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PALAEOVEGETATION OF EUROPE DURING THE BÖLLING–ALLERÖD INTERSTADIAL COMPLEX WARMING (12.4–10.9 ka BP)

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Abstract. The available pollen data on 186 sites (896 samples) of the Böllin–Alleröd interstadial complex (12.4–10.9 ka) were summarised and entered in the electronic database. Results of the classification of sections with palynological data were analysed in the GIS. Based on the species composition and diversity of plants, as well as peculiarities of their ranges, we can establish the palaeovegetation coenoses during the latest interstadial warming of the final stages of the Late Pleniglacial.

Key words: pollen data, palaeovegetation, Bölling–Alleröd interstadial complex, Europe.

INTRODUCTION

The Bölling–Alleröd interstadial complex (BAl) (12.4–10.9 ka BP) is distinguished within the Late Neopleistocene as a distinct warming immediately preceding the Younger Dryas cold stage. The pollen materials related to the latest interstadials Bölling (12.4–12.0 ka BP) and Alleröd (11.8–10.9 ka BP) and intermediate Older Dryas cooling (12.0–11.8 ka BP)

Though a great volume of palynological data on the BAl complex interval has been published, but there are a few works providing synthesis of materials on this time interval (Grichuk, 1965; Bohncke *et al.*, 1988; Zimenkov, Valchik, 1989; Bohncke, 1993; Zelikson, 1994; Berglund *et al.*, 1994; Hoek, Bohncke, 1997; Bos, 1998). The most comprehensive descriptions of the Alleröd palaeovegetation in Eastern Europe were given by Zelikson (1994) and Quaternary Environments Network (QEN) participants. There are also palaeoclimatic characteristics of this period inferred from palaeobotanic data and coleopteran assemblages. In the north of Central Europe deviations of January temperatures from modern values were –7 to –13°C, and farther south –1°C (Velichko *et al.*, 1997) and those of July – no more than –1°C (Zelikson, 1994; Velichko *et al.*, 1997). In the territory adjoining to the middle reaches of the Volga River mean July temperatures were 2–3°C and January ones 3–4°C below modern values (Kremenetskii *et al.*, 1998). In northwestern Europe, both pollen data and plant macroremains suggest temperatures at the BAl interval to be 11–14°C in July and –13.9°C in January (Bohncke *et al.*, 1988; Hoek, Bohncke, 1997; Bos, 1998, Coope *et al.*, 1998; Lotter *et al.*, 2000).

MATERIALS AND METHODS

Data on the BAl interval (12.4–10.9 ka BP) have been obtained from 99 sections (553 samples altogether), primarily of fluvial-lacustrine and lacustrine-paludal sediments. 279 pollen taxa have been identified from the sections (including 67 determined to the species level and 179 — to the genus level). Data from the another 89 sections (326 samples) have been taken from the palynological database developed by Kozharinov (1994). Unfortunately, this database contains mostly information on arboreal pollen and total spectra composition of the central Russian Plain, and no data on non-arboreal pollen and spores is avaiable. Almost all of the sampled horizons are dated by radiocarbon to the BAl interval or alternatively could be dated biostratigraphically.

The analysis of the collected material was conducted with the use of the traditional methods of pollen spectra interpretation, and the mathematical methods such as multidimen-

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sional scaling (MDS) (Shepard, 1962) and cluster analysis (Oldenderfer, Bleshfild, 1989). For the palynological material the correlation between the axes (MDS) and geographical position was established on the basis of a matrix of range coefficients of Kendall correlations (Markova *et al.*, 2002 a, 2002 b; 2003; Simakova, Puzachenko, in press).

RESULTS

Mathematical processing of the palynological database on the Bölling–Alleröd interstadial complex resulted in the data being grouped into 11 clusters. Table 1[1] provides information on the distribution of the taxa and life forms by using cluster analysis; their geographical distribution is shown in fig. 1.

