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Vegetation and climate of the Butėnai Interglacial (Holsteinian) in Lithuania

Ona KONDRATIENĖ and Vaida ŠEIRIENĖ

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Palaeobotanical (mainly palynological) data from 38 sections of Lithuania and adjacent areas were used in order to resolve some palaeogeographical problems. The Butėnai Interglacial (Holsteinian) had one distinct climatic optimum, represented by the B_2–B_4 pollen zones. This was a period of warm and wet climate with notable mild winters. The average annual temperature might have been 2–4°C warmer and the annual precipitation some 300 mm greater than at present in Lithuania. There was probably no permanent snow cover during winters. Isopollen maps for the main forest constituents allow deduction of the directions of migration of individual tree taxa.

Ona Kondratienė and Vaida Šeirienė, Institute of Geology and Geography, Ševčenkos 13, LT-2600 Vilnius, Lihuania; e-mail: vaidasei@geologin.lt *(received: January 3, 2002; accepted: Fabruary 17, 2003).*

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INTRODUCTION

In the East Baltic region the Middle Pleistocene Butėnai Interglacial is well established and correlated palynologically with the Holsteinian Interglacial (Likhvin, Mazovian). The geochronology of the interglacial is still under discussion. Predominant opinion suggests a time interval between 350–440 thousand year and Lithuanian data do not contradict this interpretation (Gaigalas and Molodkov, 1993). Palaeogeographical questions, however (climate, number of climatic optima, relief, prevailing soils, *etc*.) are still highly disputed.

The Butėnai Interglacial lacustrine sediments are widespread. They have been found throughout Lithuania except in the central part (Fig. 1). Most of the sections have been examined in the northeastern area (Utena region), considered to be the stratotypical region, the Butėnai-938 section being the stratotype. In most sections deposition took place not only during the Butėnai Interglacial, but also during the late glacial and the first half of next glaciation. In most cases these deposits lie quite deeply and can be reached only by boreholes. All these sections (Fig. 1) have been studied palynologically (Kondratienė, 1962, 1996). Macrofossils have been investigated in detail only from exposures (Riškienė, 1972, 1979; Velichkevich, 1982). Molluscs, mammals, ostracods and diatoms have been studied only in individual sections (Zubovitch, 1974; Voznyachiuk *et al*., 1984; Šeirienė, 1993, 1998). All this palaeontological data, as well as data from the adjacent areas: Latvia (Danilans, 1973), Belarus (Yakubovskaya, 1977), Kaliningrad (Kondratienė and Eriukhin, 1974), Poland (Borówko-Dłużakowa and Słowański, 1991; Krupiński, 1995; Janczyk-Kopikova, 1996; Winter and Lisicki, 1998) have been used in this palaeogeographical analysis.

MATERIAL AND METHODS

Pollen diagrams, ordered acccording to plant ecological groups, were constructed in order to resolve the climatic conditions during the interglacial and define more exactly the limits between the vegetational phases. For this purpose, the six most characteristic and complete sections from the Butėnai stratotype area were chosen. Pollen species were grouped into 7 groups: 1 — broad-leaved trees (*Quercus, Ulmus, Carpinus, Tilia, Acer, Fagus, Corylus*); 2 — fir (*Abies*), 3 — representatives of boreal forest (*Pinus, Picea, Betula, Alnus*, *Larix, Hippophaë); 4* — mosses and ferns, *5* — heliophytes *(Artemisia*, Chenopodiaceae*, Helianthemum, Ephedra*); 6 — herbaceous plants; 7 — subarctic and arctic plants (*Betula nana, Alnaster, Dryas octopetala*, *Botrychium boreale, Lycopodium appressum, Lycopodium alpinum, etc*.).

For estimation of the range of the climatic variability during the interglacial two different methods were used. The first of

