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Main stages of natural environmental changes in Lithuania during the Late Glacial and Holocene

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The main significant stages of development of vegetation, climate and soils, as well as other palaeogeographical conditions during the Late Glacial and Holocene have been distinguished and are discussed in the paper. The data used in this work have been obtained from investigations of pollen and diatoms in lake and bog sediments, including those of the old Baltic Sea stages in the western part of Lithuania. Six types of pollen diagrams are distinguished for the Late Glacial and Holocene in Lithuania, and the net-like method suggested earlier by the author (Кабайлене, 1969) is used to obtain a reconstruction of the different stages of forest history.

Three stages of natural environmental changes have been distinguished in the Late Glacial and five stages have been singled out in the Holocene. The cold and dry Pre-Alleröd (11900–14000 BP) climate favoured a tundra and forest–tundra vegetation. Considerable warming took place in this area in the Alleröd (10900–11900 BP), with birch and pine becoming dominant. The cooling of the climate during the Younger Dryas gave rise to a forest–tundra vegetation. During the Preboreal and the first half of the Boreal (8100–10000 BP) the climate was warm and dry and the forests were dominated by birch and pine. The Late Boreal, Early and Late Atlantic and Early Subboreal (3700–8100 BP) were the warmest and most humid Holocene stage, so that broad-leaved forests and alder flourished; during the Early Subboreal spruce increased. The amounts of broad-leaved trees and spruce decreased and of herbs increased during the Late Subboreal (2500–3700 BP), birch and pine spread, suggesting a moderately warm, dry climate. The Early Subatlantic (1000–2500 BP) were marked by a spread of dence alder and spruce forests, indicating greater humidity. In the Late Subatlantic (the last 1000 years) climate became cool, pine and birch prevailed among trees, the landscapes were more open.

Key words: environment, vegetation, climate, soils, lakes, peatbogs, pollen, diatoms, Lithuania

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INTRODUCTION

The goal of this paper was to single out and characterise the main stages of the natural environmental changes that took place during the Late Glacial and Holocene, i. e. development of vegetation, climate, soils, lakes and peatbogs. For this purpose, the pollen and diatom data obtained both by the author of the present paper and other researchers have been summarized (Kabailienė, 1959, 1987, 1990, 1993, 1998, 1999; Kunskas, 1962, 1974; Savukynienė, 1974; Seibutis, Savukynienė, 1998; Seibutis, Sudnikavičienė. 1960; Sudnikavičienė, 1963; Кабайлене, 1965, 1983, 2002; Кунскас, Вайчвилене, Савукинене, 1975). The Late Glacial and Holocene pollen stratigraphy of Lithuania has been studied in 93 lakes, bogs and localities (in 226 sections). These data were used for reconstruction of vegetation composition by the net-like method (Кабайлене, 1969).

Eight main stages of natural environmental changes have been distinguished to a different extent – some of them comprised several chronozones, while others dealt with only one. For reconstruction of vegetation composition, the territory of Lithuania was divided into six parts (Western, North-western, Central, South-western, South-eastern and North-eastern).

METHODS

To reconstruct the composition of vegetation and climate conditions, pollen data from the Late Glacial and Holocene sediments taken in more than 90 Lithuanian lakes and peatbogs were used; moreover, in West Lithuania, pollen from sediments corresponding to old Baltic Sea stages were also studied. For reconstruction of vegetation, the area of Lithuania was divided into six parts differing in geomorphological (Guobytė, 2002) and physical geographical conditions (Basalykas, 1965): Western, North-western, Central, South-western, South-eastern, North-eastern regions (Fig. 1).

The vegetation composition for different stages was reconstructed in each part separately. Reconstruction of the vegetation composition characteristic of a certain land area at a certain period of time is as yet an unresolved problem, as it is impossible to transform the percentage compositions of pollen analysis data at one sampling point to vegetational descriptions without additional assumptions. Pollen data from numerous sampling points (sites) are necessary in order to reconstruct the vegetation. In reaching this conclusion, the author considers a pollen spectrum at one site to depend on the composition of the adjacent vegetation, its density and distribution. Analysis of pollen data from several sites and determination of their average values may help to reduce the effect of uneven composition, density and distribution of vegetation.

The method proposed by M. Kabailienė (1969, 1979) can be applied to territories with several sampling sites distributed fairly densely and evenly, i. e. net-like.

Reconstruction of the average composition of a forest (or other vegetational association) by the net-like method can be divided into some stages:

– selection of sites and establishment of the size of the territory. A land area with a radius of about 100 km appears to be required for the reconstruction of forest composition, as data on pollen transport by wind (Table 1) show that the majority of the pollen of plants growing in such area will be deposited within it;

– correction of pollen analysis data by using the coefficients of effective pollen productivity (Table 2) and pollen transportation by wind (Table 3). To employ these coefficients, it is necessary to know distances from the sampling point and the edge of the forest.

Table 4 presents an example of pollen spectrum correction by relative pollen productivity values and by using the coefficients of pollen transportation by wind;

– correlation of the corrected pollen diagrams;

– calculation of the corrected average spectra. These corrected spectra for synchronous levels at all the sites can then be used to calculate the average values or percentage (geometric means) for each taxon.

The average composition of the forests in the Western, North-western, Central, South-western, South-eastern and North-eastern parts of Lithuania during the Holocene was defined using the net-like method, and cyclograms were constructed (Figs. 2–7).

Pollen data for 226 sections from 93 lakes, mires and localities were used for this purpose (Fig. 1). The net-like method cannot be applied to the reconstruction of Weichselian Late Glacial vegetation patterns as shrubs and herbs were prevailing at that time (still there is the lack of data on the pollen productivity of herb species and the wind transportation and deposition of their pollen).

Quantitative climatic parameters (such as mean annual, January and July temperatures, average precipitation) of past climates of different stages were calculated applying the methods of Russian authors M. Muratova, T. Boyarskaya and A. Liberman (Муратова, Боярская, Либерман, 1972) and Lithuanian past forest composition reconstructed by the net-like method from pollen data (Kabailienė, 1998, Table 5).

Table 1. **Radius of the territory (km) from which to the sampling point (to the area unit per time unit) 75% of pollen of various trees and shrubs are brought when the distance to the forest edge is different (wind velocity and turbulence are average) (Kabailienė, 1979)**

1 lentelė. **Spindulys teritorijos (km), iš kurios į stebėjimo tašką (ploto vienetą per laiko vienetą) atnešama 75 % įvairių medžių ir krūmų žiedadulkių (vėjo greitis ir oro turbulentiškumas – vidutiniai), kai nuotolis iki miško yra įvairus (Kabailienė, 1979)**

Distance to the forest edge, km	Trees and shrubs												
	Picea	*Pinus*	*Betula*	*Alnus*	*Quercus*	*Tilia*	*Ulmus*	*Carpinus*	*Fagus*	*Fraxinus*	*Populus*	*Corylus*	*Salix*
0	14.0	220	160	190	55.0	80.0	100	10.0	18.0	22.0	100	15.0	120
1	16.0	330	210	220	69.0	140	130	17.0	20.0	30.0	120	190	520
2	21.0	440	280	290	95.0	180	210	26.0	30.0	51.0	150	250	900
5	38.0	900	400	450	190	270	300	50.0	70.0	81.0	290	370	990
10	70.0	>1000	700	600	250	500	600	82.0	110	120	330	770	>1000
20	100	>1000	>1000	950	400	600	900	150	180	200	550	>1000	>1000
50	225	>1000	>1000	>1000	900	>1000	>1000	220	300	400	980	>1000	>1000
100	340	>1000	>1000	>1000	>1000	>1000	>1000	290	420	900	>1000	>1000	>1000