The distribution of coenoses among clusters is as follows: cluster 1 — shrub tundra and forest-tundra coenoses, cluster 2 — those of forest-tundra with patches of tundra-steppe, cluster 3 — periglacial birch and pine-birch forests, locally with steppe and tundra plant communities, cluster 4 — periglacial coniferous-broad leaf forests, cluster 5 — periglacial spruce and spruce-pine forests, cluster 6 — periglacial open pine-birch forests (parklands), cluster 7 — periglacial forest-steppe, cluster 8 — broad leaf forests, cluster 9 — periglacial forest-tundra-steppe, cluster 10 — periglacial pine-birch forests, with some broad leaf species, cluster 11 — periglacial grass-herb and Chenopodiaceae steppe.

Sections with palynospectra belonging to cluster 1 are confined to the northernmost regions of Europe (north of 59°N in Eastern Europe and north of 53°N in Western Europe). Sections with cluster 2 spectra are located south of this zone. Clusters 7 and 8 spectra correspond to southern areas of Europe (south of 50°N). Clusters 6, 4 and 3 are found in central regions, between 47 and 55°N. Clusters 9 and 10 are limited to northern regions of Western Europe, cluster 5 — to the east of the Russian Plain, and cluster 11 is localized in the southeast of the Russian Plain (east of the lower Volga R.). The geographic distribution of the identified clusters reveals certain features of periglacial zonality in the palaeovegetation of the BAl period; the zonal pattern, however, was essentially different from interglacial zonality.

Total composition of pollen spectra and analysis of indicator taxa distribution provided evidence of tundra and forest-tundra communities being still quite common in the BAl time, especially north of 51°N in Western Europe and north of 58°N in Eastern Europe; their limit shifted northward by approximately 2° since the second half of the last glaciation.

The maximum amount of pollen and spores *Sphagnum*, *Betula* sect. *Nanae*, *Salix*, *Populus*, Ericaceae, *Empetrum*, *Hippophae rhamnoides*, *Juniperus*, *Selaginella selaginoides*, *Alnaster fruticosus*, *Huperzia selago*, *Diphasium*, *Armeria* is concentrated in these latitudes. Southwards the proportion of tundra and forest-tundra communities is noticeably reduced; they are actually found only n the Alpine-Carpathian mountain regions.

The maximum amount of *Sorbus,* Cannabaceae, *Filipendula, Hedera*, Rubiaceae, Umbelliferae, Rosaceae, Ranuncullaceae, *Thalictrum, Rumex* pollen is also found in sections of northern European.

Typical representatives of steppe phytocoenoses at the time interval under consideration were still widely spread all over the European territory. Chenopodiaceae and *Ephedra* formed part of the steppe palaeophytocoenoses on the Iberian and Balkan peninsulas, in the south of the Russian Plain, and participated in tundra-steppe in the north of Europe. As compared with the preceding time interval (LGT), the maximum concentrations of Chenopodiaceae and *Ephedra* pollen are found farther north (north of 52°N) during the BAI interstadial.

Pollen of *Helianthemum*, Papaveraceae, *Plantago, Sanguisorba,* Saxifragaceae concentrated in Europe north of 53°N, as well as in the Mediterranean regions. Sections with considerable amounts of grass pollen are grouped in Central Europe and in the southwestern Mediterranean. Asteraceae pollen is found mostly in Central Europe, while Cichoriaceae is known from Western Europe and the Mediterranean regions. Therefore, palaeophytocoenoses of open landscapes prevailed in the northern and southern parts of Europe. Steppe communities were dominant south of 50°N.

As follows from total pollen spectra composition, forest coenoses prevailed in Central Europe and in some mountains (the Apennines, Alps, Carpathians, Crimean mountains, southern part of the Podolian Upland), *Pinus*, *Betula* and *Picea* being the main forest-forming taxa. The maximum concentrations of *Pinus* pollen were found in spectra from the north of Western Europe, central Eastern Europe, and mountain regions. The amount of pine is noticeably reduced in palaeophytocoenoses from the plains Europe south of 52°N.

The maximum concentrations of birch pollen are found in sections located north of 50°N.

Most of spruce pollen findings are limited to the eastern regions of the Russian Plain (north of 52°N). As a subdominant species, spruce took part in forest palaeophytocoenoses in the west of the Russian Plain and in the Alpine-Carpathian mountain regions. Pine-birch forests were widely spread in Europe north of 51°N, and pine-spruce forests — north of 53°N, mostly in the east of the Russian Plain.

