INSTITUTE OF BOTANY

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PINEWOOD GROWTH DYNAMICS IN UŽPELKIŲ TYRELIS OLIGOTROPHIC BOG DURING THE SUBATLANTIC PERIOD

Summary of doctoral dissertation

Natural sciences: biology (botany), 2B

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BOTANIKOS INSTITUTAS

Rūtilė Pukienė

PUŠYNŲ AUGIMO DINAMIKA UŽPELKIŲ TYRELIO AUKŠTAPELKĖJE SUBATLANČIO LAIKOTARPIU

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SANTRAUKA

Racionaliam gamtinių išteklių naudojimui ir sėkmingam aplinkosauginės politikos formavimui būtini duomenys ne tik apie dabartinės augalijos sudėtį, augalų rūšių produktyvumą, bendrijų funkcionavimą, bet ir apie jų raidos procesus. Be antropogeninių ir endoekogeninių (Šennikov, 1964) sukcesijų, ilgalaikiu požiūriu reikšminga ir natūrali egzoekogenetinė, tame tarpe ir klimatogeninė fitocenozių kaita. Augalijos sukcesijų procesai yra ilgalaikiai, tiesiogiai juos stebėti sudėtinga. Duomenų apie ilgesnius laikotarpius teikia paleobotaniniai augalijos liekanų tyrimai. Praeities augalijos ir gamtinės aplinkos tyrimams naudojami žiedadulkių ir sporų, augalų liekanų durpėse, ežerinėse ir kitose nuosėdose analizė (Kabailienė, 1990; Savukynienė et al., 1978). Specifinės, tiksliai datuotos informacijos apie praeities gamtinės aplinkos pokyčius teikia praeityje augusių medžių metinių rievių (metinio radialinio prieaugio) tyrimai.

Įvairiose pasaulio dalyse daugelyje pelkių randami vienas ar keli stipriai susiskaidžiusios durpės sluoksniai (" ribos horizontai"), dažnai su gausiomis medžių kelmų liekanomis (Chotinskij, 1971; Birks, 1975; Tallis, 1975 ir kt.). Tačiau tyrimų durpynuose, be kitų metodų naudojant ir subfosilinės medienos metinių rievių analizę, kol kas tėra atlikta nedaug (Munaut, 1966; Tallis, 1975; Becker, 1979; McNally, Doyle, 1984; Leuschner, Delorme, Hofle, 1987; Brown, Baillie, 1992; Lageard, Chambers, Thomas, 1992 ir kai kurie kiti).

Lietuvoje praeities augalijos tyrimams iki šiol nebuvo naudojama subfosilinių (nuosėdose užsikonservavusių) medžių liekanų metinių rievių dendrochronologinė analizė. Šio darbo hipotezė: dendrochronologiniai durpių kloduose užsikonservavusios praeities medžių medienos tyrimai gali papildyti palinologinę ir durpių analizę bei duoti naujos informacijos apie praeities augaliją, miškų augimo ir ekosistemų kaitos ypatybes, ekologinių sąlygų svyravimus.

Šis darbas yra mokslinių tyrimų, pradėtų Dendroklimatochronologijos laboratorijoje jau 1971 m., tęsinys (Bitvinskas, 1974, 1978). Darbe atliktais subfosilinių paprastosios pušies medžių liekanų, surinktų Užpelkių Tyrelio pelkės durpių kloduose, dendrochronologiniais tyrimais siekta atstatyti aukštapelkės *Pinus sylvestris* L. medynų augimo dinamiką: pušynų išplitimo bei nunykimo fazes, medžių metinio radialinio prieaugio, kaip biomasės produktyvumo rodiklio, svyravimus; tai pat istoriškai įvertinti ekologinių sąlygų raidą. Tikslui pasiekti, darbe buvo sprendžiami šie uždaviniai:

- išaiškinti aukštapelkinių augimviečių paprastosios pušies metinio radialinio prieaugio serijų sinchronizavimo ypatumus;
- kryžmiškai datuoti praeities medžių augimo laikotarpius;
- sudaryti ilgalaikę medžių metinio radialinio prieaugio chronologiją;
- atlikti pelkinių augimviečių pušies metinio radialinio prieaugio priklausomybės nuo klimatinių veiksnių analizę bei ištirti klimatinių veiksnių rekonstrukcijos galimybes;
- remiantis atstatyta pušynų augimo dinamika, įvertinti ekologinių sąlygų kaitą.

Tai pirmas Lietuvoje darbas, kuriame paleoekologiniams tyrimams panaudota užsikonservavusios aukštapelkės durpėje medienos metinių rievių analizė. Kryžmiškai datuojant pavyzdžių metinio radialinio prieaugio serijas, palyginta virš šešių milijonų serijų porų kombinacijų. Tyrimais nustatyta raistinės ir plyninės augalijos fazių kaita pelkėje per daugiau kaip 2000 metų. Raistinėms fazėms sudarytos penkios *Pinus* *sylvestris* metinio radialinio prieaugio chronologijos, apimančios 80% viso 2145 metų ilgio periodo. Medžių stiebų metinio radialinio prieaugio priklausomybės nuo klimatinių veiksnių nustatymui panaudoti nauji matematinės analizės metodai: autoregresinis modeliavimas ir variacijos pirminių komponentų analizė. Pagal Užpelkių Tyrelio aukštapelkės pušynų augimo dinamiką kokybiškai rekonstruota pastarųjų dviejų tūkstantmečių ekologinių sąlygų kaita. Rezultatų atitikimas kitų autorių praeities klimato Europoje vertinimams rodo, kad nustatyti paleoaplinkos kitimai nebuvo tik vietinės reikšmės, bet atspindėjo Europos masto makroklimatinius procesus.

Pagrindiniai darbo rezultatai svarstyti moksliniuose pranešimuose: VII Jaunųjų mokslininkų - botanikų Sąjunginėje konferencijoje Berezinos rezervate (Baltarusija, 1987); V Visasąjunginėje konferencijoje dendrochronologiniais klausimais (Sverdlovskas, RSFSR, 1990); tarptautinėje konferencijoje "Medžių rievių tyrimai ir miškų džiūvimas" (Kaunas, 1993); Baltijos jūros regiono dendrochronologų pasitarime (Kopenhaga, Danija, 1993); tarptautinėje konferencijoje " Medžių rievės, aplinka ir žmonija: tarpusavio ryšiai ir procesai" (Tucson, JAV, 1994); tarptautiniame pasitarime " Europos dendrochronologijos pasiekimai" (Travemiundė, Vokietija, 1994); tarptautinėje konferencijoje " Senųjų miestų ir archeologinių radinių geochronologija, dendrochronologija ir radiokarboninis datavimas" (Vilnius, 1994); VDU Kauno Botanikos sodo 1991-1994 m. darbų ataskaitinėje konferencijoje (Kaunas, 1995); V konferencijoje " Absoliutaus datavimo metodai" (Gliwice-Rudy, Lenkija, 1995); tarptautiniame pasitarime " Baltijos tinklas pakrančių ekosistemų modelinių rūšių biojvairovei ir produktyvumui tirti" (Nida, 1995), tarptautiniame simpoziume " Modelinių rūšių duomenų bazės naudojimas" (Vilnius, 1996).

Darbo rezultatai ir išvados paskelbti 11 mokslinių publikacijų.

Disertaciją sudaro 136 puslapiai, 13 lentelių, 52 paveikslai, 268 šaltinių literatūros sąrašas ir 8 priedai, sudarantys 11 puslapių.

IŠVADOS:

