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# Hydrological dynamics and fire history of the last 1300 years in western Siberia reconstructed from a high-resolution, ombrotrophic peat archive

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## Abstract

Siberian peatlands provide records of past changes in the continental climate of Eurasia. We analyzed a core from Mukhrino mire in western Siberia to reconstruct environmental change in this region over the last 1300 years. The pollen analysis revealed little variation of local pine-birch forests. A testate amoebae transfer function was used to generate a quantitative water-table reconstruction; pollen, plant macrofossils, and charcoal were analyzed to reconstruct changes in vegetation and fire activity. The study revealed that Mukhrino mire was wet until the Little Ice Age (LIA), when drought was recorded. Dry conditions during the LIA are consistent with other studies from central and eastern Europe, and with the pattern of carbon accumulation across the Northern Hemisphere. A significant increase in fire activity between ca. AD 1975 and 1990 may be associated with the development of the nearby city of Khanty-Mansiysk, as well as with the prevailing positive Arctic Oscillation.

## Keywords

- Testate amoebae; Pollen; Macrofossils; Transfer function; Peat; Siberia; Charcoal

## 43 **Introduction**

44 Northern hemisphere peatlands are important archives of past environmental  
45 change and sinks of carbon (Charman, 2002; Loisel et al., 2014). However, climate  
46 change and human impacts (e.g. wetland drainage and nutrient deposition) trigger  
47 increased emission of this stored carbon into the atmosphere (Payne et al., 2013; Ward  
48 et al., 2013). Given these ongoing stressors, there is an urgent need to better understand  
49 the various processes involved in peatland dynamics (Dise, 2010; Loisel and Yu, 2013).  
50 Paleoenvironmental approaches provide a useful perspective on the present state and  
51 long-term history of peatlands (Seddon et al., 2014), and the application of coupled  
52 biotic and abiotic proxies enables a detailed reconstruction of climate change, peatland  
53 ecosystem development, and changes in the surrounding landscape (Gałka et al., 2013).

54 The last millennium is a critical period for paleoenvironmental study, as it  
55 features both climatic variability, such as the Medieval Warm Period (MWP) and the  
56 Little Ice Age (LIA), and increasing anthropogenic impacts, leading up to the dramatic  
57 increases in pollution and global temperatures observed over the last 200 years (Jones  
58 and Mann, 2004). Peatland ecosystems experience various types of anthropogenic and  
59 natural disturbances, including wetland drainage, forest management, and fire (Dise,  
60 2010). The response of peatlands to disturbance and climate change has been well  
61 studied in Europe (Lamentowicz et al., 2008; Lamentowicz et al., 2011; van der Knaap et  
62 al., 2011), but the paleoecology of Siberian bogs remains largely unexplored.

63 The hydrological dynamics of Siberian peatlands over the last millennium are of  
64 particular interest, and testate amoebae, protists that are abundant in peatlands and  
65 sensitive to hydrological conditions, can be used as a reliable proxy for the quantitative  
66 reconstruction of past variability in water tables (Blundell et al., 2008; Booth et al.,  
67 2008; Hendon and Charman, 2004; Turner et al., 2014). However, while some research  
68 has explored the ecology and taxonomy of testate amoebae in Siberian bogs (Bobrov et  
69 al., 2013; Kurina et al., 2010; Muller et al., 2009), modern calibration studies have not  
70 been carried out in this region. Such calibration data sets for testate amoebae are  
71 urgently needed so that this proxy can be utilized for the reconstruction of past  
72 hydrological variations in western Siberia.

73

74           Several analyses of Siberian peatlands have focused on carbon accumulation  
75 (Beilman et al., 2009; Borren et al., 2004; Lapshina and Plogova, 2011; Lapshina et al.,  
76 2001; Turunen et al., 2001), but few peatland studies in this region have generated  
77 paleoecological inferences (Bobrov et al., 2013; Kremenetski et al., 2003; Liss et al.,  
78 2001; Peregon et al., 2007a; Peregon et al., 2007b; Pitkänen et al., 2002). This is in  
79 contrast to work in Northwest Europe and North America, where a large number of  
80 high-resolution, multi-proxy studies have been performed in peatlands (Blundell and  
81 Barber, 2005; Booth et al., 2006; Kaislahti Tillman et al., 2010; Swindles et al., 2007;  
82 Turner et al., 2014). The lack of such studies in Siberia is unfortunate, as Siberian  
83 peatlands cover much larger areas than in other parts of Eurasia. Moreover,  
84 paleoenvironmental records from Siberian peatlands have the potential to improve our  
85 understanding of past changes in both the continental climate of Eurasia and pristine  
86 vegetation that no longer exists in Europe (Solomeshch, 2005).

87           Charcoal records from peatlands have been used to reconstruct past fire activity  
88 in Europe (Gałka et al., 2013; Sillasoo et al., 2011) and North America (Lavoie and  
89 Pellerin, 2007), but only limited research of this type has been carried out in Siberia  
90 (Turunen et al., 2001), despite the global importance of peatland fires (Turetsky et al.,  
91 2015). It is believed that during the last decade burning has increased in Siberia due to  
92 the prevailing positive Arctic Oscillation (Balzter et al., 2005). This relationship can only  
93 be verified with a paleoecological approach, since mapped fire data and instrumental  
94 weather data cover only short time scales. Over longer intervals, increased fire activity  
95 may be related to the prolonged drought events that are recorded by hydrological  
96 changes in peatlands. Charcoal data have not been regularly compared to quantitative  
97 paleohydrological reconstructions (Tweiten et al., 2009). Nevertheless, the study by  
98 Marcisz et al. (2015) showed that a coupled analysis of charcoal and testate amoebae  
99 could improve our understanding of past droughts and heat waves over long temporal  
100 scales.

101           In this study we apply three methodological approaches that previously have not  
102 been used together in Siberia: (i) a testate amoebae transfer function was used for a  
103 quantitative water table reconstruction; (ii) pollen and plant macrofossils were used to  
104 reconstruct vegetation history; and (iii) a charcoal record was used to infer past fire

105 activity. The integration of these proxies allows us to explore the response of boreal  
106 peatlands, forest communities, and fire regimes to climate change. This research focus  
107 aligns well with the PAGES—Asia2k research program (Ahmed et al., 2013). A modern  
108 calibration study also improves our understanding of testate amoebae ecology in the  
109 boreal region of Siberia.

110

## 111 **Study site**

112 The Mukhrino mire is located on the eastern bank of the Irtysh River, near the  
113 confluence with the Ob River in the middle taiga area of western Siberia, about 20 km  
114 from Khanty-Mansiysk (60°54' N, 68°42' E). This region is located in the Boreal climate  
115 zone, which corresponds to the Sub-Arctic climate zone of western Europe (Fig. 1). The  
116 mean annual temperature is  $-1.3^{\circ}\text{C}$ , the coldest month being January, with a mean  
117 temperature of  $-18.9^{\circ}\text{C}$ ; the warmest month is July, with a mean temperature of  $17.1^{\circ}\text{C}$ .  
118 The mean annual precipitation is 553 mm (Kremenetski et al., 2003). In 2009, the  
119 Mukhrino Field Station was built at the margin of a giant mire complex. It is managed by  
120 the UNESCO Chair of Environmental Dynamics and Climate Change at Yugra State  
121 University, Khanty-Mansiysk, Russia (Elger et al., 2012). The Mukhrino mire complex is  
122 typical for the West Siberian middle taiga. It is a complex of oligotrophic-raised bogs  
123 (*Pinus sylvestris* and *P. sibirica*, *Eriophorum vaginatum*, *Ledum palustre*, *Chamaedaphne*  
124 *calyculata*, *Betula nana*, and *Sphagnum fuscum*) patterned with ridge-hollows (*Carex*  
125 *limosa*, *Scheuchzeria palustris*, *Sphagnum balticum*, *S. jensenii*, and *S. papillosum*) and  
126 oligo-mesotrophic fens (*Carex rostrata*, *Menyanthes trifoliata*, *E. russeolum*, *S. fallax*, *S.*  
127 *jensenii*, and *S. majus*) (Filippov and Lapshina, 2008). This area is characterized by the  
128 absence of permafrost (Bleuten and Filippov, 2008). The Mukhrino peatland has a peat  
129 thickness between 3 m and 4.5 m. Its hydrology is dependent on micro-topography and  
130 changes seasonally. During the summer, groundwater in poor fens and hollows is  
131 between 5 cm and 20 cm below the moss surface, while in raised bog areas with  
132 *Sphagnum* hummocks the water table is 40 cm to 80 cm below the surface (Bleuten and  
133 Filippov, 2008).

134

135

136

## 137 **Materials and methods**

### 138 *Field sampling*

139 In summer 2012, a 1m peat core was sampled with a long serrated knife and  
140 sliced in the field into 1cm samples. Each slice was divided into four subsamples to be  
141 used in the four analyses. These peat samples were then packed into plastic bags and  
142 transported to the laboratory. They were kept refrigerated until processing.

143 In addition, 65 moss samples and 5 liverworts were collected in the summers of  
144 2012 and 2013 in the mire around Mukhrino station for the construction of a calibration  
145 data set to be used in the testate amoebae transfer function. Surface samples were taken  
146 along a wet-dry gradient from pools to the tops of hummocks. Water table depth was  
147 measured once during the sampling campaign, together with pH and conductivity.

148

### 149 *Chronology and peat accumulation rate*

150 Eleven AMS (Accelerator Mass Spectroscopy)  $^{14}\text{C}$  dates were obtained in the  
151 Poznań Radiocarbon Laboratory (Poland) in 2013. The samples subjected to dating  
152 contained *Sphagnum* stems and leaves and these were carefully cleaned from rootlets to  
153 avoid contamination by younger carbon (Table 1). The basis for the chronology of the  
154 Mukhrino peat profile is a Bayesian age-depth model constructed using the OxCal v. 4.2  
155 program (Bronk Ramsey, 2008), with the application of the IntCal13 (Reimer et al.,  
156 2013) and NH1 post-bomb (Hua et al., 2013) atmospheric curves. For the calculation of  
157 the model with a 0.5cm resolution, the *P\_Sequence* function with parameters  $k_0=1$  and  
158  $\log_{10}(k/k_0)=0.3$  was applied. The most distinct changes in the peat structural  
159 composition and pollen concentration of the profile were introduced using the *Boundary*  
160 command. The first boundaries were established at depths of 100 cm and 0 cm (the  
161 bottom and top of the model, respectively), followed by 86.5 cm and 50.5 cm (both  
162 reflecting rapid changes in pollen concentration and bulk density (cf. Fiałkiewicz-Kozieł  
163 et al., 2015)). The age of the top of profile (0 cm) was set as AD 2012.7 (the August  
164 2012—the date of the core retrieval). Hereafter, ages are presented as median ( $\mu$ ) values  
165 of the modeled ages, and expressed as AD years. The peat accumulation rate (P),

166 expressed as cm/yr, was calculated according to the formula:  $P_{\text{depth}} = 1\text{cm} / (\mu_{\text{depth}-0.5\text{cm}} -$   
167  $\mu_{\text{depth}+0.5\text{cm}})$ .

168

### 169 ***Pollen and charcoal***

170 Twenty-four samples (1 cm thick, each 2 cm<sup>3</sup> in volume) were prepared with a  
171 standard preparation procedure with the application of hydrofluoric acid to remove  
172 silica, followed by acetolysis (Berglund and Ralska-Jasiewiczowa, 1986). A *Lycopodium*  
173 tablet (20,848 spores, produced by the University of Lund) was added to each sample to  
174 enable the calculation of pollen concentrations (Stockmarr, 1971). Pollen slides  
175 mounted with glycerin were analyzed using a light microscope at 400× and 1000×  
176 magnification and counted to a sum of arboreal pollen (AP) >500 grains. Two samples  
177 with pollen concentrations <10,000 grains/cm<sup>3</sup> were counted to <500 AP grains. Then,  
178 on the same slides, microscopic charcoal particles (10-100 μm in length) were counted  
179 at 200× magnification, alongwith *Lycopodium* spores, until a sum of 200 was reached  
180 (Finsinger and Tinner, 2005; Tinner and Hu, 2003). Pollen grains were identified with  
181 the assistance of the modern pollen slide collection of the Institute of Geocology and  
182 Geoinformation of Adam Mickiewicz University in Poznań (Poland), as well as available  
183 keys and atlases (e.g. Beug, 2004; Moore et al., 1991). Percentages of pollen and spores  
184 were calculated relative to the sum of trees, shrubs, and herbs, excluding the pollen of  
185 wetland plants and dwarf shrubs. Charcoal accumulation rates (CHAR), expressed as  
186 charcoal pieces/cm<sup>2</sup>/yr, were calculated by multiplying charcoal concentrations (CHAC,  
187 pieces/cm<sup>3</sup>) by the sediment accumulation rate for each analyzed level (Davis and  
188 Deevey, 1964).