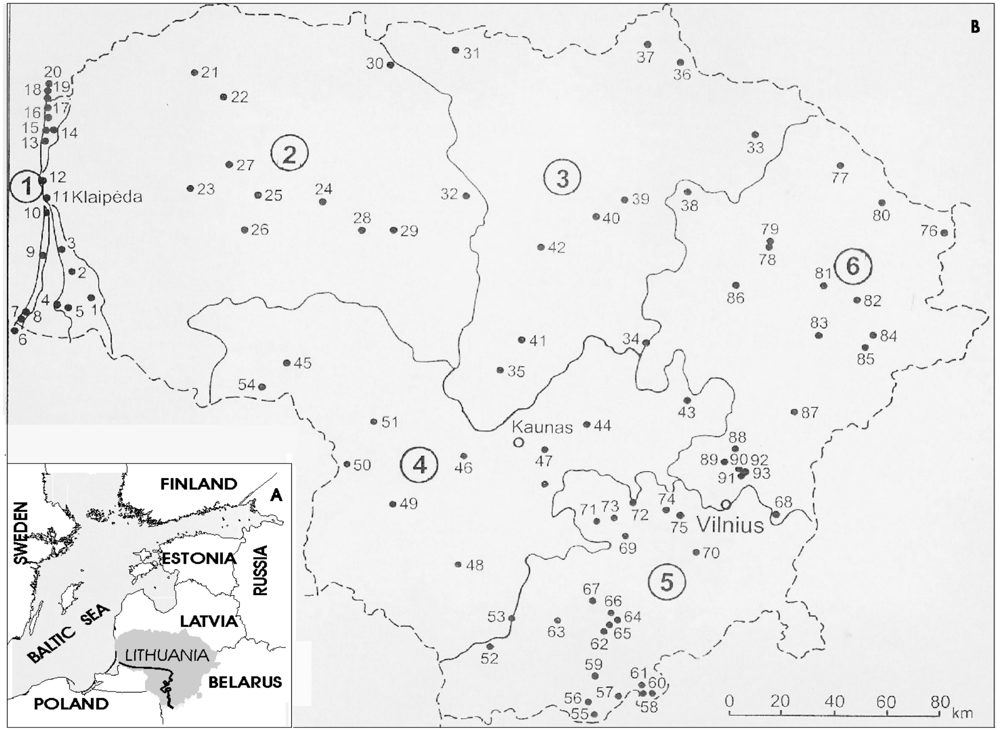

Fig. 1. Subdivision of Lithuania on geomorpohlogical, physical and geographical grounds and locations of the lakes, mires and localities serving as sources of the pollen data used for reconstruction of the Holocene forest composition by the net-like method. Regions of Lithuania: 1 – Western, 2 – Northwestern, 3 – Central, 4 – Southwestern, 5 – Southeastern, 6 – Northeastern. Lakes, mires and localities: Western Lithuania (1): *1* – Aukštumalė mire, *2* – Svencelė mire, *3* – Tyras mire, *4* – 26 borehole on the Ventės Ragas Horn, *5* – 25 borehole on the territory of the Nemunas river delta, *6* – borehole in Morskoje settlement, *7* and *8* – boreholes in Nida settlement, *9* – borehole in Juodkrantė settlement, *10* – borehole in Smiltynė settlement, *11* – boreholes on the River Dangė valley in Klaipėda and borehole 92, *12* – boreholes 93 and 91a to the North of Klaipėda, *13, 14, 15* – Pajūris mire, *16* – borehole 4 in Būtingė settlement, *17* – Nida mire, *18* – Kirbė mire, *19* and *20* – the shore of Lake Papė. Northwestern Lithuania (2): *21* – Raudonoji mire, *22* – Gedrimai mire, *23* – Reiskių tyrelis mire, *24* – Pakivis mire, *25* – Lake Biržulis, *26* – Paršežeris mire, *27* – Pareškėtis mire, *28* – Šventragis mire, *29* – Tytuvėnų tyrelis mire, *30* – Mūšos tyrelis mire. Central Lithuania (3): *31* – Javidonys mire, *32* – Šulinînkai mire, *33* – Lake Samanis, *34* – Ežerbala mire, *35* – Normainiai mire, *36* – Skrebiškiai peatbog, *37* – Kirkilai peatbog, *38* – Šepeta mire, *39* – Gailiai mire, *40* – Sargėnai mire, *41* – Labūnava mire, *42* – Alionys mire. Southwestern Lithuania (4): *43* – Šližiai mire, *44* – Leonava mire, *45* – Laukesa mire, *46* – Ežerėlis mire, *47* – Ežeras mire, *48* – Lake Žuvintas, *49* – Gabiauriškis mire, *50* – Nopaitis mire, *51* – Aukštoji plynia mire, *52* – Lake Veisiejas, *53* – Krikštonys Outcrops, *54* – Pagėgiai Outcrops. Southeastern Lithuania (5): *55* – Lake Grūda, *56* – Lake Mergelės Akelės, *57* – Čepkelių raistas mire, *58* – The Katra river bed, *59* – Kojaraistis mire, *60* – Pelesa mire, *61* – Dūba mire, *62* – Lake Glebas, *63* – Lake Ilgis, *64* – Lake Glūkas, *65* – valley of the river Varėnė, *66* – Lake Varėnis, *67* – Leikiškė mire, *68* – Rimšiškė mire, *69* – Lake Bebrukas, *70* – Baltoji Vokė mire, *71* – Antaveršis mire, *72* – Hole of Strėva, *73* – The devil's pit, *74* – Lake Akmena, *75* – Lake Galvė. Northeastern Lithuania (6): *76* – Lake Drūkšiai, *77* – Vaboliai mire, *78* – Lake Lydekis, *79* – Lake Baltys, *80* – Drusėnai mire, *81* – Lake Tauragnai, *82* – Lake Gruodiškis, *83* – Labanoras mire, *84* and *85* – Lake Kretuonas, *86* – Leliūnai mire, *87* – Lake Asveja, *88* – Žalesa mire, *89* – Lake Gudeliai, *90* – Lake Gulbinai, *91* – Lake Mažieji Gulbinai, *92* – Lake Kryžiuočiai, *93* – Lake Akis