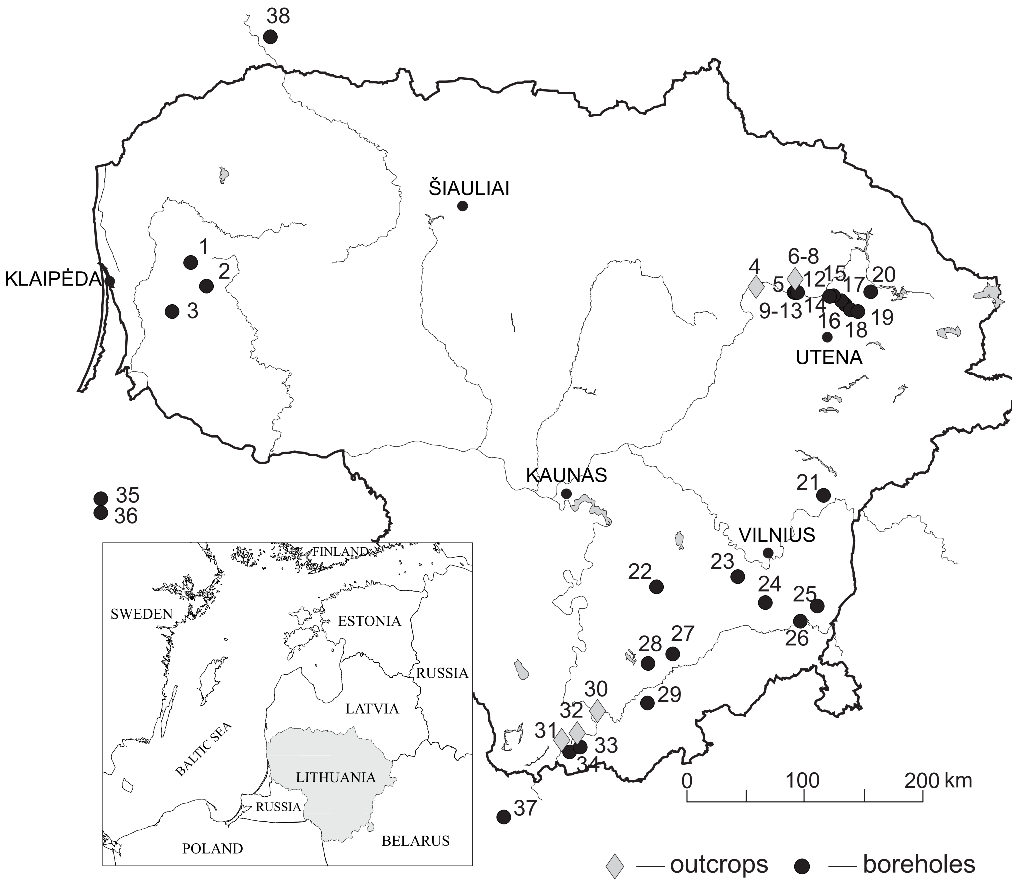

Fig. 1. Sites of the Butėnai Interglacial palaeontological investigations

1 — Žadeikiai-27, 2 — Stančaičiai-25, 3 — Skomantai-22, 4 — Lašinia, 5 — Butėnai-184, 6 — Butėnai-1, 7 — Butėnai-2, 8 — Butėnai-3, 9 — Butėnai-937, 10 — Butėnai-938, 11 — Butėnai-185, 12 — Butėnai-108, 13 — Butėnai-157, 14 — Gaigaliai-921, 15 — Trumpeliai-75, 16 — Šiekštis-922, 17 — Sudeikiai-936, 18 — Stumbrė-878, 19 — Daržiniai-941, 20 — Jakštai-955, 21 — Pailgiai-30, 22 — Aukštadvaris-651, 23 — Račkūnai-685, 24 — Kaišialakiai-700, 25 — Senasalis-137, 26 — Vilkiškės-68, 27 — Puodžiai-53, 28 — Gailiai-478, 29 — Lavysas-490, 30 — Čiasai, 31 — Gailiūnai, 32 — Neravai, 33 — Druskininkai-268, 34 — Druskininkai-276, 35 — Sosnovka, 36 — Domnovo, 37 — Židovščizna, 38 — Pulvernieki, 39 — Kraslava

these is based on the theory of probability (Muratova *et al.*, 1972). This method allows evaluation of the pollen composition and gradation of the trees according to their distribution. A limitation of the method is that it cannot be used for treeless landscapes. To compensate for this, the climatic indicator species method (Velichko and Gurtivaya, 1986) was also used. This method is based on the assumption that an individual species has reached equilibrium with the physical environment in the period concerned. The climatic indicator taxa used (*Betula nana, Dryas octopetala, Pinus s/g Diploxylon, Ephedra distachis, Lycopodium alpinum, Botrychium boreale, Taxus baccata, Buxus sempervirens, etc.*) have distributions that are clearly related to certain climatic parameters. In this case the mean July and January temperatures tolerated by each taxon were used. Climatic parameters were taken from the sector where all these species overlap.

The directions of tree migration were deduced using isopollen maps for the main tree taxa. The percentages of particular tree pollen in relation to all other trees were calculated in order to construct the maps. The mean values of pollen spectra of all samples at each time interval (phase) were taken and the relative percentage values for the individual pollen taxa for each time level at all sites (where this level was recognised) were used. Difficulties in compilation were caused by uneven distribution of the Butėnai age sections (they are absent in central Lithuania). For best results the sections from Latvia, Kaliningrad and Belarus were included.

HISTORY OF VEGETATION CHANGES

On the basis of vegetation composition the Butėnai Interglacial can be subdivided into 10 zones (Kondratienė, 1996). The vegetation of each zone has its own distinctive features (Fig. 2).

Zone B_1: this spans from the late glacial into the beginning of the Butėnai Interglacial. It can be divided into two parts.

Firstly, the subzone B_{1a} a period of treeless areas. After the retreat of the ice-sheet, only sparse herb communities, characteristic of open landscapes, could exist because of the cold climate and poor soils. The composition of plant communities was restricted. Species of *Artemisia*, Chenopodiaceae, Cyperaceae and rarely Poaceae families were predominant. Representatives of subarctic flora were also common. Climate amelioration then influenced soil development. It caused the spread of shrubs, especially the sea buckthorn (*Hippophaë*). Later on, the first forest pioneers, pine and birch, appeared. At the end of this subzone B_{1a}, the favourable climate enabled, birch (*Betula*) and pine (*Pinus*) to expand, forming sparse pine-birch mixed forests. Subzone B_{1b} — the period of pine and birch forest predominance. This phase was short, though sometimes distinguishable in pollen diagrams.

Coniferous forests dominated during the zone B_2. *Picea* (up to 45%), *Pinus* (20–30%) and *Alnus* (20–40%) were the main components of the forest. Larch (*Larix)* was abundant at the beginning of this phase and yew (*Taxus baccata*) in the second part. Pollen of deciduous trees (*Quercus, Ulmus, Tilia*) does not exceed 3–5%. Values of herb pollen were low. Forest was dense, luxuriant, and moist.

Zone B_3 represents the climatic optimum of the interglacial. During this phase, coniferous forest was widespread, where fir (*Abies*) and spruce (*Picea*) dominated. The first among the broad-leaved taxa that appeared and spread were oak (*Quercus*), elm (*Ulmus*), hazel (*Corylus*) and lime (*Tilia*), followed by hornbeam (*Carpinus*). Hornbeam spread simultaneously with fir. The proportion of broad-leaved trees in this forest was not significant (their pollen reaches 10–15%, locally up to 35%). Most probably they overgrow moist areas. The sediments of this phase contain the largest number of extinct and exotic plant species: *Abies alba* Miller, *Larix decidua* Miller, *Taxus baccata* Linnaeus, *Ilex aquifolium* Linnaeus, *Buxus sempervirens* Linnaeus, *Azolla interglacialica* Nikitin, *A. pseudopinnata* Nikitin, *Caulinia goretskyi* Dorofeev, *C. tenuissima* A. Brown, *Carex paucifloroides* Vielichkevich, *Nymphaea cinerea* Vielichkevich., *Ranunculus sceleratoides* Nikitin, *Pilea lituanica* Riškienė, (Riškienė, 1979; Velichkevich, 1982; Kisieliene, unpubl.).

In the next zone B_4 climate deterioration (drying and cooling) caused extinction of the thermophilous species and spread of pine followed by the spread of birch and larch. *Pinus* (60–80%) and *Picea* (10–15%) dominated the pollen spectrum. Values of fir (*Abies*) pollen were low (2–3%), and the number of spores was low.