189

### 190 ***Testate amoebae***

191 Fossil testate amoebae were analyzed in subsamples taken at 1cm intervals,  
192 whereas modern testate amoebae assemblages used to create the new transfer function  
193 were examined from surface moss samples. All of these samples were prepared by  
194 sieving and back-sieving (Booth et al., 2010). The testate amoebae were analyzed at  
195 200–400× magnification, and a minimum of 150 tests per sample were performed  
196 whenever possible (Payne and Mitchell, 2008). The identification was performed at the

197 highest possible taxonomical resolution based on the available literature (e.g.  
198 Grospietsch, 1958; Mazei and Tsyganov, 2006; Ogden and Hedley, 1980).

199

## 200 ***Macrofossils***

201 For the analyses of plant macrofossils, contiguous samples of 3 cm<sup>3</sup> (96 core  
202 samples) were analyzed at varying resolutions (2-cm resolution between 0 cm and 10  
203 cm depth; 1-cm resolution below 10 cm depth). Each sample was wet sieved through a  
204 0.2 mm mesh and macrofossils were identified under a binocular microscope using  
205 several keys (Birks, 2007; Grosse-Brauckmann, 1974, 1992; Laine et al., 2011; Tobolski,  
206 2000) and reference specimens collected in Siberia. Additionally, macroscopic charcoal  
207 particles were counted wherever present.

208

## 209 ***Bulk density and ash content***

210 Bulk density (BD; g cm<sup>-3</sup>) and ash content (AC; %) were measured to characterize  
211 the physical properties of the peat. BD was determined on the basis of 5-cm<sup>3</sup>  
212 subsamples, which were dried at 105°C for 24 h and then weighed. The dry weight (g)  
213 was divided by the fresh sample volume (cm<sup>3</sup>) (Chambers et al., 2011). AC for 94  
214 duplicates was obtained by measuring the LOI<sub>550</sub>, where LOI<sub>550</sub> is the loss on ignition at  
215 550°C as defined by Heiri et al. (2001), and calculating using the equation  $AC = 100\% -$   
216  $LOI_{550}$ .

217

## 218 ***Numerical analyses***

219 A Hellinger-transformed testate amoebae community matrix was used as a  
220 response matrix (Legendre and Gallagher, 2001). Redundancy analyses (RDA) were  
221 employed to relate abiotic variables (water table, pH and conductivity) to biotic  
222 communities. The significance of the model, axes, and variables was tested using a  
223 Monte Carlo test with 999 permutations. Computations were performed in R 3.0.1  
224 (Team, 2013), using the *vegan* package (Oksanen et al., 2011).

225 A quantitative water table reconstruction was developed using the local testate  
226 amoebae calibration data set from 68 moss samples collected in the Mukhrino peatland



227 in 2012 and 2013. The training set was based on the relative abundance (percentage of  
228 entire community in a sample) and tested using common models in paleoecology, such  
229 as partial least squares (PLS), weighted averaging (WA), and weighted averaging partial  
230 least squares (WA-PLS) (Juggins and Birks, 2012). Prior to analysis, species present in  
231 less than three samples were removed. The best performing model was assessed using  
232 RMSEP,  $R^2$ , and maximum bias criteria. Then, the model was used for the quantitative  
233 inference of the water table. Sample specific errors of the reconstruction were calculated  
234 using bootstrapping (Birks, 1995). Calculations were performed using C2 software  
235 (Juggins, 2003).

236

## 237 **Results and Interpretation**

### 238 ***Ecology of testate amoebae***

239 A total of 64 testate amoebae taxa species and subspecies from 23 genera were  
240 identified at the Mukhrino mire. The most abundant taxa were *Archerella flavum* (20%),  
241 *Hyalosphenia papilio* (15%), *Assulina muscorum* (8%), and *Phryganella acropodia* (7%).  
242 The Shannon-Weiner diversity index ranged between 1.37-2.59. RDA revealed three  
243 clusters of species (Fig. 3A). Species composition shows that *Assulina muscorum*, *A.*  
244 *seminulum*, *Trigonopyxis arcula*, *Trinema lineare*, and *Arcella catinus* are correlated with  
245 low depth to water table (DWT), whereas *Nebela carinata* is an indicator of wet  
246 conditions. *Hyalosphenia papilio* occurs in plots with higher pH and conductivity (EC),  
247 and a moderately wet environment. *Cyclopyxis arcelloides*, *Diffflugia bacillifera*, *D.*  
248 *bacilliarum*, *D. globulosa*, and *Amphitrema wrightianum* are related to lower pH and  
249 conductivity. Other species are located in the middle of the hydrological gradient. The  
250 full model explains 19.2% of the variation. DWT is strongly negatively correlated with  
251 axis 1 (13.1% variation explained), whereas pH and conductivity are negatively  
252 correlated with axis 2 (4.9% variation explained). The overall permutation test (999  
253 random permutations) showed that RDA was significant and axes 1 and 2 were highly  
254 significant (axis 1— $p < 0.001$ , axis 2— $p < 0.002$ ). DWT was the most significant variable  
255 ( $p < 0.001$ ), followed by pH ( $p < 0.005$ ) and conductivity ( $p < 0.021$ ).

256

### 257 ***Testate amoeba calibration data set***

258 RDA revealed DWT as the most important variable for testate amoeba  
259 communities. Consequently, we used this variable for building the transfer function. The  
260 calibration tests show that the model performed well and generated acceptable levels of  
261 significance (Table 2). For the reconstruction, WA-PLS component 2 was selected, as it  
262 had the lowest RMSEP (7.7 cm) and highest  $R^2$ (0.74) (Fig. 3B,C, Table 2). Subsequently,  
263 WA-PLS was applied for the quantitative estimation of the past water table dynamics.

264

### 265 ***Chronology, sediment accumulation rate, bulk density and ash content***

266 Tenout of eleven<sup>14</sup>C dates provide a reliable age-depth model spanning the past  
267  $1300 \pm 30$  years, with an agreement index ( $A_{\text{model}}$ ) of 82% ( $A_{\text{model}}=60\%$  is the lowest  
268 critical value; Bronk Ramsey, 2008)(Fig. 2). Date Poz-59502 was excluded; its individual  
269 agreement of 0% decreased the  $A_{\text{model}}$  below the critical value. The peat accumulation  
270 rates featured a close correspondence with peat properties. Those peat sections  
271 characterized by lower BD and AC have higher accumulation rates compared to sections  
272 with higher values for these physical parameters (Fig.2). Significant changes in bulk  
273 density were followed by changes in plant composition, as revealed by the macrofossil  
274 analysis (Fig. 4). The highest peat accumulation rate values occurred at ca. AD 1997–  
275 2012 (1.18–1.41 cm/yr) and ca. AD 1970–1980(0.89–0.9 cm/yr). Slightly lower  
276 accumulation occurred at ca. AD 1948–1970 (0.74–0.76 cm/yr) and ca. AD 1980–1997  
277 (0.64–0.65 cm/yr). The period between ca. AD 1948 and 2012 featured the lowest BD  
278 and AC (0.05–0.09 g/cm<sup>3</sup> and 1.3–2.6%, respectively). During the oldest period (ca. AD  
279 712–780), peat accumulated at the rate of 0.18–0.23 cm/yr. During that interval, BD was  
280 high and fluctuated between 0.09– 0.11 g/cm<sup>3</sup>, with the exception of a distinct increase  
281 to 0.15 g/cm<sup>3</sup>. AC ranged from 2.3 to 3.9%, with one distinct peak of 4.8% at ca. AD  
282 737. The lowest rates of peat accumulation occurred between ca. AD 780 and  
283 AD 1948(0.02–0.03 cm/yr). This interval is characterized by the highest values of BD  
284 (0.09–0.19 g/cm<sup>3</sup>) and AC (2.7–6.9%, peaking at ca. AD 1425). These high BD values  
285 were strongly related to the presence of *E. vaginatum* tissues and unidentified organic  
286 matter (Figs. 2 and 4). Very low rates of peat accumulation may also suggest some  
287 discontinuities during that period, and this prompts a very careful interpretation of  
288 charcoal accumulation rates (CHAR) for this section.

289

## 290 **Peatland and forest development**

291 Four proxies, including plant macrofossils (Fig. 4), pollen (Fig.5), testate amoebae  
292 (Fig. 6), and charcoal (Fig. 7), were used to reconstruct the main developmental stages of  
293 the Mukhrino bog, fire history, and changes in the composition of the surrounding  
294 vegetation. These stages were delimited visually to five zones (MU1-5).

295

### 296 **MU1 (100-86 cm, ca. AD 712-780)**

297 At the beginning of the record, testate amoebae indicate a high water table.  
298 *Archerella flavum* dominates, accompanied by *Hyalosphenia papilio*, *Heleopera sphagni*,  
299 and *Amphitrema wrightianum*. This assemblage suggests pool *Sphagnum* communities.  
300 DWT oscillates around 12 cm (Fig. 6).

301 Macrofossils also indicate a relatively high groundwater table, as *Sphagnum* cf.  
302 *balticum* remains from sec. Cuspidata (Fig. 4) are typical for wet parts of the mire (e.g.,  
303 carpets and lawns). *Eriophorum vaginatum* also suggests moist conditions (Hölzer,  
304 2010).

305 The pollen spectra (*Pinus sylvestris* type, *Pinus sibirica* type, and *Betula*) reflect  
306 the presence of pine-birch forests, not only in this zone but in the entire profile,  
307 suggesting that vegetation composition varied little over the last 1300 years. Additional  
308 arboreal components of the forest include *Populus*, *Salix*, and *Alnus* in moist habitats, as  
309 well as “dark coniferous” forest, including *Picea* sect. *Eupicea* and *Abies*. In this zone, the  
310 pollen of *Picea* sect. *Eupicea* (probably *P. abies* ssp. *obovata*) reaches its maximum values  
311 (2.5–4.5%). However, at the end of this zone (ca. AD 750) declining *Picea* percentages  
312 suggest a slight retreat of spruce.

313 CHAR reached 1935 pieces/cm<sup>2</sup>/yr at ca. AD 730, then decreased. CHAC  
314 oscillated between 1945 and 8690 pieces/cm<sup>3</sup>.

315

### 316 **MU2 (86-58 cm, ca. AD 780-1882)**

317 In Zone MU2, the testate amoebae record features the disappearance of  
318 *Archerella flavum* and *Sphagnum balticum*. Concurrently, percentages of dry indicators,  
319 such as *Arcella catinus*, *Trigonopyxis arcula*, and *Phryganella acropodia*, increase. DWT  
320 increases gradually from approximately 13 to over 40 cm.

321 Toward the top of this zone, *Sphagnum magellanicum* and *Eriophorum vaginatum*  
322 macrofossils indicate gradually decreasing bog surface wetness, and at the same time  
323 *Sphagnum cf. balticum* disappears abruptly *Sphagnum magellanicum* has a broad niche,  
324 but generally occurs at a water table depth of ca. 24 cm (Hölzer, 2010). Wood and  
325 Ericaceae remains appear in this zone, suggesting a lower water table and the  
326 development of local shrub communities (Fig. 4).

327 The pollen assemblages in Zone MU2 are similar to those of the previous zone. A  
328 minor peak in *Abies* pollen percentages (2.5%) occurs in the older part of MU2, whereas  
329 in the younger part of the zone there is a peak in *Corylus* (1.8%; probably *C. avellana*).  
330 Such low *Corylus* pollen percentages indicate long-distance transport (cf. Tallantire,  
331 2002).

332 This zone is characterized by high CHAR values (56–737 pieces/cm<sup>2</sup>/yr) and a  
333 maximum of CHAC at ca. AD 1505(29,800 pieces/cm<sup>3</sup>).

334

### 335 **MU3 (58–40 cm, ca. AD 1882–1970)**

336 *Arcella catinus* percentages decline considerably in Zone MU3, whereas other dry  
337 indicators, such as *Trigonopyxis arcula* and *Phyganella acropodia*, remain relative  
338 abundant. *Nebela militaris* first becomes abundant in this zone. This species usually  
339 indicates a higher water table than *T. arcula* or *P. acropodia*, but the habitat was still  
340 quite dry, as indicated by the abundance of *Sphagnum fuscum*. DWT indicates a gradually  
341 increasing water table.