1 pav. Lietuvos suskirstymas geomorfologiniu bei fiziniu geografiniu pagrindu; ežerai, pelkės bei vietovės, kurių nuosėdose ištirtos žiedadulkės ir sporos. Jos panaudotos holoceno miškams atkurti įvairiuose Lietuvos regionuose: Vakarų (1), Šiaurės vakarų (2), Vidurio (3), Pietvakarių (4), Pietryčių (5) ir Šiaurės rytų (6) Lietuvos dalyse: Vakarų Lietuva (1): *1* – Aukštumalė, *2* – Svencelės pelkė, *3* – Tyrų pelė, *4* – 26-as gręžinys Ventės rage, *5* – 25-as gręžinys Nemuno upės deltos teritorijoje, *6* – Morskoje (Pilkopės) gręžinys, *7* ir *8* – Nidos gyv. gręžiniai, *9* – Juodkrantės gyv. gręžinys, *10* – Smiltynės gyv. gręžinys, *11* – Dangės slėnio Klaipėdoje gręžiniai ir 92-as gręžinys, *12* – gręžiniai Nr. 93 ir 91a, *13, 14* ir *15* – Pajūrio pelkės gręžiniai, *16* – 4-as gręžinys prie Būtingės, *17* – Nidos pelkė, *18* – Kirbės pelkė, *19, 20* – Papės ežero pakrantė. Šiaurės vakarų Lietuva (2): *21* – Raudonoji pelkė, *22* – Gedrimų pelkė, *23* – Reiskių tyrelis, *24* – Pakivio pelkė, *25* – Biržulio ežeras, *26* – Paršežerio pelkė, *27* – Pareškėčio pelkė, *28* – Šventragio pelkė, *29* – Tytuvėnų tyrelio pelkė, *30* – Mūšos tyrelio pelkė. Vidurio Lietuva (3): *31* – Javidonių pelkė, *32* – Šulininkų pelkė, *33* – Samanio ežeras, *34* – Ežerbalos pelkė, *35* – Normainių pelkė, *36* – Skrebiškių durpynėlis, *37* – Kirkilų durpynėlis, *38* – Šepetos pelkė, *39* – Gailių pelkė, *40* – Sargėnų pelkė, *41* – Labūnavos pelkė, *42* – Alionių pelkė. Pietvakarių Lietu-va (4): *43* – Šližių pelkė, *44* – Leonavos pelkė, *45* – Laukesos pelkė, *46* – Ežerėlio pelkė, *47* – Ežero pelkė, *48* – Žuvinto ežeras, *49* – Gabiauriškio pelkė, *50* – Nopaičio pelkė, *51* – Aukštosios plynios pelkė, *52* – Veisiejo ežeras, *53* – Krikštonių atodangos, *54* – Pagėgių atodangos. Pietryčių Lietuva (5): *55* – Grūdos ežeras, *56* – Mergelės Akelės, *57* – Čepkelių raistas, *58* – Katros upės senvagė, *59* – Kojaraisčio pelkė, *60* – Pelesos pelkė, *61* – Dūbos pelkė, *62* – Glebo ežeras, *63* – Ilgio ežeras, *64* – Glūko ežeras, *65* – Varėnės upės slėnis, *66* – Varėnio ežeras, *67* – Leikiškės pelkė, *68* – Rimšiškės pelkė, *69* – Bebruko ežeras, *70* – Baltosios Vokės pelkė, *71* – Antaveršio pelkė, *72* – Strėvos įgriuva, *73* – Velnio duobė, *74* – Akmenos ežeras, *75* – Galvės ežeras. Šiaurės rytų Lietuva (6): *76* – Drūkšių ežeras, *77* – Vabolių pelkė, *78* – Lydekio ežeras, *83* – Gruodiškio ežeras, *83* – Labanoro pelkė, *84, 85* – Kretuono ežeras, *86* – Leliūnų pelkė, *87* – Asvejos ežeras, *88* – Žalesos pelkė, *89* – Gudelių ežeras, *90* – Gulbinų ežeras, *91* – Mažųjų Gulbinų ežeras, *92* – Kryžiuočių ežeras, *93* – Akies ežeras

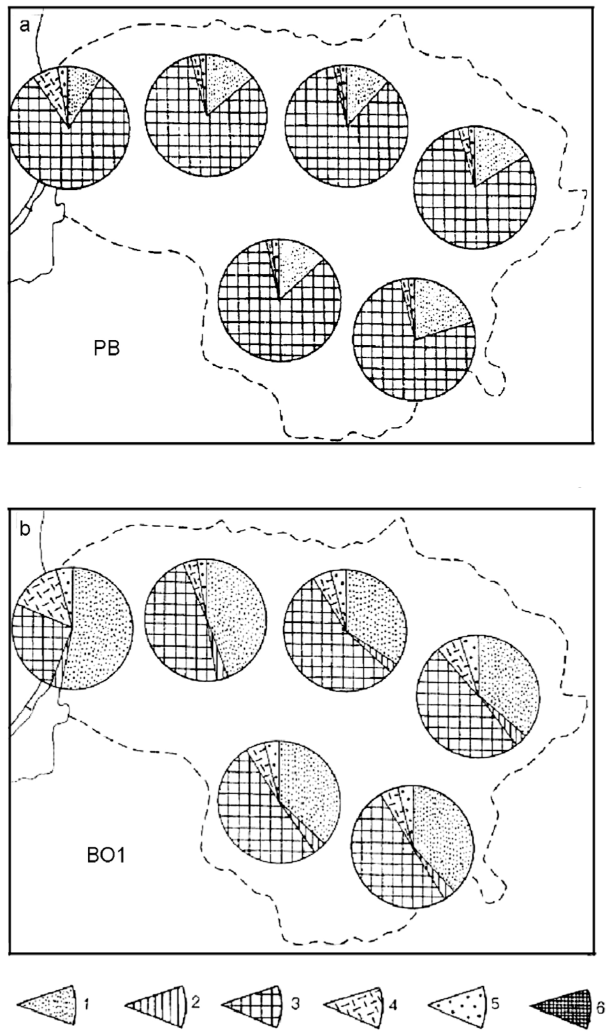

Fig. 2. Average composition of forests in the western, northwestern, central, southwestern, southeastern and northeastern parts of Lithuania 8100–10000 years ago (*a* and *b*) defined by the net-like method using pollen data from the 93 lakes, mires and other localities (226 sites): *1* – pine, *2* – spruce, *3* – birch, *4* – alder, *5* – elm, lime and oak, *6* – hornbeam
2 pav. Vidutinė miškų sudėtis prieš 8100–10000 metų (*a* ir *b*) Vakarų, Šiaurės vakarų, Vidurio, Pietvakarių, Pietryčių ir Šiaurės rytų Lietuvoje, atkurta tinkliniu metodu panaudojant 93 ežerų, pelkių ir atskirų gręžinių nuosėdų žiedadulkių tyrimo duomenis (226 pjūviai): *1* – pušis, *2* – eglė, *3* – beržas, *4* – alksnis, *5* – guoba, liepa, ąžuolas, *6* – skroblas