Zone B_5 is characterised by thin forest where birch (up to 75%) and pines (up to 60%) with an admixture of *Larix* (5–6%) dominated. Pollen of deciduous trees was rare and does not exceed 5–10%.

The deterioration of climate was not uniform. During the zone B_6 the climate got warmer. Alder and spruce spread again in the forest. Most probably, there were no conditions for broad-leaved trees to grow in Lithuania.

The next deterioration of climate forced pine-birch mixed forest with an admixture of larch to spread (zone B_7).

During the next zone B_8 continuous deterioration of climate thinned out the forest. Numbers of tree pollen decreased to 40–60%, birch and pine being predominant. Pollen values of plants indicating open habitats, such as *Betula nana,* herbs and spores increased.

Appearance of treeless areas and domination of herbaceous plants (up to 40–60%) and spores (30–50%) were characteristic of zone B_9. Pine (*Pinus*) and birch (*Betula*) were predominant among trees. Single pollen grains of deciduous trees were observed. Pollen of *Ephedra, Helianthemum, Hippophaë* appeared sporadically. Herbaceous plants were dominated by *Artemisia. Thalictrum* pollen was also noticeable (up to 15%). Vegetation of the zone B_9 has some features characteristic of periglacial flora: elements of tundra and steppe.

During the period of general deterioration of climate a few short events of climate amelioration took place which modified the ecology of the treeles areas. A new ice advance then swept away all vegetation.

Thus, in the stratotype area of the Butėnai Interglacial, we have sections with an uninterrupted succession covering late glacial and interglacial phases and the beginning of the next glaciation. There are sections where the upper lacustrine sediments gradually give way to glaciolacustrine deposits (varved clay) (Trumpeliai-75, Fig. 4). All these successional stages may be clearly distinguished in the diagrams, representing plant ecological groups (Figs. 3 and 4): in the lowermost part — late glacial (domination of treeless landscape); in the middle part — interglacial (domination of forest); and in the uppermost part — early glacial (extinction of forest). The limit between the late glacial and the beginning of the interglacial pollen zones is quite distinctive. Climatostratigraphically it can be related with the formation of forest and the disappearance of elements of subarctic flora, and placed between the subzones B_{1a} and B_{1b}. The upper limit more complicated, between the interglacial and the early glacial. A small peak of herb pollen can be noticed in the zones B_4 and B_6 (Butėnai-184, Butėnai-937, Butėnai-938; Figs. 3 and 4), but representatives of subarctic flora and heliophytes are absent from these zones, these appearing between the zones B_7 and B_8. This level can be considered as the upper limit of the interglacial, where moreover, organic sediments are commonly replaced by terrigenous clastic deposits. This means that the substantial degradation of forest cover began at the end of the zone B_7. A well-developed forest cover, with no elements of subarctic vegetation, existed during the previous time periods.

Only one climatic optimum (zone B_3) was recognised in all sections the interglacial succession analysed (Figs. 3 and 4). Continuous forest cover existed during this period as herbaceous pollen make only 1–3% in the pollen diagrams. Mostly organic sediments accumulated in the lakes, their thickness ranging from 2–10 m. The deposits are pollen-rich (about 0.5 million/g). If one considers, that 10–15% thousand pollen grains were deposited on 1 cm^2 every year (Dąbrowski, 1971), linking sedimentation rate to pollen concentration suggests that the duration of zone B_3 might have been about 4–5 thousand years. Other zones may have lasted a little shorter.