342 An abrupt transition between *Sphagnum magellanicum* and *S. fuscum* took  
343 place ca. AD 1900; this shift was accompanied by an increase in the percentages of  
344 Ericaceae, as well as higher wood remains.

345 In MU3, *Artemisia* reaches its highest percentages in the profile (ca. AD 1882–  
346 1966; 3.5–5.5%), possibly reflecting higher landscape openness. Spheroidal

347 carboniferous particles (SCP) appear in this zone, suggesting coal burning in the  
348 surrounding area or distant transport from industrialized areas (Swindles et al., 2015).

349 CHAC decreased from 7716 to 616 pieces/cm<sup>3</sup>, while CHAR ranged between 264  
350 and 637 pieces/cm<sup>2</sup>/year. Macroscopic charcoal (particles >200 µm) at the depth  
351 corresponding to ca. AD 1900 indicate local fires (Fig. 4).

352

#### 353 **MU4 (40-22.5 cm, ca. AD 1970-1994)**

354 In Zone MU4 testate amoebae assemblages, *Nebela militaris* continues to indicate  
355 a low water table, but the reconstructed water depth shows a gradual increase, reaching  
356 a value of approximately 9 cm.

357 At this time the bog was dominated by *Sphagnum fuscum* (as high as 90%).  
358 *Polytrichum* first occurs in MU4, suggesting a low water table and hummock  
359 development. *Pinus* bark suggests the presence of pines in the hummocky dwarf shrub-  
360 *Sphagnum* communities. Ericaceae and wood remains decreased gradually, perhaps  
361 reflecting a higher water table.

362 Pollen data in MU4 feature the highest value of *Rubus chamaemorus* (max. 2%);  
363 its presence suggests the development of a hummock. SCP values increase after ca. AD  
364 1985, likely signaling the increasing industrialization in the region (Swindles et al.,  
365 2015). CHAR increased abruptly to 6899 pieces/cm<sup>2</sup>/yr in ca. AD 1975. At the same time,  
366 CHAC was 7726 pieces/cm<sup>3</sup>.

367

#### 368 **MU5 (22.5-0 cm, ca. AD 1994-2012)**

369 The microfossil record in Zone MU5 suggests a low water table, as indicated by  
370 the stable values for *Sphagnum fuscum* and *Polytrichum* remains, although *Hyalosphenia*  
371 *elegans*, *H. papilio*, and *Archerella flavum* point to higher habitat wetness. Other species,  
372 such as *Nebela militaris*, *Phryganella acropodia*, and *Trigonopyxis arcuata*, decreased in  
373 this period.

374 A decrease in the *Rubus chamaemorus* pollen percentages suggests the retreat of  
375 hummock habitats from the coring location.

376 SCP records reveal increased coal burning between AD1994 and AD 2000 (max.  
377 267 particles/cm<sup>2</sup>/yr). CHAR and CHAC reached maximum values of 914 pieces/cm<sup>2</sup>/yr  
378 and CHAC of 759 pieces/cm<sup>3</sup>, respectively, with a decreasing trend toward the top of the  
379 zone.

380

## 381 **Discussion**

### 382 ***Calibration data set and ecology of testate amoebae***

383 Numerous studies have analyzed testate amoebae ecology in various  
384 biogeographical settings in Russia (Bobrov et al., 1999; Bobrov et al., 2002; Bobrov et al.,  
385 2003; Bobrov et al., 2013; Mazei and Embulaeva, 2009; Mazei et al., 2009; Mazei et al.,  
386 2007; Payne et al., 2012; Tsyganov et al., 2015), but there have been few such studies in  
387 Siberian peatlands (Bobrov et al., 2002; Kurina et al., 2010; Mazei and Kabanov, 2008).  
388 Our calibration study at Mukhrino mire illustrates the relationship between testate  
389 amoebae community composition and several environmental parameters. The  
390 redundancy analysis demonstrated the importance of water table depth, which is  
391 consistent with findings from other regions (Lamentowicz and Mitchell, 2005; Qin et al.,  
392 2013; Tolonen et al., 1994; Van Bellen et al., 2014). Acidity was a less important  
393 parameter, perhaps due to the limited range of the sampled habitats. The overall species  
394 composition of testate amoebae at Mukhrino mire was not different from those  
395 described in Europe or North America (Booth, 2007; Charman et al., 2007). The most  
396 abundant species in wet parts of the gradient are the mixotrophic species *Hyalosphenia*  
397 *papilio* and *Archerella flavum*, as well as *Nebela carinata*. In *Sphagnum fuscum*  
398 hummocks, which were the driest part of the gradient, *Assulina muscorum*, *Trigonopyxis*  
399 *arcula*, and *Arcella catinus* dominated.

400 A characteristic feature of this Siberian peatland is that minerotrophic species are  
401 absent, as the habitat is purely organic and very acidic. An advantage of our study is that  
402 the training set was taken from a pristine bog, large enough to exclude any bordering  
403 effect, and then applied to a core also representing pristine conditions. In Europe, in  
404 contrast, testate amoebae training sets are often collected from raised bogs that have  
405 experienced disturbance, possibly biasing reconstructions derived from them. We think  
406 that the new calibration data set from Siberia is important for its inferences concerning

407 paleohydrological dynamics in order to better assess the processes that drive carbon  
408 accumulation. In our application of the testate amoebae transfer function to the 1300-  
409 year-long core from Mukhrino mire, the composition of the modern communities was  
410 similar to that of the fossil assemblages, and thus the transfer function could be used to  
411 reconstruct past hydrological conditions with confidence (Juggins and Birks, 2012).

### 412 ***Hydrology, fires, and forests in western Siberia***

413         As the Mukhrino mire record is the first from Siberia in which the paleohydrology  
414 of the last millennium has been quantitatively reconstructed based on a modern-  
415 calibration training set, we can only relate our findings to other records from other parts  
416 of Eurasia. The dry stage at AD 780–1882 in the Mukhrino profile is similar to dry  
417 intervals described in other studies from central and eastern Europe (Gałka et al., 2014;  
418 Lamentowicz et al., 2009). In the case of Polish sites, however, unstable hydrological  
419 conditions rather than permanent drought prevailed (Marcisz et al., 2015). This may  
420 suggest that the drought increased in intensity from west to east, being most severe in  
421 continental areas like western Siberia. The recent study of Feurdean et al. (2015)  
422 provides a regional summary of paleohydrological change in bogs of central and eastern  
423 Europe and supports the interpretation of the LIA as dry in eastern sites and  
424 contrastingly wet in western sites.

425         Under the continental conditions of western Siberia, the influence of climate on  
426 peatlands during the LIA may have been different than was the case in oceanic western  
427 Europe. In western Europe, wet conditions may have arisen due to increased summer  
428 precipitation and a change in air circulation patterns (Magny et al., 2010; Magny et al.,  
429 2008). The growth of alpine glaciers during the LIA is consistent with higher  
430 moisture (Holzhauser et al., 2005), and the only existing high-resolution bog record from  
431 the eastern Swiss Alps revealed a wet trend during the LIA (van der Knaap et al.,  
432 2011). Similarly, the peatlands of the British Isles indicate moist conditions during the  
433 LIA (Charman et al., 2006). Changes in temperature may also be involved in the shifts  
434 observed in the Mukhrino mire record. Cool temperatures could have limited peat  
435 accumulation, generating changes in our proxies that are suggestive of a dry phase. The  
436 extensive carbon accumulation database from northern latitudes reveals such a trend  
437 during the LIA, with carbon sequestration rate declining during the transition from the  
438 MWP to the LIA. This was probably because the LIA featured the combination of lower

439 temperatures and increased cloudiness, suppressing net primary productivity (Charman  
440 et al., 2013). However, given the distance between western Europe and Siberia, it may  
441 be the case that the climatic causes of dry conditions during the LIA at eastern sites were  
442 different from those operating further to the west.

443 Because our study is based on a single core, alternative explanations for the  
444 peatland development and peat accumulation changes should be taken into account. The  
445 patterns that we have observed could also be related to autogenic development of the  
446 peatland itself. Peat vegetation forms various distinct microhabitats in the Mukhrino  
447 mire, including very wet pools with open water, flarks overgrown by pines (so-called  
448 *ryam* forest, which is typical for raised bogs in western Siberia), and *Sphagnum* lawns.  
449 Changes in the water table may have been caused by migration (or alternative  
450 development) of those microhabitats on the peatland surface. Moreover, because the  
451 core was sampled on the margin of the flark, it is plausible that what we have  
452 interpreted as low water table conditions is instead related to the change of surface  
453 microhabitats from a pool to the flark (Zobel, 1988). It may be the case that the observed  
454 hydrological shifts are related to both internal feedbacks (Swindles et al., 2012) and  
455 allogenic forcing (Barber, 1981); additional work at Mukhrino is needed to determine  
456 the relative importance of these factors.

457 Fire is a key process that influences the physical and biological structure of boreal  
458 forests (Stocks et al., 2001). Wildfires affect all characteristics of the ecosystem,  
459 including species composition and diversity, biogeochemical cycles and energy flows,  
460 and carbon cycling (van Bellen et al., 2012). Wildfires in boreal ecosystems are highly  
461 dependent not only on climatic conditions (such as heat waves or hydrological stress),  
462 but also on forest management and the accumulation of woody debris (Gennaretti et al.  
463 (2013). Our study revealed a lack of dramatic shifts in vegetation in the Mukhrino area  
464 over the last 1300 years. *Pinus sylvestris*, *P. sibirica*, and *Betula* were the dominant taxa,  
465 with *Alnus*, *Picea*, *Populus* and *Abies* as additional components (Fig. 5). However, one  
466 intriguing change is the decline of *Picea* (probably *Picea abies* ssp. *obovata*) at AD 750, a  
467 time of stable hydrological conditions and decreasing fire activity. *Picea abies* is thought  
468 to be poorly adapted to fire and drought due to its relatively thin bark and shallow root  
469 system (Niklasson et al., 2002; Zackrisson, 1977). Thus, the parallel declines in *Picea* and  
470 CHAR in the Mukhrino record are somewhat unexpected, although paleoecological



471 studies from Fennoscandia, where this phenomenon has been widely investigated, also  
472 feature unclear findings (Bradshaw et al., 2010). Several studies reported the expansion  
473 of *P. abies* during times of increased fire activity (Barnekow et al., 2008; Brown and  
474 Giesecke, 2014; Carcaillet et al., 2007; Rosén and Hammarlund, 2007), but others found  
475 that fire decreased prior to *P. abies* expansion (Tryterud, 2003; Ohlson et al., 2011).  
476 Additional studies spanning longer time scales are needed to better understand the  
477 relationship between *P. abies* and fire in Siberia and other boreal regions.

478         The charcoal record from Mukhrino mire is of particular relevance given the  
479 significant amount of carbon emitted by burning peatlands (French et al., 2004;  
480 Kasischke et al., 2005; Turetsky et al., 2015). The Mukhrino profile featured maximum  
481 CHAR values at ca. AD 1975 and two smaller peaks (at ca. AD 1984 and AD 2000),  
482 indicating higher fire activity during the last 60 years than at any point in the last  
483 millennium (Fig. 7). This shift may be linked with the fast development of the nearby  
484 city of Khanty-Mansiysk, which saw fast population growth starting in the 1950s. The  
485 finding of oil and gas in the region had a major impact on the development of local  
486 industry and caused a rapid influx of population from 18,000 in 1956 to 1,478,000 in  
487 2006 (official data from the Khanty-Mansi Autonomous Okrug). This substantial  
488 increase in population not only had an impact on the development of the city itself, but  
489 also contributed to the pressure on the environment in the region. Human penetration  
490 into forests increased, contributing to higher fire activity during recent decades. A key  
491 change was the completion of a bridge across the Irtysh River in around 2005, as only a  
492 few hunters visited the Mukhrino area prior to this improved access. Moreover, the  
493 nearest oil fields, located 100-200 km away, started to develop on the left bank of the  
494 Irtysh River only 5-7 years ago. Thus it appears that fires in the Mukhrino area have  
495 experienced little human influence during most of the last 1300 years. A similar increase  
496 in fire activity over the past 60 years is noticeable in boreal forests of Canada (Stocks et  
497 al., 2002).