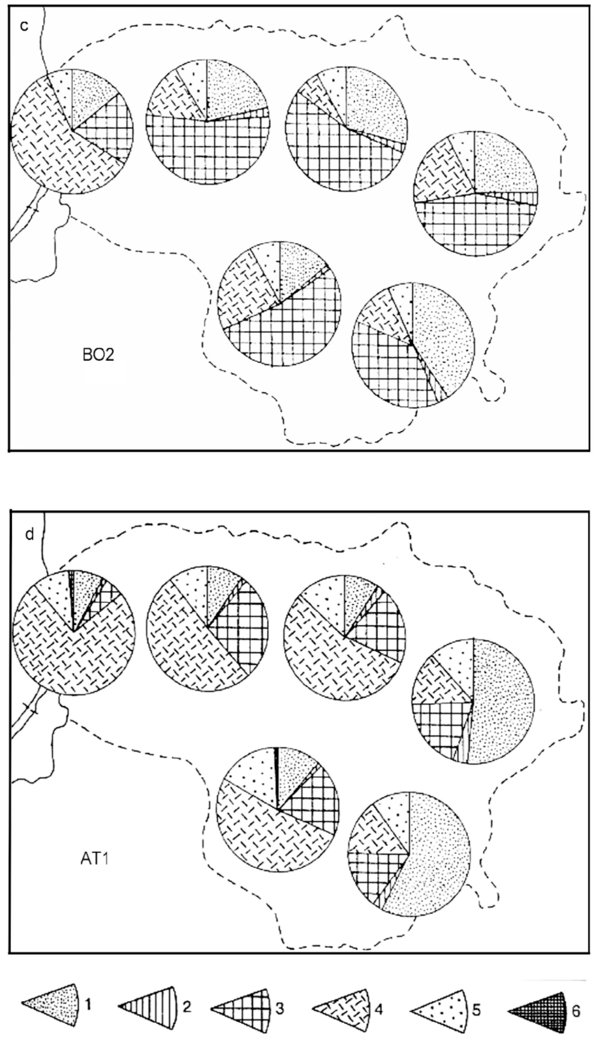

Fig. 3. Average composition of forests in the western, northwestern, central, southwestern, southeastern and northeastern parts of Lithuania 6500–8100 years ago (*c* and *d*) defined by the net-like method using pollen data from 93 lakes, mires and other localities (226 sites): *1* – pine, *2* – spruce, *3* – birch, *4* – alder, *5* – elm, lime and oak, *6* – hornbeam
3 pav. Vidutinė miškų sudėtis prieš 6500–8100 metų (*c* ir *d*) Vakarų, Šiaurės vakarų, Vidurio, Pietvakarių, Pietryčių ir Šiaurės rytų Lietuvoje, atkurta tinkliniu metodu panaudojant 93 ežerų, pelkių ir pavienių pjūvių nuosėdų žiedadulkių tyrimo duomenis (226 pjūviai): *1* – pušis, *2* – eglė, *3* – beržas, *4* – alksnis, *5* – guoba, liepa, ąžuolas, *6* – skroblas

Changes in lake water level were determined by applying diatom analysis data (Kabailienė, 1999; (Кабайлене, 2002)

DISCUSSION

Using pollen analysis data of many lake and mire deposits, the development of vegetation composition, climate and soils in six different physical geographical and geomorphological regions of Lithuania during the Late Glacial and Holocene is discussed. To study the development of lake and mire water level fluctuations, the diatom analysis data and the data on lithological composition of deposits were adapted.

1. Stages of natural environmental changes during the Late Glacial

During the Late Glacial (10000–14000 BP) three different stages of development are single out: Pre-Alleröd (11900–1400 BP), Alleröd (10000–11900 BP) and Younger Dryas (10900–11900 BP). For restoration of vegetation composition and climate, the following data of pollen analysis are used: 1) change of AP / NAP percentage relation, 2) data on the quantity and composition of herbs, dwarf

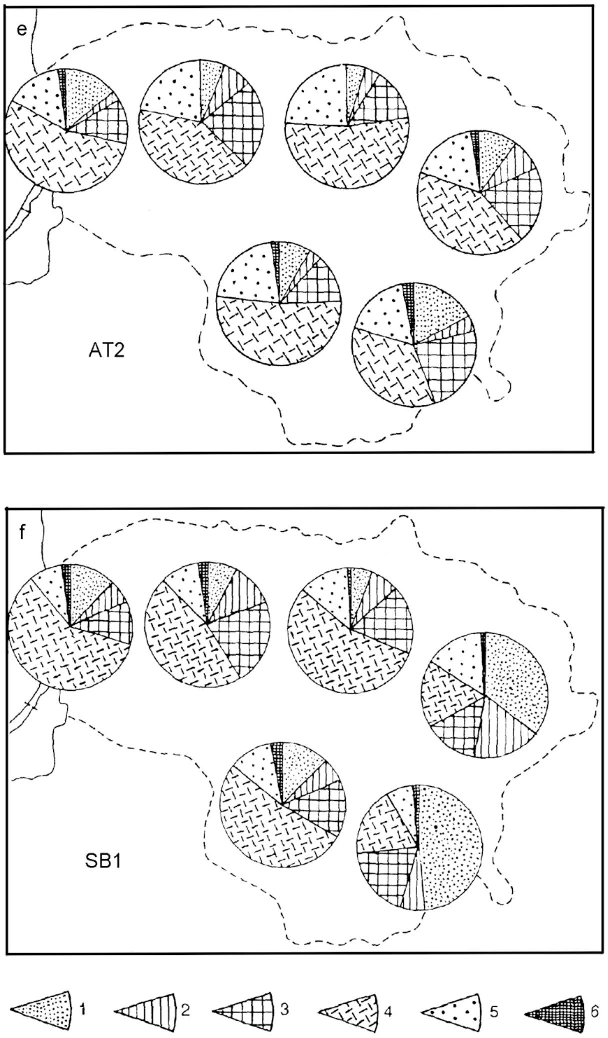

Fig. 4. Average composition of forests in the western, north-western, central, southwestern, southeastern and northeastern parts of Lithuania 3700–6500 years ago (*e* and *f*) defined by the net-like method using pollen data from 93 lakes, mires and other localities (226 sites): *1* – pine, *2* – spruce, *3* – birch, *4* – alder, *5* – elm, lime and oak, *6* – hornbeam

4 pav. Vidutinė miškų sudėtis prieš 6500–8100 metų (*e* ir *f*) Vakarų, Šiaurės vakarų, Vidurio, Pietvakarių, Pietryčių ir Šiaurės rytų Lietuvoje, atkurta tinkliniu metodu panaudojant 93 ežerų, pelkių ir pavienių gręžinių nuosėdų žiedadulkių tyrimo duomenis (226 pjūviai): *1* – pušis, *2* – eglė, *3* – beržas, *4* – alksnis, *5* – guoba, liepa, ąžuolas, *6* – skroblas

shrubs, shrubs and trees. For restoration of the evolution of soils, mainly data on the lithological composition of deposits and other geological data were used.

a. The Pre-Alleröd stage (11900–14000 BP)

These are the Oldest Dryas, Bölling and Older Dryas chronozones. The oldest sediments (sand, silt and clay) of the Oldest Dryas have been detected in some deepest sediment sections (lakes Bebrukas, Ilgis, Tytuvėnų tyrelis, Varėnis and Leikiškė bog, Fig. 1).

This is a cold climate period, when land was still stiffened by permafrost. Soil formation processes were

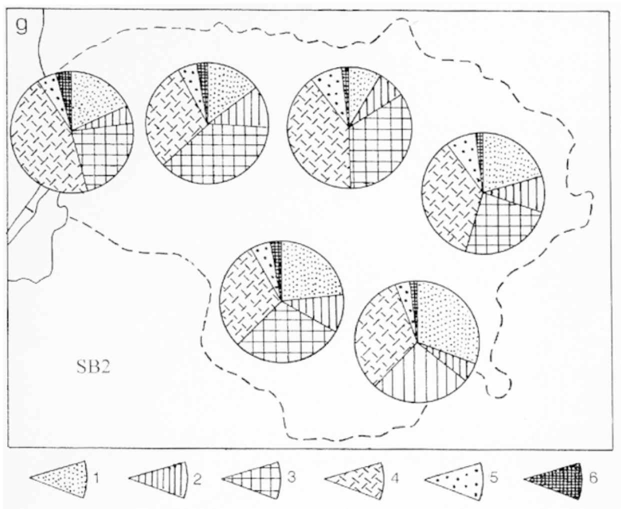

Fig. 5. Average composition of forests in the western, north-western, central, southwestern, southeastern and northeastern parts of Lithuania 2500–3700 years ago (*g*) defined by the net-like method using pollen data from 93 lakes, mires and other localities (226 sites): *1* – pine, *2* – spruce, *3* – birch, *4* – alder, *5* – elm, lime and oak, *6* – hornbeam

5 pav. Vidutinė miškų sudėtis prieš 2500–3700 metų (*g*) Vakarų, Šiaurės vakarų, Vidurio, Pietvakarių, Pietryčių ir Šiaurės rytų Lietuvoje, atkurta tinkliniu metodu panaudojant 93 ežerų, pelkių ir pavienių gręžinių nuosėdų žiedadulkių tyrimo duomenis (226 pjūviai): *1* – pušis, *2* – eglė, *3* – beržas, *4* – alksnis, *5* – guoba, liepa, ąžuolas, *6* – skroblas