Broadleaf species were present in forest communities of the temperate regions of Europe (south of 51°N in Western Europe and south of 57°N in eastern Europe) and in the Mediterranean regions.

Pollen spectra from sections located in the north of Western Europe contain rather low pollen vlues of *Quercus, Ilex*, *Corylus, Acer, Ulmus, Carpinus, Rhamnus*, those from west of the Russian Plain — grains of *Tilia, Quercus, Corylus, Ulmus, Carpinus*, and in the central part of the plain — *Tilia, Quercus, Corylus*, *Ulmus.* Such genera as *Tilia, Fagus*, *Fraxinus, Corylus, Carpinus* and *Ulmus* grew in the Carpathian mountains and in the southern Alps. Pine-birch forests with *Quercus,*

[1] for Table 1 see the end of this article

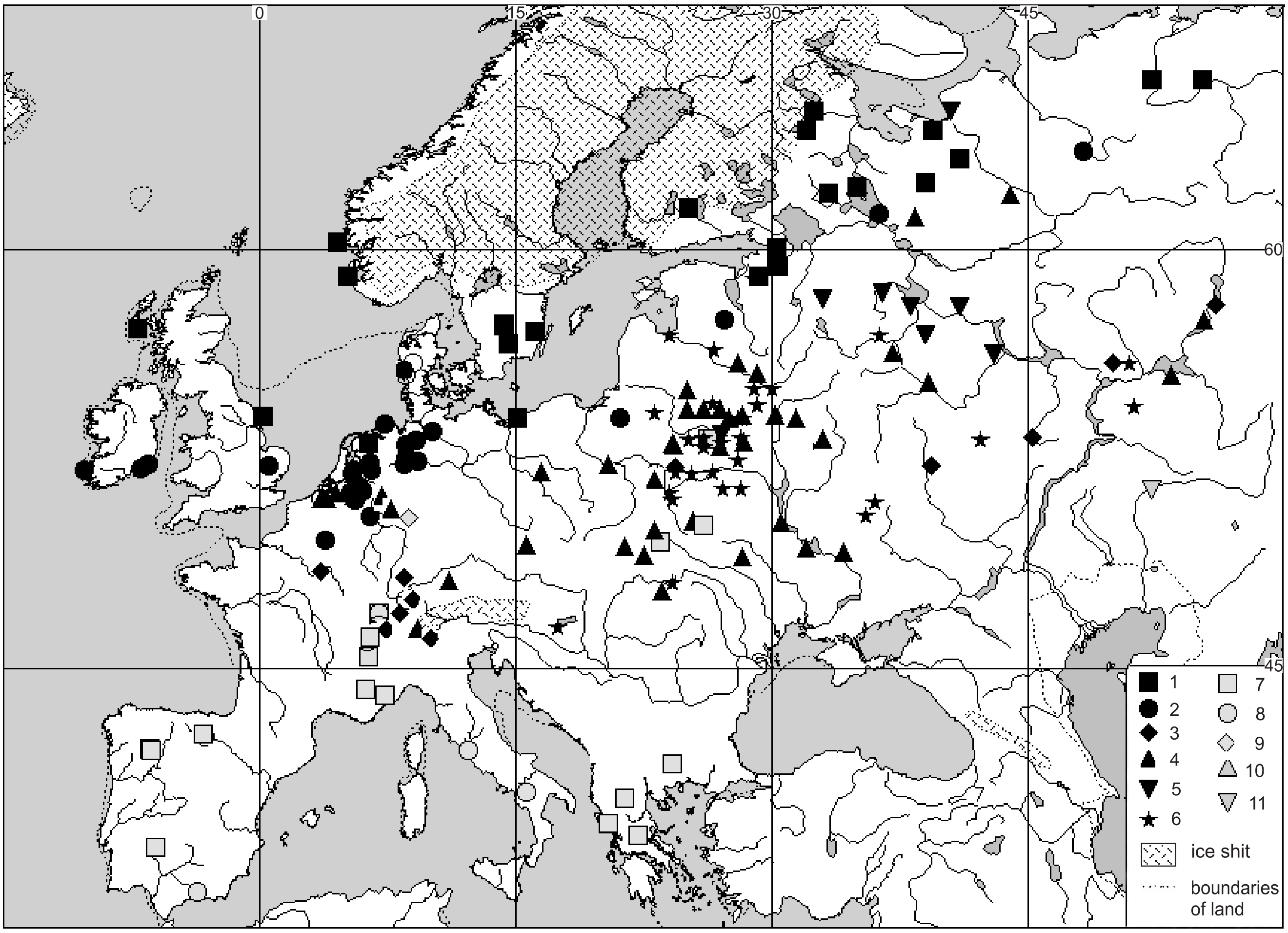

Fig. 1. The geographical distribution of the eleven clusters during the Bölling–Alleröd interstadial complex