498         An alternative explanation for the observed increase in fire is that changes in  
499 climate may have caused increased burning and extended fire seasons during the last  
500 half of the twentieth century in Canada and Siberia (Dale et al., 2001; Kirilenko and  
501 Sedjo, 2007; Wotton and Flannigan, 1993). Barichivich et al. (2014) showed that rapid  
502 summer warming since the 1980s is a significant driver of increased evapotranspiration,

503 which affects summer drought severity in the northern latitudes. In turn, drier  
504 conditions may lead to higher intensity of fires and longer growing seasons in Siberia  
505 and other boreal regions (Flannigan et al. (2013).The Arctic Oscillation (AO) also  
506 appears to influence the inter-annual variability of fire in Siberia, with higher fire  
507 activity during the positive phase of the AO (Balzter et al., 2005, 2007; Sukhinin et al.,  
508 2004). Our record provides data that can be related to AO as well as to human activity,  
509 however, we need more peat profiles from W Siberia to be sure that this is climatic  
510 forcing.

511

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525

## 526 **Captions to figures**

527 Figure 1. Map of Eurasia showing the location of Mukhrino mire and indicating the range  
528 of boreal forests.

529 Figure 2. Age-depth model for the Mukhrino mire core with bulk density and ash  
530 content. Dates are listed on the left, along the depth scale (see Table 1), each of these are  
531 presented with individual agreement of modeled and calibrated date, which is placed in

532 square brackets (for details see Bronk Ramsey (2008)). Abbreviations: Poz – laboratory  
533 code of Poznań Radiocarbon Laboratory, TPS – total pollen sum.

534 Figure 3. Result of the redundancy analysis (RDA) of testate amoeba communities (A)  
535 and measured environmental variables (pH and depth to the water table – DWT) from  
536 modern surface samples collected from Mukhrino mire, (B) observed vs. predicted  
537 model, and (C) residuals of the weighted averaging partial least squares model with  
538 bootstrap cross validation (WA-PLSboot).

539 Species abbreviations: AMP WRI – *Amphitrema wrightianum*, ARC ARE – *Arcella*  
540 *arenaria*, ARC ART – *Arcella artocrea*, ARC BAT – *Arcella bathystoma*, ARC CAT – *Arcella*  
541 *catinus*, ARC DIS – *Arcella discoides*, ARC SP – *Arcella* sp., ARCH FLA – *Archerella flavum*,  
542 ARC HEM – *Arcella hemisphaerica*, ARGSP – *Argygnia* sp., ASS MUS – *Assulina muscorum*,  
543 ASS SCA – *Assulina scandinavica*, ASS SEM – *Assulina seminulum*, BULIND – *Bullinularia*  
544 *indica*, CEN AER – *Centropyxis aerophila*, CEN ACU – *Centropyxis aculeata*, CEN ORB –  
545 *Centropyxis orbicularis*, CEN CAS – *Centropyxis cassis*, CEN PLA – *Centropyxis platystoma*,  
546 CEN SP – *Centropyxis* sp., COR DUB – *Corythion dubium*, CRY OVI – *Cryptodiffugia*  
547 *oviformis*, CYC ARC – *Cyclopyxis arcelloides*, CYCKAH – *Cyclopyxis kahli*, CYPSP –  
548 *Cyphoderia* sp., CYP AMP – *Cyphoderia ampulla*, DIFBACC – *Diffflugia baccilliarum*,  
549 DIFBACI – *Diffflugia bacilifera*, DIFBRE – *Diffflugia brevicola*, DIFGLO – *Diffflugia globulosa*,  
550 DIF LAN – *Diffflugia langeniformis*, DIF LEI – *Diffflugia leidyi*, DIF LIM – *Diffflugia limnetica*,  
551 DIFOBL – *Diffflugia oblonga*, DIFURC – *Diffflugia urceolata*, DIFSP – *Diffflugia* sp., EUGCIL –  
552 *Euglypha ciliata*, EUG COM – *Euglypha compressa*, EUGCOMGLA – *Euglypha compressa*  
553 *glabra*, EUG CRI – *Euglypha cristata*, EUG ROT – *Euglypha rotunda*, EUGSTR – *Euglypha*  
554 *strigosa*, EUG TUB – *Euglypha tuberculata*, EUGSP – *Euglypha* species, HEL PET –  
555 *Heleopera petricola*, HEL SPH – *Heleopera sphagni*, HEL ROS – *Heleopera rosea*, HYAELE –  
556 *Hyalosphenia elegans*, HYA PAP – *Hyalosphenia papilio*, NEB CAR – *Nebela carinata*, NEB  
557 MIL – *Nebela militaris*, NEB TIN – *Nebela tinctoria*, PHRACR – *Phryganella acropodia*, PHR  
558 PAR – *Phryganella paradoxa*, PHYGRI – *Physochila griseola*, PLA SPI – *Placocista spinosa*,  
559 PSE GRA – *Pseudodiffflugia gracilis*, SPH LEN – *Sphenoderia lenta*, TRI ARC – *Trigonopyxis*  
560 *arcula*, TRI SP – *Trigonopyxis* sp., TRINENC – *Trinema enchelis*, TRIN LIN – *Trinema*  
561 *lineare*.

562 Figure 4. Plant macrofossil diagram for Mukhrino mire. Abbreviations: UOM –  
563 unidentified organic matter. Non-% variables are provided as absolute values; , 5 times  
564 exaggeration is presented as white silhouette.

565 Figure 5. Pollen percentage diagram for Mukhrino mire, 5 times exaggeration is  
566 presented as white silhouette. SCP AR - spheroidal carbonaceous particles (SCPs)  
567 accumulation rate.

568 Figure 6. Testate amoebae percentage diagram for Mukhrino mire, 5 times exaggeration  
569 is presented as white silhouette. WA PLS Comp 2 (weighted averaging partial least  
570 squares component 2) – model used for the DWT (depth to the water table) quantitative  
571 reconstruction.

572 Figure 7. Summary diagram for Mukhrino mire with comparison of testate amoebae–  
573 based water table reconstruction (DWT), charcoal influx (CHAR), and charcoal  
574 concentration (CHAC). WA PLS Comp 2 (weighted averaging partial least squares  
575 component 2) – model used for the DWT (depth to the water table) quantitative  
576 reconstruction.

577

## 578 **Tables**

579 Table 1. Results of radiocarbon dating from the Mukhrino profile. Abbreviations: Poz –  
580 laboratory code of the Poznań Radiocarbon Laboratory (Poland).

581 Table 2. Transfer function performance statistics. The best model is WAPLS Component  
582 2.

583

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- 586 Ahmed, M., Anchukaitis, K.J., Asrat, A., Borgaonkar, H.P., Braidia, M., Buckley, B.M., Büntgen, U.,  
587 Chase, B.M., Christie, D.A., Cook, E.R., Curran, M.A.J., Diaz, H.F., Esper, J., Fan, Z.-X., Gaire, N.P., Ge,  
588 Q., Gergis, J., González-Rouco, J.F., Goosse, H., Grab, S.W., Graham, N., Graham, R., Grosjean, M.,  
589 Hanhijärvi, S.T., Kaufman, D.S., Kiefer, T., Kimura, K., Korhola, A.A., Krusic, P.J., Lara, A., Lézine, A.-  
590 M., Ljungqvist, F.C., Lorrey, A.M., Luterbacher, J., Masson-Delmotte, V., McCarroll, D., McConnell,  
591 J.R., McKay, N.P., Morales, M.S., Moy, A.D., Mulvaney, R., Mundo, I.A., Nakatsuka, T., Nash, D.J.,  
592 Neukom, R., Nicholson, S.E., Oerter, H., Palmer, J.G., Phipps, S.J., Prieto, M.R., Rivera, A., Sano, M.,  
593 Severi, M., Shanahan, T.M., Shao, X., Shi, F., Sigl, M., Smerdon, J.E., Solomina, O.N., Steig, E.J., Stenni,  
594 B., Thamban, M., Trouet, V., Turney, C.S.M., Umer, M., van Ommen, T., Verschuren, D., Viau, A.E.,  
595 Villalba, R., Vinther, B.M., von Gunten, L., Wagner, S., Wahl, E.R., Wanner, H., Werner, J.P., White,  
596 J.W.C., Yasue, K., Zorita, E., 2013. Continental-scale temperature variability during the past two  
597 millennia. *Nature Geoscience* 6, 339-346.
- 598 Balzter, H., Gerard, F.F., George, C.T., Rowland, C.S., Jupp, T.E., McCallum, I., Shvidenko, A., Nilsson,  
599 S., Sukhinin, A., Onuchin, A., Schmullius, C., 2005. Impact of the Arctic Oscillation pattern on  
600 interannual forest fire variability in Central Siberia. *Geophysical Research Letters* 32, L14709.
- 601 Barber, K.E., 1981. Peat stratigraphy and climatic change. A palaeoecological test of the theory of  
602 cyclic bog regeneration. A.A. Balkema, Rotterdam.
- 603 Barichivich, J., Briffa, K., Myneni, R., Schrier, G., Dorigo, W., Tucker, C., Osborn, T., Melvin, T., 2014.  
604 Temperature and Snow-Mediated Moisture Controls of Summer Photosynthetic Activity in  
605 Northern Terrestrial Ecosystems between 1982 and 2011. *Remote Sensing* 6, 1390-1431.
- 606 Beilman, D.W., MacDonald, G.M., Smith, L.C., Reimer, P.J., 2009. Carbon accumulation in peatlands  
607 of West Siberia over the last 2000 years. *Global Biogeochemical Cycles* 23.
- 608 Berglund, B.E., Ralska-Jasiewiczowa, M., 1986. Pollen analysis and pollen diagrams, in: Berglund,  
609 B.E. (Ed.), *Handbook of Holocene Paleoecology and Paleohydrology*. Wiley & Sons Ltd.,  
610 Chichester-Toronto, pp. 455-484.
- 611 Beug, H.-J., 2004. *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete*. .  
612 Verlag Dr. Friedrich Pfeil, München.
- 613 Birks, H.H., 2007. Plant macrofossil introduction, in: Elias, S.A. (Ed.), *Encyclopedia of Quaternary*  
614 *Science*. Elsevier, Amsterdam, pp. 2266-2288.
- 615 Birks, H.J.B., 1995. Quantitative Palaeoenvironmental Reconstructions, in: Maddy, D., Brew, J.S.  
616 (Eds.), *Statistical Modelling of Quaternary Science Data*. Quaternary Research Association,  
617 Cambridge, pp. 161-254.
- 618 Bleuten, W., Filippov, I., 2008. Hydrology of mire ecosystems in central West Siberia: the  
619 Mukhrino field station, in: Glagolev, M.V., Lapshina, E.D. (Eds.), *Transactions of UNESCO*  
620 *Department of Yugorsky State University "Dynamics of Environment and Global Climate*  
621 *Change"*.
- 622 Blundell, A., Barber, K., 2005. A 2800-year palaeoclimatic record from Tore Hill Moss, Strathspey,  
623 Scotland: the need for a multi-proxy approach to peat-based climate reconstructions.  
624 *Quaternary Science Reviews* 24, 1261-1277.
- 625 Blundell, A., Charman, D.J., Barber, K., 2008. Multiproxy late Holocene peat records from Ireland:  
626 towards a regional palaeoclimate curve. *Journal of Quaternary Science* 23, 59-71.
- 627 Bobrov, A.A., Charman, D.J., Warner, B.G., 1999. Ecology of Testate Amoebae (Protozoa:  
628 Rhizopoda) on Peatlands in Western Russia with special attention to Niche Separation in closely  
629 Related Taxa. *Protist* 150, 125-136.
- 630 Bobrov, A.A., Charman, D.J., Warner, B.G., 2002. Ecology of Testate Amoebae from Oligotrophic  
631 Peatlands: Specific Features of Polytypic and Polymorphic Species. *Biology Bulletin of the*  
632 *Russian Academy of Sciences* 29, 605-617.
- 633 Bobrov, A.A., Siegert, C., Andreev, A.A., Schirrmeister, L., 2003. Testaceans (Protozoa: Testacea)  
634 in Quaternary Permafrost Sediments of Bykovsky Peninsula, Arctic Yakutia. *Biology Bulletin* 30,  
635 191-206.

