + Z_{r_{m+1}} + Z_{r_{m+2}} + Z_{r(T-1)+m}}{T}, \tag{2.1}$$

where $Zr_{vid.}$ – increment norm or mean periodic increment; Zr_m; Zr_{m+1}; Zr_{m+2} … $Zr_{(T-1)+m}$ – annual radial increment; m – positive number, when T=11, m=T-10; T – levelling period.

Radial increment indices were calculated the following formula:

$$IZr = \frac{Zr\left(\frac{T-1}{2} + m\right)}{Zr_{vid.}} \cdot 100, \tag{2.2}$$

where $Zr\left(\frac{T-1}{2} + m\right)$ radial increment of a certain calendar year in the middle of T period.

To calculate increment norm, 11 years levelling period was applied, revealing the effect of 11 and 22 year solar activity cycles on tree radial increment (Стравинскене, 1981 a; 1983 б, 1987; Stravinskienė, 1998 b, c; Stravinskienė, Venclovienė, 1998).

Assessment of climatic conditions was based on long-term data of meteorological stations and agrometeorological bulletins.

2.3. Principles for compiling masterchronologies

Dating of tree annual radial increment and identification of its extremes uses quite simple methods based on abundant experimental data and enabling to generalize dendrochronological information from a large region (Schweingruber, 1989). The first stage in compiling chronologies is dating of wood samples and synchronization of annual radial increment data, taking into account especially narrow annual rings (if the width of annual ring was measured) and the portion of late wood within annual ring (if late and early parts of annual ring were measured separately). Comparing radial increment data among themselves, synchronization of all available tree ring series is done. To detect "false" or "falling out", rings crossdating according to pointer years was applied. This term is used by F.H.Schweingruber (1989, 1996) to assess the quality of annual rings. "Positive" are called years when within annual ring of normal width wide portion of late wood is formed, while "negative" – when late part of annual ring is very narrow. Assessing only according to the width of annual ring, "negative" years are consireded narrow-ringed, while "positive" – years of wide rings. This is important for dating and synchronization of local increment series, for the rings of pointer years considerably differ from earlier and later rings by their width and the ratio of early and late wood. According to the rings of "negative" years, dendroscales are compared among themselves and with already available masterchronology. In the absence of masterchronology, they may be compared to increment series of one standard stand. It is sought, that annual radial increment dynamics of compared among themselves dendroscales would coincide within not less than 15-20 years interval. Having defined the identity of pointer years visually, synchronousness coefficient is calculated. For this purpose Bitvinskas' (1974) formula was applied:

$$C_x = \frac{n^+ \cdot 100}{n-1}, \tag{2.3}$$

where C_x – coefficient of synchronousness; n^+ - number of rings of tallying direction; n – number of rings compared.

In each sample plot about 10-15% of sample trees pertain asynchronous radial increment dynamics. Compiling dendroscales, dendrochronological information of such trees was not used (Стравинскене, 1980).

2.4. Assessment of tree crown morphological indices

Tree crown morphological indices were assessed according to international study program and methodic on air pollution impact to forests (Manual on methods …, 1994). Crown defoliation means foliage loss, compared to standard tree – tree of the same growth and development class, growing in the vicinity, or to a photo of the tree, or to the same tree with imaginable full foliage (Ozolinčius, 1998). To assess defoliation of sample trees special atlases of reference trees were used (Muller, Stierlin, 1990). Significant crown defoliation is a sign of tree damage. Relatively healthy are considered trees with crown defoliation less than 10%. According to the defoliated part of crown, tree damage type is ascertained: 1 – top (defoliation difference between the upper and the rest crown part exceeds 20%); 2 – under-top (crown part under top is the most sparse); 3 – base (defoliation of the bottom crown part exceeds that of other parts by not less than 20%); 4 – inner (most sparse is the inner part of the crown); 5 – peripheral (more than 25% of branches have dry tops); 6 – uniform (all parts of the crown are almost evenly defoliated) and 7 – window (Lesinski, Armolaitis, 1992).

Foliage discolouration – a part of needles or leafs, which have changed the colour due to negative external factors is an important indicator. Foliage discoloration is visually evaluated and 5 percentage classes are applied. Retention age of pine needles is evaluated with 0.1 year accuracy.

The amount of dead branches in the crown was evaluated applying 5 percentage classes: 0 – 0-15% of dead branches, 1 - 16-30%, 2 – 31-50%, 3 – more than 50% of dead branches.

Pine trees from urban environment, growing in forest parks, were studied in sample plots distributed according to the requirements of international study program and methodic on air pollution impact to forests (Manual on methods …, 1994). Trees for the studies of city limes were selected individually (Stravinskienė, Dičiūnaitė, 1999).

Evaluating tree condition visually, certain errors are inevitable, but they are inessential and depend on the number of sample trees: with greater number of sample trees measurement inaccuracies decrease (Gertner, Kohl, 1995; Dobbertin et al., 1997). In our studies due to a great number of sample trees errors are inessential, while the validity of indices is high.

2.5. Application of dendrochronological methods to evaluate tree response to climatic changes and air pollution

Analyzing forest growth changes due to climatic variations and air pollution, it is important to ascertain the development of these processes not long ago and in recent decades. Most suitable for this purpose are dendrochronological tree ring analysis methods – relatively inexpensive and allowing to analyze abundant data and take advantage of registered in annual rings information over many years (Kairiūkštis, 1981). Applying these methods, it is actual to evaluate the dynamics of climatic background. At present assessment of annual radial increment of coniferous stands due to air pollution is based on various methods, which may be distributed into 3 groups (Kairiūkštis, Stravinskienė, 1992; Стравинскене, 1998).

1.Control stand methods based on absolute and relative annual radial increment comparison of damaged (under study) and relatively healthy (control) stands.

2.Methods of reference (control) trees, based on radial increment comparison of trees belonging to different damage (defoliation) classes and relatively healthy trees.

3.Methods based on qualitative analysis of dendrochronological series and tree increment dependance on climatic as well as anthropogenic factors.

Applying methods of the third group, increment losses due to anthropogenic activity are evaluated with the greatest accuracy. However, they may be applied only in those regions where long-term statistically reliable masterchronologies are compiled according tree species and forest types, as well as where sufficient amount of statistical material on tree increment formation depending on climatic factors is collected.

Methods of the second group should be used to assess background forest damages. They rely on assumption, that relatively healthy trees have no increment losses, therefore, their increment is compared to the increment of trees of various damage classes. However, even relatively healthy trees may have certain increment losses. Besides, relatively healthy trees in the same conditions of background air pollution may be genetically more resistant. Applying this method, increment losses are evaluated with some error.

Similar shortcomings are characteristic also to the method of control stand, applied to assess increment changes due to local pollution. In the case of local pollution, both control and investigated stand are under the same background pollution load. Calculating increment losses as the difference between increments of control and investigated stands, background pollution effect is eliminated. Comparing not actual, but relative increment values (indices), to a certain degree are eliminated differences in natural growth rates of control and investigated stands. Period for comparison is chosen within time span since the onset of anthropogenic impact until the year of studies (Stravinskienė, 1995).

The most important problem applying this method is assessment subjectivity, which is preconditioned by selection of the “norm” or “standard”. Accuracy of the chosen method may be increased selecting the best control; if suitable control stan is chosen, assessment of increment losses becomes more precise.

Three variants are available: 1) masterchronologies of annual radial increment of Lithuanian coniferous and broadleaved trees; 2) stands growing in territories without local pollution; 3) standards, elaborated by deriving mean radial increment data of relatively healthy trees (crown defoliation up to 10%) in a certain stand.

The first variant should be applied to evaluate background pollution impact on tree increment in stands situated further away from local pollution sources. It was used to assess forest drainage and fertilization effect on tree radial increment as well as to foresee favorable for forest drainage and fertilization efficiency climatic periods. This methodical solution is not applicable to stands affected by local pollution of cities and industrial centres, because they are under the influence of both background and local pollution.

Control stand method was used to estimate radial increment, losses in the zones of local pollution impact, when climatic conditions are similar to all stands. It was conditionally agreed, that background pollution level is the same on the whole Lithuanian territory (Kairiūkštis, 1999). Having chosen for local pollution control a stand growing in relatively clean place, increment differences reflect only the impact of local pollution on trees. It is necessary to evaluate, if radial increment of the control stand since the start of growth was not higher than that of studied stands, if their dynamics and range of fluctuations were similar until the onset of local pollution. Neglecting this factor may cause some errors in assessment accuracy of increment changes.

As an alternative to this variant, was suggested standard elaborated analyzing annual radial increment of relatively healthy (defoliation up to 10%) trees. Reference (control) trees are chosen in stands of the same age, forest type, site conditions and biometric indices. This standard is an intermediate variant, obtained by adjusting requirements on "increment norms" of control stand and reference trees. The choice of this standard is based on assumption, that relatively healthy trees are most resistant to anthropogenic impact (Stravinskienė, 1997; Стравинскене, 1998). Their response to the impact of adverse environmental factors is the weakest.