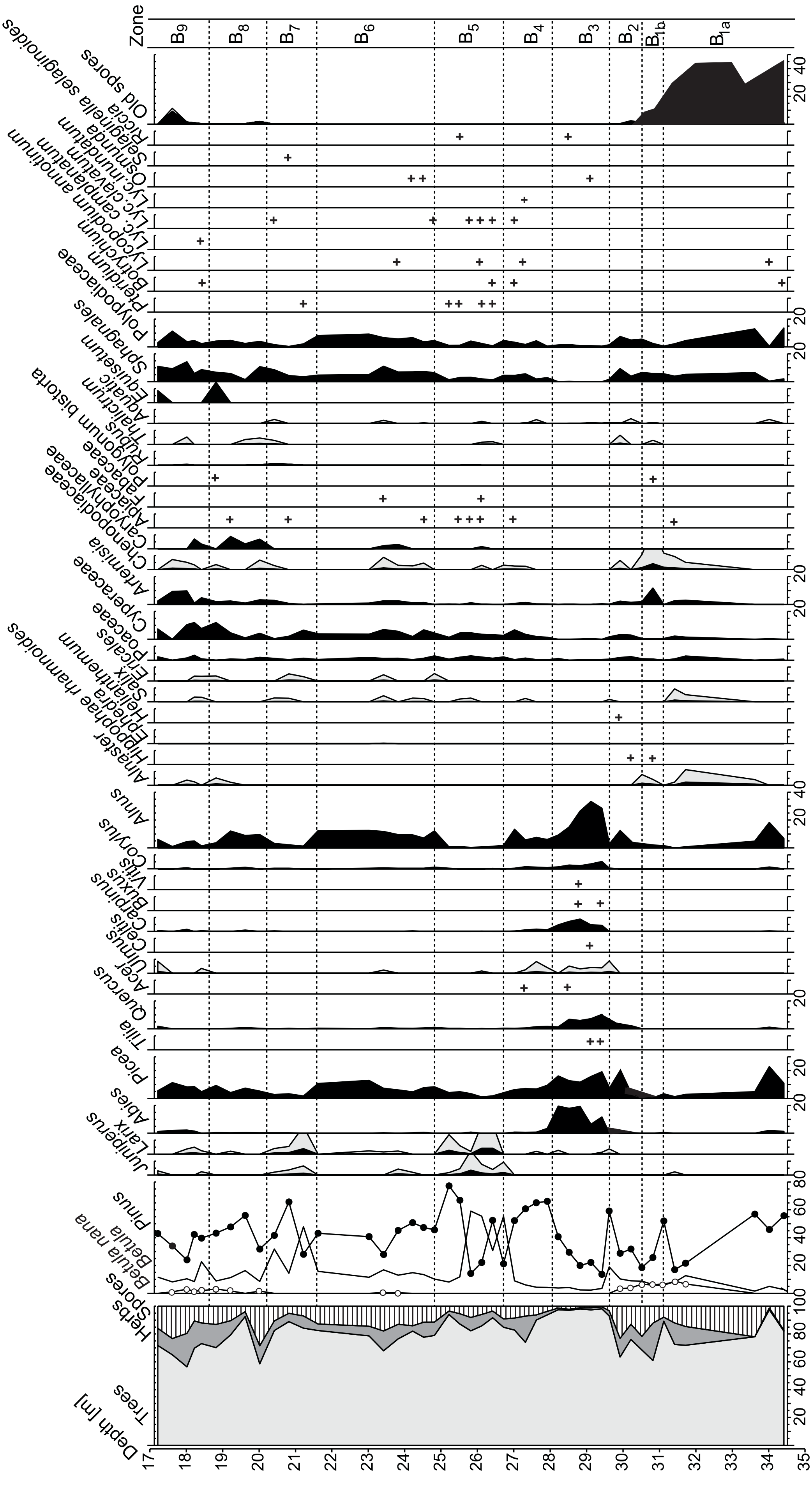

Fig. 2. Pollen diagram of the section Butėnai-938 borehole

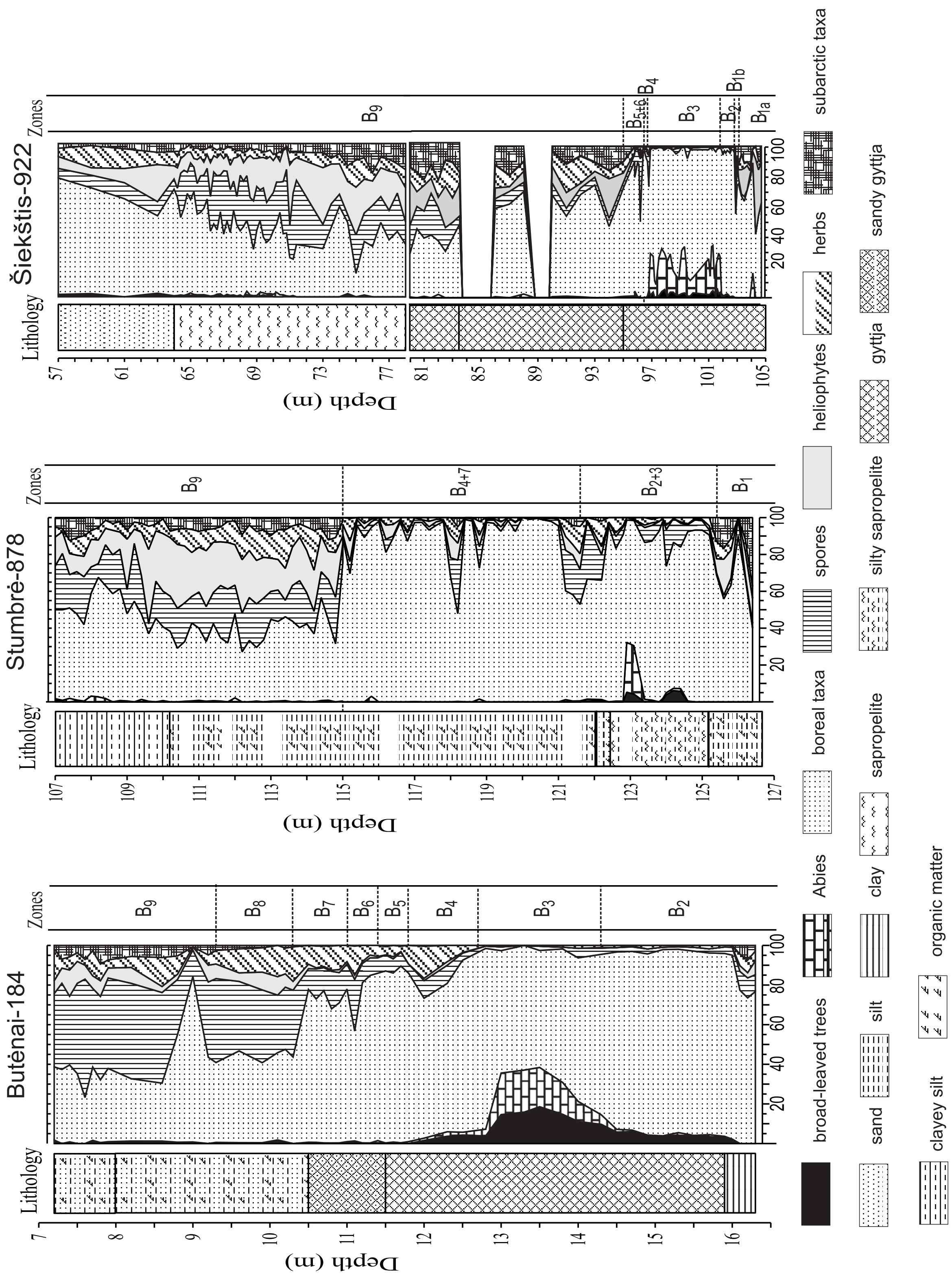

Fig. 3. Pollen diagrams of plant groups in sections Butėnai-184, Stumbrė-878 and Šiekštis-922