For explanations of the clusters see the text

Tilia, Corylus, Acer, Ulmus existed in the Dnieper River valley. Forests of pine and broadleaf species (with *Quercus, Acer* and *Ulmus*) grew in the southeast of the Russian Plain.

Forest and forest-steppe plant communities of the Mediterranean included *Quercus, Rhamnus, Castenea, Myrica, Cedrus, Ostrya, Taxus, Olea, Pinus, Abies, Fagus, Fraxinus, Ilex, Tilia, Acer, Ulmus, Carpinus, Corylus*.

Qualitative and quantitative analyses of pollen and spores permitted to identify 13 palaeophytocoenoses (I to XIII) in two main vegetation provinces (European and Mediterranean) that existed in Europe during the BAI interstadial (12.4–10.9 ka BP) (Fig. 2).

European vegetation provinces:

I. Periglacilal shrub tundra with *Salix, Betula nana*, Ericales, *Hippophae, Juniperus* and small patches of open pine-birch forests north of 51°N in Western Europe and north of 61°–63°N in Eastern Europe.

II. Periglacial forest-tundra-steppe — combination of shrub tundra, pine-birch forests and tundra-steppe plant communities — north of 49–51°N in Western and Central Europe and between 59 and 62°N in Eastern Europe.

III. Periglacial birch forests with tundra-steppe elements (Western Europe); between 47and 49°N and west of 15E.

IV. Periglacial pine-birch forests (northern taiga) between 50°N and 52°N, 15° and 21°E (Central Europe) and on the Middle Danube Lowland.

V. Periglacial forest-steppe of forelands and middle mountains — a combination of light pine forests with broadleaf species (*Quercus, Corylus, Ulmus*) and herb-grass steppes, between 44° and 49°N in Western Europe.

VI. Mountain forests of the Carpathian-Alpine region — pine and spruce forests with some broadleaf species (the Carpathian Mts) and pine-birch forests with broadleaf species (the Alps)

VII. Periglacial pine-birch forests (northern taiga) with some tundra-steppe plant communities — between 60° and 62°N on the Russian Plain.

VIII. Periglacial spruce and pine-birch forests with patches of steppe coenoses — between 52° and 60°N and east of 33°E on the Russian Plain.

IX. Periglacial pine-birch and spruce forests with some nemoral elements, in combination with patches of steppes with *Stipa* and *Festuca* and shrub tundra between 50° and 53°N in the western and central regions of the Russian Plain.

X. Periglacial forest-steppe — pine-birch forests in combination with meadow steppe and tundra communities — south of 50°N on the Russian Plain.