In our studies annual radial increment losses or additional increment (%) were calculated by comparing radial increment data of control and investigated stands by the formula:

$$Z_n = \frac{Z_k - Z_t}{Z_k} \cdot 100, \tag{2.4}$$

where Z_n – losses of annual radial increment (additional increment – when the increment of sample stand is higher than that of control stand); Z_k – increment of control stand; Z_t – increment of investigated stand.

Application of methods depends also on the age of studied trees. Studying younger trees, the method of control stand is more suitable than that of masterchronologies, e.g. in the case of fertilization impact on tree radial increment. More reliable results are obtained comparing data received by different methods.

3. Annual radial increment masterchronologies of conifers and broadleaves on the main Lithuanian forest habitats

Synchronous fluctuations of radial increment of trees, determined by dendroecological and dendrochronological study and expressed in masterchronologies, enlarge the possibilities of this field in ecology science. Long-time masterchronologies of high precision is one of the cases to use dendrochronological methods for indication of natural environment state changes. Up till now there wasn't long-time tree annual radial increment database of masterchronologies from various places of the Republic, differentiated according to habitats (dry, moderately humid, wet) and forest types prepared. Now long-time masterchronologies of high precision are established by using large dendrochronological database of trees, growing in the objects without local air pollution exists (Stravinskiene, 1998). Presented masterchronologies were formed according to conditions of habitats and forest types. Similar types of forests and habitats with high (not less 80%) synchronicity of annual radial increment dynamics were joined together in order to form masterchronology representing a wider diapason of environmental conditions.

3.1. Impact of climatic factors on tree annual radial increment formation

Studies on the impact of the main climatic indices – air temperature (mean annual, during active vegetation period, in May, at the end of summer, in early autumn, in the cold period) and precipitation quantity (annual, during vegetation period, over active vegetation period, in summer, July, August, July-August, autumn, cold period) on tree radial increment have shown, that rise of the mean vegetation period temperature and less than the norm amount of precipitation on overmoistured and marshy forest sites induce tree growth, while precipitation surplus acts as growth limiting factor. Correlation ties of annual radial increment of pines growing in *Pinetum carecoso-sphagnosum* and *Pinetum myrtillo-sphagnosum* forest types with mean air temperatures in May-June (r=0.49-0.52) as well as precipitation of May-August (r=-0.45;-0.47) and July (r=-0.40–-0.52) are quite strong and reliable (P=0.99). Correlation ties with mean annual, May-August, October-April temperatures, as well as annual, summer and August precipitation quantity are weaker, but also reliable (P=0.95). Reliable positive correlation of annual radial increment of pine trees were ascertained also with air temperatures of the last two years (at the end of spring and beginning of summer), and negative – with precipitation in July and August. Analysis of climatic factors has shown, that years with mean May-June temperature, exceeding more than by 10% mean norm of many years, were repeated in Lithuania in the period of 1892-1998 every 9-13 years; in those years the rise of tree radial increment is observed. The formation of tree annual radial increment is influenced not only by climatic conditions of the current, but also of the last two years; correlation ties were ascertained with climatic indices even over the last three-four years (Stravinskienė, 1980, 1981;

Kairiūkštis, Stravinskienė, 1987). Relationship between annual radial increment of conifers and solar activity (Wolf's numbers) are characterized by not high correlation coefficient (r does not exceed –0.40; P=0.95), increment correlation of broadleaves with solar activity indices is still weaker (r=-0.20 – -0.25; P=0.95).

It is established that annual radial increment of Black alder growing in *Alnetum carecocum* and *Alnetum carecoso-calamagrosticosum* forest types is determined by the mean air temperature of vegetation beginning and by the precipitation amount of July-August. Mean temperature of May-June (higher than mean air temperature of these months during many years) is a favourable factor (r=0.53-0.59) stimulating the growth of black alder and precipitation surplus is an unfavourable factor limiting the growth. Annual radial increment of Black alder is higher when May-June is warmer, and the quantity of precipitation in July-August is less than the annual norm. Cold and rainy beginning of vegetation period negatively affects the growth – the lack of warmth becomes a limiting factor.

The impact of precipitation on radial tree increment in sites of normal humidity is less important than that of temperature; here some influence is exercised by autumn, January-February and April air temperature (r=0.18-0.21; P=0.95). Reliable correlation was ascertained between pine and spruce annual radial increment and the temperature of July-August (r=0.28-0.29; P=0.95).

Absolute minimums of winter temperatures down to -30°C have no effect on annual radial increment, however, in the years of cold winters and following them cold springs and cool summers (in 1909, 1928, 1940-1942, 1953 and 1979) decrease of tree annual radial increment is observed on all studied habitats even up to 30-40%, as compared with the mean increment norm of many years.

3.2. Masterchronologies of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten).

Masterchronology of Scots pine in *Pinetum vacciniosum* and *Pinetum vaccinio-myrtillosum* forest types (Na and Nb habitats) generalizes and illustrates the dynamics of pine annual radial increment in dry habitats. It includes 168-year period (beginning in 1830, lasting till 1997). In order to form this masterchronology the dendrochronological data of 509 growing trees was used.

The base for Scots pine masterchronology in *Pinetum myrtillo-sphagnosum* forest type (Ub habitat), reflecting annual radial increment of pines growing in marshy habitats or ones with temporary redundant humidity was masterchronology, formed for 1870–1978 year period. In order to extend the masterchronology, 289 tree wood samples from 1979–1997 year periods were used. Totally annual radial increment data of 457 trees was used to form the masterchronology of 128-year duration. Before the forming process, the dendroecological data was dated and synchronised among itself.

Masterchronology of Scots pine in *Pinetum carecoso-sphagnosum* forest type (Pb habitat), reflecting annual radial increment dynamics of pines growing on marshy habitats was formed from dendrochronological data of 395 living trees. The duration of masterchronology – 158 year. It includes dendrochronological information of 1840–1997 year period.

Masterchronology of Norway spruce in *Piceetum oxalidosum* and *Piceetum myrtillo-oxalidosum* forest types was formed from dendrochronological data of 16 local annual radial increment successions, by using the dendrochronological data of 374 conditionally healthy trees (defoliation up to 10%) annual radial increment data. Since 1975 the tendency of a decrease in fluctuation amplitudes has been observed. Dendrochronological investigations have determined gradual Norway spruce annual radial increment decrease since 1981. It indicates permanent gradual deterioration of Norway spruce ecological state determined by a complex of unfavorable environmental factors (climatic conditions, phonic technogenic pollution etc.). Significant value of annual radial increment minimum is observed in 1992–1993.

The masterchronology of Norway spruce in *Piceetum carecoso-calamagrosticosum* forest type (Uc habitat) was formed by using the dendrochronological data of 400 trees. It includes 128-year period (beginning in 1870, lasting till 1997). Large amplitudes of annual radial increment fluctuation are characteristic for this masterchronology, representing humid habitats of Norway spruce. An increase in the annual radial increment is observed in the periods: 1979–1880, 1892–1895, 1912, 1923-1926, 1946, 1949-1950, 1958, 1968, 1992-1994; a decrease – in the periods: 1887-1889, 1908-1910, 1927-1930, 1941-1942, 1954-1957, 1965, 1977-1979 and 1996-1997.

For conifers growing on drier habitats, factors limiting the growth are lack of humidity and low temperature of vegetation period. That' s why the dynamics of tree annual radial increment of dryer habitats is quite different from the habitats of temporarily redundant humidity, bogging up and marshy habitats. The dynamics can even be asynchronous, especially during droughts or longtime rainy periods. The largest amplitudes of annual radial increment fluctuation are characteristic for Scots pine *(Pinus sylvestris* L.*)* of *Pinetum myrtillo-sphagnosum* and of *Pinetum carecoso-sphagnosum* forest types growing on habitats of temporarily redundant humidity, bogging up and especially marshy, and the smallest amplitudes – for trees growing in normal or dry forest sites habitats.

3.3. Masterchronologies of Black alder (*Alnus glutinosa (*L.*)* Gaertn.) and Downy birch (*Betula pubescens* Ehrh)

The masterchronologies of black alder and downy birch growing on forest habitats of temporarily redundant humidity and marshy are established using large dendrochronological data of deciduous trees, growing in the objects without local air pollution.

Using the dendrochronological data of 519 trees the masterchronology of black alder in *Alnetum carecosum* forest type (Pc habitat) was formed. Its duration – 128 years (from 1870 to 1997). In 1905–1951 period annual radial increment series segment was formed by using the largest number of trees – even 425. Significant recurrence of tree annual radial increment of the dendroscale is attributed to solar activity cycles of 11 years. The largest amplitudes of annual radial increment fluctuation are characteristic for 1870–1875 and 1910–1978 periods. Annual radial increment deviations from average annual radial increment norm are more than 20%. In 1886–1909 and since 1979 the amplitude of increment fluctuation did not exceed 20% of annual radial increment norm.