1. Lietuvos aukštapelkių durpių kloduose užsikonservavusi subfosilinė paprastosios pušies mediena (kelmai ir stiebai) išsaugo nepakitusią metinių rievių struktūrą kelis tūkstančius metų. Jos tyrimui ir rievių kryžminiam datavimui gali ir turėtų plačiau būti taikomi dendrochronologiniai metodai. Apie pusės (47%) Užpelkių Tyrelio subfosilinės medienos pavyzdžių metinio radialinio prieaugio serijos turėjo pakankamai ryškią bendrąją dinamiką, leidžiančią jas sinchronizuoti. Aukštapelkinių augimviečių pušies prieaugio serijų sinchronizavimą apsunkinantys veiksniai yra palyginus neilgas medžių amžius (vidutiniškai 107 metai), atskiriems medžiams būdingas prieaugio kaitos individualumas dalį ar visą augimo laikotarpį, dažnai pasitaikančios "iškrentančios" ir "dvigubos" metinės rievės, taip pat kai kuriais šimtmečiais ryškus prieaugio dinamikos cikliškumas, sąlygojantis asinchroniškai gretinamų serijų pseudopanašumą.
2. Nustatyta, kad per paskutinius du su puse tūstančio metų Užpelkių Tyrelio aukštapelkėje vyko periodiška raistinės ir plyninės augalijos fazių kaita. Tiriamajame plote pirmoji *Pinus sylvestris* L. medyno fazė prasidėjo II a. pr.Kr., medynas nunyko VI a. po Kr. Antroji medyno fazė prasidėjo masiniu medžių atželimu VI - VII amžių po Kr. sandūroje ir baigėsi IX amžiaus pradžioje. Trečioji pušyno fazė truko nuo X a. vidurio iki XII a. pradžios. Ketvirtosios fazės medynas pradėjo formuotis antroje XII a. pusėje ir nunyko XV a. pabaigoje. Penktoji pušyno fazė prasidėjo XVIII a. pabaigoje ir truko iki durpyno eksploatacijos pradžios. Tokia detali pelkės medyno istorija Lietuvoje atkurta pirmą kartą.
3. Atlikus dabar augančių aukštapelkinėse augimvietėse *Pinus sylvestris* medžių metinio radialinio prieaugio ryšių su klimatiniais rodikliais analizę, nustatyta, kad skirtinguose Lietuvos regionuose medžiai nevienodai reaguoja į klimatinių sąlygų kaitą. Užpelkių Tyrelio aukštapelkėje *Pinus sylvestris* medžių metinis radialinis prieaugis teigiamai koreliuoja su ramybės sezono pabaigos ir vegetacijos sezono mėnesių temperatūra ir neigiamai koreliuoja su metine kritulių suma. Rytų Lietuvoje, labiau kontinentinio klimato sąlygomis, medžių prieaugio koreliacija su metine temperatūra yra neigiama, teigiamą įtaką turi žiemos (gruodžio - sausio mėnesių) ir einamųjų metų rugsėjo krituliai.
4. Dėl neišreikštos prieaugio serijose amžiaus kreivės aukštapelkinių augimviečių pušies prieaugio chronologijų standartizavimas (indeksavimas) neturi statistiškai patikimos vienareikšmės įtakos koreliacinių ryšių su klimatiniais rodikliais stiprumui. Prieaugio serijų autoregresijos pašalinimas išryškina metinio prieaugio koreliaciją su tais klimatiniais veiksniais, kurie turi priešingą poveikį einamųjų ir sekančiųjų metų prieaugiui.
5. Pirminių komponentų išskyrimas iš individualių medžių prieaugio variacijos ir šių komponentų amplitudžių panaudojimas daugiamačiuose regresijos modeliuose leidžia rekonstruoti didesnę klimatinių parametrų variacijos dalį negu vienmačiai modeliai, besiremiantys vidutine visų barelio medžių prieaugio chronologija. Pagal Užpelkių Tyrelio pušų prieaugio chronologijos reikšmių fluktuacijas rekonstruojama 16,4% vidutinės vasario - rugsėjo mėnesių temperatūros variacijos, o pritaikius regresijos modelį, kurio nepriklausomi kintamieji yra medžių prieaugio variacijos dviejų pirminių komponentų amplitudės - 24,2%.
6. Nepalankūs laikotarpiai paprastosios pušies augimui Užpelkio Tyrelio aukštapelkėje, rodantys pelkės vandens lygio pakilimo, vegetacijos sezono temperatūros pažemėjimo ir (arba) kritulių pagausėjimo tendencijas, rekonstruojami Subatlančio laikotarpio pradžioje iki I a. pr. Kr., IV amžiaus po Kr. pirmoje pusėje, V - VI amžiais po Kr., IX a., XII a. viduryje, XVI - XVIII a. Optimalūs padidėjusio medžių metinio prieaugio periodai, rodantys pelkės nusausėjimo, sauso ir (arba) šilto klimato sąlygas, buvo mūsų eros pirmaisiais amžiais, VII - VIII a., XI a., XIX a. antroje pusėje - XX amžiuje. Šie periodai atitinka kitų autorių atliktus praeities klimato Europoje vertinimus. Atitikimas tarp *Pinus sylvestris* augimo sąlygų kaitos Užpelkių Tyrelio aukštapelkėje ir kitų autorių paleoklimatinių rekonstrukcijų rodo, kad medyno augimo dinamika priklausė ne tik nuo vietinių ekologinių sąlygų, bet atspindėjo ir Europinio masto klimato fluktuacijas.
7. Įrodyta, kad subfosilinės medienos, užsikonservavusios aukštapelkių durpėse, tyrimas dendrochronologiniais metodais, pasitelkiant radioanglies datavimo ir paleobotaninius nuosėdų analizės metodus, suteikia galimybę atkurti praeities augalijos kaitos aspektus ir įvertinti paleoekologinių sąlygų svyravimus. Siekiant papildyti ir patikslinti gautą šiame darbe informaciją, t.y. vienerių metų tikslumu datuoti praeities medžių augimo laikotarpius ir sudaryti ištisinę aukštapelkinių augimviečių pušies metinio radialinio prieaugio chronologiją, būtina pratęsti tyrimus panašaus pobūdžio objektuose - aukštapelkėse, kuriose augančių pušų prieaugio dinamika būtų panaši į Užpelkių Tyrelio medžių ir kuriose pušynas būtų augęs tais laikotarpiais, kai Užpelkių Tyrelio pelkės tirtame plote medynas buvo nunykęs.

INTRODUCTION

For the efficient use of natural resources and development of successful environmental policy not only data on the present status of flora composition, plant species productivity and functioning of phytocoenoses but also knowledge of the processes of changes in them is necessary. Besides to anthropogenic and endo-ecogenetic (Shennikov, 1964) successions, natural exo-ecogenetic changes in phytocoenoses including climagenetic ones are also important, especially in a long time scale. Since changes in vegetation are slow and long - lasting, direct observation of them is complicated. Data covering longer periods is obtained by palaeobotanical studies of plant remnants. For investigating past vegetation and environments the analysis of pollen and spores, plant remnants contained in peat, lacustrine sediments and other deposits is used (Savukyniene et al., 1978; Kabailienė, 1990). Additional accurately dated information about past environmental changes and events is obtained by investigating annual rings (annual radial growth layers) of trees that grew in the past.

Many bogs in different parts of the world contain one or more layers of highly humified peat (recurrence horizons) often with abundant macrofossils of wooden plants (Chotinskij, 1971; Birks, 1975; Tallis, 1975, etc.). However, palaeoecological studies that include the analysis of annual rings of subfossil timbers from peat deposits are so far sparse (Munaut, 1966; Tallis, 1975; Becker, 1979; McNally, Doyle, 1984; Leuschner, Delorme, Hofle, 1987; Brown, Baillie, 1992; Lageard, Chambers, Thomas, 1992 and some others).

In Lithuania the dendrochronological analysis of annual growth layers of tree remnants preserved in deposits has not been used for investigating past vegetation history until recently. The following general hypothesis has been pursued by this study: dendrochronological research on timbers of trees that grew in the past and were preserved in anoxic peat deposits of our bogs can provide additional information to that gained by pollen or peat composition analysis and help to reconstruct aspects of past vegetation history and palaeowoodland dynamics, fluctuations in past ecological conditions.

This study is a continuation of scientific research that was begun at the Laboratory of Dendroclimatochronology already in 1971 (Bitvinskas, 1974, 1978). The main purpose of the study is to establish by the means of dendrochronological analysis of subfossil timbers, collected from oligotrophic peat deposits, the growth dynamics of *Pinus sylvestris* L. palaeowoodlands in Užpelkių Tyrelis raised bog: the history of pine forest establishment and extinction and fluctuations of pine tree annual radial growth - an indicator of its bioproductivity; also assess environmental changes historically.

In order to achieve the purpose the following research tasks have been formulated:

- to find out the specific features in synchronization of tree ring series of *Pinus sylvestris* from oligotrophic bog habitat;
- to cross-date and place in time the growth spans of pine trees from the past;
- to develop the long-term chronology of pine tree annual radial increment;
- to analyse relations between annual radial growth of *Pinus sylvestris* from oligotrophic bog habitat and climatic factors and assess possibilities of climatic reconstructions;
- to assess variations in past ecological conditions basing on the reconstructed dynamics of past pinewood growth.

This is the first study in Lithuania in which tree ring analysis of subfossil timbers preserved in oligotrophic peat deposits has been used in palaeoenvironmental investigation. In the process of cross-dating more than six million combinations of tree-ring series overlap have been checked. The recurrent changes between the phases of woodland and open-land type bog vegetation during more than 2000 years were detected by this research. Five *Pinus sylvestris* tree-ring chronologies were developed for pinewood phases that covered 80% of the total 2145 year length period. In the investigation of dependence of tree stem annual radial growth on climatic factors methods of autoregressive modeling and principal component analysis have been used. Qualitative reconstruction of changes in ecological conditions during the last two millennia has been performed basing on the growth dynamics of Užpelkių Tyrelis bog pinewoods. Correspondence between the obtained results and evaluations of past European climate by other authors indicates that detected environmental changes were not only of local-scale but also reflected European-scale macroclimatic processes.