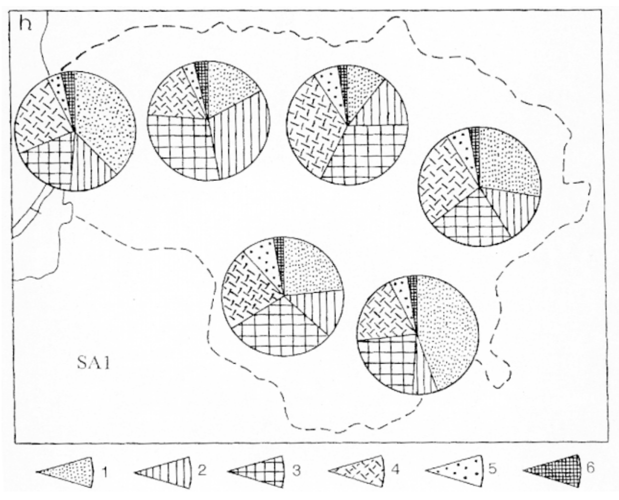

Fig. 6. Average composition of forests in the western, north-western, central, southwestern, southeastern and northeastern parts of Lithuania 1000–2500 years ago (*h*) defined by the net-like method using pollen data from 93 lakes, mires and other localities (226 sites): *1* – pine, *2* – spruce, *3* – birch, *4* – alder, *5* – elm, lime and oak, *6* – hornbeam

6 pav. Vidutinė miškų sudėtis prieš 1000–2500 metų (*h*) Vakarų, Šiaurės vakarų, Vidurio, Pietvakarių, Pietryčių ir Šiaurės rytų Lietuvoje, atkurta tinkliniu metodu panaudojant 93 ežerų, pelkių ir pavienių gręžinių nuosėdų žiedadulkių tyrimo duomenis (226 nuosėdų pjūviai): *1* – pušis, *2* – eglė, *3* – beržas, *4* – alksnis, *5* – guoba, liepa, ąžuolas, *6* – skroblas

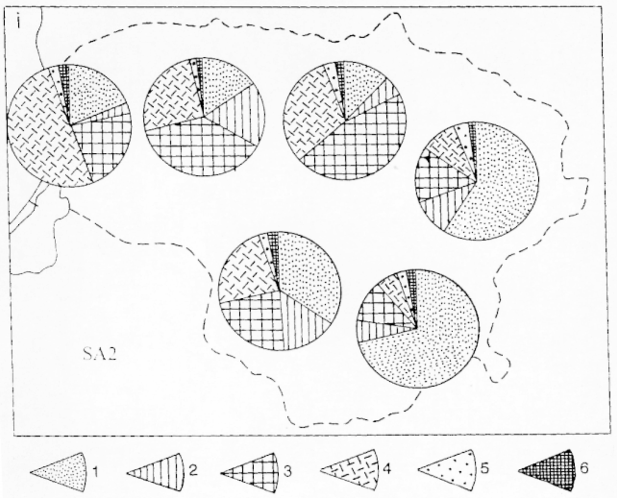

Fig. 7. Average composition of forests in the western, northwestern, central, southwestern, southeastern and northeastern parts of Lithuania 0–1000 years ago (*i*) defined by the net-like method using pollen data from 93 lakes, mires and other localities (224 sites): *1* – pine, *2* – spruce, *3* – birch, *4* – alder, *5* – elm, lime, oak, *6* – hornbeam

7 pav. Vidutinė miškų sudėtis prieš 0–1000 metų (*i*) Vakarų, Šiaurės vakarų, Vidurio, Pietvakarių, Pietryčių ir Šiaurės rytų Lietuvoje, atkurta tinkliniu metodu panaudojant 93 ežerų, pelkių ir pavienių gręžinių nuosėdų žiedadulkių tyrimo duomenis (224 nuosėdų pjūviai): *1* – pušis, *2* – eglė, *3* – beržas, *4* – alksnis, *5* – guoba, liepa, ąžuolas, *6* – skroblas

weak. Soils were calcareous with organic matter dissipating rapidly, thus resulting in their low content in the sediments. Lakes were accumulating only terrigenous sediments such as sand, silt and clay. The sediments of the Oldest Dryas are rich in herb pollen (mainly wormwood *Artemisia*) as well as couch grass (Poaceae) and sedge (Cyperaceae). Moreover, the tundra of the Oldest Dryas was overgrown with dwarf bushes, such as *Betula nana, Betula humilis* and *Salix*. Conditions for trees to grow were unfavourable.

With the warming in the Bölling (12300–13000 BP) the tree birch species (*Betula pubescens* and *Betula verrucosa*) spread, but Cyperaceae were also significant, and pine (*Pinus*) as well as Poaceae could grow in some places. The Bölling warming was rather low and short-lasting, soil formation processes were weak and interrupted by solifluction, forest-tundra vegetation was growing. Lakes accumulated sand, silt and clay. In Lithuania, there are no reliably dated sections with organic-rich beds formed in the Bölling.

During the Older Dryas cold period (11900–12300 BP) herb vegetation spread again. Sediments of lakes Ilgis and Drūkšiai were found to contain increased amounts of buckthorn (*Hippophae rhamnoides*) pollen. The pollen composition shows that the climate during the Younger Dryas was not only cold but also dry: such xerophytes as *Artemisia* and Chenopodiaceae were spreading, *Juniperus* and *Salix* were also growing. Of cold-loving plants during the Older Dryas, dwarf birches (*Betula nana* and *Betula humilis*), polar *Salix*, *Selaginella* and other plants of tundra-like vegetation were growing. Moreover, many sediment sections of that period showed presence of *Botrychium* spores.

b. The Alleröd stage (10900–11900 BP)

The beds formed during the Alleröd warming were distinguished in the majority of the sediment sections studied. They are notable for a higher content of organic matter, decrease in herb pollen and increase in tree pollen (up to 95%). These sediments, in Lithuania as a rule, contain high amounts of *Pinus* pollen. Beside pine trees, birch (*Betula*) was also spreading. These two tree groups in the Alleröd formed rare pine and birch forests. Herbs were suppressed. Some sediment sections (mainly in the southeastern and northeastern regions) in the Alleröd were found to contain spruce (*Picea*) pollen. Early *Picea* pollen maximum in other areas of Lithuania came later, and spruce spread there only in the Younger Dryas.

The changes in vegetation composition show that the Alleröd climate was warmer and more humid, and some localities in the south-western region of Lithuania were found to have alder, hazel and elm growing on the south-exposed slopes.