The masterchronology of black alder in *Alnetum carecoso-calamagrosticosum* (Uc habitat) was formed by using the data of 675 growing trees. Its duration – 114 years (from 1883 to 1996). Annual radial increment recurrence of 11 years is characteristic for annual radial increment dynamics. Amplitudes of annual radial increment fluctuation are not large (the deviations from norm do not exceed 20%). The higher annual radial increment related with favorable climatic conditions is observed in 1872-1873, 1879, 1888, 1894, 1907, 1915-1916, 1926-1927, 1935, 1949-1950, 1965-1966, 1975-1976, 1983 and 1992-1993 year periods. The lower radial increment, related with low air temperature of vegetation periods, unfavorable distribution of precipitation, is observed in 1874-1875, 1884, 1892, 1909-1910, 1919-1920, 1929-1930, 1941-1943, 1962-1963, 1979-1981 and 1995-1996 years.

The masterchronology of Birch in *Betuletum carecosum* forest type (Pc habitat) was formed by using the annual radial increment data of 279 trees, its duration – 97 years (from 1900 to 1996). Large fluctuations of annual radial increment of birch are characteristic for this masterchronology. Significant annual radial increment minimums are observed in 1903, 1910 (annual radial increment is 25% less than increment norm), in 1919 (20% less), in 1933 (38% less) and in 1979 (18% less). Annual radial increment maximums are expressed in 1904, 1914, 1925 and 1948. Since 1950 the amplitude of annual radial increment fluctuations becomes smaller.

The masterchronology of birch in *Betuletum carecoso-calamagrosticosum* forest type (Uc habitat) was formed by using the annual radial increment data of 286 trees. Its duration – 97 years (from 1900 to 1996), the largest capacity was observed in 1937–1990 – dendrochronological data of 210 trees was used. Characteristic fluctuations of annual radial increment are attributed to 11-year solar activity cycles. Annual radial increment minimums are most significant expressed in 1909 (radial increment is 27% less than average annual radial increment norm) and 1980 (28% less).

Presented masterchronologies are different in absolute sizes, but synchronous in increment extremes (the characteristics of minimums and maximums). In the habitats of temporarily redundant humidity, bogging up and especially marshy ones, where factors limiting the growth are humidity surplus and lack of warmth, minimums of tree annual radial increment are observed in the cool, rainy and large solar activity years. For conifers growing on drier forest sites, factors limiting the growth are lack of humidity and low temperature during vegetation period.

4. Analysis of ecoclimatic fluctuations of masterchronologies and annual radial increment forecast

4.1. Analysis of ecoclimatic fluctuations of tree annual radial increment

Most authors, analysing relations between tree radial increment and natural processes (Fritts, 1987; Kairiūkštis, Dubinskaitė, 1990; Stravinskienė, Venclovienė, 1998; Шиятов, Мазепа, 1987 et al.), point out changes in radial increment fluctuation amplitudes, length of phases and cycles.

By methods of spectral and harmonic analysis 8-14 year radial increment fluctuation cycle was ascertained in masterchronologies of trees growing on normal humidity sites. For pines on permanently overmoistured and marshy sites is characteristic 11-year cycle with more pronounced extremes every 22 years, for black alders – 11-year increment cycle. On forest sites of normal humidity less expressed 5.5; 7 and 8-year annual radial increment cycles, while on wetter sites – 7.5 and 13-year cycles for pine were determined. In dendroscales repeated increase or decrease of amplitudes of these fluctuations is observed, as well as changes in the length of cyclic fluctuations. Fluctuations of 6-14 and 20-25 year cyclic amplitudes are obvious in masterchronologies of pines and spruces growing on normal humidity sites. In 1870-1920 small radial increment cyclic amplitudes are observed, while in 1830-1870 and 1940-1970 – big fluctuation amplitudes. Fluctuations of the big amplitudes repeat almost every 100 years. Values of radial increment masterchronologies, forecast Tj periods, amplitudes and phases are presented.

4.2. Approximation and forecast of tree annual radial increment fluctuations

Radial increment forecast, based on its fluctuation cyclicity, applies modified multiperiodical formula by Berri, Liberman, Šijatov (1979):

$$Y_{(t)} = A_0 + \sum_{j=1}^{n} Aj \cos\left(\frac{2\pi t}{Tj} - \varphi j\right), \qquad (4.1)$$

where $Y_{(t)}$ – annual radial increment index in t-year of actual or forecasted age; A_0 – mean of indices; Aj, Tj, φj – amplitude, period and phase of j-cosinusoid.

Based on compiled (Stravinskienė, 1998) and given in chapter 3 data on masterchronologies, annual radial increment prognosis until 2018 for prevailing tree species of Lithuanian forests was done.

Annual radial increment forecast for Scots pine (*Pinus sylvestris* L.) in *Pinetum vacciniosum*, *Pinetum vaccinio-myrtillosum*, *Pinetum myrtillo-sphagnosum* and *Pinetum carecoso-sphagnosum* forest types. Norway spruce (*Picea abies* (L.) Karst.) annual radial increment forecasts are given for *Piceetum oxalidosum* and *Piceetum myrtillo-oxalidosum* as well as *Piceetum carecoso-calamagrosticosum* forest types. Synchronousness of pine and spruce masterchronologies and approximated as well as forecasted annual radial increment fluctuations is quite high. Synchronousness of actual and approximated radial increment of *Pinetum carecoso-sphagnosum* and *Piceetum carecoso-calamagrosticosum* forest types in 1870-1997 reaches 83.5%, while that of *Pinetum myrtillo-sphagnosum* – 81.6%. This proves the suitability and purposefulness of cyclic models and their use in forecasts.

Black alder (*Alnus glutinosa* (L.) Gaertn.) annual radial increment prognoses are given for *Alnetum carecosum* and *carecoso-calamagrosticosum* forest types. Birch (*Betula pubescens* Ehrh.) annual radial increment forecasts are provided for *Betuletum carecosum* and *Betuletum carecoso-calamagrosticosum* forest types. Forecast indices of radial annual increment for black alder and birch are presented. The greatest increment fluctuation amplitudes among studied broadleaves are characteristic to *Alnetum carecosum* and *Betuletum carecosum* forest types. Synchronousness between approximated and forecasted annual radial increment series dynamics and masterchronologies of broadleaves in 1970-1997 is slightly less than that of conifers – comprises 72-79%.

Annual radial increment forecasts are given for a short (15-20 years) period, thus, they may be reliably applied to assess and foretell changes in the state of natural environment. According to forecast, on sites of permanent surplus humidity and marshy sites in 2001-2003 should be awaited annual radial increment minimum. This is related to worsening of ecoclimatic conditions on these forest site types and will affect not only decrease of timber production, but also productivity and stability of forest ecosystems. On dry and normal humidity habitats at that time forecasted tree annual radial increment indices only insignificantly deviate from the mean norm of many years. It allows to think, that among environmental factors in the discussed period the most important may be surplus humidity, which will be a limiting factor on permanently overmoistured and marshy sites, but a neutral one – on dry and normal humidity habitats.

Forecasted tree increment and increased productivity of forest ecosystems should be awaited around 2006-2010.

5. Dendrochronological studies of tree condition and growth in objects affected by local pollution

5.1. Studies on the state and growth of conifers in the town

Environment of the town is affected by various environmental factors, including anthropogenical ones, especially local air pollution. Trees growing here suffer both from local and regional air pollution, thus they are more sensitive, more quickly deteriorate and die, than trees growing in forest ecosystems. Urban forests and forest parks – still rare object of dendrochronological studies, for in their surroundings it is difficult to assess the causes of tree state changes related to anthropogenical impact of urbanized environment (von Lührte, 1992). Studies on tree state in urbanized environment are carried out in Lithuania since 1994 (Stravinskienė, 1997).