The research material was presented at the scientific conferences:

the 7th Conference of Young Scientists - Botanists (1987, Berezina, Byelorussia); the 5th Conference of the Soviet Union on Dendrochronology (1990, Sverdlovsk, Russia); the International Workshop on Dendrochronology "Tree Rings Studies and Forest Decline" (1993, Kaunas, Lithuania); the Meeting of Dendrochronologists from around the Baltic Sea (1993, Copenhagen, Denmark); the International Conference on Tree Rings, Environment, and Humanity: Relationships and Processes (1994, Tucson, USA); the International Dendrochronological Meeting " Advances in European Dendrochronology" (1994, Travemünde, Germany); the Conference on geochronology and dendrochronology of old town's and radiocarbon dating of archaeological findings (1994, Vilnius, Lithuania); the Conference on 1991 - 1994 Research Reports of VMU Kaunas Botanical Gardens (1995, Kaunas, Lithuania); the 5th Conference " Methods of Absolute Dating" (1995, Gliwice-Rudy, Poland); the International Meeting " Baltic Network of Biodiversity and Productivity of Selected Species in Coastal Ecosystems" (1995, Nida, Lithuania); the International Symposium " The Usage of the Database of Selected Species"(1996, Vilnius, Lithuania).

The results are published in 11 scientific publications.

The dissertation consists of 136 pages, including 13 tables, 52 figures, 268 references, and 8 appendixes consisting of 11 pages.

CONTENTS OF THE WORK

Chapter 1. The use of tree radial growth studies for the assessment of changes in ecological conditions.

1.1. Cross - dating of tree - ring series: the methodical principle for the construction of long-term chronologies. Research works on the development of long - term tree ring chronologies using synchronization (cross - dating) of ring sequences from historical timber (i.e. preserved *in situ*, construction timber, wooden articles, etc.) are surveyed.

1.2. Reconstruction of climatic and other ecological factors by use of dendrochronological methods. Applications of tree - ring studies for reconstructing variations in environmental conditions are discussed.

1.2.1. Quantitative reconstructions in North America
and

1.2.2. Dendroclimatic and dendroecological studies in Europe. Studies on the relationships between tree ring growth and environmental factors as well as reconstructions of these factors using living tree radial growth chronologies are shortly reviewed in these two sections.

1.2.3. Historical information obtained from buried (subfossil) trees. A review of not numerous studies on past environmental changes using analysis of growth dynamics of subfossil trees buried in deposits is presented.

Chapter 2. Oligotrophic bogs: a source of information on past environmental changes.

2.1. Basic information on the development of bogs in Lithuania. In Lithuania only 50 - 70 % of the total annual precipitation is evaporated. Excess humidity causes bog development in places with suitable relief and geological structure (Seibutis, 1958). There are about 330 thousand ha peateries larger than 1 ha (5.1 % of the territory) in Lithuania (Skaisgirys, 1966). About two thirds of bogs are of lake origin (Seibutis, 1958). The region is in a zone of raised oligotrophic bogs, the group of sphagnum bogs with central pit complexes and not prominent micro relief (Kac, 1948).

In Lithuania peat accumulation started in the Late Glacial during the warmer Alleriod period (Kabailienė, 1990). Mass formation of bogs took place in the end of the Boreal - in the beginning of the Atlantic (Kabailienė, 1990; Seibutis, 1958). Peat layers from the dry Subboreal period contain a great amount of woody plant remains (Kabailienė, 1990). In the Subatlantic period oligotrophic bogs have become predominant, protuberance of raised bogs has been formed (Kabailienė, 1990; Savukynienė et al. 1978).

The area of bogs is extremely decreasing because of human activities during the last century. Eight physical geographical regions (from 22) of Lithuania have already lost their major (more than 50 ha) vegetating bogs (Kunskas, 1986).

2.2. Plant communities in oligotrophic bogs. In this section the communities of oligotrophic peat-forming plants in Lithuania are surveyed. According to the present time floristic - sociological syntaxonomy (Balevičienė, 1991) plant communities in Lithuanian oligotrophic bogs belong to two phytocoenotic classes: *Oxycocco - Sphagnetea* Br.-Bl. et R.Tx. 1943 in which communities without wooden plants are united, and *Vaccinietea uliginosi* Lohmeyer et R.Tx. 1955 with prevailing Ledo - Pinetum association for which the dominance of *Pinus sylvestris* stand is characteristic.

2.3. Specific features of *Pinus sylvestris* in boggy habitats. Peculiarities of Scots pine growth conditions in oligotrophic bog habitats (Sukachiow, 1905, McVean, 1963, Smoliak, 1963, Läänelaid, 1979, 1981, Karpavičius, 1981, 1984, etc.) and morphological forms of *Pinus sylvestris: P. sylvestris f. uliginosa, P. sylvestris f. litwinowii, P. sylvestris f. willcommii, P. sylvestris f. pumila* (Abolin, 1915; Dendrologija, 1973, Läänelaid, 1979) are shortly described.

Chapter 3. Sites and materials of the study. Subfossil wood specimens for the dendrochronological investigation have been collected from peat layers of exploited peat bog Užpelkių Tyrelis. The bog is located in the North - west part of Lithuania, in the region of Žemaitija Hills, Plungė district, 47 km east of the Baltic sea and 1 km north of Plateliai lake, 138 m above sea level. Geographical co-ordinates: latitude 56°05' N, longitude 21°50' E. The earth surface of this region is undulated as well as the bottom of the bog and more or less the layers of peat. The bog was investigated by the Administration of Peat Resources in 1959, before peat harvesting, and by the researchers from the former Geographical Section of the Institute of Zoology and Parasitology (the present Institute of Geography) dr. M.Grigelytė and dr. N.Savukynienė (Savukynienė et al. 1978). The area of the bog is 36.7 ha, mean thickness of peat is 3.4 m, the highest 8.0 m.

3.1. Development of Užpelkių Tyrelis bog according to pollen and peat analysis. The peat bog is of a lake origin, its formation started in the Boreal (Savukynienė et al. 1978). In the beginning of the Subboreal mesotrophic carex - sphagnum plant communities began to predominate. The turn to the oligotrophic bog phase began in the dry period at the end of Subboreal. In the Subatlantic period all the area of the bog was oligotrophic, except the eutrophic outlier in the south.

3.2. Specimens of subfossil *Pinus sylvestris* timber. Specimens of timber, preserved in the layers of oligotrophic peat, were collected by scientists and workers of the dendroclimachronological laboratory under the supervision of dr. T.Bitvinskas, during the expeditions in 1971 - 1972. Timbers, found in the peat, consisted of *Pinus sylvestris* stumps, with a longer or shorter section of stem (on average 20-40 cm height), and prostrated trunks. The structure of tree rings was excellently preserved. For the investigation the stem part cross-sections were sampled. More than 300 specimens of subfossil pine were collected in total. About half of the specimens were collected from the area, levelled during peat harvesting (about 1 m below the original bog surface). Other specimens were collected from two excavations through peat deposits. The first excavation (1m width, 60 m length) was located south-east of the harvested area and covered the original surface peat layers of about 1 m in thickness. The second one (2m width, 120 m length) was excavated in the levelled area and covered oligotrophic peat layers from 1 to 2.8 m in depth. The deepest timbers were found in the depth of 2.6 m. Excavated trees were 17 to 236 years old, on average 107 years old.

Twenty-eight specimens of subfossil timber from various depths were dated by ^{14}C method in the Estonian Institute of Zoology and two specimens in the Institute of History of Material Culture in St. Petersburg (Russia).

3.3. Dendrochronological sites of living Scots pine trees in oligotrophic bogs. In order to investigate the environmental factors influencing the growth of pine in oligotrophic bogs the annual radial growth of living Scots pine trees from two bog sites was analyzed. The first site was selected in the same Užpelkių Tyrelis bog in marginal areas undisturbed during peat harvesting. The second dendrochronological site was located in the east Lithuania, in Utena district, Daunoriai forestry, in an oligotrophic bog, geographical co-ordinates: 55°26′ N, 25°57′ E, 153 m above see level. The characteristic of both sites: pure *Pinus sylvestris* stand, Ledo - Pinetum association, poor peat-bog habitat. Mean age of the stand in the Užpelkių Tyrelis site was about 100 years, mean stand height (H) was 10 m and mean stand diameter (D) was 11 cm. The mean age of the stand in the Daunoriai site was about 160 years, H 11m, D 13 cm. Ten model trees were sampled at the breast height in the Užpelkių Tyrelis site and eleven trees in the Daunoriai site, two radii per tree. In the Daunoriai site the trees were selected in a profile from a bog lake towards the bog margin where the bog met a steep hillside.