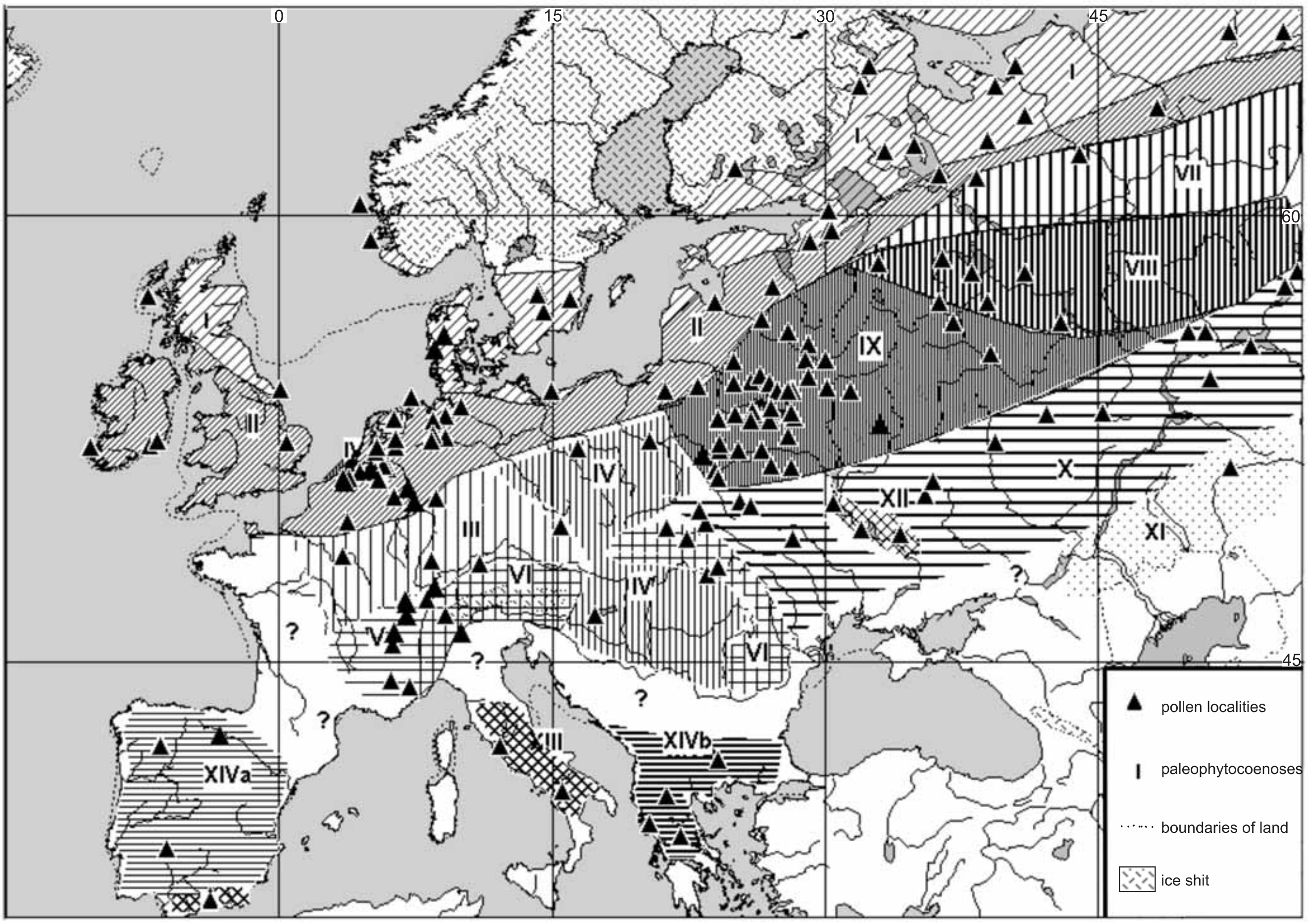

Fig. 2. Palaeovegetation of Europe during the Bölling–Alleröd interstadial complex

For explanations of the palaeophytocenoses see the text

XI. Periglacial steppe (east of the Volga R.)

XII. Riverine pine and broadleaf forests with *Quercus*, *Tilia*, *Corylus*, *Acer* (in large river valleys in the central and southern parts of the Russian Plain.

Mediterranean vegetation province:

XIII. Mediterranean pine-broadleaved forests and hard-leaved shrubs with *Taxus, Olea, Ostrya, Tilia, Quercus, Fagus, Fraxinus, Acer, Ulmus, Abies* (the Apennine Peninsula)

XIV. Mediterranean forest-steppe

XIV a. Combination of broadleaved forests, hard-leaved shrubs with *Quercus, Fraxinus, Myrica* and sagebrush-herb associations (the Iberian Peninisula)

XIV b. Combination of xerophytic forests with *Abies, Tilia, Carpinus, Pistacia, Myrica, Castanea, Ilex, Fraxinus, Acer, Ulmus, Quercus* and sagebrush-grass plant communities (the Balkan Peninsula).