<u>Defoliation of pine crowns, state of branches, tops, age of needles.</u> Mean pine crown defoliation in Kaunas pine stands in 1994 was 27.9%, in 1995 – 27.8%, in 1996 – 29.6%, in 1997 – 30.9%, while in 1998 – 32.5%. This by 8-10% exceeds mean defoliation of pines in Lithuanian forests. The greatest defoliation was defined in Panemunė (30.8-38.8%), Petrašiūnai (41.9-43.5%), Palemonas (37.7-51.9%) objects and in Kleboniškis forest park sites nearby highway (42.6%), least (11.5-17.6%) – in the surroundings of Botanical Garden and Jiesia landscape reserve. It was found, that in 1994-1998 crown defoliation of pines was reliably increasing (P=0.95). Most (80%) relatively healthy (defoliation up to 10%) trees were found in Botanical Garden. This shows good condition of pines, indicating favorable conditions for the tree species. Only 5-10% of relatively healthy sampled trees were detected in Kleboniškis–2, Lampėdžiai, Pažaislis and Šilainiai objects, elsewhere relatively healthy trees were not found. In Kaunas pine stands prevail trees of 1 and 2 defoliation class, indicating weak (crown defoliation 11-25%) and average (defoliation 26-60%) crown damage degree. The least amount of dead branches was ascertained in Botanical Garden district (4.0±0.2%), Jiesia landscape reserve (6.5±0.7%), Lampėdžiai (5.9±0.9%) surroundings and Kleboniškis forest park sites further away from highway (5.7±0.8%); crowns of trees here are healthy. More (over 15%) dead branches were found in Kleboniškis forest park nearby highway, in Palemonas, near Petrašiūnai trolley-bus route and on the right side of Raudondvaris highway.

Short needle retention (2 and less years) shows worsening condition of pine trees: under unfavorable environmental conditions needles die, fall down, crowns become transparent. Short needle retention is characteristic to Kleboniškis-1 object nearby Vilnius-Klaipėda highway, Panemunė, Palemonas, Petrašiūnai, Vičiūnai pine stands. Just these districts are polluted by sulphur dioxide and nitrogen oxides.

Assessing environmental condition of Kaunas town according to pine crown defoliation and other morphological tests (needle age, state of crowns and branches), in 1994-1998 was observed worsening tendency: the number of healthy trees was decreasing, defoliation was increasing, state of tree tops was worsening, the number of dead branches was growing, while the age of needles was becoming shorter. Having checked variation reliability of pine crown morphological indices by the help of F criterion, it was found, that in 1994-1998 the state of sampled pines was worsening in significantly, except Kleboniškis-2 and Lampėdžiai objects.

Dynamics of pine trees annual radial increment in 1969-1998. According to the data on annual radial increment of pine trees in each investigation object, local dendroscales were compiled (data series of annual radial increment). Reliable annual radial increment decrease of pines in 1977-1980 is related to unfavorable for growth climatic conditions, especially with winter frosts of 1978-1979. Increment decrease was affected also by environmental pollution, the adverse effect of which becomes even stronger on tree condition and growth after climatic extremes (Juknys, 1990; Stravinskienė, 1995). Another increment reduction period started in 1990 and continued till 1996. In 1995-1996 observed stabilization of increment decrease was undoubtedly relevant to depression of industrial activity and declining phase of 11-year solar activity cycle.

Periods of good growth in 1974-1975 and 1987-1989 are close to annual radial increment cycles of Lithuanian forests and are preconditioned by favorable ecoclimatic background.

The greatest pine radial increment losses were ascertained in Panemunė, Pažaislis, Palemonas, Vičiūnai pine forests and forest parks, the least – in Botanical Garden district, Jiesia landscape reserve and part of Kleboniškis forest park situated further away from Vilnius- Klaipėda highway.

Zonation of urbanized environment according to pine annual radial increment losses. According to values of pine annual radial increment losses, taking into account crown defoliation values, increment decrease intervals, reflecting the state of pine ecosystems, were defined: 0 state class (annual radial increment losses up to 10%) indicate favorable environmental conditions not only for pine radial increment formation, but also for other forms of life; 1 and 2 classes (slightly and moderately damaged trees, increment losses 11-

40% and 41-55%) prevail in Kaunas city and may indicate less favorable and averagely risky conditions for life; 3 and 4 classes (increment losses 56-70% and over 71%) indicate heavily and rather heavily damaged stands and unfavorable environmental conditions. By using GIS program, maps of zones of pine radial increment losses were worked out, illustrating the state of environment and variation of its suitability to biota over three recent decades.

5.2. Studies on the state and growth changes of broadleaves in the town

Deciduous trees may serve as town environmental indicators; their worsening condition is a serious signal on environmental pollution effect or the impact of unfavorable climatic factors. On the other hand, the state of broadleaves in the town is less studied, because conifers are regarded to be better indicators of environmental state.

Lime (*Tilia sp.*) crown defoliation, foliage dechromation, amount of dead branches, fruiting. Mean defoliation (33.4±2.1%) of *Tilia cordata* Mill. and foliage dechromation (9.2±1.5%) is the highest, while that of *T.platyphylla* Scop – the lowest (respectively 28.0±1.2% and 5.1±0.6%) among studied lime species. Defoliation of European lime (*T. europaea* L.) reaches 30.8±1.7%, dechromation – 6.6±0.9%, while that of Crimean lime (*T .euchlora* K. Koch) – respectively 30.9±3.0% and 6.7±1.8%. Most sampled limes (53% of large-leafed, 55% of European limes, 60% of small-leafed and 58% of Crimean limes) are moderately defoliated. Slightly damaged trees comprise 43% of large-leafed, 40% of European, 37% of small-leafed and 39% of Crimean limes. Relatively healthy trees are scarce. Lime crown dechromation is not frequent, 86% sampled trees have only signs of it. European limes have 7.6±1.1%, small-leafed – 6.7±1.9%, large-leafed – 4.3±0.7%, while Crimean – 4.8±2.1% of dead branches. Best fruiting pertain large-leafed (56% abundantly, 39% - moderately, 5% - slightly), in the second place – European (42% - abundantly, 46% - moderately, 12% - slightly) limes. Fruiting indices of small-leafed lime are similar, while the fruiting of Crimean limes is the worst.

Results of Lime dendrochronological studies allow to conclude on the state of annual radial increment of different species. Variations of the state are based on complex impact of environmental pollution and favorable or unfavorable climatic factors. Synchonousness of large-leafed (*T. platyphylla* Scop.) and small-leafed (*T. cordata* Mill.) lime radial increment reach 67%, large-leafed (*T. platyphylla* Scop.) and Crimean (*T. euchlora* K. Koch.)– 63%, European (*T. europaea* L.) and Crimean (*T. euchlora* K. Koch.) – 60%, small-leafed (*T. cordata* Mill.) and Crimean (*T. euchlora* K. Koch.)– 53%. Annual radial increment of the species varies synchronously. Radial increment dynamics of European and large-leafed as well as European and small-leafed in some periods is asynchronous (C_x=48%). Radial increment maximums were registered in 1880 and 1954, minimums – in 1910 and 1980. In 1950-1960 and 1982-1993 radial increment of all lime species was higher, while in 1910-1940 and 1970-1982 – lower than the norm. Impact to extremal climatic conditions on radial increment decrease was ascertained in 1941, 1963, 1979, 1992 and 1994 due to cold winters and dry summers caused by high solar activity. Decrease in lime increment since 1982 was preconditioned by reduced solar activity and improvement of local conditions: eliminated soil compaction danger, open ground areas established around trees, replaced soil cover, due to industrial depression decreased local air pollution.

Reliable correlation between lime radial increment and precipitation in May-September was ascertained. Radial increment of European limes positively correlates with mean air temperature in October (0.22) and precipitation in August (0.24), negatively – with mean air temperatures in February (-0.28) and April (-0.36) as well as with precipitation in November (-0.33).

It was found that *T. platyphylla* Scop. are of the best state – least crown defoliation and foliage dechromation, small amount of dry branches, abundant fruiting, greatest annual radial increment, as compared to other lime species. *T. europaea* L. and *T. euchlora* K. Koch. are in worse state – their radial increment is less, worse is the state of morphological indices. The state of *T. cordata* Mill. according to radial increment is moderate, while according to morphological tests – the worst: crown defoliation and foliage dechromation is the highes, rather abundant dead branches.

5.3. Dendrochronological studies of local industrial pollution on pine (*Pinus sylvestris* L.) and spruce (*Picea abies* (L.) Karsten) radial increment

Structure and dynamics of Jonava "Achema" emissions. In emission stream of one of the largest local pollution sources in Lithuania – Jonava mineral fertilizers plant "Achema" - prevail CO, SO_2, NO_2, NH_3 and mineral dust. Since 1971 the amounts and concentrations of emitted pollutants were gradually increasing. The biggest compound stream of emissions was in 1979-1982 – every year 34-40 thou. tons of pollutants were emitted into the atmosphere. In the zone of intensive pollution sulphates amounted 100 kg/ha, while in average pollution zone – 87 kg/ha, which 2.5 and 2.2 times exceeds background concentrations. Nitrate emissions in the zone of intensive pollution 5.9 times, while in average pollution zone 4.8 times exceeded background ones. Since 1983 the amount of emissions started decreasing and until 1994 was reduced 8 times.

Many scientists have proved that high concentrations of sulphur dioxide are harmful to plants, causes necrosis, gradual degradation and decline.