Table 2. **Relative effective pollen productivity values calculated using pollen data of surface deposits from various Lithuanian lakes and average (geometric) relative effective pollen productivity of various trees (Kabailienė, 1979)**
2 lentelė. **Santykinio efektyviojo medžių žiedadulkių produktyvumo dydžiai, apskaičiuoti pagal įvairių Lietuvos ežerų dugno paviršinių nuosėdų tyrimo duomenis, ir vidurkinis žiedadulkių produktyvumas (Kabailienė, 1979)**

Lakes	Trees				
	Pinus	*Picea*	*Betula*	*Alnus*	*Quercus*
Alaušas	1.98	1	0.92	0.35	1.94
Vievis	1.22	1	0.26	0.16	0.35
Daugai	2.23	1	0.26	0.21	0.28
Plateliai	2.45	1	0.86	1.04	0.55
Lėnas	1.8	1	0.62	0.55	1.20
Average (geometric) relative effective pollen productivity of various trees	1.8	1	0.51	0.37	0.66

Table 3. **Coefficients of pollen transportation by wind (Kabailienė, 1979)**
3 lentelė. **Žiedadulkių pernašos vėju koeficientai (Kabailienė, 1979)**

Distance to the forest edge, km	Trees and shrubs										
	Pinus	*Picea*	*Betula*	*Alnus*	*Quercus*	*Tilia*	*Ulmus*	*Carpinus*	*Fagus*	*Corylus*	*Salix*
2	0.79	1	0.78	0.75	0.84	0.88	0.78	1.35	1.04	1.62	1.03
10	0.47	1	0.48	0.46	0.60	0.57	0.50	1.38	0.95	1.01	0.59
50	0.24	1	0.27	0.25	0.39	0.33	0.29	1.38	0.84	0.56	0.29
100	0.17	1	0.19	0.18	0.31	0.25	0.22	1.05	0.79	0.41	0.20

Table 4. **Example of pollen spectrum correction (Kabailienė, 1979)**
4 lentelė. **Žiedadulkių spektro koregavimo pavyzdys (Kabailienė, 1979)**

Trees	Pollen spectrum		Correction of pollen spectrum by the coefficients – relative effective pollen productivity values		Correction of pollen spectrum by coefficients pollen transport by wind	
	Quantity	%	Quantity	%	Quantity	%
Pinus	120	60	$\frac{120}{1.8}=86.7$	49.0	$\frac{120\times0,21}{1.8}=14.0$	16.5
Picea	60	30	$\frac{60.0}{1}=60.9$	33.9	$\frac{60\times1}{1}=60$	71.0
Quercus	20	10	$\frac{20}{0.66}=30.3$	17.1	$\frac{20\times0,35}{0.66}=10.6$	12.5
Total	200	100	177	100	84.6	100

Table 5. **Climatic indices of the Holocene in Lithuania restored according to the modified method of Muratova et al. (Муратова, Боярская, Либерман, 1972)**
5 lentelė. **Lietuvos holoceno klimato rodikliai (M. Kabailienės atkurti pagal šiek tiek pakeistą M. V. Muratovos, T. D. Bojarskos ir A. A. Libermano metodiką (Муратова, Боярская, Либерман, 1972)**

Chronozone	Index	Average annual temperature, °C ΔT=+5°C *	Average January temperature, °C ΔT=-5°C *	Average July temperature, °C ΔT=-3°C *	Average annual precipitation, mm Δm=-207 mm *
Late Subatlantic	SA2	6	-5	17	681
Early Subatlantic	SA1	7	-5	17	731
Late Subboreal	SB2	6	-6	17	607
Early Subboreal	SB1	11	-7	17	732
Late Atlantic	AT2	12	-8	17	802
Early Atlantic	AT1	9	-9	17	769
Late Boreal	BO2	6	-12	17	651
Early Boreal	BO1	6	-12	16	570
Preboreal	PB	2	-13	16	550

* Corrections – the modern climatic indices restored using pollen analysis data of surface deposits of lakes according to the method of Muratova et al., 1972.
* Pataisos – dabartiniai klimato rodikliai, atkurti M. V. Muratovos ir kt. (1972) metodu panaudojant ežerų paviršinio nuosėdų sluoksnio žiedadulkių analizės duomenis.

The Alleröd warming was also notable for the spread of solifluction process, when clayey and various-grained sand interlayers were formed in the lakes Bebrukas and Dūba. Thermokarst processes were also spread widely. The buried ice blocks melted, and thermokarst lake basins were formed. During this gradual melting process, deposits (mainly sand) covering the burried ice were getting wet. These wet sites were soon covered with moss and herbs. Therefore, in the Alleröd, gyttja and peat (of moss, herbs and tree remnants) layers were formed, and after the ice had melted entirely these layers sunk down onto the bottom of the lakes formed; then the Younger Dryas and Holocene sediments were accumulating above the Alleröd peat and gyttja. The wetness of the Alleröd is confirmed by the fact that not only organic matter but also carbonate-rich sediments were accumulating in the lakes of that period. Diatom analysis shows that the water level of the lakes in the Alleröd was not high, water was cold and of oligotrophic type.

c. The Younger Dryas stage (10000–10900 BP)

The beginning of the Younger Dryas is notable for significant changes in vegetation. Many sediment sections show a significant increase in herb pollen and a decrease in tree pollen. Cyperaceae and Poaceae herbs, as well as dwarf birches (*Betula nana* and *Betula humilis*), *Selaginella selaginoides, Ophioglossum, Botrychium* – dry meadow plants, and *Hippophaë rhamnoides* were spread. Abundant *Artemisia*, Chenopodiaceae, as well as Ephedra indicate that climate in the Younger Dryas was not only cold, severe, but also dry. Rare groves of *Pinus* and *Betula* rather soon declined and were replaced by herbs and bush vegetation. Lake water level was higher, with oligotrophic, clear and cold water. Under conditions of permafrost, soils formed in the Alleröd atrophied and became drained.

2. Stages of natural environmental changes during the Holocene

During the Holocene (0–10000 BP), five different stages of natural environmental changes were distinguished: Preboreal and Early Boreal (8100–10000 BP), Late Boreal, Early and Late Atlantic and Early Subboreal (3700–8100 BP), Late Subboreal (2500–3700 BP): Early Subatlantic (1000–2500 BP), Late Subatlantic (the last 1000 years). The composition of vegetation in six different regions of Lithuania was restored by pollen data, using the net-like method. Data on the average composition of forests in six regions of Lithuania were used for calculate the quantitative climatic parameters (annual, January and July temperatures and average precipitation). For restoration of soil development, changes of lithological data on deposits, data on vegetation composition and climate were applied.

a. The Preboreal and Early Boreal stages (8100–10000 BP)

In the second half of the Younger Dryas, climatic conditions were gradually becoming milder; warmer climate plants (Polygonaceae, *Filipendula*) thickened and other plants spread wider in the Preboreal, while tundra and forest-tundra vegetation decayed, and tree vegetation showed a significant proliferation. Birch dominated in the Preboreal (Fig. 2). Birch forests, though not dense, grew in all Lithuania. Some birch forests contained also pine (*Pinus*) admixture, mostly in the south-eastern region of Lithuania. In the same region, around the lakes Glebas, Ilgis, Galvė, etc., the birch was accompanied by rich herb vegetation (Cyperaceae, Poaceae, etc.). Cyperaceae birch forests with admixture of *Pinus*, *Picea* and black alder (*Alnus glutinosa*), as well as juniper (*Juniperus*), willow (*Salix*), fernery (*Dryopteris*) and moss (*Bryales*) in the undergrowth were common in this region. These sedge (Cyperaceae) – birch (*Betula*) forests were growing on poor, most often wetland soils, where sand or sometimes sandy loam occurred under the peat. Peat-moss (*Sphagnum*), birch forests, most often with admixture of *Pinus*, Cyperaceae and *Eriophorum*, were also growing on poor soils. An important constituent part of Preboreal forests was *Juniperus*. This plant loving dry sunny habitats disappeared only later when the forests became denser in the Boreal. Heather (*Calluna*) was also growing on some sandy sites.

If compared to the Younger Dryas, great large changes are seen in vegetation, indicating both warming and dryness. The end of the Preboreal and beginning of the Boreal climate became even warmer, but it was dry and pinewoods expanded in Lithuania, often with birch admixture. Cyperaceae peatmoss pinewoods contained pine and birch in equal proportions. The undergrowth was occupied by *Rhamnus* and *Salix*, abundant various herbs such as sedge (*Cyperaceae*), reed, *Menyanthes*, horsetail (*Equisetum*), fern (*Polypodiaceae*) and peat-moss (*Sphagnum*). These pinewoods spread mainly along hill foots where soils contained more organic matter.