3.4. Meteorological data. Meteorological data (average monthly temperature and monthly precipitation sum) from Telšiai meteorological station (55°59′ N, 22°15′ E, 149 m above see level) and from Utena station (55°59′N, 22°15′ E, 149 m above see level) has been used for analyzing relationships between tree radial growth and climatic variables. Tree ring data from the Užpelkių Tyrelis site has been compared with Telšiai meteorological data and the data from the Daunoriai site has been compared with Utena meteorological data.

Chapter 4. Methods of investigation.

4.1. Sample preparation and measurement. Wood samples were prepared and annual radial growth (tree ring width) was measured using standard dendrochronological technique (Bitvinskas, 1974). Surface of stem part cross-sections of subfossil timbers was sanded and tree ring width was measured in 2 to 4 radii per specimen by stereomicroscope MBC-2 with magnification 2 x 8 and accuracy of 0.05 mm. Measurement surface of the wood cores from living trees was prepared by sledge microtome, annual increment was measured using automatic measurement system with accuracy of 0.01 mm. Annual growth records were verified by visual cross-dating on the wood cores at first, and later by synchronizing the annual growth graphs.

4.2. Dendrochronological methods of synchronization (cross-dating) of tree-ring sequences.

4.2.1. Mathematical methods of synchronization. For synchronizing annual growth series of subfossil timbers all the series were compared in pairs. All possible positions of overlap with no less than 30 years overlapping were checked. In each position the following parameters of series similarity were calculated: the coefficient of parallel variation (Bitvinskas, 1974; Huber, Gierz, 1970), correlation coefficient, and Student's t value (Baillie, Pilcher, 1973; Aniol, 1983; Schou, Rytter, 1992). The coefficients of parallel variation and correlation coefficients were calculated in our laboratory by the program designed for the computer M-6000. The Student's t values were calculated by the PC program CATRAS during the author's visit to the lab of Dendrochronology of Joensuu University (Finland).

4.2.2. Visual methods of synchronization. In order to synchronize growth series and also for locating " missing" and " false" rings besides mathematical methods also visual cross-dating has been used. Superimposed graphs of growth series have been compared on a light box in a process of stepwise sliding one graph against another by one year and looking for the position of the best correspondence. Final conclusion about synchronism has been made basing on the complex use of visual as well as mathematical methods. The conclusion is accepted if cross-dating of two growth series is replicated by comparison with growth series of other trees that have been growing during the same time period.

4.3. Calibration of radiocarbon ages. Radiocarbon dates of subfossil timber specimens were calibrated according M. Stuiver and G.W.Pearson (1986) calibration curve by using Groningen computer program (Van der Plich, Mook, 1989). A part of the dates was calibrated at the laboratory of dendrochronology of Joensuu University (Finland), and another part - in the Institute of Material Culture History in St. Petersburg (Russia).

4.4. Methods used in the analysis of exogenic factors influencing tree growth dynamics.

4.4.1. Standardization of chronologies. We used absolute ring with (measurement data) series in the process of cross-dating the growth of subfossil trees. For the analysis of relationships between tree growth and climatic factors we used three types of living tree site chronologies: that of averaged measurement data (ABS), standardized chronology of indices (STD) and of residuals from autoregressive modeling (RES). Site

chronologies were computed by averaging the growth series of individual trees. For computing index chronologies the age curve from series was removed by fitting a spline function. Detrending, autoregressive modeling and chronology computation were carried out using ARSTAN40 PC program from ITRDB Program Library (1994), designed in the University of Arizona (USA) (Cook, Holmes, 1986).

4.4.2. Correlation and regression. Relationships between the growth chronologies and climatic variables were analysed by using simple linear correlation. We used EXCEL PC program for calculating correlation coefficients and Student's t values to estimate their statistical significance. To investigate the possibilities of climatic reconstructions we used simple regression models with site chronology data as the predictor, and multiple regression model, where the amplitudes of the most significant principal components from the growth data of site trees were used as the predictors. The regression models and climatic estimates were computed also by using EXCEL program.

4.4.3. Principal component analysis. For analysing the relationships between annual radial growth of trees and climatic variables the principal component method (Zhukovskaja, Muchnik, 1976; Fritts, 1976; Belonin et al., 1978; Wonnacott, Wonnacott, 1979; Stupneva, 1984a, b) was used to reexpress the variability of annual growth of individual trees by the reduced number of principal components. We used ARSTAN 40 program for the principal component analysis and for computing the time series of principal component amplitudes. Those components were considered as significant for which the cumulative product of eigenvalues exceeded 1 (unparametric value) (Belonin et al., 1978; Briffa et al., 1983, etc.).

Chapter 5. Pine woodland phases in Užpelkių Tyrelis peat bog during the Subatlantic period.

5.1. Specific features in synchronization of radial growth series from oligotrophic bog - grown pine. In the process of cross-dating the tree ring series of subfossil timbers, more than six million combinations of series overlap have been checked. It has been established that strong interrelationships between the growth patterns were characteristic of a smaller part of the trees. Prevalence of short series also complicated the synchronization process.

In poor oligotrophic bog habitat trees grow under specific conditions. The variation of their annual growth is determined not so much by climatic factors, common to all the trees, as by interaction of climatic and edaphic factors that differs depending on the conditions of micro - habitat (Karpavičius, 1994). Because of that, not all the trees in the site demonstrate parallelism between their annual growth fluctuations. Analysis of similarity between the growth dynamics of living Scots pine trees from oligotrophic bog habitat revealed that inter-tree correlation coefficients between growth series ranged from +0.79 to +0.08 (within Užpelkių Tyrelis site) and from +0.81 to -0.14 (Daunoriai site). Similar results were obtained by J.Karpavičius, who had found that the coefficient of parallel variation greater than 60 % was characteristic of only 30 to 60 % of the trees from the site (Karpavičius, 1984). For reliable synchronization of tree ring series with not high degree of similarity replication of cross-dating is necessary - i.e. a group of more than a pair of series should be cross-dated (Pikšrytė, Bitvinskas, 1989). However, part of the series of bog - grown pine trees, the growth dynamics of which is very different from the others, can not be synchronized.

It was noticed that annual growth patterns of synchronously - grown Scots pine trees from oligotrophic bogs often were similar only during some interval of the common growth period. The similarity decreased or disappeared in another interval. In such cases low values of the numerical parameters of similarity were obtained because mathematical methods, used in the study, estimated similarity over the total period of the series overlap.

The numerical parameters of similarity between series are distortedly low if some series contain " missing" or " false" rings. These anomalous growth effects that often occur in bog - grown pine series (Pikšrytė, 1989) were identified by visual cross-matching between the ring series of trees that grew during the same time period. The series with anomalies were corrected by inserting " zero increment" ring or by combining double rings that were formed within one year.

The authors that investigated dynamics of pine radial growth at the lakeside stands with high ground water table (Pakalnis, 1978; Kriukelis, 1995) have established clear cyclicity in radial growth fluctuations, related with lake water level as well as ground water level fluctuations. Rather distinct cyclicity can be noticed in the growth dynamics of Scots pine from oligotrophic bog habitat during some periods of time, too. Because of these cyclic fluctuations high values of correlation can be obtained in non-synchronous positions of series overlap if phases of the expressed cycles coincide, i.e. the phenomenon of pseudo - synchronism is noticed. When calculating the mathematical parameters of similarity among the tree ring series, in some cases the good parameters of similarity (e.g. t value greater than 4.0) have been obtained in three or four positions of overlap of the same two series.

Because of the above mentioned peculiarities, complex use of visual as well as mathematical methods is necessary for synchronizing radial growth series of bog - grown pine. The use of mathematical parameters facilitates selection of likely positions of synchronism between series, but visual comparison of annual growth curves enables to locate " missing" or " false" rings and the intervals of synchronous fluctuations, and also make the final conclusion about synchronism.

5.2. <u>Cross - dating of radial growth series of subfossil trees and construction of long - term chronology.</u> About half (47.0%) of the growth series of the subfossil pine trees were cross-dated and used for construction of long-term chronology. Mostly short-lived trees were declined. Cross- dating revealed clustering of tree life spans in particular intervals of a time scale. It was established that pine woodland had not been covering the study area for the whole period since the bog turned to oligotrophic phase. Separate afforestation phases became evident. These phases are represented by five clusters of cross-dated timbers (Pikšrytė, 1996).

The tree ring chronologies for those afforestation phases do not overlap (or do not overlap properly) and can not be cross-dated by the means of dendrochronology with the accuracy of one year (with the exception of the last phase the chronology for which is dated against the living tree ring chronology from the Užpelkių Tyrelis bog). The clusters of cross-dated timbers were absolutely dated by radiocarbon method. There are 2 to 8 radiocarbon-dated samples in each cluster. In the most cases the ^{14}C dates of the dated rings in the clusters corresponded within confidence limits to the relative dendrochronological dates of these rings.

The dating (based on the calibrated ^{14}C dates) and other characteristics of the tree clusters representing pinewood spread phases during more than two millennia are presented in table 1.