Tree annual radial increment variation in the impact zone of industrial pollution. Until the onset of pollution (in 1965) fluctuations of annual radial increment in pine and spruce stands are close to solar activity 11 and 12-year cycles, which in their turn lead to climatic background variation. Increment maximums coincided with favorable for growth warm periods, while minimums were relevant to low air temperature at the beginning of vegetation periods, when precipitation amount is close to norm, as well as in cold and rainy vegetation periods. In the first five-year period after fertilization start tree annual radial increment in the zones of intensive (8-12 km) and average (13-24 km) pollution are similar, i.e. close to the control, or insignificantly higher. At the beginning of another five-year period a decrease in radial increment is observed, depending on the distance from pollution source and the age of stands. In the zone of intensive pollution pine radial increment in 1973-1977 comprised 83-90%, while that of spruce – 83-87%, in the zone of average pollution – 88-94% and 87-91% respectively from the control increment (Stravinskienė, 1995). In 1978-1982 increment of the studied pine and spruce forests decreased even more: in intensive pollution zone pine increment reached only 60-75%, spruce increment – 50-70% from the increment of control stands in that year. Unfavorable climatic conditions have reinforced negative impact of pollutants, which after a very cold winter of 1978-1979 caused weakening of conifers and their degradation. In 1983-1984 pine radial increment in intensive pollution zone made up only 75-83%, that of spruce stands – 68-78% from the control, while in average pollution zone pine increment reached 82-88%, spruce stands – 74-81% from the control increment of that years. During the discussed period spruce radial increment decrease is more obvious than that of pine, in younger stands it is less than in older stands. In 1986-1988 increment decrease became stable, it was not decreasing, though in 1988-1989 climatic conditions were not favorable (cold and rainy vegetation periods) for increment formation. In 1989-1995 increment was restored; increment losses are on the level of the first five-year period (1968-1972) pollution.

<u>Tree annual radial increment structure and its changes due to local pollution.</u> Late wood in pine annual rings on average makes up 32.5±1.1% of radial annual increment. In years of the greatest increment on average is produced 28.0±1.5% of late wood, in years of the least increment – 35±1.7% from annual ring width. In annual rings of spruce less late wood is found – on average 22.5±1.7%, in years of greatest increment 18.3±1.8%, in least increment years – 26.0±1.2% (Стравинскене, 1983). It was ascertained, that under local industrial pollution late wood of slightly injured spruce trees on average comprised 24.5±1.2%, that of slightly damaged pines – 32.5±1.9% from annual ring width. Moderately injured young (20-40 years) pines have more late wood (38.5±1.3% from annual ring width) than older ones (over 60 years – 35.0±0.9%). Annual rings of moderately injured spruce trees produce

late wood according to age: 30.1±1.9% (20-40 years) and 27±2.2% (over 60 years). Heavily injured conifers, as compared to other injury groups, have the greatest amount of late wood. Late wood ratio, characterizing wood quality, reliably (P=0.95) increases by about 10-12% in annual rings of spruce and pine injured by local industrial pollution (Stravinskienė, 1995).

Pine and spruce volume increment losses due to local pollution. Mean increment losses over 28 years of local industrial pollution in the zone of intensive contamination in 60-year old pine stands comprised 2.66 m^3/ha, in spruce stands – 3.08 m^3/ha. The greatest volume increment losses were registered in the 3rd and 4th five-year periods of local industrial pollution, when the plant was heavily polluting environment. In 1978-1982 spruce stands lost 23.92 m^3/ha, pine stands – 20.64 m^3/ha of wood, while in 1983-1987 spruce stands suffered 21.65 m^3/ha, pine stands – 18-92 m^3/ha wood losses. Volume increment losses due to pollution are greater in spruce stands than in pine stands. Volume increment losses of spruce stands in five-year periods are distributed as follows: in 1968-1972 – 3.72 m^3/ha; 1973-1977 – 15.03 m^3/ha; 1978-1982 – 23.92 m^3/ha; 1983-1987 – 21.65 m^3/ha and 1988-1992 – 12.82 m^3/ha. This shows greater sensitivity of spruce to air pollution, revealed by a stronger reaction to pollution effect.

6. Crown defoliation impact on tree radial increment

In the system of European forest monitoring most widely used morphological test – tree crown defoliation – is one of the most important signs of tree response to air pollution (Ozolinčius, 1998). According to applied in Europe forest monitoring methodics (Manual on methods …, 1994), trees are considered healthy, if their crown defoliation does not exceed 10%. Carrying out dendroindicational studies for a more reliable indication of environmental state by retrospective tree annual ring analysis methods, especially in local pollution objects, it is important to define correlation between tree crown defoliation and its annual radial increment.

6.1. Pine crown defoliation impact on radial increment

To define correlation between crown defoliation and annual radial increment of pines, data on annual radial increment and crown defoliation of 2 Kraft class pines were used. The habitats of studied pines – Na and Nb, forest types – *Pinetum vacciniosum* and *Pinetum vaccinio-myrtillosum*, crown defoliation – up to 10%, 20%, 40%, 60% and 80%, age – 80 years. Having analyzed pine crown defoliation and radial increment data, it was found, that the values of tree radial increment are inversely proportional to crown defoliation degree: radial increment of most defoliated (60-80%) trees is the least, that of relatively healthy and less defoliated (0-10% and 20%) – the highest. It was found, that between tree crown defoliation and radial increment exists inverse close to linear dependance (correlation coefficient between current year defoliation and radial increment reaches – 0.73; in 3 recent years - -0.68; in 5 recent years - -0.52; in 10 recent years - -0.45; P=0.95) (Stravinskienė, 1995, 1997).

Undamaged trees have insignificant radial increment losses (up to 10%), slightly damaged - 11-40%, moderately damaged - 41-55%; heavily damaged - 56-70%, rather heavily - over 70%. With tree age increases crown defoliation and its impact on radial increment reduction.

Dependance of annual radial increment on crown defoliation degree may be expressed by the following equation:

$$Zr = 0,14 + \frac{1,94}{0,1D[1,5 - 0,13(8 - 0,1D) + 1]}, \tag{6.1}$$

where Zr – tree annual radial increment (mm), D – tree crown defoliation (%). As far as studied and compared was annual radial increment of older pines (the same age) of varying defoliation degree, age index in the formula was not necessary.

Based on annual radial increment data of trees with varying defoliation, mean widths of annual rings, mean square deviations and confidential intervals were ascertained under corresponding crown defoliation.

6.2. Spruce crown defoliation impact on radial increment

To assess spruce annual radial increment dynamics and tree response to environmental changes, 85 spruce trees of 2 Kraft class, 60 and 80 years old with different crown defoliation – up to 10%, 20%, 40% and 60% were studied. They grow in *Piceetum oxalidosum* and *Piceetum myrtillo-oxalidosum* forest types, on Nc and Nc-Lc habitats. Increment decrease has been ascertained since 1989-1990. In younger (60 years) spruce stands the most significant decrease in radial increment was registered in 1993, followed by an adverse effect of drought in 1992. Since 1993 was observed an insignificant increase of all defoliation degrees as well as increment of 60 and 80-year-old spruce trees. It was found that relatively healthy trees with defoliation up to 10% have the greatest annual radial increment as compared to the increment of other defoliation groups. Spruce annual radial increment dynamics of all defoliation groups (up to 10%, 20%, 40% and 60%) is similar, differ only the values of radial increment. The range of annual radial increment fluctuations of relatively healthy trees is slightly greater, than that of defoliated to a different degree. This difference is more characteristic to younger trees. With greater crown defoliation radial increment fluctuations decrease. In 1980 was registered decrease of spruce annual radial increment in all defoliation groups, except relatively healthy trees. An insignificant augmentation of spruce increment in 1981-1985 was related to favorable climatic conditions, while since 1990 observed sharp increment decrease was preconditioned by the impact of solar activity maximum (over 22-year cycle) on forests and climate. Younger spruce trees (up to 60 years), crown defoliation of which in 1994-1995 comprised 40% and 60%, were better growing in 1990 and 1991. However, during latter survey the trees were already dead (Papilė and Pakražantė objects). Mean while, the condition of relatively healthy (defoliation up to 10%) and slightly damaged (defoliation 11-25%) trees remained almost unchanged. Mean widths of spruce annual rings and their confidential intervals under a certain crown defoliation differ insignificantly from analogous pine radial increment and their crown defoliation indices. Mean annual radial increment of 80-year-old spruce trees defoliated to a different degree was quite different from the control and made up: 20% defoliation – 85%, 40% defoliation – 65-70%, while 60% defoliation – only 50% of the increment of relatively healthy spruce trees. Increment dynamics and absolute values of younger spruce trees from 40% and 60% defoliation groups, as compared among them selves differ insignificantly. Radial increment differences and the condition of trees defoliated to a different degree may be preconditioned by individual response of trees to environmental changes (Stravinskienė, 1995, 1997).