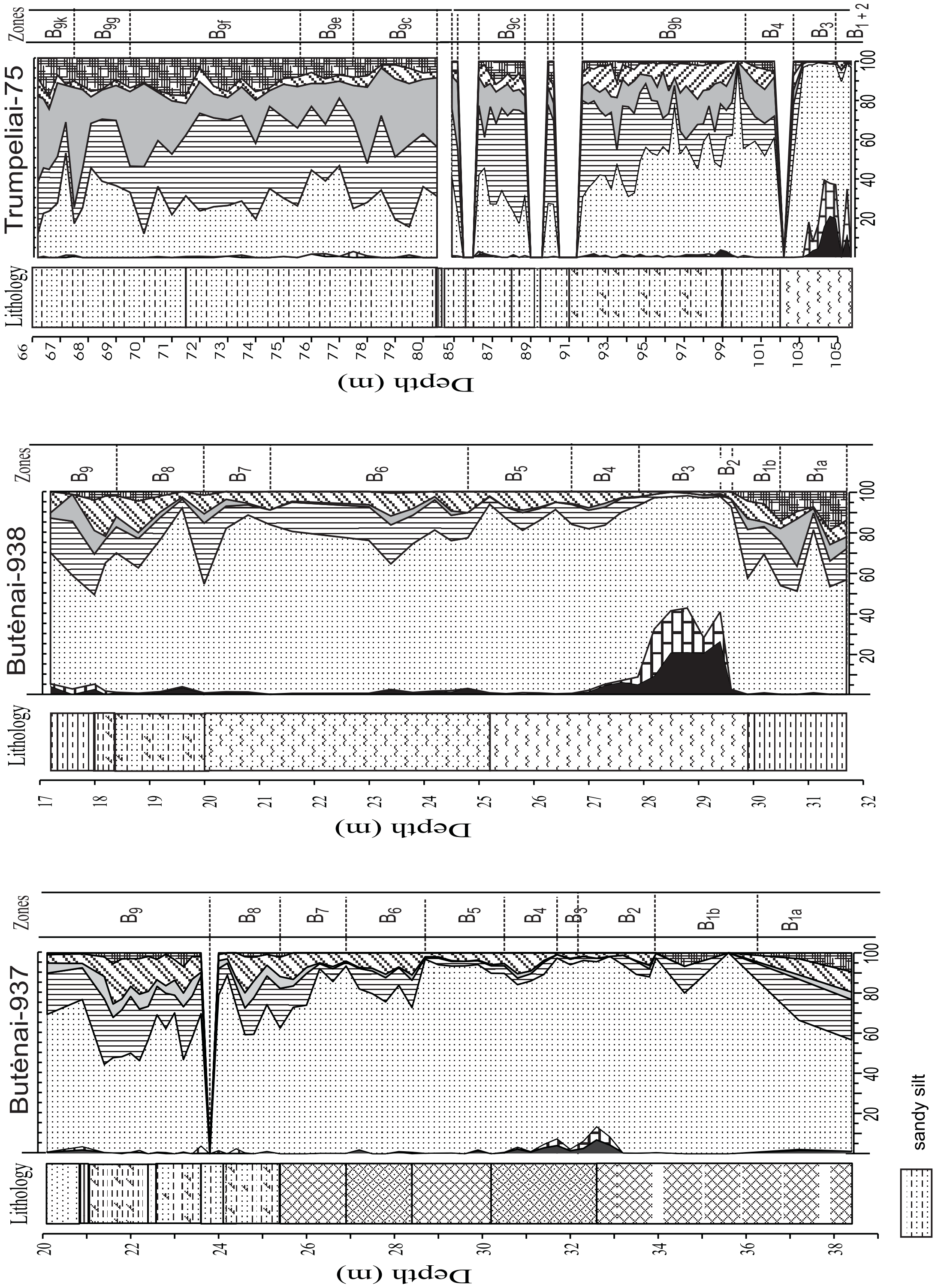

Fig. 4. Pollen diagrams of plant groups in sections Butėnai-937, Butėnai-938 and Trumpeliai-75
Other explanations as in Figure 3

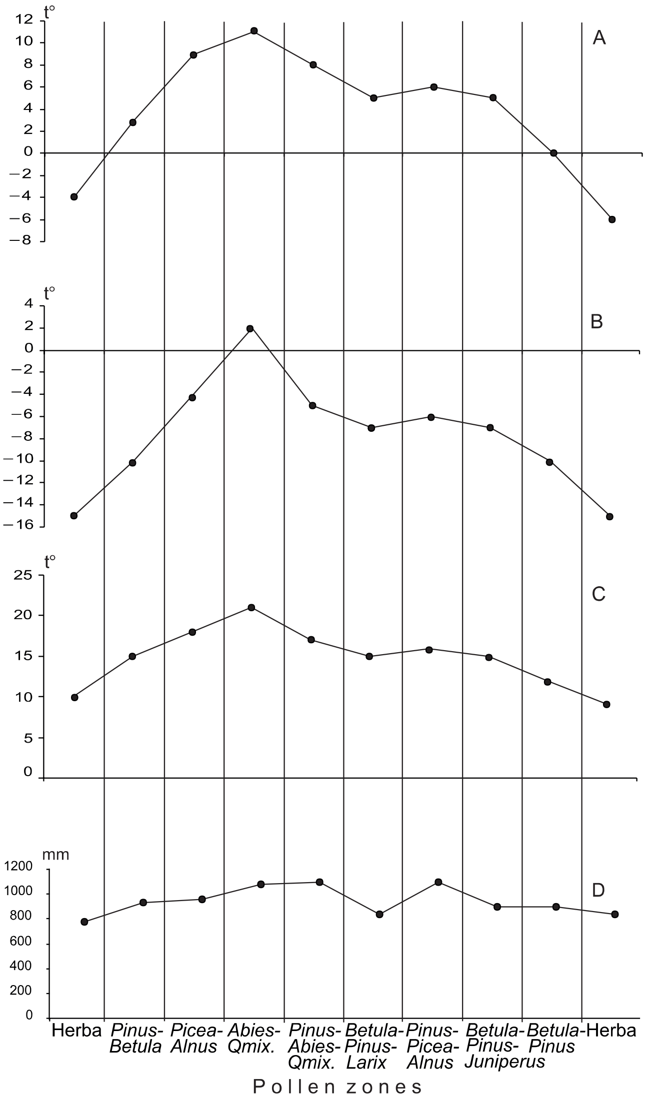

Fig. 5. Reconstructed climatic parameters

A — annual temperature; B — January temperature; C — July temperature; D — annual precipitation