636 Bobrov, A.A., Wetterich, S., Beermann, F., Schneider, A., Kokhanova, L., Schirrmeister, L.,  
637 Pestryakova, L.A., Herzsuh, U., 2013. Testate amoebae and environmental features of polygon  
638 tundra in the Indigirka lowland (East Siberia). *Polar Biology* 36, 857-870.  
639 Booth, R.K., 2007. Testate amoebae as proxies for mean annual water-table depth in Sphagnum-  
640 dominated peatlands of North America. *Journal of Quaternary Science* 23, 43-57.  
641 Booth, R.K., Lamentowicz, M., Charman, D.J., 2010. Preparation and analysis of testate amoebae  
642 in peatland paleoenvironmental studies. *Mires and Peat* 7 (2010/11), 1-7.  
643 Booth, R.K., Notaro, M., Jackson, S.T., Kutzbach, J.E., 2006. Widespread drought episodes in the  
644 western Great Lakes region during the past 2000 years: Geographic extent and potential  
645 mechanisms. *Earth and Planetary Science Letters* 242, 415-427.  
646 Booth, R.K., Sullivan, M.E., Sousa, V.A., 2008. Ecology of testate amoebae in a North Carolina  
647 pocosin and their potential use as environmental and paleoenvironmental indicators. *Ecoscience*  
648 15, 277-289.  
649 Borren, W., Bleuten, W., Lapshina, E.D., 2004. Holocene peat and carbon accumulation rates in  
650 the southern taiga of western Siberia. *Quaternary Research* 61, 42- 51.  
651 Bradshaw, R.H.W., Lindbladh, M., Hannon, G.E., 2010. The role of fire in southern Scandinavian  
652 forests during the late Holocene. *International Journal of Wildland Fire* 19, 1040-1049.  
653 Bronk Ramsey, C., 2008. Deposition models for chronological records. *Quaternary Science*  
654 *Reviews* 27, 42-60.  
655 Chambers, F.M., Beilman, D.W., Yu, Z., 2011. Methods for determining peat humification and for  
656 quantifying peat bulk density, organic matter and carbon content for palaeostudies of climate  
657 and peatland carbon dynamics. *Mires and Peat* 7, 1-10.  
658 Charman, D., Blundell, A., MEMBERS, A., 2007. A new European testate amoebae transfer  
659 function for palaeohydrological reconstruction on ombrotrophic peatlands. *Journal of*  
660 *Quaternary Science* 22, 209-221.  
661 Charman, D.J., 2002. *Peatlands and environmental change*. John Wiley & Sons, Chichester.  
662 Charman, D.J., Beilman, D.W., Blaauw, M., Booth, R.K., Brewer, S., Chambers, F.M., Christen, J.A.,  
663 Gallego-Sala, A., Harrison, S.P., Hughes, P.D.M., Jackson, S.T., Korhola, A., Mauquoy, D., Mitchell,  
664 F.J.G., Prentice, I.C., van der Linden, M., De Vleeschouwer, F., Yu, Z.C., Alm, J., Bauer, I.E., Corish,  
665 Y.M.C., Garneau, M., Hohl, V., Huang, Y., Karofeld, E., Le Roux, G., Loisel, J., Moschen, R., Nichols,  
666 J.E., Nieminen, T.M., MacDonald, G.M., Phadtare, N.R., Rausch, N., Sillasoo, Ü., Swindles, G.T.,  
667 Tuittila, E.S., Ukonmaanaho, L., Väliranta, M., van Bellen, S., van Geel, B., Vitt, D.H., Zhao, Y., 2013.  
668 Climate-related changes in peatland carbon accumulation during the last millennium.  
669 *Biogeosciences* 10, 929-944.  
670 Charman, D.J., Blundell, A., Chiverrell, R.C., Hendon, D., Langdon, P.G., 2006. Compilation of non-  
671 annually resolved Holocene proxy climate records: stacked Holocene peatland palaeo-water  
672 table reconstructions from northern Britain. *Quaternary Science Reviews* 25, 336-350.  
673 Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland,  
674 L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F.J., Stocks, B.J., Wotton, B.M., 2001.  
675 Climate change and forest disturbances. *Bioscience* 51, 723-734.  
676 Davis, M.B., Deevey, E.S.J., 1964. Pollen accumulation rates: estimates from late-glacial sediment  
677 of Roger Lake. *Science* 145, 1293-1295.  
678 Dise, N.B., 2010. Peatland response to global change. *Science* 326, 810-811.  
679 Elger, K., Opel, T., Topp-Jørgensen, E., Rasch, M., 2012. INTERACT Station Catalogue. Aarhus  
680 University.  
681 Feurdean, A., Galka, M., Kuske, E., Tantau, I., Lamentowicz, M., Florescu, G., Liakka, J., Hutchinson,  
682 S.M., Mulch, A., Hickler, T., 2015. Last Millennium hydro-climate variability in Central-Eastern  
683 Europe (Northern Carpathians, Romania). *The Holocene* 25, 1179-1192.  
684 Fiałkiewicz-Kozieł, B., Kołaczek, P., Michczyński, A., Piotrowska, N., 2015. The construction of a  
685 reliable absolute chronology for the last two millennia in an anthropogenically disturbed peat  
686 bog: Limitations and advantages of using a radio-isotopic proxy and age-depth modelling.  
687 *Quaternary Geochronology* 25, 83-95.

688 Filippov, I.V., Lapshina, E.D., 2008. Peatland unit types of lake-bog systems in the Middle Priob'ie  
689 (Western Siberia), in: ED, G.M.a.L. (Ed.), Transactions of UNESCO Department of Yugorsky State  
690 University "Dynamics of Environment and Global Climate Change, pp. 115-124  
691 Finsinger, W., Tinner, W., 2005. Minimum count sums for charcoal-concentration estimates in  
692 pollen slides: Accuracy and potential errors. *Holocene* 15, 293-297.  
693 Flannigan, M., Cantin, A.S., de Groot, W.J., Wotton, M., Newbery, A., Gowman, L.M., 2013. Global  
694 wildland fire season severity in the 21st century. *Forest Ecology and Management* 294, 54-61.  
695 French, N.H.F., Goovaerts, P., Kasischke, E.S., 2004. Uncertainty in estimating carbon emissions  
696 from boreal forest fires. *Journal of Geophysical Research: Atmospheres* 109, D14S08.  
697 Gałka, M., Miotk-Szpiganowicz, G., Goslar, T., Jęśko, M., van der Knaap, W.O., Lamentowicz, M.,  
698 2013. Palaeohydrology, fires and vegetation succession in the southern Baltic during the last  
699 7500 years reconstructed from a raised bog based on multi-proxy data. *Palaeogeography,*  
700 *Palaeoclimatology, Palaeoecology* 370, 209 - 221.  
701 Gałka, M., Tobolski, K., Górski, A., Milecka, K., Fiałkiewicz-Kozieł, B., Lamentowicz, M., 2014.  
702 Disentangling the drivers for the development of a Baltic bog during the Little Ice Age in  
703 northern Poland. *Quaternary International* 328-329, 323-337.  
704 Gennaretti, F., Arseneault, D., Bégin, Y., De Deyn, G., 2013. Millennial stocks and fluxes of large  
705 woody debris in lakes of the North American taiga. *Journal of Ecology*, n/a-n/a.  
706 Grospietsch, T., 1958. Wechseltierchen (Rhizopoden). Kosmos Verlag, Stuttgart.  
707 Grosse-Brauckmann, G., 1974. Über pflanzliche Makrofossilien mitteleuropäischer Torfe. II.  
708 Weitere Reste (Früchte und Samen, Moose u.a.) und ihre Bestimmungsmöglichkeiten - On plant  
709 macrofossils in central European peat. II. Other remnants (e.g. fruits and seeds, mosses) and  
710 possibilities for their identification. *Telma* 4, 51-117 (in German).  
711 Grosse-Brauckmann, G., 1992. Über pflanzliche Makrofossilien mitteleuropäischer Torfe. III.  
712 Früchte, Samen und einige Gewebe (Fotos von fossilen Pflanzenresten) - On plant macrofossils  
713 in central European peat. III. Fruits, seeds and some tissues (photos of fossil plant remains).  
714 *Telma* 22, 53-102 (in German).  
715 Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and  
716 carbonate content in sediments: reproducibility and comparability of results. *Journal of*  
717 *Paleolimnology* 25, 101-110.  
718 Hendon, D., Charman, D.J., 2004. High-resolution peatland water-table changes for the past 200  
719 years: the influence of climate and implications for management. *The Holocene* 14, 125-134.  
720 Hölzer, A., 2010. Die Torfmoose Südwestdeutschlands und der Nachbargebiete. Weissdorn -  
721 Verlag Jena, Jena.  
722 Holzhauser, H., Magny, M., Zumbuhl, H.J., 2005. Glacier and lake-level variations in west-central  
723 Europe over the last 3500 years. *The Holocene* 15, 789-801.  
724 Hua, Q., Barbetti, M., Rakowski, A.Z., 2013. Atmospheric Radiocarbon for the Period 1950-2010.  
725 *Radiocarbon* 55, 2059-2072.  
726 Jones, P.D., Mann, M.E., 2004. Climate over past millennia. *Rev. Geophys.*, 42 pp.  
727 Juggins, S., 2003. C2 User guide. Software for ecological and palaeoecological data analysis and  
728 visualisation. University of Newcastle, Newcastle upon Tyne, UK.  
729 Juggins, S., Birks, J., 2012. Quantitative Environmental Reconstructions from Biological Data, in:  
730 Birks, H.J.B., Lotter, A.F., Juggins, S., Smol, J.P. (Eds.), *Tracking Environmental Change Using Lake*  
731 *Sediments. Developments In Paleoenvironmental Research.* Springer, pp. 431-494.  
732 Kaislahti Tillman, P., Holzkämper, S., Kuhry, P., Sannel, A.B.K., Loader, N.J., Robertson, I., 2010.  
733 Long-term climate variability in continental subarctic Canada: A 6200-year record derived from  
734 stable isotopes in peat. *Palaeogeography, Palaeoclimatology, Palaeoecology* 298, 235-246.  
735 Kasischke, E.S., Hyer, E.J., Novelli, P.C., Bruhwiler, L.P., French, N.H.F., Sukhinin, A.I., Hewson, J.H.,  
736 Stocks, B.J., 2005. Influences of boreal fire emissions on Northern Hemisphere atmospheric  
737 carbon and carbon monoxide. *Global Biogeochemical Cycles* 19, GB1012.  
738 Kirilenko, A.P., Sedjo, R.A., 2007. Climate change impacts on forestry. *Proc Natl Acad Sci U S A*  
739 104, 19697-19702.

740 Kremenetski, K.V., Velichko, A.A., Borisova, O.K., MacDonald, G.M., Smith, L.C., Frey, K.E., Orlova,  
741 L.A., 2003. Peatlands of the Western Siberian lowlands: current knowledge on zonation, carbon  
742 content and Late Quaternary history. *Quaternary Science Reviews* 22, 703-723.

743 Kurina, I.V., Preis, Y.I., Bobrov, A.A., 2010. Testate amoebae inhabiting middle taiga bogs in  
744 Western Siberia. *Biology Bulletin* 37, 357-362.

745 Laine, J., Harju, P., Timonen, T., Laine, A., Tuittila, E.S., Minkkinen, K., Vasander, H., 2011. The  
746 Intricate Beauty of Sphagnum Mosses e a Finnish Guide to Identification. University of Helsinki  
747 Department of Forest Sciences Publications, Helsinki.

748 Lamentowicz, M., Cedro, A., Gałka, M., Miotk-Szpiganowicz, G., Mitchell, E.A.D., Pawlyta, J., Goslar,  
749 T., 2008. Last millennium palaeoenvironmental changes from a Baltic bog (Poland) inferred from  
750 stable isotopes, pollen, plant macrofossils and testate amoebae. *Palaeogeography,*  
751 *Palaeoclimatology, Palaeoecology* 265, 93-106.

752 Lamentowicz, M., Gałka, M., Pawlyta, J., Lamentowicz, Ł., Goslar, T., Miotk-Szpiganowicz, G., 2011.  
753 Climate change and human impact in the southern Baltic during the last millennium  
754 reconstructed from an ombrotrophic bog archive. *Studia Quaternaria* 28, 3-16.

755 Lamentowicz, M., Milecka, K., Gałka, M., Cedro, A., Pawlyta, J., Piotrowska, N., Lamentowicz, Ł.,  
756 van der Knaap, W.O., 2009. Climate- and human-induced hydrological change since AD 800 in an  
757 ombrotrophic mire in Pomerania (N Poland) tracked by testate amoebae, macro-fossils, pollen,  
758 and tree-rings of pine. *Boreas* 38, 214-229.