CONCLUSION

The performed analysis of an extensive palynological material provided evidence of a considerable warming during the BAl interstadial. In Europe forest phytocoenoses expanded their ranges noticeably. In the central regions of the Russian Plain spruce forest played an important role in the palaeovegetation. Tundra and steppe communities still existed in the periglacial flora. An analysis of indicator taxa distribution suggests that the steppe communities were somewhat reduced in Western Europe, in the Mediterranean regions and in the center of Eastern Europe. Hypoarctic elements (*Selaginella, Betula nana, Alnaster, Huperzia, Armeria*) were also reduced in their ranges in comparison with the Late Glacial Transition period and occurred in the north of Europe and in mountains. Highly frequent occurrence of *Hippophae*, Chenopodiaceae, *Ophioglossum* in northern regions suggests landscapes with disturbed vegetation cover and some pioneer communities. Broadleaf species participated in periglacial forests in the south of Western Europe, in Central Europe (forelands and middle mountains) and in the center of the Russian Plain. In the Mediterranean regions broadleaf species occurred in the xerophyte forests of the Apennine Peninsula and were present in forest-steppe communities on the Iberian and Balkan peninsulas. Within the limits of the periglacial forest belt, the succession of main coenoses from west to east was as follows: periglacial birch forests — periglacial pine-birch forests — periglacial pine-birch and spruce forests with nemoral elements — periglacial spruce and birch-pine forests. Spatial distribution of palaeophytocoenoses suggests a periglacial zonality of interstadial type in the vegetation. The reconstructed palaeo-vegetation provides support for a noticeably warmer and wetter climate at the Bölling-Alleröd interstadial.

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T a b l e 1

Distribution of the taxa and live forms — based on cluster analysis

Cluster / Taxon	1	2	3	4	5	6	7	8	9	10	11
Trees	0.38	**0.62**	0.79	0.79	0.86	0.71	0.53	**0.80**	0.74	**0.91**	0.00
Herbs	0.44	0.46	0.30	0.26	0.12	0.32	**0.60**	0.35	0.41	0.22	**0.93**
Spores	**0.50**	0.03	0.07	0.16	0.14	0.12	0.42	0.00	1.00	0.00	0.01
Lycopodium	**0.250**	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vaccinium	**0.207**	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Calluna	**0.146**	0.000	-	0.000	-	0.000	0.000	0.000	-	0.000	-
Dryas	**0.170**	0.078	0.025	0.006	0.000	0.000	0.019	0.000	0.050	0.034	0.000
Helianthemum	**0.084**	0.000	0.000	0.000	0.000	0.000	0.071	0.059	0.000	0.000	0.000
Equisetum	**0.333**	0.000	0.000	0.000	0.000	0.000	-	0.000	**0.333**	0.000	0.000
Salix	**0.335**	0.274	0.071	0.172	0.047	0.118	0.091	0.008	0.016	0.012	0.047
Chenopodiaceae	**0.104**	0.128	0.002	0.004	0.000	0.000	**0.100**	0.005	0.010	0.025	0.057
Juniperus	0.062	**0.315**	0.025	0.040	0.000	0.000	0.049	0.046	0.000	0.014	0.000
Rumex	0.083	**0.262**	0.089	0.048	0.000	0.054	0.050	0.000	0.000	0.054	0.000
Hippophae	0.148	0.127	**0.479**	0.076	0.000	0.000	0.075	0.000	0.000	0.007	0.250
Artemisia	0.078	0.159	**0.354**	0.093	0.000	0.000	**0.287**	0.000	0.000	**0.368**	0.000
Onagraceae	0.019	0.063	**0.333**	0.059	0.000	0.000	0.083	0.000	0.000	0.000	0.000
Betula	0.504	0.458	**0.855**	0.274	**0.801**	0.201	0.128	0.000	0.000	0.792	0.118
Pinus	0.168	0.101	**0.291**	0.631	0.162	**0.414**	0.325	0.133	0.015	0.210	0.030
Selaginella	**0.089**	0.039	0.011	**0.140**	0.031	0.016	0.051	0.010	0.000	0.000	0.016
Sphagnum	0.007	0.037	0.000	**0.163**	0.000	0.083	**0.115**	0.000	0.000	0.000	0.000
Betula nana	**0.101**	0.046	0.000	0.073	**1.000**	0.327	0.014	0.000	0.000	0.000	0.000
Picea	0.039	0.000	0.000	0.163	**1.000**	0.292	0.003	0.000	0.000	0.016	0.000
Tilia	0.001	0.000	0.000	0.050	**0.500**	0.000	0.095	**0.273**	0.000	0.000	0.000
Larix	0.000	0.000	0.000	0.086	0.000	**0.500**	0.005	0.000	0.000	0.000	0.000
Caryophyllaceae	0.000	0.000	0.000	0.000	0.000	**0.500**	0.075	0.000	0.000	0.000	0.000
Empetrum	0.149	0.137	0.000	0.047	0.000	**0.524**	0.006	0.028	0.000	0.000	0.000
Ilex	0.000	0.048	0.000	0.000	0.000	0.000	**0.071**	0.000	0.000	0.000	0.000
Abies	0.001	0.000	0.000	0.006	0.000	0.000	**0.048**	0.500	0.000	0.000	0.000
Fagus	0.000	0.000	0.000	0.050	0.000	0.000	0.004	**0.502**	0.000	0.000	0.000
Quercus	0.000	0.004	0.000	0.001	0.021	0.000	**0.193**	0.604	0.000	0.021	0.000
Acer	0.000	0.048	0.000	0.000	0.000	0.000	0.060	**0.333**	0.000	0.000	0.000
Fraxinus	0.012	0.000	0.000	0.050	0.000	0.000	0.024	**0.859**	0.000	0.000	0.000
Polemoniaceae	0.050	0.098	0.188	0.067	0.000	0.000	0.222	**0.485**	0.000	0.074	0.000