With the age of trees, increases their crown defoliation and its impact on radial increment reduction.

7. Forest drainage and fertilization impact on tree radial increment

7.1. Changes in Scots pine, Norway spruce and Black alder annual radial increment due to forest drainage

Trees growing on overmaistured and marshy forest habitats are characterized by small annual radial increment: in premature and mature Lithuanian pine stands 1.14-1.54 mm, spruce stands – 0.88-1.26 mm, in mature black alder stands – 1.43-1.65 mm (Stravinskienė, 1981), analogous situation is in similar climatic regions (Вомперский, 1968; Залитис, 1968; Смоляк, 1969 etc.).

The most important means to increase forest productivity on bogging up and marshy forests is forest drainage (Kapustinskaitė, 1983). It was found, that forest drainage efficiency (according to radial increment augmentation) depends on a complex of climatic conditions in the year of drainage (Stravinskienė, 1981; Стравинскене, 1983, 1988).

1951-1955 is considered to be a dry period, for during vegetation periods of 1951, 1952, 1953 and 1955 precipitation comprised only 70% of the summer norm, and only in 1954 precipitation quantity in summer was close to the norm of many years. At that time forest drainage was efficient on those sites, where ground water level had to be far lower, namely on wet sites, while inefficient it was on dry and normal humidity sites. Already in the first five-year period after drainage, at the start of dry period (1951-1953) pine radial increment depending on tree age increased by 5-22%. In younger pine stands (40-60 years) increment augmentation is more obvious: in the 1st five-year period – 22%, 2nd – 38%, 3rd – 28%, 4th – 27%, 5th – 24% from the increment of control stands (Stravinskienė, 1981; Стравинскене, 1983). Annual radial increment of older drained pine stands, starting with the 6th, while that of younger ones – with the 9th five-year period, already does not differ from the control.

1956-1959 years are attributed to a rainy period. Forest drainage them on overmoistured and wet habitats were less efficient. During the first five years after drainage in rainy period pine radial increment augmented in not significant (3-8% from control), while the greatest extra increment is observed at younger age in dried pine stands in the third-fourth five-year period after drainage, later it decreases.

Having drained pine and spruce stands at the beginning of dry periods, greater additional annual increment is obtained, as compared to tree growth results after drainage during a rainy period. Additional tree increment due to drainage is inversely proportional to the age of trees during drainage: the younger stands are drained, the greater additional increment is obtained (Stravinskienė, 1981). The greatest additional increment is obtained having drained 40-60-year-old pine stands at the onset of dry period, the least, while in some cases even increment reduction – having drained older stands during a rainy period.

Higher drainage efficiency during dry period is explained by two favorable for tree growth on overmoistured and marshy sites factors – technical and natural effect of drainage on trees. Due to this effect the reguired ground water level is attained more quickly and trees adapt over a shorter time to changing soil moisture conditions.

Very weak or no response at all was observed in annual radial increment of Black alder stands drained in different periods. Augmentation of Black alder annual radial increment on drained sites is rather insignificant. It depends on the age – an insignificant positive effect is observed in drained young *Alnetum* c*arecosum* and *Alnetum carecoso-calamagrosticosum* forests already 1-2 years after drainage, slightly increases during 3-5 five-year periods, later it does not differ from annual radial increment of undrained stands.

In older drained Black alder stands was ascertained a negative drainage effect, which is expressed by a decrease in annual radial increment. This confirms the conclusion by T.Kapustinskaitė, based on long-term studies on the growth and biological productivity of black alder stands, that drainage of older black alder stands is not purposeful (Kapustinskaitė, 1983).

Due to forest drainage changes the structure of tree annual rings. Under the effect of drainage increases the portion of late wood in annual rings: drainage in favorable dry period makes this increment more obvious, while in rainy period – less vivid (Стравинскене, 1983).

7.2. Forest fertilization impact on pine radial increment

Mineral fertilization of Scots pine growing on poor podzolic sandy soils yields positive results at younger age – under the impact of fertilizers tree annual radial increment augments by 20-45%, as compared to the control (Вярбила, 1983; Шлейнис, 1985).

Results of dendrochronological studies on Scots pine annual radial increment changes due to fertilization in 40-year-old stands growing on intermediate type peat soils (Pb habitat) in the surroundings of "Akmenės cementas" have shown, that annual radial increment of trees fertilized by traditional mineral fertilizers – nitrogen (carbamide – 80 kg/ha of nitrogen active substance) and phosphorus (superphosphate – 100 kg/ha of phosphorus active substance) has grown by 15-45% (P=0.95), as compared to the control.

Having fertilized with carbamide (80 kg/ha of nitrogen active substance), pine annual radial increment in the first year after fertilization increased by 20%, later it differed from the control by 10-15%. The greatest fertilization effect according to additional annual radial increment was recorded in pines stands fertilized by superphosphate in the second and fourth year after treatment, when pine annual radial increment augmented respectively by 46% and 30%, as compared to the control. Meanwhile, increment rise in the first and third year after fertilization made up only 16% and 17% (comparing to the control). Positive impact of superphosphate fertilizers became obvious in dry 1992 and 1994 years, when pine annual radial increment (comparing to the control) augmented by 46% and 30%.

To obtain additional pine increment, non-traditional fertilizers were applied as well – acid reaction (pH=3.0) phosphogypsum by Kėdainiai "Lifosa" (doses 5 t/ha and 10 t/ha) and a mixture of phosphogypsum (5 t/ha) with superphosphate (100 kg/ha of phosphorus).

The greatest effect of fertilization with non-traditional fertilizers according to pine annual radial increment rise was ascertained in the study object treated by twofold phosphogypsum doze (10 t/ha) – increment has augmented even by 39-47%, as compared to the control. Having fertilized with 5 t/ha of phosphogypsum, pine annual radial increment has grown by 11-30%, while with the mixture of phosphogypsum (5 t/ha) and superphosphatum (100 kg/ha of phosphorus) – by 18-23%, as compared to the control.

In favorable climatic period under greater growth intensity the need for various mineral elements increases, while in unfavorable for the growth period, when the growth is limited not by soil poorness, but by other factors, assimilation of mineral substances from fertilizers and the soil slows down. Therefore, fertilization during optimal for tree growth time preconditions by 25-30% greater annual radial increment, than fertilizing under unfavorable conditions. It was found, that having fertilized 2-3 years before increment maximum, revealed in masterchronologies and reflecting the onset of favorabe growth period, positive impact of fertilizers becomes obvious for 6-7 years, while having fertilized in the phase of climatic cycle 2-3 years before increment minimum, the impact of fertilizers is obvious only for 3-4 years. This is relevant to better assimilation of nutrients in favorable for growth climatic period and worse assimilation – in growth depression years.

To achieve the greatest efficiency of silvicultural measures, forest drainage and fertilization should be conducted in accordance with masterchronologies and annual radial increment forecasts, when until maximum remain only 2-3 years.

CONCLUSIONS

In the result of long-term dendroecological and dendroindicational studies on tree annual radial increment and condition in stands of different tree species growing in various Lithuanian forest habitats, affected by different management measures and environmental pollution of varying intensity, as well as having analyzed main tendencies of investigated indices, the following conclusions were drawn.

1.Analysis of the impact of the most important climate factors on tree radial increment has indicated, that in geographical latitude of Lithuania tree increment formation is preconditioned by air temperature and precipitation during the vegetation period:

a) on overmoistured and marshy forest habitats increment of the mean vegetation period temperature and less than the norm precipitation amount promotes tree growth, while surplus precipitation acts as growth limiting factor; increment correlation's with mean May-June temperatures (r=0.49-0.52) as well as May-August (r=0.45; -0.47) and July (r=-0.40; -0.52) precipitation are close and reliable (P=0.99);

b) in habitats of normal humidity precipitation impact on tree increment is less important than temperature; here reliable correlation was ascertained between pine and spruce annual radial increment and mean July-August temperature (r=0.28-0.29; P=0.95); some effect is observed by air temperatures in autumn, January-February and April (r=0.18-0.21; P=0.95);

c) absolute minimums of winter temperatures down to -30°C have no impact on tree annual radial increment, however, in the years (1909, 1928, 1940-1942, 1953 and 1979) of very cold winters followed by cold springs and cool summers annual radial increment decrease is observed in all studied habitats even up to 30-40%, compared to mean increment norm of many years;

d) correlation of annual radial increment of conifers with solar activity (Wolf's numbers) is not close, but reliable (r=-0.40; P=0.95), that of broadleaves – still weaker (r=-0.20 (-0.25); P=0.95).