759 Lamentowicz, M., Mitchell, E.A.D., 2005. The ecology of testate amoebae (Protists) in Sphagnum  
760 in north-western Poland in relation to peatland ecology. *Microbial ecology* 50, 48-63.

761 Lapshina, E.D., Plogova, N.N., 2011. Spatial Dynamics of peat growth and carbon accumulation in  
762 sphagnum bogs (Boreal West Siberia), *West Siberian Peatlands and Carbon Cycle: past and*  
763 *present. Proceedings of the Third International Field Symposium Khanty-Mansiysk, June 27 -*  
764 *July 5, 2011.*

765 Lapshina, E.D., Pologova, N.N., E.Ya., M., 2001. Pattern of development and carbon accumulation  
766 in homogenous *Sphagnum fuscum*-peat deposit on the south of West Siberia, in: Vasiliev, S.,  
767 Titlyanova, A., Velochko, A. (Eds.), *West Siberian Peatlands and Carbon Cycle: past and present.*  
768 *Proceedings of International Field Symposium, Noyabrsk August 18 - 22, 2001, pp. 101-104.*

769 Lavoie, C., Pellerin, S., 2007. Fires in temperate peatlands (southern Quebec): Past and recent  
770 trends. *Canadian Journal of Botany* 85, 263-272.

771 Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of  
772 species data. *Oecologia* 129, 271-280.

773 Liss, O.L., Abramova, K.I., L.I.Avetov, 2001. Bog ecosystems of West Siberia and their  
774 environmental importance. Tula: Publishing house 'Grif i Ko'.

775 Loisel, J., Yu, Z., 2013. Surface vegetation patterning controls carbon accumulation in peatlands.  
776 *Geophysical Research Letters* 40, 5508-5513.

777 Loisel, J., Yu, Z., Beilman, D., Philip, C., Jukka, A., David, A., Andersson, S., Fiałkiewicz-Kozieł, B.,  
778 Barber, K., Belyea, L., Bunbury, J., Chambers, F., Charman, D., de Vleeschouwer, F., Finkelstein, S.,  
779 Garneau, M., Hendon, D., Holmquist, J., Hughes, P., Jones, M., Klein, E., Kokfelt, U., Korhola, A.,  
780 Kuhry, P., Lamarre, A., Lamentowicz, M., Large, D., Lavoie, M., MacDonald, G., Magnan, G., Gałka,  
781 M., Mathijssen, P., Mauquoy, D., McCarroll, J., Moore, T., Nichols, J., O'Reilly, B., Oksanen, P., Peteet,  
782 D., Rchard, P., Robinson, S., Rundgren, M., Sannel, B., Tuittila, E.-S., Turetsky, M., Valiranta, M., van  
783 der Linden, M., van Geel, B., van Bellen, S., Vitt, D., Zhao, Y., Zhou, W., 2014. A database and  
784 synthesis of existing data for northern peatland soil properties and Holocene carbon  
785 accumulation. *Holocene* 24, 1028-1042.

786 Magny, M., Arnaud, F., Holzhauser, H., Chapron, E., Debret, M., Desmet, M., Leroux, A., Millet, L.,  
787 Revel, M., Vannièrè, B., 2010. Solar and proxy-sensitivity imprints on paleohydrological records  
788 for the last millennium in west-central Europe. *Quaternary Research* 73, 173-179.

789 Magny, M., Gauthier, E., Vannièrè, B., Peyron, O., 2008. Palaeohydrological changes and  
790 human impact history over the last millennium recorded at Lake Joux in the Jura Mountains,  
791 Switzerland. *The Holocene* 18, 255-265.

792 Marcisz, K., Tinner, W., Colombaroli, D., Kołaczek, P., Słowiński, M., Fiałkiewicz-Kozieł, B., Łokas,  
793 E., Lamentowicz, M., 2015. Long-term hydrological dynamics and fire history during the last



794 2000 years in CE Europe reconstructed from a high-resolution peat archive. *Quaternary Science*  
795 *Reviews* 112, 138-152.

796 Mazei, Y., Kabanov, A.N., 2008. Testate amoebae from the sedge-sphagnum forested mire in the  
797 north of Karelia (Russia). *Izv. Penza. gos. pedagog. univ. im. i Vv. Gg. Bbelinskogo.* 10, 101-104.

798 Mazei, Y., Tsyganov, A.N., 2006. Freshwater testate amoebae. KMK, Moscow.

799 Mazei, Y.A., Embulaeva, E.A., 2009. Changes of soil-inhabited testate amoebae communities along  
800 forest-steppe gradient in the middle Volga region. *Arid Ecosystems* 15, 13-23.

801 Mazei, Y.A., Tsyganov, A.N., Bubnova, O.A., 2009. The structure of amoeba communities in boggy  
802 biotopes of the southern Taiga (Russian European Part). *Ucpiechi Sovriemennoi Biologii* 129,  
803 67-77.

804 Mazei, Y.A., Tsyganov, A.N., Bubnova, O.A., 2007. Structure of a community of testate amoebae in  
805 a Sphagnum dominated bog in upper sura flow (Middle Volga Territory). *Biology Bulletin* 34,  
806 382-394.

807 Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen analysis. Blackwell Scientific Publication.

808 Muller, S., Bobrov, A.A., Schirrmeister, L., Andreev, A.A., Tarasov, P.E., 2009. Testate amoebae  
809 record from the Laptev Sea coast and its implication for the reconstruction of Late Pleistocene  
810 and Holocene environments in the Arctic Siberia. *Palaeogeography, Palaeoclimatology,*  
811 *Palaeoecology* 271, 301-315.

812 Niklasson, M., Lindbladh, M., Björkman, L., 2002. A long-term record of Quercus decline, logging  
813 and fires in a southern Swedish Fagus-Picea forest. *Journal of Vegetation Science* 13, 765-774.

814 Ogden, C.G., Hedley, R.H., 1980. An Atlas of Freshwater Testate Amoebae. Oxford University  
815 Press, London.

816 Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens,  
817 M.H.H., Wagner, H., 2011. Vegan: Community Ecology Package. R package version 1.17-7.

818 Payne, R.J., Jassey, V.E.J., Leith, I.D., Sheppard, L.J., Dise, N.B., Gilbert, D., 2013. Ammonia exposure  
819 promotes algal biomass in an ombrotrophic peatland. *Soil Biology and Biochemistry* 57, 936-  
820 938.

821 Payne, R.J., Lamentowicz, M., van der Knaap, W.O., van Leeuwen, J.F.N., Mitchell, E.A.D., Mazei, Y.,  
822 2012. Testate amoebae in pollen slides. *Review of Palaeobotany and Palynology* 173, 68-79.

823 Payne, R.J., Mitchell, E.A.D., 2008. How many is enough? Determining optimal count totals for  
824 ecological and palaeoecological studies of testate amoebae. *Journal of Paleolimnology* 42, 483-  
825 495.

826 Peregon, A., Uchida, M., Shibata, Y., 2007a. *Sphagnum* peatland development at their southern  
827 climatic range in West Siberia: Trends and peat accumulation patterns. *Environmental Research*  
828 *Letters* 2.

829 Peregon, A., Uchida, M., Shibata, Y., 2007b. *Sphagnum* peatland development at their southern  
830 climatic range in West Siberia: trends and peat accumulation patterns. *Environmental Research*  
831 *Letters* 2, 045014.

832 Pitkänen, A., Turunen, J., Tahvanainen, T., Tolonen, K., 2002. Holocene vegetation history from  
833 the Salym-Yugan Mire Area, West Siberia. *Holocene* 12, 353-362.

834 Qin, Y.M., Mitchell, E.A.D., Lamentowicz, M., Payne, R.J., Lara, E., Gu, Y.S., Huang, X.Y., Wang, H.M.,  
835 2013. Ecology of testate amoebae in peatlands of central China and development of a transfer  
836 function for paleohydrological reconstruction. *Journal of Paleolimnology* 50, 319-330.

837 Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H.,  
838 Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatte, C.,  
839 Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu,  
840 M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht,  
841 J., 2013. Intcal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP.  
842 *Radiocarbon* 55, 1869-1887.

843 Seddon, A.W.R., Mackay, A.W., Baker, A.G., Birks, H.J.B., Breman, E., Buck, C.E., Ellis, E.C., Froyd,  
844 C.A., Gill, J.L., Gillson, L., Johnson, E.A., Jones, V.J., Juggins, S., Macias-Fauria, M., Mills, K., Morris,  
845 J.L., Nogues-Bravo, D., Punyasena, S.W., Roland, T.P., Tanentzap, A.J., Willis, K.J., Aberhan, M., van  
846 Asperen, E.N., Austin, W.E.N., Battarbee, R.W., Bhagwat, S., Belanger, C.L., Bennett, K.D., Birks,  
847 H.H., Ramsey, C.B., Brooks, S.J., de Bruyn, M., Butler, P.G., Chambers, F.M., Clarke, S.J., Davies, A.L.,

848 Dearing, J.A., Ezard, T.H.G., Feurdean, A., Flower, R.J., Gell, P., Hausmann, S., Hogan, E.J., Hopkins,  
849 M.J., Jeffers, E.S., Korhola, A.A., Marchant, R., Kiefer, T., Lamentowicz, M., Larocque-Tobler, I.,  
850 Lopez-Merino, L., Liow, L.H., McGowan, S., Miller, J.H., Montoya, E., Morton, O., Nogue, S.,  
851 Onoufriou, C., Boush, L.P., Rodriguez-Sanchez, F., Rose, N.L., Sayer, C.D., Shaw, H.E., Payne, R.,  
852 Simpson, G., Sohar, K., Whitehouse, N.J., Williams, J.W., Witkowski, A., 2014. Looking forward  
853 through the past: identification of 50 priority research questions in palaeoecology. *Journal of*  
854 *Ecology* 102, 256-267.

855 Sillasoo, U., Väliiranta, M., Tuittila, E.S., 2011. Fire history and vegetation recovery in two raised  
856 bogs at the Baltic Sea. *Journal of Vegetation Science* 22, 1084-1093.

857 Solomeshch, A.I., 2005. The West Siberian Lowland in: Fraser, L.H., Keddy, P.A. (Eds.), *The*  
858 *World's Largest Wetlands. Ecology and Conservation*, pp. 11-62.

859 Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen and Spores* 16,  
860 615-621.

861 Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch,  
862 K.G., Logan, K.A., Martell, D.L., Skinner, W.R., 2002. Large forest fires in Canada, 1959-1997.  
863 *Journal of Geophysical Research* 108.

864 Stocks, B.J., Wotton, B.M., Flannigan, M.D., Fosberg, M.A., Cahoon, D.R., Goldammer, J.G., 2001.  
865 *Boreal Forest Fire Regimes And Climate Change*, in: Beniston, M., Verstraete, M. (Eds.), *Remote*  
866 *Sensing and Climate Modeling: Synergies and Limitations*. Springer Netherlands, pp. 233-246.

867 Swindles, G.T., Morris, P.J., Baird, A.J., Blaauw, M., Plunkett, G., 2012. Ecohydrological feedbacks  
868 confound peat-based climate reconstructions. *Geophysical Research Letters* 39.

869 Swindles, G.T., Plunkett, G., Roe, H.M., 2007. A multiproxy climate record from a raised bog in  
870 County Fermanagh, Northern Ireland: a critical examination of the link between bog surface  
871 wetness and solar variability. *Journal of Quaternary Science* 22, 667-679.

872 Swindles, G.T., Watson, E., Turner, T.E., Galloway, J.M., Hadlari, T., Wheeler, J., Bacon, K.L., 2015.  
873 Spheroidal carbonaceous particles are a defining stratigraphic marker for the Anthropocene.  
874 *Scientific reports* 5, 10264.

875 Team, R.D.C., 2013. R: A language and environment for statistical computing. R Foundation for  
876 Statistical Computing, Vienna, Austria. ISBN 3-900051-00-3, URL <http://www.R-project.org>.

877 Tinner, W., Hu, F.S., 2003. Size parameters, size-class distribution and area-number relationship  
878 of microscopic charcoal: relevance for fire reconstruction. *The Holocene* 13, 499-505.

879 Tobolski, K., 2000. Przewodnik do oznaczania torfów i osadów jeziornych, *Vademecum*  
880 *Geobotanicum*. Wydawnictwo Naukowe PWN, Warszawa p. 508 ss.