In figures 1 and 2 synchronized radial growth series of the trees from two clusters (" LCWUT13b" and "LCWUT60a") and the cluster mean chronologies are presented.

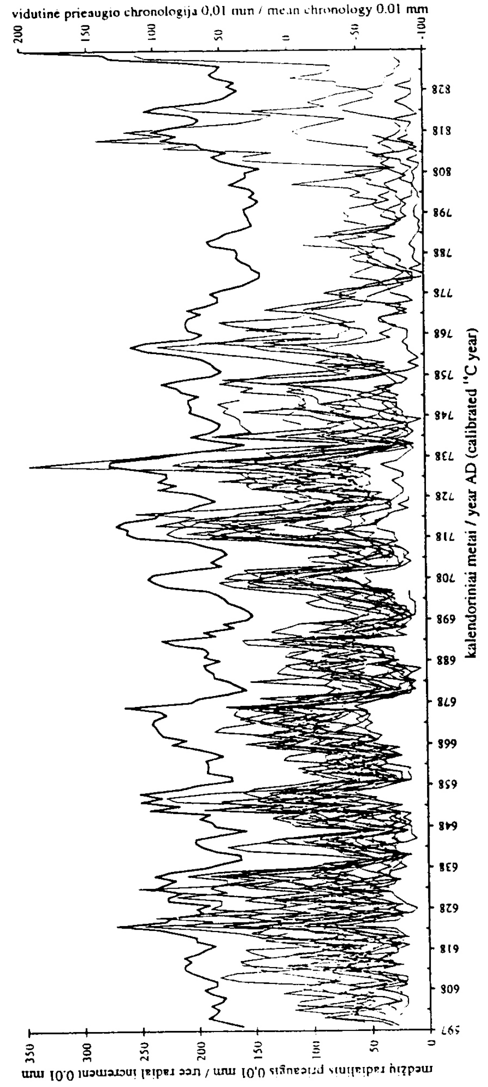

Fig. 1. A fragment from a subfossil tree group " LCWU130B" (VI - IX c. AD): synchronized radial growth series. A heavier line represents mean chronology of the group.

1 pav. Užpelkių Tyrelio iškastinių medžių grupės " LCWU130B"(VI - IX a. po Kr.) sinchronizuoti radialiniai prieaugiai. Storesnė linija rodo grupės vidutinį prieaugį.

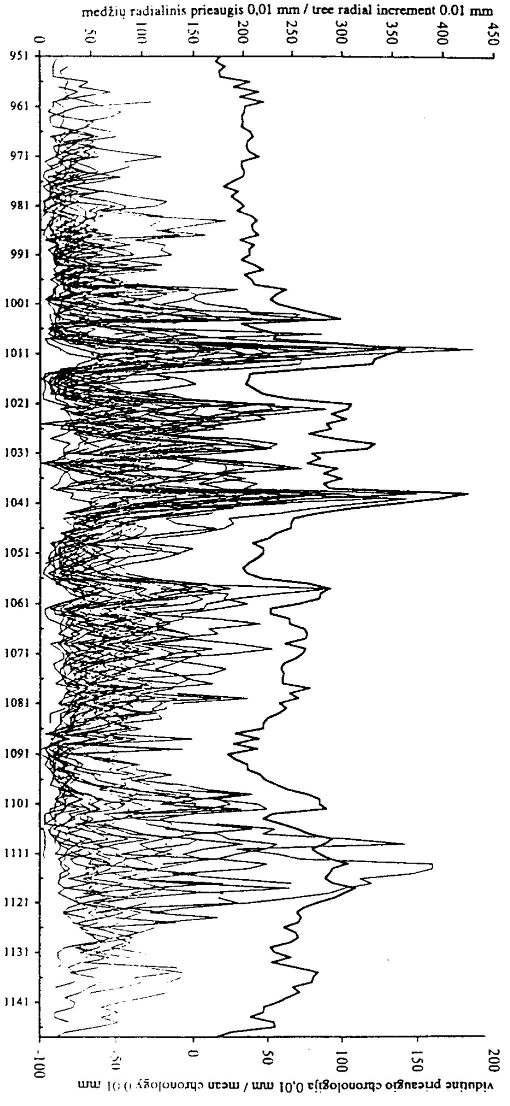

Fig. 2. A fragment from a subfossil tree group " LCWUT60A" (IX - XII c. AD): synchronized radial growth series. A heavier line represents mean chronology of the group.

2 pav. Iškastinių medžių grupės " LCWUT60A" (IX - XII a. po Kr.) sinchronizuoti radialiniai prieaugiai. Pastorinta linija rodo grupės vidutinį prieaugį.

Table 1. Characteristics of the tree clusters representing pinewood spread phases in Užpelkių Tyrelis oligotrophic bog

Code of tree cluster	Year of the first ring	Year of the last ring	Chronology length (years)	Number of trees in the cluster
LCWUT99z	173 BC	593 AD	766	42
LCWUT13b	551 (597)* AD	837 AD	287	23
LCWUT60a	951 AD	1148 AD	198	43
LCW1319a	1143 AD	1474 AD	332	25
LCWUTXXa	1773 AD	1924 AD	152	5

*) - beginning of mass germination

The reconstructed dynamics of *Pinus sylvestris* woodstand growth in Užpelkių Tyrelis oligotrophic bog is represented in figure 2: part b shows distribution of dated tree life spans in a time scale and part a shows a plot of fluctuations of averaged annual radial growth of the trees (an indicator of bioproductivity) around the millennial mean value.

The oldest afforestation phase lasted for almost eight centuries from the second century BC to about the 6th century AD in the study area. First solitary pine trees settled in the beginning of the 2nd century BC. The oldest trees have settled on undulating surface of the bog. For example, stem base depth of contemporary trees No 551 and No 1365 (the difference between their germination dates was 5 years) differed by 0.45 m, though the trees grew 11 meters apart. Undulation of peat layers also persisted afterwards as peat deposits have been accumulating.

A more intensive formation of pine woodstand can be noticed at the very end of the 2nd century BC and about the turn for the first millennium AD. At the end of the first century AD and at the turn for the third century AD some gradual change in forest generations can be traced. Pine stand was very thin for about a century and a half at the end of the phase. The final stage is represented by only two or three long-lived trees with narrow rings.

The mass regeneration of pinewood took place around the turn for the 6th century AD. That afforestation phase lasted till the second half of the 9th century. Pine trees spread quite rapidly on to the area again in the middle of the 10th century, after a phase of an open-land type vegetation that lasted for about a century. The stand lived untill the middle of the 12th century.

In the second millennium AD, pinewood began to spread in the middle of the 12th century again. This afforestation phase ended in the 15th century and no pine trunks were found in posterior peat layers for about three centuries. A new afforestation phase started only in the second half of the 18th century and lasted till the beginning of peat exploitation.

The chronologies of *Pinus sylvestris* annual radial growth, constructed basing on the ring width series of subfossil timbers from Užpelkių Tyrelis peat bog, all together cover 1714 years. This makes 80% of the total 2145 years' period.

Chapter 6. Analysis of relationships between the radial growth of *Pinus sylvestris* from oligotrophic bog habitats and the variability of climatic factors. In order to interpret the results of the research on pinewood growth dynamics in the past, reaction of living bog-grown pine trees to changes in ecological conditions was analysed. Relations of three types of mean chronologies: average absolute ring width data (ABS), standardized (STD)

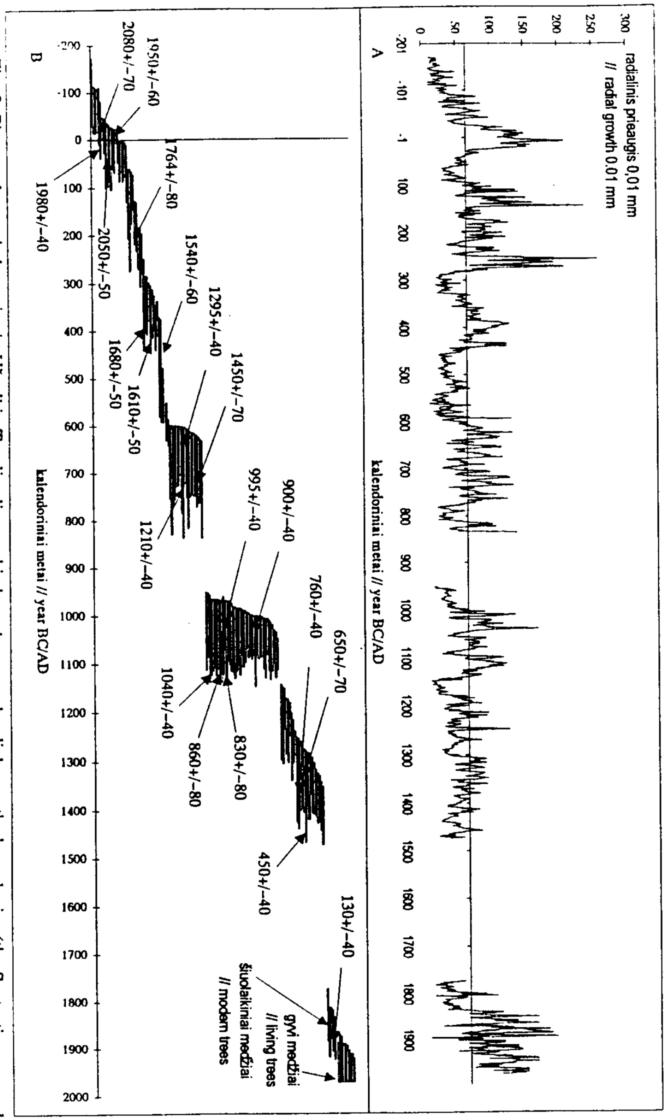

Fig. 3. Pinewood growth dynamics in Užpelkių Tyrelis oligotrophic bog: A - annual radial growth chronologies (the fluctuations around mean value); B - pinewood growth history: the distribution of pine tree life spans in a time scale. Radiocarbon dated rings are marked in black, the numbers represent ^{14}C dates (yr BP).