Table 1 continued

Taxon \ Cluster	1	2	3	4	5	6	7	8	9	10	11
Alnus	0.006	0.004	0.003	0.065	**0.281**	0.121	0.009	**0.345**	0.214	0.121	0.080
Carpinus	0.001	0.022	0.000	0.000	0.000	0.000	0.076	**0.561**	1.000	0.197	0.000
Corylus	0.006	0.058	0.000	0.040	0.000	0.000	0.103	**0.214**	1.000	0.375	0.000
Ulmus	0.005	0.000	0.004	0.028	0.000	0.000	**0.116**	0.341	1.000	0.000	0.000
Cichoriaceae	0.127	0.073	0.090	0.050	0.000	0.000	**0.289**	0.040	**1.000**	0.034	**0.240**
Plantago	0.000	0.000	0.000	0.000	0.000	0.000	0.071	0.000	**1.000**	0.000	0.000
Trifolium	0.000	0.000	0.000	0.000	0.000	0.000	-	0.000	**1.000**	0.000	0.000
Brassicaceae	0.000	0.011	0.375	0.005	0.000	0.000	0.096	0.000	**1.000**	0.015	0.000
Rubus	**0.353**	0.052	0.000	0.045	0.000	0.000	0.057	0.000	**1.000**	0.000	0.000
Umbelliferae	0.114	0.143	0.025	0.000	0.000	0.150	0.113	0.000	**1.000**	0.025	0.000
Ephedra	0.072	0.108	0.000	0.000	0.000	0.000	0.114	0.000	**0.333**	0.000	0.000
Armeria	0.087	0.024	0.000	**0.152**	0.150	0.050	0.024	0.000	**0.267**	0.025	0.000
Ericaceae	0.000	0.000	-	0.000	-	0.000	0.000	0.000	-	**1.000**	-
Populus	**0.103**	0.142	0.042	0.041	0.000	0.000	0.000	0.000	0.000	**0.242**	0.000
Huperzia selago	**0.141**	0.203	0.003	0.053	**0.137**	0.000	0.031	0.000	0.000	**0.277**	0.000
Thalictrum	0.018	**0.159**	-	0.184	-	0.000	0.000	0.000	-	**0.351**	-
Saxifragaceae	0.008	0.083	0.000	0.000	0.000	0.000	0.082	0.000	0.000	**0.202**	0.000
Cyperaceae	0.014	0.060	0.000	0.039	0.000	0.000	0.070	**0.333**	0.000	**0.511**	0.000
Poaceae	0.019	0.054	0.042	0.055	0.000	0.250	**0.357**	0.000	0.000	0.000	**1.000**
Asteraceae	**0.025**	0.000	0.000	**0.070**	0.000	0.000	**0.071**	0.000	0.000	0.000	0.000