881 Tolonen, K., Warner, B.G., Vasander, H., 1994. Ecology of Testaceans (Protozoa: Rhizopoda) in  
882 mires in southern Finland: II. Multivariate analysis. *Archiv für Protistenkunde* 144, 97-112.

883 Tsyganov, A.N., Komarov, A.A., Mitchell, E.A.D., Shimano, S., Smirnova, O.V., Aleynikov, A.A.,  
884 Mazei, Y.A., 2015. Additive partitioning of testate amoeba species diversity across habitat  
885 hierarchy within the pristine southern taiga landscape (Pechora-Ilych Biosphere Reserve,  
886 Russia). *European Journal of Protistology* 51, 42-54.

887 Turetsky, M.R., Benscoter, B., Page, S., Rein, G., van der Werf, G.R., Watts, A., 2015. Global  
888 vulnerability of peatlands to fire and carbon loss. *Nature Geosci* 8, 11-14.

889 Turner, T.E., Swindles, G.T., Roucoux, K.H., 2014. Late Holocene ecohydrological and carbon  
890 dynamics of a UK raised bog: impact of human activity and climate change. *Quaternary Science*  
891 *Reviews* 84, 65-85.

892 Turunen, J., Tahvanainen, T., Tolonen, K., Pitkanen, A., 2001. Carbon accumulation in West  
893 Siberian mires, Russia. *Global Biogeochemical Cycles* 15, 285-296.

894 Tweiten, M.A., Hotchkiss, S.C., Booth, R.K., Calcote, R.R., Lynch, E.A., 2009. The response of a jack  
895 pine forest to late-Holocene climate variability in northwestern Wisconsin. *Holocene* 19, 1049-  
896 1061.

897 van Bellen, S., Garneau, M., Ali, A.A., Bergeron, Y., 2012. Did fires drive Holocene carbon  
898 sequestration in boreal ombrotrophic peatlands of eastern Canada? *Quaternary Research* 78, 50-  
899 59.

900 Van Bellen, S., Mauquoy, D., Payne, R.J., Roland, T.P., Daley, T.J., Hughes, P.D.M., Loader, N.J.,  
901 Street-Perrott, F.A., Rice, E.M., Pancotto, V.A., 2014. Testate amoebae as a proxy for

902 reconstructing Holocene water table dynamics in southern Patagonian peat bogs. *Journal of*  
903 *Quaternary Science* 29, 463-474.  
904 van der Knaap, W.O., Lamentowicz, M., van Leeuwen, J.F.N., Hangartner, S., Leuenberger, M.,  
905 Mauquoy, D., Goslar, T., Mitchell, E.A.D., Lamentowicz, Ł., Kamenik, C., 2011. A multi-proxy, high-  
906 resolution record of peatland development and its drivers during the last millennium from the  
907 subalpine Swiss Alps. *Quaternary Science Reviews* 30, 3467-3480.  
908 Ward, S.E., Ostle, N.J., Oakley, S., Quirk, H., Henrys, P.A., Bardgett, R.D., 2013. Warming effects on  
909 greenhouse gas fluxes in peatlands are modulated by vegetation composition. *Ecol Lett* 16,  
910 1285-1293.  
911 Wotton, B.M., Flannigan, M.D., 1993. Length of the Fire Season in a Changing Climate. *Forest*  
912 *Chron* 69, 187-192.  
913 Zackrisson, O., 1977. Influence of forest fire on the north Swedish boreal forest. *Oikos* 29, 22-32.  
914 Zobel, M., 1988. Autogenic succession in boreal mires – a review. *Folia Geobotanica et*  
915 *Phytotaxonomic* 23, 417-445.

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Fig. 1.

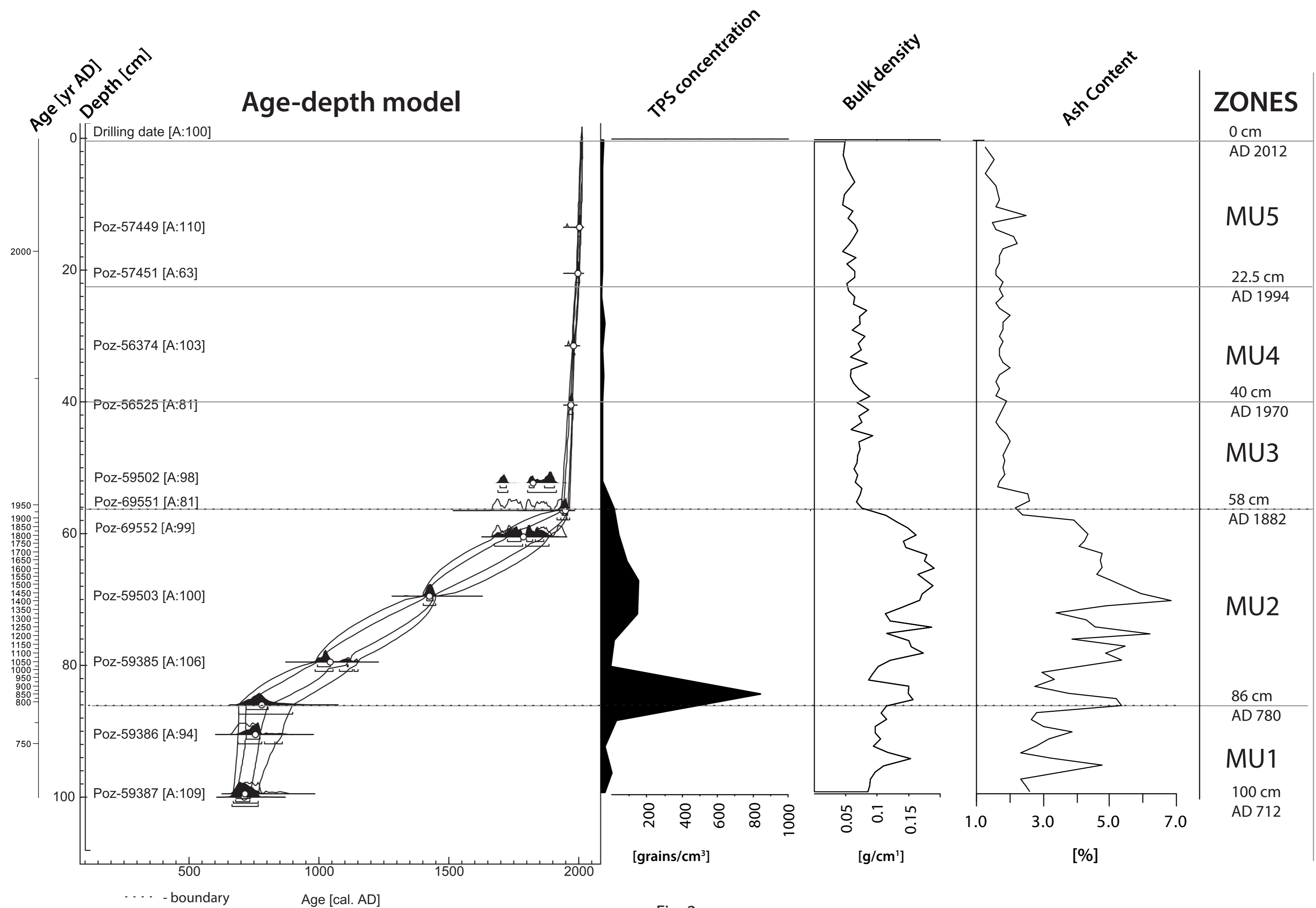


Fig. 2.

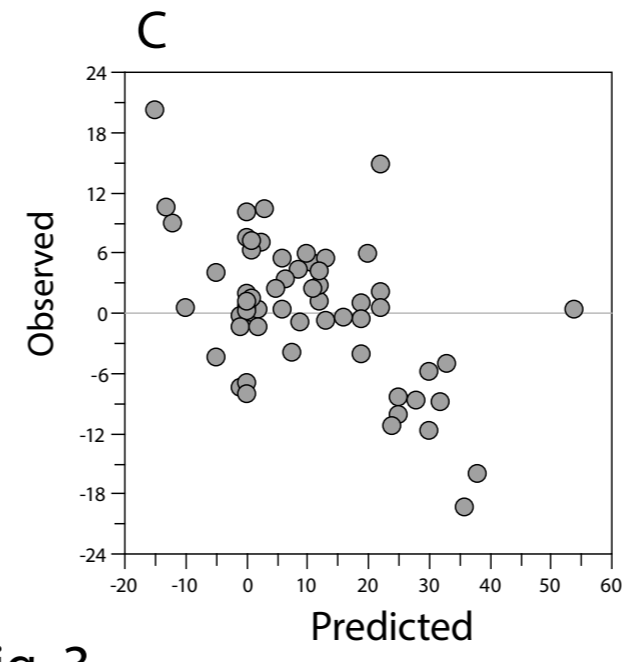
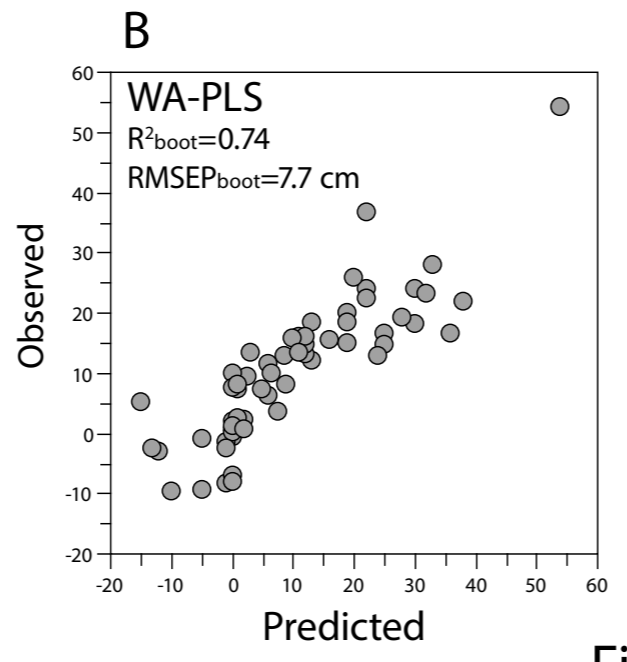
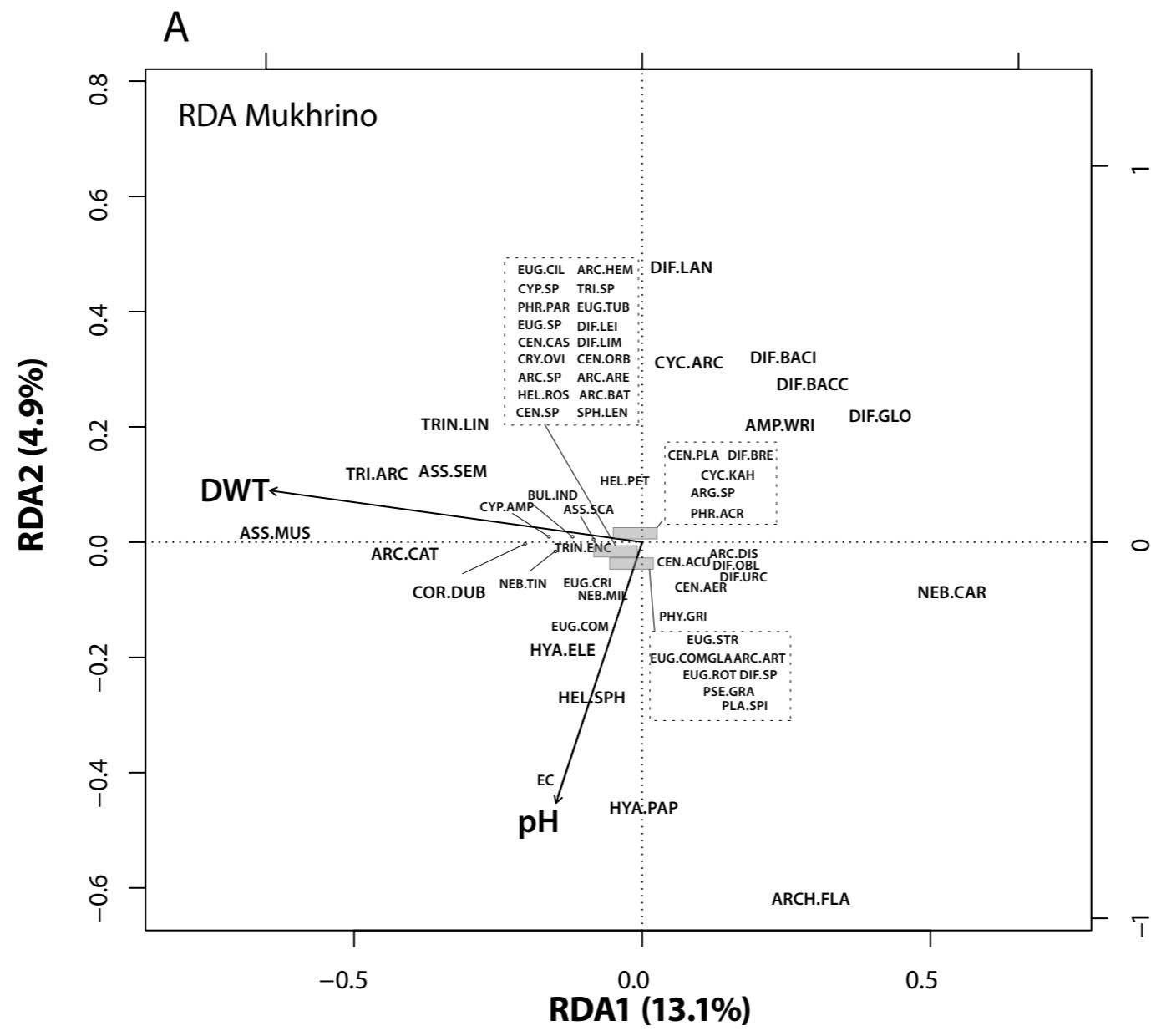


Fig. 3.