3 pav. Pušynų augimo dinamika Užpelkių Tyrelio aukštapelkėje: A - vidutinės metinio radialinio prieaugio chronologijos (fliuktuacijos apie vidurkį); B - pušynų augimo istorija: medžių gyvenimo laikotarpių išsidėstymas laiko skalėje. Radioanglies metodu datuotos medžių rievės pažymėtos juodai, skaičiai rodo radioanglies datas metais nuo šių laikų.

and residuals (RES) (see section 4.4.1) - and also chronologies of principal component amplitudes (PC) (see section 4.4.3) from Užpelkių Tyrelis and Daunoriai oligotrophic bog sites (see section 3.3) with climatic parameters were studied. Averaged monthly temperatures and monthly precipitation sums from April (for Užpelkių Tyrelis site data) and March (for Daunoriai site data) of the previous year till October of the current (i.e. ring formation) year and also annual temperature and precipitation for the current and two (for Užpelkių Tyrelis) to three (for Daunoriai) previous years were used as climatic parameters.

6.1. Correlation between the mean chronologies of tree radial increment and climatic variables. Coefficients of correlation between Užpelkių Tyrelis tree growth data and climatic parameters were calculated for the period 1924-1972 (49 years). Coefficients exceeding +/-0.24 (at the 0.1 significance level) and exceeding +/-0.28 (at the 0.05 level) show statistically significant correlation. Correlations between Daunoriai growth data and climatic parameters were calculated for the period 1925-1991 (67 years). Coefficients exceeding +/-0.20 (at the 0.1 significance level) and exceeding +/-0.24 (at the 0.05 level) are significant.

The temperature of vegetative season months has a positive influence on the growth of trees in Užpelkių Tyrelis bog site. Coefficient of correlation of ABS chronology with April temperature is r=+0.38, with June r=+0.29, with September r=+0.33. Temperatures in the previous vegetative season also have positive effect, especially in previous June (correlation with the ABS chronology r=+0.36). Positive correlation was also obtained between tree growth and temperatures in late winter and early spring (for the RES chronology r=+0.35 with February temperature and r=+0.25 with temperature in March). Prevailing positive effects of temperatures in separate months on tree growth in Užpelkių Tyrelis bog result in positive correlation between tree growth and annual temperature of the current year (r=+0.24 for the ABS chronology). Meanwhile, the radial increment of pine trees correlates negatively with annual temperature (for the RES chronology r=-0.33) in Daunoriai bog which is located in the eastern part of Lithuania under conditions of more continental climate.

A prevailing influence of precipitation on Užpelkių Tyrelis bog tree growth is negative. The most significant correlation of tree growth is with previous September (for the ABS chronology r=-0.31) and current April (r=-0.29) precipitation. Significant positive correlation was obtained only with previous August (for the RES chronology r=+0.29). Correlation with annual precipitation is slightly negative (for the STD chronology r=-0.23). The precipitation of previous years has also negative effect (correlation of the RES chronology with the precipitation in the year before last r=-0.28).

The analysis has revealed that on the whole the relationships between annual radial growth of pine in oligotrophic bogs and monthly climatic parameters are not very strong. Differing reaction of tree growth to climatic parameters was noticed in different regions of Lithuania. That corroborates the results obtained by other authors (Karpavičius, 1984 a).

Because an age curve is not expressed in growth series of oligotrophic bog-grown pine, detrending has no significant uniform effect on the results of tree growth - climate correlation analysis. The removing of first order autocorrelation from annual radial growth series improves correlations with the meteorological factors that have opposite effect on the tree ring formation in the current and next year (e.g. May temperature for Daunoriai site trees, previous July to September precipitation for Užpelkių Tyrelis site trees). After removing series autocorrelation, significant correlations persist between tree annual growth and meteorological conditions in the previous growth season. This means, that these correlations have not only been a result of autocorrelation in the growth series.

Because temperature has positive effect on the growth of the Užpelkių Tyrelis bog pine trees almost entirely from February till September, correlation between the tree growth and averaged temperature for that period was calculated. Coefficient of correlation between standard Užpelkių Tyrelis chronology and average February - September temperature is +0.40. Model of linear regression between annual radial growth of Užpelkių Tyrelis bog pine trees (STD chronology) and that climatic parameter has been established. The equation of the regression is:

$$\hat{Y}_i=6,25+2,08x_i$$

where $\hat{Y}_i$ means estimated average temperature of February - September period for the year *i*,

x_i is a value of the standard chronology in the year *i*.

Sixteen per cent of the variation in average February - September temperature is explained by the regression model.

6.2. Information obtained from the time series of tree growth principal component amplitudes. The analysis of annual radial growth dynamics of individual trees from the oligotrophic bog sites by use of principal component (PC) method has revealed that the first PC explains about 40% of the variance in ring with series: 40.9% for Užpelkių Tyrelis site trees and 38.5% for Daunoriai site trees. Three PC's are significant in the Užpelkių Tyrelis site tree group: the second PC explains 18.4%, the third explains 12.1% of the variance in the growth series and the total explained variance makes up 71.7%. Four PC's are significant in the Daunoriai site tree group: the second PC explains 17.0%, the third 11.0%, the forth 9.9% of the variance in the tree growth and the total explained variance makes up 76.4%.

In both sites the weight of the first PC that accounts for the major part of the variance is almost equal in the growth series of all the trees. The weights of higher order PC's are varying in the growth dynamics of individual trees, tree groups with differing weights can be separated. Loading of these PC's on the growth series of several trees shows that these PC's represent not a random variation in individual tree growth but express some specific reaction of a group of trees to some external factor.

Correlations between the chronologies of PC amplitudes and the climatic parameters were analysed. Since the weight of the first PC is almost equal in the growth dynamics of all the trees, correlations of the first PC amplitudes with climatic parameters are similar to those of the site mean chronology. The higher-order PC chronologies reveal the relationships with the climatic parameters that have different effect on separate tree groups. For example, the different effect is especially characteristic of the climatic factors of the summer months in Daunoriai bog site. Precipitation in current and previous July correlates negatively with the second PC amplitudes (r=-0.43 for previous July and r=-0.37 for current July precipitation) but positively with the third and fourth PC's (correlation of the third PC is r=+0.24 for the previous July and r=+0.37 for the current July precipitation). Meanwhile, the mean chronologies show no significant correlation. The chronology of the fourth PC correlates negatively with the previous year precipitation (r=-0.39). The weight of this PC tends to change from positive to negative in the growth dynamics of the trees along the direction from the bog center lake to the bog margin. Consequently, the negative reaction to previous year precipitation is more

characteristic of the trees growing closer to the bog center and with the positive weight of that PC (No 2,6,7) but a more positive reaction is characteristic of the trees growing closer to the bog margin and with a negative weight of the 4 PC (No 8,9, 10, 11).

Since amplitudes of separate PC's show different correlations with climatic factors, multiple regression was used to evaluate the total relations between climatic variables and the amplitudes of significant PC (used as predictors). The mean standard chronology (STD) for Užpelkių Tyrelis site shows best correlation with the fluctuations in average February-September temperature (see section 6.1). By use of multiple regression approach, a regression model with the first two principal components of the tree increment data set used as predictors was established to estimate that climatic parameter. The regression equation is:

$$\hat{Y} = 8,37+0,25x_1+0,26x_2$$

where $\hat{Y}$ means estimated average temperature of February - September period; x_1 is the amplitude of the first PC of the tree annual radial increment data set from Užpelkių Tyrelis site; x_2 is the amplitude of the second PC.

Coefficient of multiple correlation R=0,49.

24% of the variation in average February to September temperature is reconstructed by this model.

In figure 3 the actual values for average February - September temperature and reconstructed by the multiple regression model are compared.