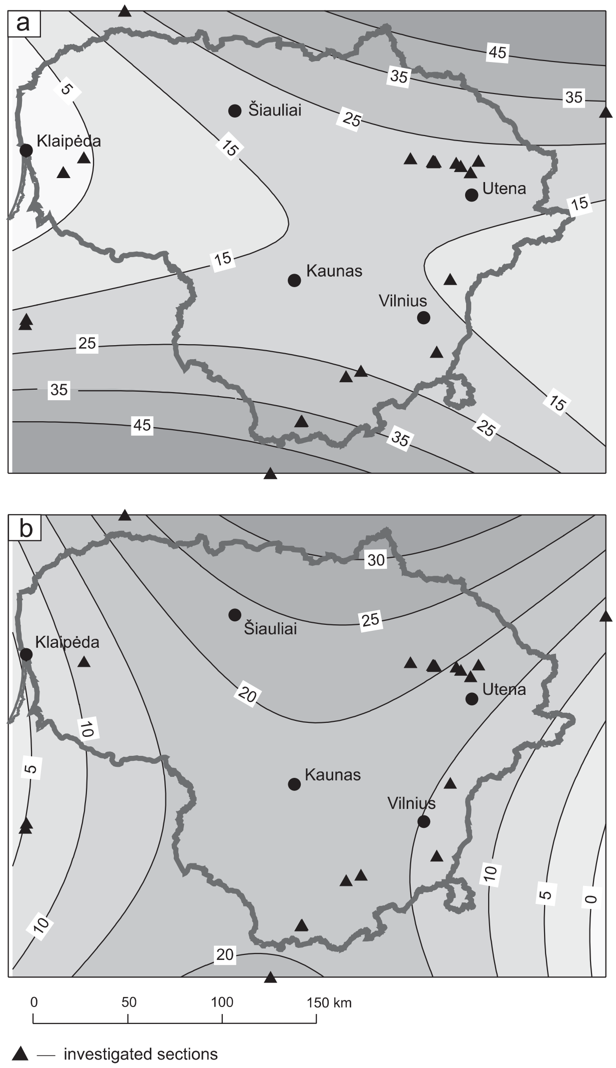

Fig. 6. Isopollen map for *Picea* during the zones: a — B_2; b — B_3

CLIMATE

From the period of the late glacial, during the Butėnai Interglacial and up to the beginning of the next glaciation, climate was not stable (Fig. 5).

Dry and severe climate was typical of the late glacial period. The mean temperature in January might have ranged from –15– –20°C and did not reach more than +12°C in summer (July). Annual precipitation was only about 300 mm. However, climate then warmed quite rapidly, but remained dry. Mean temperature in July increased up to (+15°C) at the end of the subzone B_{1b}. The climate became moister at the end of the zone B_2, enabling the spread of spruce and alder, followed by the spread of thermophilous species: (*Taxus baccata*), broad-leaved linden (*Tilia platyphyllos*) and Serbian spruce (*Picea omorica*). At the end of this zone, precipitation could be about 900 mm, mean year temperature increased to about +9°C, whereas the mean July temperature was up to +18°C. The average temperature in January did not fall below –4°C.

The thermal maximum of the interglacial was reached during the zone B_3. It was a period of warm and wet climate with especially mild winters. The mean January temperatures fluctuated between –1 to +4°C. It seems likely that there was no permanent snow cover during winter (Kondratienė, 1979). Climatic conditions were favourable for such thermophilous plants as *Abies alba, Taxus baccata, Picea omorica, Buxus sempervirens, Ilex aquifolium, Hedera helix, Pterocarya, Vitis, Osmunda cinnamomea* and *O. claytoniana.* Several species of *Brassenia*, *Nymphaea*, *Najas* and a lot of *Potamogeton* species were widespread in the lakes (Riškienė, 1979; Kondratienė, 1996). During the climatic optimum the annual precipitation might have ranged from 1000–1200 mm.

After the climatic optimum, a gradual deterioration of climate (cooling and drying) began. During the zone B_4 the annual precipitation fell to 750 mm, mean January temperatures fell to –5°C and July temperatures fell to +17°C. This tendency of climatic decline also continued during the zone B_5. The