2. By spectral and harmonic analysis methods, the following regularities of cyclic tree radial increment fluctuations and their dependance on climatic changes were ascertained:

a) 8-14 and 20-25-year-long radial increment fluctuation cycles are characteristic of pine and spruce annual radial increment in normal humidity sites; here also less expressed 5.5 and 7 year radial increment cycles were determined;

b) in permanently overmoistured and marshy habitats pine and spruce have a characteristic 11-year radial increment cycle with more distinct extremes every 22 years, black alder – 11-year increment cycle, in wetter habitats less expressed 7.5 and 13 year increment cycles were ascertained as well.

3. Application of dendrochronological study methods enable to evaluate both current and past environmental condition, depending on the abundance and time interval of applied dendrochronological information. According to annual radial increment of growing trees, masterchronologies for Scots pine (*Pinus sylvestris* L.) in *Pinetum vacciniosum* and *vaccinio-myrtillosum*, *Pinetum myrtillo-sphagnosum* and *Pinetum carecoso-sphagnosum* forest types, Norway spruce (*Picea abies* (L.) Karsten) – in *Piceetum oxalidosum*, *Piceetum myrtillo-oxalidosum* and *carecoso-calamagrosticosum* forest types, Black alder (*Alnus glutinosa* (L.) Gaertn.) – in *Alnetum carecosum* and *Alnetum carecoso-calamagrosticosum* forest types, Downy birch (*Betula pubescens* Ehrh.) – in *Betuletum carecosum* and *Betuletum carecoso-calamagrosticosum* forest types were compiled, reflecting changes of climatic conditions, short-term and average cycles over the last 100-170 years. They may be used as the standard (control) to assess efficiency of management measures (forest drainage, fertilization, etc.) as well as to evaluate and forecast negative impact of environmental pollution on forest ecosystems.

4. Elaborated annual radial increment forecasts for Scots pine (*Pinus sylvestris* L.) in *Pinetum vacciniosum* and *vaccinio-myrtillosum*, *Pinetum myrtillo-sphagnosum* and *Pinetum carecoso-sphagnosum* forest types; for Norway spruce (*Picea abies* (L.) Karst.) in *Piceetum oxalidosum* and *myrtillo-oxalidosum, Piceetum carecoso-calamagrosticosum* forest types; Black alder (*Alnus glutinosa* (L.) Gaertn.) in *Alnetum carecosum* and *Alnetum carecoso-calamagrosticosum* forest types; Downy birch (*Betula pubescens* Ehrh.) – in

Betuletum carecosum and *Betuletum carecoso-calamagrosticosum* forest types indicate, that:

a) permanently overmoistured bogging up and marshy forests at the beginning of 21st century (around 2001-2003) decline of ecoclimatic conditions and annual radial increment minimum is expected;

b) in normal humidity and dry habitats an insignificant deviation of annual radial increment from mean norm of many years is expected;

c) in the discussed period the most important environmental factor of forest ecosystems may be surplus humidity, which will be limiting in overmoistured, bogging and marshy, but neutral – in dry and normal humidity habitats;

d) around 2006-2010 augmentation of tree annual radial increment and forest ecosystems productivity is forecasted.

5. Studies of pine and lime morphological indices (crown defoliation, foliage discolouration, condition of tops and branches, fruiting, retention age of pine needle retention) and radial increment, as well as evaluation of the condition of city plantations and environmental quality indicate, that:

a) the period of 1994-1998 the highest pine crown defoliation in Kaunas is characteristic to Panemunė (30.8-38.8%), Petrašiūnai (41.9-43.5%), Palemonas (37.7-51.9%) objects and in Kleboniškis forest park sites (42.6%) in the vicinity of Kaunas-Klaipėda highway, the least (11.5-17.6%) – in less polluted environment of Botanical Garden and Jiesia Landscape Reserve;

b) a considerable decrease of pine annual radial increment in 1977-1980 is related to unfavourable for growth climatic conditions, especially to the impact of winter frosts in 1978-1979. Increment decrease was influenced also by environmental pollution. Another period of increment decrease started in 1990 and continued until 1996, since 1997-1998 stabilization tendency in pine annual radial increment reduction is observed, related to declining phase of 11-year Solar activity cycle;

c) according to the values of pine mean annual radial increment losses in 1969-1998, and taking into account crown defoliation values, increment reduction intervals, revealing the condition of pine stands, were ascertained and maps of pine radial increment loss zones in Kaunas city were worked out. They illustrate environmental condition and its suitability to biota, as well as the condition of pine forests over 3 recent decades;

d) ascertained by dendrochronological methods decline of the condition of city environment is confirmed also by pine crown defoliation and other morphological tests (discolouration, age of needles, condition of tops and branches): in 1994-1998 insignificantly, but reliably was decreasing the number of healthy trees, crown defoliation was increasing, condition of tops and branches was declining, retention age of needles was shortening. This is relevant to traffic pollution increment in recent years;

e) broadleaves are more resistant to environmental pollution than conifers, however, in those urban places, where conifers cannot grow due to high environmental pollution, the condition of broadleaves may indicate the effect of anthropogenic and climatic factors:

- among lime trees studied in Kaunas the best condition pertain large-leafed limes (*Tilia platyphylla* Scop.) – they have least crown defoliation and foliage discolouration (respectively 28.0±1.2% and 5.1±0.6%), small amount of dry branches, abundant fruiting, highest mean annual radial increment;

- most damaged are small-leafed limes (*Tilia cordata* Mill.); their crown defoliation and foliage discolouration are the highest (respectively 33.4±2.1%; 9.2±1.5%), quite many dry branches, low mean annual radial increment;

- European (*Tilia europaea* L.) and Crimean (*Tilia euchlora* K. Koch) limes occupy an interim position, their condition is very similar – defoliation and discolouration indices are respectively 30.8±1.7%; 6.6±0.9% and 30.9±3.0%; 6.7±1.8%.

6. Having analyzed the condition and growth of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten) in Jonava "Achema" local pollution effect objects, it was found, that:

a) until the onset (1965) of pollution tree annual radial increment fluctuations in spruce and pine stands are close to 11 and 22-year solar activity cycles – increment maximums coincided with favorable for growth warm periods, while minimums – with low air temperature at the beginning of vegetation period, when precipitation is close to norm, as well as with cold and rainy vegetation periods;

b) during the first five-year pollution period tree annual radial increment in the zones of intensive (8-12 km) and moderate (13-24 km) pollution is similar or close to the control, or insignificantly higher;

c) permanent negative effect of pollutants on pine and spruce forests, growing in the impact zone of Jonava "Achema" started in the second five-year pollution period (1973-1977). The greatest damages to forests were caused in 1977-1981, when in the zone of intensive pollution pine annual radial increment reached only 60-75%, while that of spruce – 50-70%, compared to the control increment. Just then amounts of the plant emissions with prevailing sulphur dioxide were the highest (34-40 thou. tons annually);

d) heavily damaged 60-year-old pine stands lost per year on the average 2.66 m^3/ha, while spruce stands – 3.06 m^3/ha of wood;

e) in 1986-1988 changes in pine and spruce annual radial increment stabilized at the level of 1980-1982, while in 1989-1995 a tendency of recovery and decreasing increment losses is observed.

7. Having analysed tree crown defoliation impact an radial increment, a reliable relation between current year defoliation and radial increment of the year (r=-0.73) was ascertained, over a longer period the relation is weaker: over 3 recent years r=-0.68; over five years r=-0.52, over 10 last years r=-0.45. Undamaged trees have insignificant radial increment losses (up to 10%), slightly damaged - 11-40%, moderately damaged - 41-55%; heavily damaged - 56-70%, rather heavily - over 70%. With tree age increases crown defoliation and its impact on radial increment reduction.

8. Studies on drainage efficiency of permanently overmoisted and marshy forests have shown, that tree annual radial increment augmentation after drainage is rather dependant on climatic conditions at the time of draining:

a) having drained *Pinetum myrtillo-sphagnosum* and *Pinetum carecoso-sphagnosum* forests as well as *Pinetum carecoso-calamagrosticosum* and *Pinetum calamagrosticosum* forests at the beginning of dry period (1951-1953), the period of stand adaptation to ground water level changes became shorted. This led to tree annual radial increment augmentation already in the first five-year period after drainage, while the greatest increment effect was attained in the second and third period after drainage. Later drainage effect was decreasing and after 25-30 years has disappeared, while tree annual radial increment corresponded to the increment of control (undrained) stands);

b) having drained in rainy period (1957-1959), the level of ground water changes in significantly, stand adaptation to new ecological conditions takes longer time and radial increment augmentation is achieved 2-3 years later, as compared to drainage in dry period;

c) it is more rational to drain pine and spruce forests growing on permanently overmoistured and marshy habitats at the beginning of dry periods, because then climatic conditions are more favourable for growth and greater effect is attained by draining;

d) drainage of black alder forests is inefficient: insignificant radial increment augmentation is observed in young drained *Alnetum carecosum* and *Alnetum carecoso-calamagrosticosum* forests 1-2 years after drainage. Their radial increment is slightly higher in the 3-5 five -years periods, later it does not differ from the increment of undrained black alder forests; in older drained black alder forests negative drainage effect was ascertained, expressed by tree annual radial increment decrease.