Because pine trees from oligotrophic bog sites differ in some extent in their reaction to environmental changes, more variance in climatic parameters is reconstructed by regression models based on principal components, reexpressing the variability in individual tree growth, than by models based on site mean chronology which unify growth data of all the trees.

6.3. Possibilities of climatic reconstructions using radial growth chronologies for the past pinewood phases. A positive response of pine radial growth in Užpelkių Tyrelis bog to temperatures in late winter and vegetative season months and also a negative response to yearly precipitation was found by analysing tree radial growth - climate relationships. However, quantitative relations between the site mean chronologies and climatic parameters are not very strong and allow to reconstruct only small part (up to 16%) of the variance in the past climatic parameters. A larger part of the variance (up to 24%) is reconstructed by using a multiple regression model with the amplitudes of principal components of the site tree growth data set used as regressors (predictors) (see section 6.2). Therefore, the principal component analysis on the tree radial growth series from the historical pinewood phases in Užpelkių Tyrelis bog has also been performed.

The analysis has revealed that predominance of the first PC is more strongly expressed in the groups of crossdated trees (the first PC accounts for 50.4% and the second for only 6.5% of the variance in tree radial growth in the tree cluster " LCWUT130b'). Since tree growth series are synchronized basing on their common variance (reexpressed by the first PC), the trees with more expressed individualities in their growth dynamics (i.e. having larger weights of higher-order PC's) tend to be declined in the synchronization process, though they naturally exist in stands. Therefore, the principal component structure of the growth variance in the groups of crossdated trees slightly differs from that in the groups of living trees, sampled at random in a site.

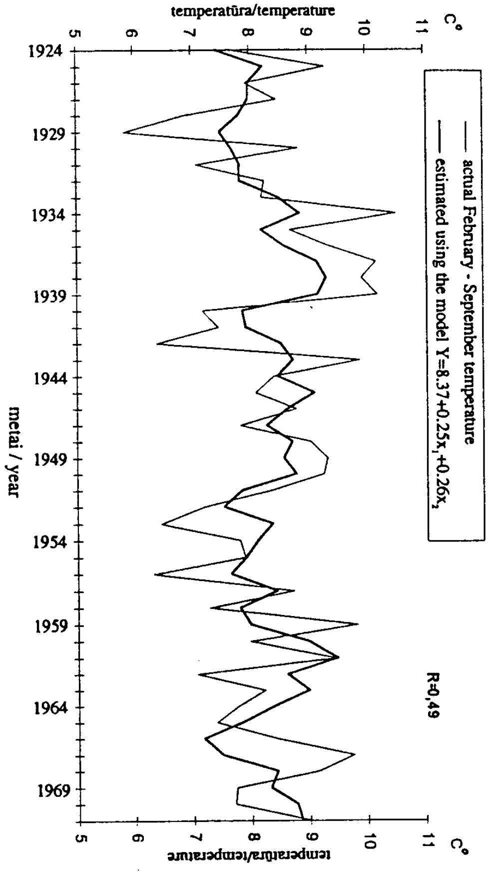

Fig. 4. Actual mean temperatures for the February through September period and that reconstructed according to the model based on two principal component amplitudes from Užpelkių Tyrelis living pine tree growth.

4 pav. Tikrosios ir rekonstruotos pagal Užpelkių Tyrelio pušų radialinio prieaugio variacijos dviejų pirminių komponentų amplitudes vidutinės vasario - rugsėjo periodo temperatūros.

So, further investigation is necessary before applying the established multiple regression models for reliable quantitative climatic reconstructions.

As it is shown by investigations of other researchers (Fritts, 1976; Briffa et al., 1983; Briffa, 1987, etc.) better results for climatic reconstructions are obtained when tree ring data from a set of sites rather than from a single site is used. So, the present study, dealing with the long-term information on tree growth from a single oligotrophic bog site, limit itself to qualitative evaluation of changes in the past ecological conditions, with the hope that further dendrochronological investigation on similar objects would result in creating a network of long-term tree ring chronologies and, thus, more reliable reconstructions of annual quantitative climatic parameters covering the last 2 to 3 millennia would become possible.

Chapter 7. Pine woodland growth dynamics in Užpelkių Tyrelis peat bog: an indicator of changes in ecological conditions during the Subatlantic period. Recurrent changes between the phases of woodland (pinewoods) and open-land type bog vegetation have been detected in the more than two-millennial vegetation history in Užpelkių Tyrelis oligotrophic bog. The spread of woodland and open-land type plant communities on oligotrophic bogs is closely related to the differences in bog water level (Seibutis, 1966; Balevičienė, 1991, etc.). Woodland type bog plant communities of the *Vaccinietea uliginosi* Lohmeyer et R.Tx. 1955 class are usually spread over dryer areas with lower water table (40 - 50 cm) (Balevičienė, 1991). Open-land type communities of the *Oxycocco - Sphagnetea* Br.-Bl. et R.Tx. 1955 class occupy wetter areas, when high water table limits the spreading of wooden plants.

During more than two-millennial history the annual radial increment of pine trees in Užpelkių Tyrelis bog has been changing from 0.1 to 2.6 mm (0.67 mm on average). Obtained correlations with climatic parameters (see section 6.1) suggest that higher rates of annual radial increment (wider rings) indicate the years with higher temperatures from late winter through vegetative season and/or lower precipitation (climatic optima), and decrease in increment rate (narrow rings) indicates colder and/or more humid periods (climatic pessima).

The oligotrophic phase of Užpelkių Tyrelis bog started at the end of the Subboreal (Savukynienė et al., 1978). The beginning of the Subatlantic period, defined by increased humidity (Kabailienė, 1991), was not suitable for pinewood establishment in the bog. The first pine trees germinated in the investigated area in the second - the first century BC. Annual radial increment was only 15% to 60% of the millennial average in the 2nd century BC. The increment rate gradually increased during the first century BC and exceeded the millennial average (0.67 mm) in the second half of the century. The woodstand growth dynamics suggest that gradual decrease in bog water level took place in the 2nd century BC. Climatic conditions become favourable for pine radial growth in the bog in the end of the first century BC (a tendency to increased temperatures and decrease in precipitation). At the end of the first century BC and in the beginning of the first century AD the annual radial increment rate of pine trees was one of the highest during the all more than two - millennial history (reached 310% of the millennial average). An optimal combination of warm and dry weather lasted almost till the end of the third century AD, annual increment of the pines in the bog in some periods reached 380% of the average.

Decreased radial increment (mostly lower than the average, sometimes only 35% of that) was characteristic of the trees that grew in the 4th century and especially in the 5th to the 6th century AD. Improved growth (increment rate reached 150-185% of the average) is observed at the end of the 4th century and in the beginning of the 5th century AD. The tree growth dynamics suggests that unfavourable climatic conditions (low temperatures and increased humidity) prevailed in the 4th - 6th centuries AD, with the exception of the end of the 4th century. Such conditions caused a rise of bog water table and gradual destruction of pine stand.

Dense stand of pine of almost the same age spread in a short time on to the bog around the turn for the 7th century AD. Higher than average annual increment rate (reaching 195% of the average) prevailed almost for two centuries. The dynamics of pine stand development and growth indicates warm and dry climate around the 7th century, because so short time of woodstand formation could be due to rapid drop of bog water table or after fire. Optimal conditions lasted for more than a century and a half and changed for worse at the end of the 8th century - in the beginning of the 9th century.

A formation of a new stand of almost the same age in the middle of the 10th century also indicates decrease in bog water level. The tree ring chronology for this pinewood phase shows three intervals of better growth when radial increment was above the two-millennial average almost continuously for 30 - 40 years.

These last two phases of pinewood spread are separated by a phase of open-land type bog vegetation that lasted for about a century. The afforestation dynamics in Užpelkių Tyrelis bog indicates that period with unfavorable climatic conditions (cold and/or wet) in the 9th century AD separated two optimal periods around the 7th century and around the 11th century.

Differently from the previous two phases, regeneration of trees of the afforestation phase that started in the 12th century was gradual and lasted for two centuries. Lower than the average radial increment rate prevailed almost continuously until the end of the phase in the 14th century. This suggests that temperatures in vegetative season were lower than those during afforestation phases in the first millennium AD and in the beginning of the second millennium. Open-land type plant communities dominated in the investigated area for about three centuries (from the end of the 15th till the end of the 18th century) after destruction of the latter afforestation phase. This was the longest gap between afforestation phases. The dominance of open-land type plant communities indicates increase of bog water table due to low temperatures and increased humidity.

The regeneration of pine stand started at the end of the 18th century again. Annual radial increment rate of pine trees exceeded two-millennial average in the middle of the 19th century and was higher than average almost continuously during the 20th century. Such dynamics indicates that tendencies to warmer and dryer climate resulted in drop of bog water table and favourable conditions for spread of pinewoods on to the bog at the end of the 18th century. High rates of tree radial increment suggest that during the last centuries almost the highest vegetative season temperatures prevailed for the last millennium.