The water level in the lakes of this period was low (the lowest in all the Holocene). An intensive bogging took place in the lakeside areas. Climate in Preboreal was medium warm, but not wet. The mean annual air temperature was lower than now, with rather low precipitation (Table 5).

Soils contained low amounts of humus and were still carbonaceous. The beginning of the Boreal was still warmer (mean annual temperature was about 6°C), but dry. It became even warmer in the Late Boreal.

b. The Late Boreal, Early and Late Atlantic and Early Subboreal stages (3700–8100 BP)

The Late Boreal was warmer and wetter, the air temperature in Lithuania's area being higher than now. Differentiation of forests was growingly manifested; dense forests of various composition covered vast areas in different physico-geographical regions. Pine prevailed in Lithuania, with a significant increase in nut-tree (*Corylus*) and alder (*Alnus*); also first elm trees (*Ulmus*) appeared (Fig. 3).

Polen of these trees increased especially in the sediments settled during the Early Atlantic (6700–7800 BP), while the peak of Holocene thermophytes, such as *Ulmus, Tilia,* oak (*Quercus*) and *Corylus*, corresponded to the sediments settled during the Early Subboreal (3700–5000 BP).

Ulmus started spreading from the west and southwest in the Boreal. Its peak in the western region of Lithuania was in the Boreal, in the south-western region – in the Early Atlantic, and in the rest part – in the Late Atlantic. A sudden decrease (synchronous in all Lithuania) in *Ulmus* pollen took place at the turn of the Late Atlantic and Early Subboreal. This event in North-west Europe is related to development of human impact.

Tilia began spreading a bit later than *Ulmus*. Its peak in all Lithuania was during the Holocene optimum – in the Late Atlantic (Fig. 4). *Tilia* pollen had also decreased rather synchronously in the turn of the Late Atlantic and Early Subboreal, i. e. at the same level as the pollen of *Ulmus*. The Holocene *Tilia* was best expressed in the south-western region of Lithuania, where a later and somewhat lower peak was distinguished in the Early Subatlantic (Fig. 4).

Quercus was migrating from the southwest. Its slight increase in the western and south-western regions took place already in the Boreal. However, the peak values of *Quercus* pollen were obtained for the Late Atlantic and Early Subboreal. A small peak in *Quercus* in the western, north-western and south-western regions was noted in the Early Subatlantic.

Hornbeam (*Carpinus*) was spreading from the west and south-west already in the Late Atlantic, although its small peak was noted only in the Early Subatlantic. *Carpinus* in Lithuania was densest in its south-western part.

Corylus started intensively spreading in the Late Boreal from the southwest. Soon, in the Late Boreal, it spread in the north-western and central parts of Lithuania. In other regions the hazel peak took place during the Holocene climatic optimum – in the Late Atlantic.

In the Early Subboreal (3700–5000 BP), precipitation was lower if compared to the Atlantic and the mean annual temperature was similar to the present one.

In the wet Atlantic, big amounts of carbonates were washed out of soils and settled in lakes to form limestone and calcareous deposits. *Ulmus* and *Tilia* decreased markedly. Mixed spruce (*Picea*) and broad-leaved (alder, birch) and pine forests of poorer soils began spreading. Soil podzolisation and bogging of wetlands was going on. The peak of *Picea* pollen was especially well-pronounced in the south-eastern region of Lithuania 4400 BP, while in its western and north-western parts the peak appeared later – approximately 3200 BP.

c. The Late Subboreal stage (2500–3700 BP)

The climate became dryer, spruce forests declined significantly and were replaced by birch and white alder (Fig. 5). The forests became lighter, with more meadows. This period was favourable for sod soil formation. Lake water level was low. In the Late Subboreal, the significance of trees decreased, while that of herbs increased. Increased amounts of Poaceae, *Artemisia,* Chenopodiaceae, Cyperaceae, *Urtica,* Asteraceae, etc. were detected; rare pollen of cultural plants were also found. This increase in herb pollen in the Late Subboreal is related to intensification of human agricultural activities. Sediments of that time were found to contain pollen of cultural cereals *(Triticum, Secale, Hordeum,* etc.) as well as of Cannabis and related weeds. Moreover, signs of forest burnings performed to form areas suitable for agriculture and pastures were found; as a rule, these sites showed the spread of *Calluna, Pteridium,* etc. The sediments of that time contained also rather big amounts of tree macroremnants (Stančikaitė, 2000).

d. The Early Subatlantic stage (1000–2500 BP)

Betula and *Alnus* spread in all Lithuania, and *Pinus* was also seen growing (Fig. 6) on south-eastern Lithuania's sandy soils. At the beginning of the same period (approx. 2300–2500 BP) *Picea* also spread (the second peak on the pollen diagrams). This peak is especially marked in the north-western and north-eastern parts of Lithuania. *Picea* in Lithuania was spreading from the east. The Early Subatlantic is also characterized by *Quercus* increase, at the same time *Carpinus* was gradually spreading from the west and south-west. The role of herbs in the landscapes decreased significantly, and that of trees increased.

The climate was warmer (air temperature was by 1–2˚C higher) and more pluvious than now (Kabailienė, 1990). Under wet climate conditions, the former (Late Subboreal) arable fields overgrew with trees in the Early Subatlantic, because primitive ploughing implements couldn't be used in wet soils. This was a period of agriculture decline (Seibutis, Sudnikavičienė, 1997). Such conditions were favourable for soil formation. Lake water level was higher.

e. The Late Subatlantic stage (the last 1000 years)

Early in the Late Subatlantic it was a bit warmer and wetter than now. The conditions were favourable for soil formation. With time, air temperatures and humidity gradually approached contemporary climate conditions, and corresponding soils were formed. With the development of intensive human activities (agriculture and husbandry), as well as the use of more perfect implements, the landscapes were becoming more open. The sediments of that time contain abundant herb pollen, including that of cultural plants, weeds, path and various pasture species. The pollen of *Pinus* and *Betula* prevailed among trees (Fig. 7), but in some areas *Alnus* and *Picea* dominated. Lake and bog sediments often contain *Carpinus, Quercus* and *Corylus* pollen. Water level in the lakes was lower than in the Early Subatlantic.

CONCLUSIONS

1. 11900–14000 BP (Pre-Alleröd) Lithuania's area was covered with tundra-type herb vegetation, as well as dwarf and other bushes. Such vegetation is typical of a cold and dry climate. Terrigenous sediments were settling in the lakes. The warmer period of the Bölling was short.

2. 10900–11900 BP, after the first ice retreat, arboreal species were spreading (rare forests of pine and birch); moreover, for the first time organic rich sediments (peat and gyttja) were formed in lakes, as well

as calcareous sediments were accumulating, since an intensive washout of carbonates from the environment was going on. A thin layer of soil was formed.

Thermokarst processes and solifluction took place. The most marked signs of ice lobe melting in the Alleröd were detected on the uplands (Aukštaitija, Švenčionys, Sūduva, Dzūkija and Kuršas-Žemaitija) formed by the last glaciation. Sediment sections done both in the central and western regions of Lithuania showed no layers of the so-called sub-sapropelic peat and gyttja.

3. In 10000–10900 BP (Younger Dryas) herb vegetation was spreading again, and the climate became cold and dry, soil formation ceased, lake water level rose.

4. In 8100–10000 BP (beginning of the Holocene – Preboreal and the first half of the Boreal) forests (birch and pine) were not dense, lake water level was low, the bogging of lakesides was going on.