9. Results of dendrochronological studies on tree annual radial increment changes due to fertilization, carried out in 40-year- old pine forests in the vicinity of ”Akmenės cementas“ indicate, that annual radial increment of trees fertilised by different mineral fertilisers increased as follows:

a) having fertilized by carbamide (80 kg/ha of nitrogen active substance), pine annual radial increment in the first year after treatment augmented by 20%, in later years it differed from the control by 10-15%;

b) the greatest fertilization effect according to additional annual radial increment was ascertained after treatment with superphosphate (100 kg/ha of phosphorus active substance) in the second and fourth year after fertilisation, when pine annual radial increment augmented respectively by 46% and 30%, compared to the control; positive effect of superphosphate was revealed in dry 1992 and 1994 years, when pine annual radial increment (compared to the control) augmented by 46% and 30%;

c) the greatest effect of fertilization by double phosphogypsum dose (10 t/ha) - increment rise by 39-47%, compared to the control. Having fertilized with 5 t/ha of phosphogypsum, pine annual radial increment has grown by 11-30%, while with a mixture of phosphogypsum (5 t/ha) and superphosphate (100 kg/ha of phosphorus) - by 18-23%, compared to the control;

d) having fertilized 2-3 years before potential increment maximum, expressed in masterchronologies and revealing the onset of favourable for growth period, positive impact of fertilizers is felt for 6-7 years, meanwhile, having fertilized in the stage of climatic cycle 2-3 years before increment minimum, the effect of fertilizers is revealed only 3-4 years. This is related to better assimilation of nutrients during favourable for grown period and worse assimilation in growth depression years.

10. Seeking the highest efficiency of forest management measures according to tree annual radial increment augmentation forest drainage and fertilization should be done in accordance with increment rise from minimum foreseen in masterchronologies and annual radial increment forecasts, so that 2-3 years remain until increment maximum.

11. Investigations have indicated, that dendrochronological methods, based on tree annual radial increment analysis, are a sufficiently universal means, providing possibilities for assessment of climatic factors and anthropogenic changes impact on radial increment of trees and forecast of ecoclimatic conditions, as well as allowing by taking them into account- optimize the terms of management measures (drainage, fertilization) in forest ecosystems and achieve desired efficiency of the measures applied.

THE PROCEEDINGS GENERALIZED BY HABILITATION WORK

1. Articles in Lithuanian periodicals and continuous publications included in a special list confirmed by Lithuanian Council of Sciences

1. **Stravinskienė V.** 1981. Dendroclimatological investigation on drained Black alder forests. *Proceedings of Lithuanian Forest Research Institute*, vol. 20, Vilnius: Mokslas, p. 102-112 (in Lithuanian).
2. **Stravinskienė V P.** 1983. Changes of radial increment of Pine forest through ecoclimatic conditions and forest draining. *Proceedings of Lithuanian Forest Research Institute*, vol. 23, Vilnius: Mokslas, p. 31-38 (in Russian).
3. **Vaičys M., Armolaitis K., Murkaitė R., .Oniūnas V., Raguotis A., Šleinys R., Skuodienė L., Slavėnienė L., Stravinskienė V.** 1986. Impact of technogenous emissions on forest phytocenoses and soils. Lithuanian Academy of Sciences: *Geografijos metraštis,* vol. XXII-XXIII, p. 197-205 (in Lithuanian).
4. **Stravinskienė V.P.** 1988. The possibilities of forecast the radial increment of trees and apply it for planning of forest draining. *Proceedings of Lithuanian Forest Research Institute,* vol. 28, Vilnius: Mokslas, p. 154-161 (in Russian).

5. **Stravinskienė V.** 1995. Impact of local environmental pollution on increment of conifers. *Miškininkystė*, vol. 36, p. 82-99 (in Lithuanian).
6. **Stravinskienė V.** 1997. Some ecological aspects of the problem of Spruce forests decline. Lithuanian Academy of Sciences: *Agricultural Sciences,* No. 3, p. 83-88 (in Lithuanian).
7. **Stravinskienė V.** 1997. Dendroecological studies of pine forest and their application for indication of the environmental status. Lithuanian Academy of Sciences: *Ecology*, No. 2, p. 62-72 (in Lithuanian).
8. **Stravinskienė V.** 1997. Assessment of urban environment status according to crown defoliation and radial increment of pine forest ecosystems. Lithuanian Academy of Sciences: *Ecology*, No. 3, p. 68-74 (in Lithuanian).
9. **Stravinskienė V.** 1998. Modern masterchronologies and prognosis of annual radial increment of conifers – Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten) – in Lithuania. Lithuanian Academy of Sciences: *Ecology*, No. 2, p. 54-62 (in Lithuanian).
10. **Stravinskienė V., Venclovienė J.** 1998. Analysis of ecoclimatic fluctuations dynamics in masterchronologies and the retrospective search of environmental pollution effects to radial increment of trees. Lithuanian Academy of Sciences: *Ecology*, No. 1, p. 84-92 (in Lithuanian).

<u>2. Articles in foreign Scientific Journals and Collections of Scientific Articles, which editors are competent scientists in the corresponding sphere</u>

11. **Stravinskienė V. P.** 1983. Dynamics of early and later wood in tree rings and their change due to forest draining. Academy of Sciences of USSR: Ecology, No. 6, p. 29-34 (in Russian).
12. **Stravinskienė V. P.** 1987. Changing of radial increment of trees growing on the zone of the industrial pollution. *Forest management* (*Лесное хозяйство)*, No. 5, p. 34-36 (in Russian).
13. **Kairiukstis L., Grigaliunas J., Skuodiene L., Stravinskiene V.** 1987. Physiological and dendrochronological indications of forest decline and their application for monitoring. *Forest Decline and Reproduction: Regional and Global Consequences* (eds. L.Kairiukstis, S.Nilsson, A.Straszak). Proceedings of International Institute For Applied Systems Analysis, 2361 Laxenburg, Austria, p. 151-169
14. **Kairiūkštis L., Stravinskienė V.** 1987. Dendrochronologies for moist forests of Lithuania and their application for ecological forecasting. *Dendrochronology around the Baltic.* Annales Academiae Scientiarum Fennicae, Series A, III Geologia-Geographica, 145. Helsinki: Suomalainen Tiedeakatemia, p. 119-135.

15. **Vaichis M., Armolaitis K., Onyunas V., Raguotis A., Ragelis A., Skuodiene L., Slaveniene L., Stravinskiene V.** 1988. Control of damaging forest biogeoceonoses by toxic emissions. Academy of Sciences of USSR: *Forestry*, No. 4, p. 3-10 (in Russian).
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17. **Stravinskienė V., Dičiūnaitė B.** 1999. Health Condition and Dendrochronological Study of the Lime Trees in Kaunas City. *Baltic Forestry*, vol. 5, No 2, p. 37-44.

3. Collections of Scientific Articles published in Lithuania, corresponding to criteria confirmed by Lithuanian Council of Sciences

18. **Kairiūkštis L., Skuodienė L., Ozolinčius R., Stakėnas V., Stravinskienė V., Grigaliūnas J., Vencloviene J.** 1998. Impact of atmospheric air pollution and climatic changes to forest ecosystems. *Ecological sustainability of region in historical perspective*, Vilnius: Lithuanian Academy of Sciences, p. 93-108 (in Lithuanian).
19. **Kairiūkštis L., Grigaliūnas J., Skuodienė L., Ozolinčius R., Stakėnas V., Stravinskienė V., Venclovienė J.** 1999. Response of forest ecosystems to climate changes and atmospheric pollution. *Ecological sustainability of Lithuania in a historical perspective*, Vilnius: Lithuanian Branch of the International Center of Scientific Culture – World Laboratory, Lithuanian Academy of Sciences, p. 434-543 (in Lithuanian).
20. **Kairiūkštis L., Skuodienė L., Ozolinčius R., Stakėnas V., Stravinskienė V., Venclovienė J.** 1997. Investigation of changes in forest state and forest monitoring. *Science of Lithuania*. Vol. V, 13-14. Vilnius: Lithuanian Academy of Sciences, p. 101– 110 (in Lithuanian).
21. **Stravinskienė V.** 1998. Modern masterchronologies of Black alder and Birch in moist forest sities of Lithuania. *Dendrochronology and Environmental Trends.* Proceedings of the International Conference “Eurodendro-98”, Kaunas, p. 219-227.

Dr. Vida Stravinskienė

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Summary of Dr. Habilitation Dissertation

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Leidėjas – Vytauto Didžiojo universitetas (S.Daukanto 28, Kaunas) SL 1557
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