The reconstructed aspects of vegetation history show that favourable ecological conditions for pine tree growth in the oligotrophic bog (warm and/or dry climatic conditions, decrease in bog water table) were in first three centuries of the first millennium AD, in the 7th - 8th centuries AD, around the 11th century and from the end of the 18th century until the present. Unfavourable (pessimal) conditions (raised bog water table, cold and/or humid climate) were in the beginning of the Subatlantic period until the first century BC, in the first half of the 4th century AD, in the 5th - 6th centuries AD, in the 9th century, in the middle of the 12th century, in the 16th - 18th centuries.

The changes in ecological conditions, reconstructed based on the growth dynamics of pinewoods in Užpelkių Tyrelis bog, agree with evaluations of past European climate by other researchers. S.I.Barash (1989) referring to chronicles and to S.I.Kostin and J.L.Rauner evaluates the first two centuries AD as the warmest in present times. He mentions increased wetness in the 4th century AD. Glaciological investigations in the Alps (Zumbühl, Holzhauser, 1988) revealed a changeable character of climate in the middle of the 1st millennium AD. Sudden glacier advances indicating increased humidity and low temperatures were detected around the 5th and around the 6th centuries AD. Significant decrease in July - August temperatures in the middle of the 6th century was established also in Northern Fenoscandia (Briffa et al., 1992). The retreat of glaciers in the Alps, indicating decrease in precipitation and increase in temperatures, was detected around the 7th century and significant glacier advance was established around the 9th century (Zumbühl, Holzhauser, 1988). This coincided with the decrease in July - August temperatures around 800 AD in Northern Fenoscandia (Briffa et al., 1992).

The period around the turn for the 2nd millennium AD (1000+/-200 years) is known as the "little climatic optimum" (Le Roy Ladurie, 1971; Borisenkov, Paseckij, 1983; Barash, 1989) or "medieval warm epoch" (Paleoclimates of the Northern..., 1995) in climatology. According to evaluations of climatologists, lower temperatures and higher humidity was characteristic for the second millennium AD to compare with the first millennium (Rauner et al., 1983, etc.). Investigators single out three periods in the history of climate of the second millennium: warm and mostly dry beginning of the millennium ("little climatic optimum"), cold period of the "little ice age" with the most expressed phase around 1550 - 1700, and warming in the end of 19th century - the 20th century (Le Roy Ladurie, 1971; Lamb, 1981; Borisenkov, Paseckij, 1983; Liachov, 1984, etc.). However, different authors indicate different time for the transitional periods. There is also an opinion that the "little ice age" period included two (or maybe more) cold episodes, that started in 1275+/-60 (the first and less expressed one) and around 1510 (Bradley, Jones, 1992).

The comparison between pinewood growth dynamics in Užpelkių Tyrelis oligotrophic bog and climatological evaluations of past climate shows that unfavourable periods, when tree radial increment rate was low or open-land type bog vegetation dominated, corresponded with the periods characterized as cold or humid: the first half of the 4th century AD (Barash, 1989; Turmanina, 1979), the 5th - 6th centuries AD (Turmanina, 1979; Zumbühl, Holzhauser, 1988; Briffa et al., 1992 (the 6th c.)), the 9th century AD (Zumbühl, Holzhauser, 1988; Briffa et al., 1992); the middle of the 12th century (Zumbühl, Holzhauser, 1988; Briffa et al., 1992), the 16th - 18th centuries (Le Roy Ladurie, 1971; Lamb, 1981; Borisenkov, Paseckij, 1983; Barash, 1989 et al.). Favourable periods, with increased tree increment rate, affirmed warm and dry climatic conditions in the first centuries of the 1st millennium AD (Barash, 1989), the 7th - 8th centuries AD (Zumbühl, Holzhauser, 1988), in the 11th century (Zumbühl, Holzhauser, 1988; Briffa et al., 1992), second half of the 19th century - 20th century (Le Roy Ladurie, 1971; Lamb, 1981, Jones, Bradley, 1992, etc.). Such correspondence indicates that growth dynamics of *Pinus sylvestris* woodstand in Užpelkių Tyrelis bog depended not only on local conditions but also reflected the larger (European) scale climatic fluctuations.

Chapter 8. Conclusions

1. Subfossil Scots pine timbers (trunks and stems) preserved in oligotrophic peat deposits of Lithuanian raised bogs retain whole structure of annual rings for several millennia. Dendrochronological methods can and should be more widely used for their analysis and cross-dating. About half (47%) of subfossil timber specimens from Užpelkių Tyrelis bog had sufficiently expressed common pattern of variation in their annual growth series, enabling to cross-date them. Factors complicating the cross-dating between the ring width series of Scots pine from oligotrophic bog habitat were relatively short age of the trees (on average 107 years), expressed individualities in the dynamics of annual growth of some trees in separate intervals or all the period of their life, often "missing" and "double" rings, and cyclicity expressed in tree growth fluctuations in some centuries that caused "pseudo-agreement" between the series in asynchronous positions of overlap.
2. It was established that recurrent changes between woodland and open-land type bog vegetation phases had been taking place in Užpelkių Tyrelis oligotrophic bog during last two millennia and a half. The first phase of *Pinus sylvestris* woodstand spread started on to the investigated area in the second century BC and ended in the sixth century AD. The second afforestation phase started around the turn for the 7th century AD by mass germination of pine trees and ended in the first half of the 9th century. The third pinewood phase lasted from the middle of the 10th century till the beginning of the 12th century. The fourth afforestation phase started in the middle of the 12th century by gradual regeneration of pines and ended at the end of the 15th century. The last pinewood phase started at the end of the 18th century and lasted till the beginning of peat harvesting in the 20th century. So detailed bog woodland history has been reconstructed in Lithuania for the first time.
3. The analysis of the relationships between annual radial growth of living *Pinus sylvestris* trees from oligotrophic bog habitats and climatic parameters have revealed different response of trees to changes in climatic conditions in different regions of Lithuania. The annual radial growth of *Pinus sylvestris* trees from Užpelkių Tyrelis bog correlates positively with temperatures from late winter through vegetative season months and negatively with annual precipitation. The radial growth of trees correlates negatively with annual temperature and positively with winter (December, January) and current September precipitation in East Lithuania, under conditions of more continental climate.
4. Because of an inexpressive age curve in growth series of pine from oligotrophic bogs, detrending of the series has no statistically significant uniform effect on the results of tree growth - climate correlation analysis. The removing of first order autocorrelation from tree growth series improves correlations with the meteorological factors that have opposite effect on tree-ring formation in the current and next year.
5. Reexpressing the variability in the growth of individual trees from a site by principal components and using the amplitudes of the most significant components in multiple regression models as regressors enables to reconstruct more variance in climatic parameters than regression models based on site mean chronology which unify growth data of all the trees. 16.4% of the variation in average February - September temperature is reconstructed basing on the fluctuations in ring width chronology for Užpelkių Tyrelis pine trees and 24.2% of that is reconstructed basing on the amplitudes of the first two principal components of individual tree growth data set.

6. Unfavourable periods for Scots pine growth in Užpelkių Tyrelis bog that indicated a raise in bog water table and tendencies to increased humidity and (or) colder vegetative seasons were reconstructed in the beginning of the Subatlantic period until the first century BC, in the first half of the 4th century AD, the 5th - 6th centuries AD, the 9th century AD, the middle of the 12th century, the 16th - 18th centuries. Favourable periods with increased pine tree increment rate that indicated warm and (or) dry climatic conditions were in the first centuries of the 1st millennium AD, in the 7th - 8th centuries AD, the 11th century, second half of the 19th century - the 20th century. These periods correspond to evaluations of past European climate according to other authors. Such correspondence shows that growth dynamics of *Pinus sylvestris* woodstand in Užpelkių Tyrelis bog depended not only on local conditions but also reflected the European scale climatic fluctuations.
7. The study has demonstrated that dendrochronological investigation of subfossil timbers from oligotrophic peat deposits of Lithuanian bogs, in conjunction with radiocarbon dating and palaeobotanical analysis of deposits, enables to reconstruct detailed aspects of past vegetation changes and evaluate fluctuations in palaeoecological conditions. For supplementing the information obtained by this research and making it more precise (i.e. for developing a continuous annual radial growth chronology for Scots pine from oligotrophic bog habitat and dating the life spans of subfossil pine trees with accuracy of one year) further dendrochronological investigations in similar objects are necessary. Such objects would be the oligotrophic bogs in which pine trees had similar annual growth dynamics to that of trees from Užpelkių Tyrelis and where pines had been growing over the periods when pinewood was depleted from the investigated area of Užpelkių Tyrelis bog.

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UŽRAŠAMS

Botanikos institutas

Rūtilė Pukienė
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AUKŠTAPELKĖJE SUBATLANČIO LAIKOTARPIU

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