5. The Late Boreal – Early subboreal stage (3700–8100 BP). From the Late Boreal, differentiation of forests began. The Holocene peak of themophyles (elm, lime, oak, ash, etc.) was observed in the Late Atlantic. Spruce forests were spreading in the Early Subboreal. The climate was warm and wet; lake water level was high but varying. Intensive soil formation took place.

6. In 2500–3700 BP (Late Subboreal), human activities intensified, forests declined, herb vegetation was spreading.

7. In 1000–2500 BP (Early Subatlantic), spruce and other trees spread again, the climate became slightly wetter and warmer. The conditions were favourable for soil formation.

8. During the Late Subatlantic (the last 1000 years) the climate became colder (Little Ice Age); due to intensive human activities landscapes became more open. Lake water level subsided; soil formation was going on.

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Meilutė Kabailienė

SVARBIAUSI GAMTINĖS APLINKOS RAIDOS ETAPAI LIETUVOJE VĖLYVUOJU LEDYNMEČIU IR HOLOCENE

S a n t r a u k a

Šio darbo tikslas yra išskirti ir apibūdinti svarbiausius vėlyvojo ledynmečio ir holoceno gamtinės aplinkos raidos etapus, t. y.

augaliją, klimatą, dirvožemius, ežerų bei pelkių raidą. Tam tikslui buvo apibendrinti tiek straipsnio autorės, tiek ir kitų tyrinėtojų gautų žiedadulkių bei diatomėjų tyrimo duomenys. Išskirti aštuoni ryškūs gamtinės aplinkos raidos etapai: trys vėlyvuoju ledynmečiu ir penki holocene. Šių etapų apimtis įvairi – vieni jų yra ilgesni (apima kelias chronozonas), kiti – trumpesni (apima vieną chronozoną).

• Prieš 11900–14000 metų (ikialeriodiniu laikotarpiu) Lietuvos teritoriją dengė daugiausia tundros tipo žolinė augalija su žemaūgiais krūmokšniais ir krūmais. Augalija būdinga šaltam ir sausam klimatui. Ežeruose kaupėsi terigeninės nuosėdos. Atšilimas biolinge buvo trumpas ir nedidelis.

• Prieš 10900–11900 metų pirmą kartą poledynmečiu išplito sumedėjusi augalija (pušų ir beržų ir retmiškis), taip pat pirmą kartą ežeruose susikaupė organine medžiaga įsodrintos nuosėdos – durpė ir gitija, kaupėsi ir karbonatingos nuosėdos. Susidarė plonas dirvožemio sluoksnis. Intensyviai vyko termokarstinis procesas, soliflukcija. Daugiausia ledo luistų tirpsmo aleriode požymių aptikta paskutiniojo apledėjimo suformuotų aukštumų teritorijose.

• Prieš 10000–10900 metų (ankstyvajame driase) vėl išplito žolinė augalija, klimatas tapo šaltas ir sausas, nutrūko aleriode prasidėjęs dirvožemio formavimasis, pakilo vandens lygis ežeruose.

• Prieš 8100–10000 metų (preborealyje ir ankstyvajame borealyje) atšilo, bet buvo ypač sausa, miškai (beržynai ir pušynai) netankūs, ežerų vandens lygis žemas, jų pakrantės pelkėjo.

• Prieš 3700–8100 metų (vėlyvasis borealis, ankstyvasis ir vėlyvasis atlantis bei ankstyvasis subborealis) klimatas buvo šiltas ir drėgnas, augo vešlūs šiltumą mėgstančių medžių miškai (jų maksimalus kiekis holocene – vėlyvajame atlantyje). Ežerų vandens lygis pakilęs, bet svyruojantis, intensyvi dirvodara. Vėlyvajame borealyje prasidėjo miškų diferenciacija. Ankstyvajame subborealyje išplito eglynai.

• Prieš 2500–3700 metų (vėlyvajame subborealyje) reiškėsi intensyvi žmogaus ūkinė veikla, sumažėjo miškų, išplito žolinė augalija. Ežerų vandens lygis neaukštas.

• Prieš 1000–2500 metų (ankstyvajame subatlantyje) padaugėjo miškų, vėl išplito eglynai, klimatas tapo drėgnesnis ir šiek tiek šiltesnis, sąlygos dirvodarai buvo palankios.

Per pastaruosius 1000 metų (vėlyvajame subatlantyje) atšalo (mažasis ledynmetis). Dėl intensyvios žmogaus ūkinės veiklos kraštovaizdis darėsi vis atviresnis. Ežerų vandens lygis pažemėjo, galutinai susiformavo šiuolaikiniai dirvožemiai.

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ГЛАВНЕЙШИЕ ЭТАПЫ РАЗВИТИЯ ПРИРОДНОЙ СРЕДЫ В ЛИТВЕ В ПОЗДНЕМ ЛЕДНИКОВЬЕ И ГОЛОЦЕНЕ

Резюме

Целью данной работы является охарактеризование главнейших этапов развития растительности, климата, почв, озер и болот в позднем ледниковье и голоцене. Для этого были обобщены данные пыльцевого и диатомового анализов, полученные как автором настоящей статьи, так и другими исследователями. Выделено восемь отчетливых этапов развития природной среды: три – в позднем ледниковье и пять – в голоцене. Одни этапы длинее (охватывают несколько хронозон), другие – более короткие (охватывают только одну хронозону).

• 11900–14000 лет назад (доаллередский этап). На территории Литвы была распространена травянистая растительность в основном тундрового типа с примесью кустарничков и кустарников. Растительность характерна для холодного и сухого климата. В озерах накоплялись терригенные отложения. Потепление в бёллинге было незначительным и кратковременным.

• 10900–11900 лет назад впервые после отступления ледника распространилась древесная растительность (сосново-березовое редколесье). Также впервые в озерах образовались органическим веществом обогащенные отложения – торф и гиттия, накопились карбонатные отложения. Местами образовался маломощный почвенный слой. Интенсивно развивались термокарстовый процесс, солифлюкция. Самое большое количество признаков таяния погребенных глыб мертвого льда в аллерёде обнаружено на территории высот, сформированных последним ледником.

• 10000–10900 лет назад (во время молодого дриаса) вновь распространилась травянистая растительность, климат был холодным и сухим, прекратилось формирование почв, повысился уровень воды в озерах.

• 8100–10000 лет назад (во время пребореала и раннего бореала) потеплело, но было очень сухо, распространились леса (березовые и сосновые), негустые, уровень воды в озерах низкий, берега заболачивались.

• 3700–8100 лет назад (поздний бореал, ранняя и поздняя атлантика и ранний суббореал) климат теплый и влажный, леса густые, в них процветали теплолюбивые древесные породы (максимальное их количество во время поздней атлантики). Уровень воды в озерах повышенный, но изменяющийся, интенсивное почвообразование. В позднем бореале началась дифференциация лесов. В раннем суббореале распространилась ель.

• 2500–3700 лет назад (в позднем суббореале) интенсивная хозяйственная деятельность человека, уменьшилось значение леса, распространилась травянистая растительность. Уровень воды в озерах невысок.

• 1000–2500 лет назад (ранняя субатлантика) увеличилось значение лесов, опять вторично распространилась ель. Климат стал более влажным, несколько потеплело. Условия для образования почв благоприятные.

• Во время последнего тысячелетия (поздняя субатлантика) похолодало (малый ледниковый период). Из-за интенсивной хозяйственной деятельности человека ландшафты становились более открытыми. Уровень воды в озерах понизился, окончательно образовались современные почвы.