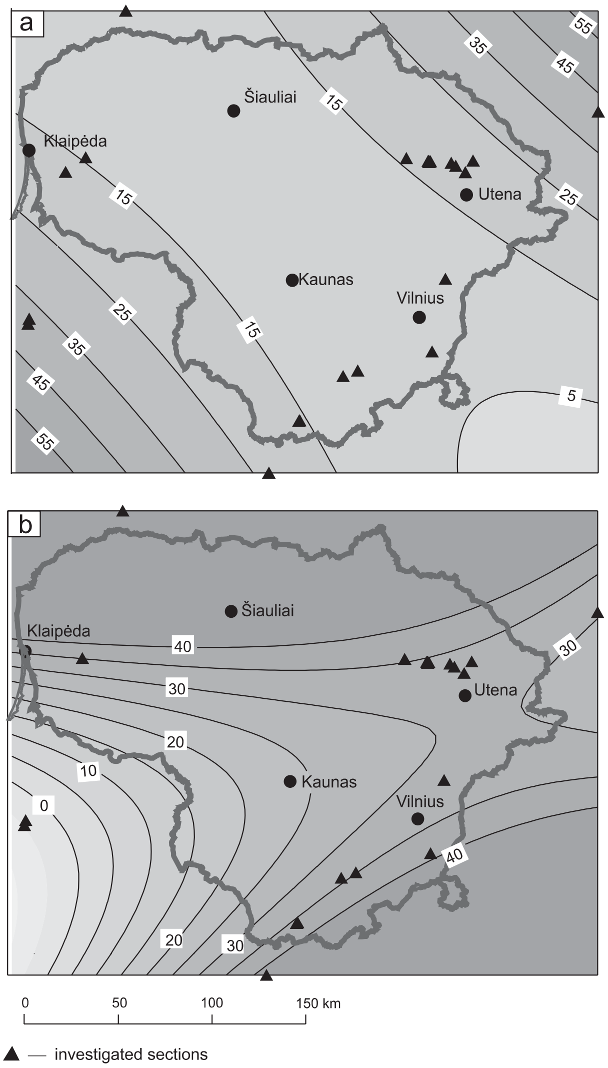

Fig. 7. Isopollen map for *Alnus* during the zones: a — B_2; b — B_3

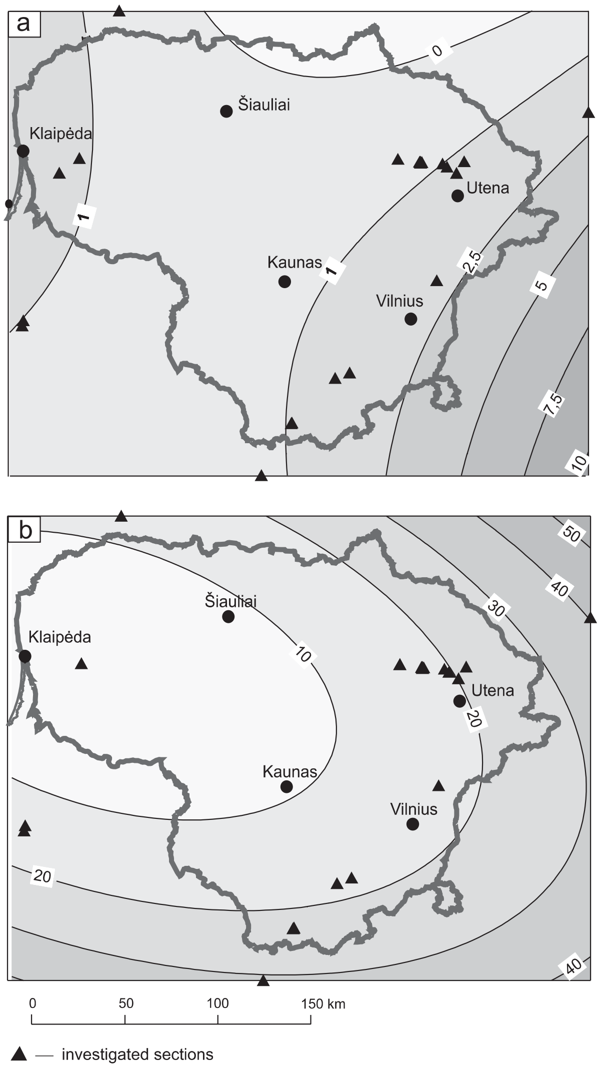

Fig. 8. Isopollen map for *Abies* during the zones: a — B_2; b — B_3

mean January and July temperatures dropped by several degrees, and precipitation by 200 mm. In comparison to a previous zone, the zone B_6 was warmer and moister. The mean annual temperature might have increased by +1°C and precipitation by 200–300 mm. The calculated climatic parameters for the zone B_7 are close to those of the zone B_5. However, climate of the zone B_7 may have been slightly colder and drier, especially during at the second part of the zone. An increasing number of heliophytes supports this presumption. The climate of the last two zones (B_8 and B_9) had subarctic features.

DIRECTIONS OF MIGRATION OF INDIVIDUAL TREE TAXA

All of the pollen diagrams studied indicate the same pattern of vegetation succession. However, participation of tree pollen during synchronous phases is not the same, indicating that forest composition varied across Lithuania. This was caused by local natural conditions, suche as relief, soil, ground water table *etc*.

The isopollen maps (Figs. 6–10) were constructed for the zones B_2 and B_3, which indicate a succession of coniferous forests with substantial participation of alder and hazel characteristic for both phases. Oak, hornbeam, alder and hazel were dominant among broad-leaved taxa. The appearance and spread of all these taxa were asynchronous.

Spruce and alder appeared in the forest at the same time — in the beginning of the zone B_2. As can be concluded from the isopollen maps (Fig. 6a) spruce migrated from the south and north-east. The Serbian spruce (*Picea omorica*) probably spread from the south, while common spruce (*Picea alba*) spread from the north-east. The present distribution of *Picea omorica* in Europe is restricted to the middle section of the Disna River, near Sarajevo in Yugoslavia (Natkevičaitė-Ivanauskaitė, 1959). However, during the Butėnai Interglacial it could have been more widespread. Later, during the zone B_3 the distribution of spruce in woodland was shaped by many factors, and in particular by soil processes. It was more common in the northern part of Lithuania (Fig. 6b), while in the south and east it was mostly replaced by fir (*Abies*).

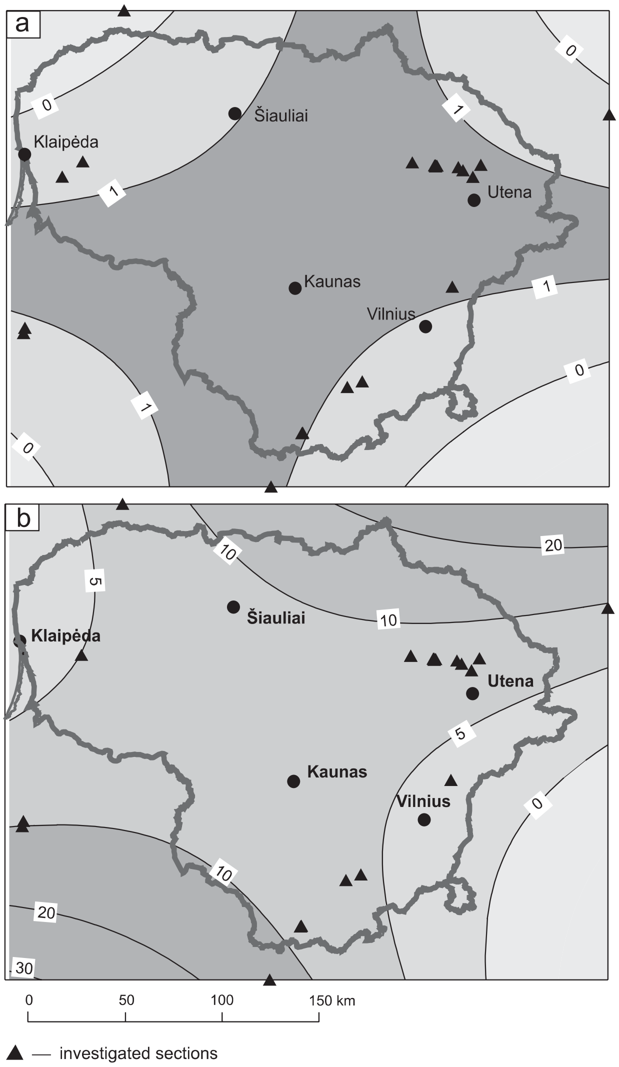

Fig. 9. Isopollen map for *Carpinus* during the zones: a — B_2; b — B_3

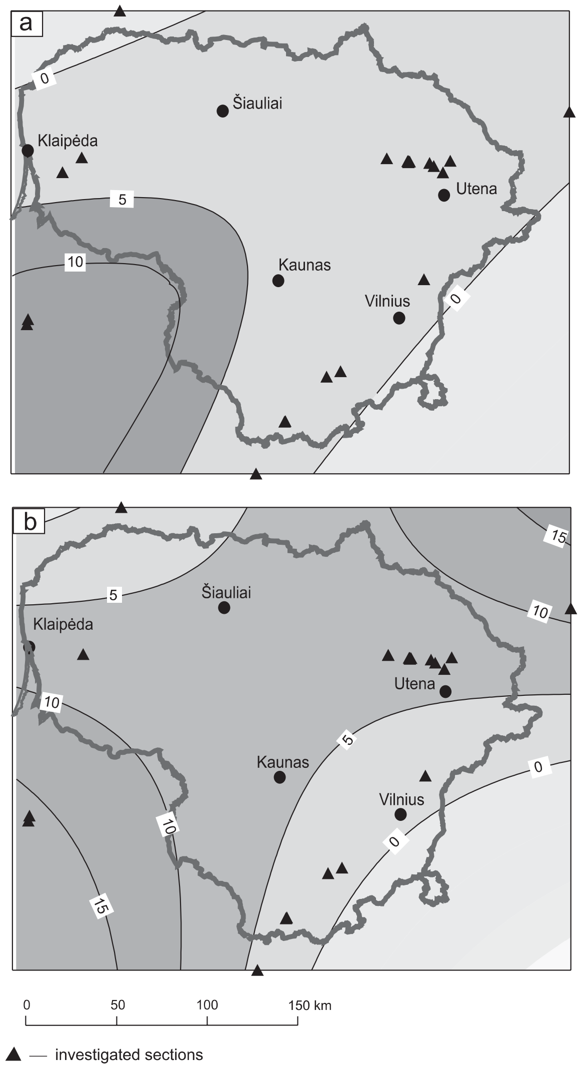

Fig. 10. Isopollen map for *Quercus* during the zones: a — B_2; b — B_3

Expansion of alder also took place from the two directions, from the south-west and the north-east (Fig. 7). This can be related to two component species: black alder (*Alnus glutinosa*) and white alder (*A. incana*). These species have different requirements in respect of soil and climate. *Alnus glutinosa* prefers a warm and wet climate, whereas *Alnus incana* prefers a cold and dry climate (Meusel *et al*., 1965). In this regard it can be concluded that the expansion of black alder took place from the south-west and white alder from the north-east. Distribution of *Alnus* pollen in the sediments of the zone B_3 is different to that of *Picea* pollen (Fig. 7). Probably, during the zone B_3, the most alders were concentrated in the northern and eastern parts of Lithuania.

Fir (*Abies*) appeared in woodland at the end of the zone B_2, arriving from the south-east. During the thermal optimum it was common in the south and east of Lithuania (Fig. 8). The northern limit of its distribution probably reached the Lithuania-Latvian border in the north, while in the east it may have moved further to the north. We can thus explain the absence or very low participation (1–3%) of fir pollen in many Latvian and Estonian Holsteinian Interglacial sections (Danilans, 1973; Kalnina, 2001; Liivrand, unpubl.). This scheme corrects the previously supposed position of this limit (Kondratienė and Raukas, 1998).

Hornbeam (*Carpinus*) is among the dominant tree taxa during the climatic optimum. It appeared simultaneously with the fir or, in some localities, a little earlier. However, the northern limit of its distribution was further to the north in comparison with the limit of fir and reached the southern part of Estonia. Only low amounts (1–3%) of fir pollen were traced in the Karuküla section, south Estonia (Liivrand, unpubl.). Hornbeam was most common in the south and north of Lithuania and spread from the south-west (Fig. 9).

Other broad-leaved trees appeared in the Lithuanian forests a little earlier than hornbeam. Oaks (*Quercus)* are noticeable in the second half of the zone B_2. They spread from the south-west (Fig. 10a). During the zone B_3 oaks grew mostly in the south-western and northeastern parts of Lithuania (Fig. 10b).

Hazel (*Corylus*) appeared from the same directions as hornbeam.

The main forest constituents varied during the Butėnai Interglacial. The basic factor driving these changes was the climate. Meanwhile, the formation of different contemporaneous plant communities was mainly shaped by edaphic and other local natural factors.

If we compare the isopollen maps for the zone B_3 and to pay attention to the ecological requirements of particular taxa, Lithuania can be subdivided into southwestern, southeastern, northeastern and central parts with similar natural conditions. Soils, formed of till loams prevailed in the southwestern and southeastern parts. These territories were well drained and the ground water level was low. Loams and sandy loams were the substrates for soil formation in the southeastern part as well, but there the groundwater level was higher. Sandy soils dominated in the central part of Lithuania. As regards the ground water level, many places there could be damp.

CONCLUSIONS

The Butėnai Interglacial is characterised by one, distinct, climatic optimum, when the average annual temperature might have been 2–4°C higher than at present in Lithuania: the mean annual temperature ranged from 9–12°C, the mean January temperature from –1–4°C, and the mean July temperature from 18–22°C. The annual precipitation might have been 300 mm higher than at present in this area.

The second part of the Butėnai Interglacial (B_5–B_7) was cooler and more continental. The climate was colder than at present in Lithuania.

The dominant tree taxa migrated from different directions. Spruce spread at the beginning of the zone B_2 from the south (*Picea omorica*) and north-east (*Picea abies*). Expansion of *Abies* started at the end of the zone B_2 from the south-west. During the thermal optimum its northern limit reached the border of Latvia and in the eastern part extended farther to the north to Latvia.

Alnus appeared and spread in woodland together with *Picea* from two directions: *Alnus glutinosa* from the south-west and *Alnus incana* from the north-east. *Quercus* spread from the south-west, *Carpinus* and *Corylus* from the south.

Loam, sandy loam soils prevailed over most of Lithuania while sandy soils covered its central part.

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