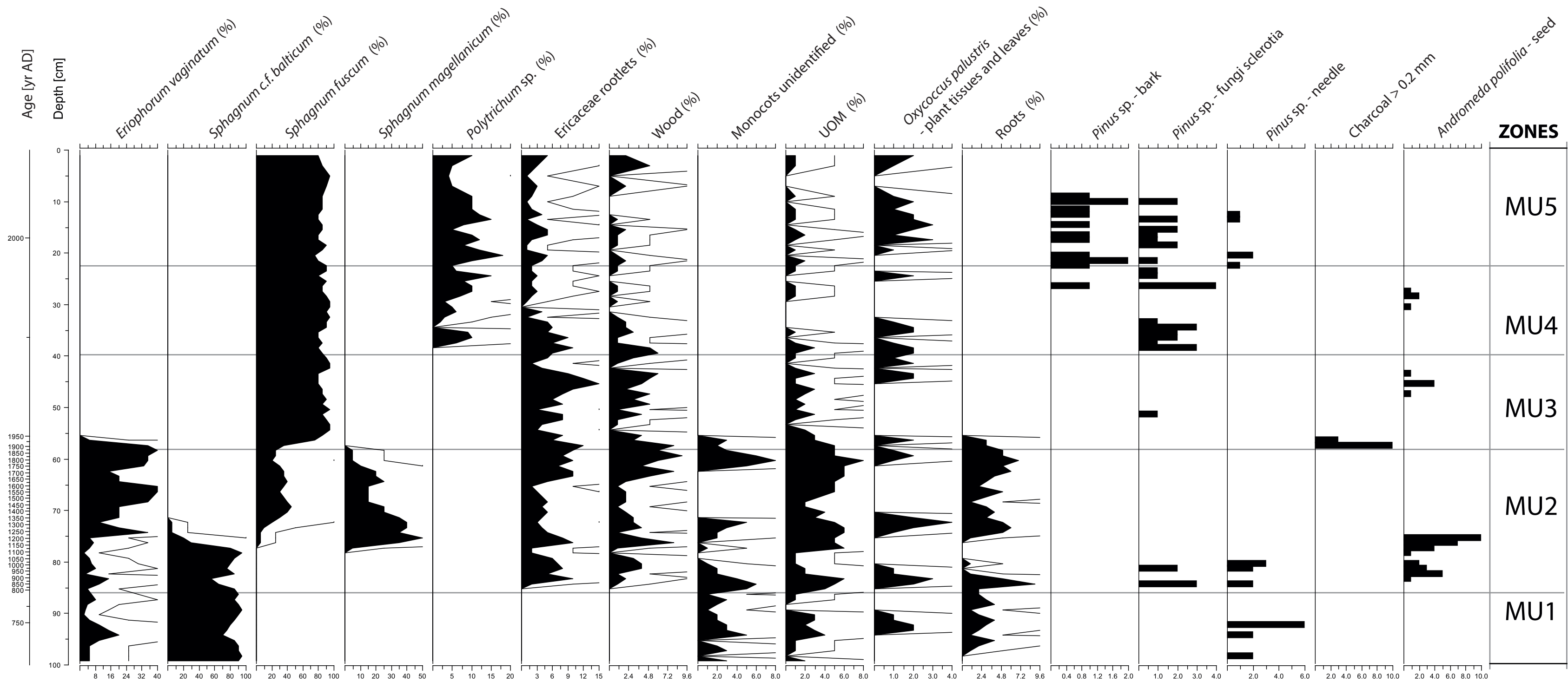


Fig. 4.

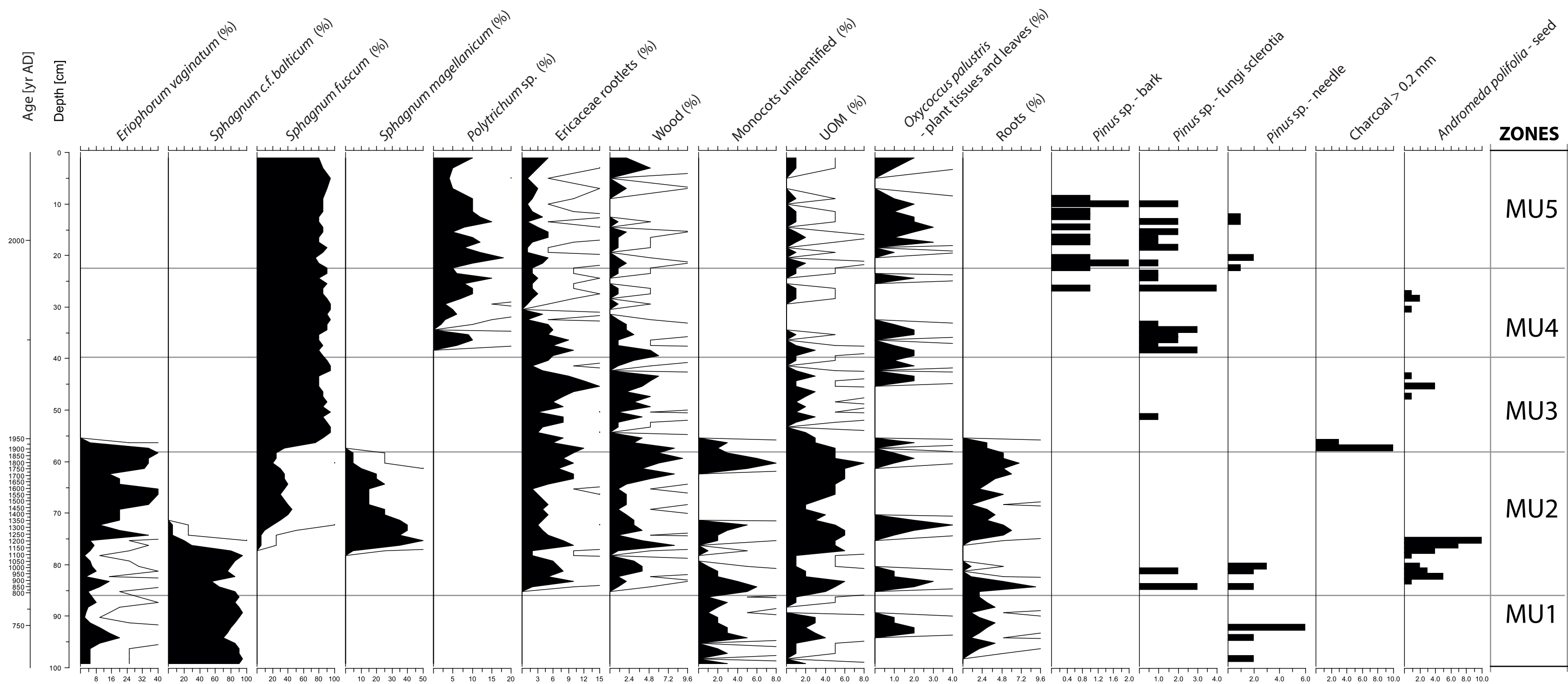


Fig. 4.



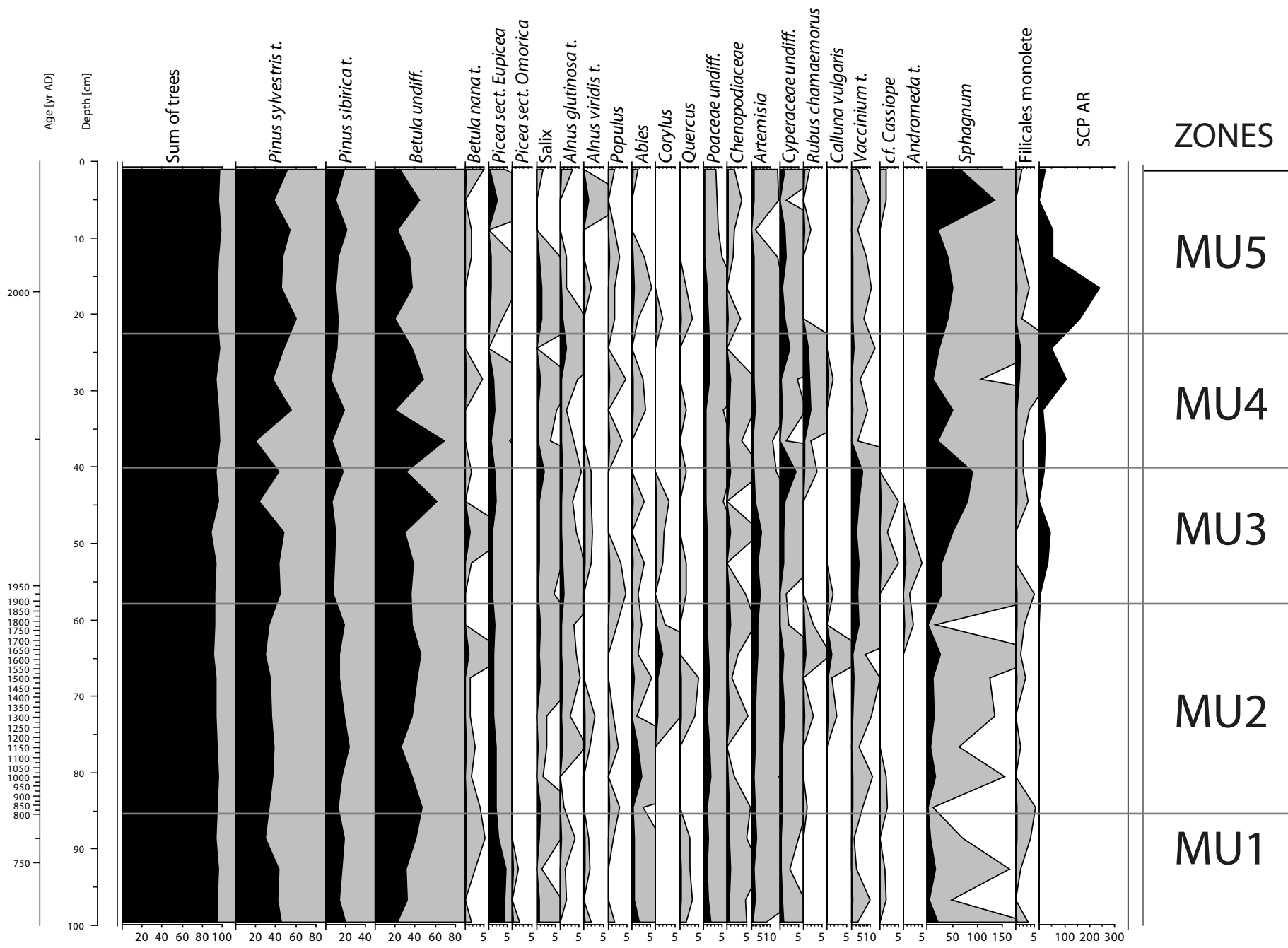


Fig. 5.

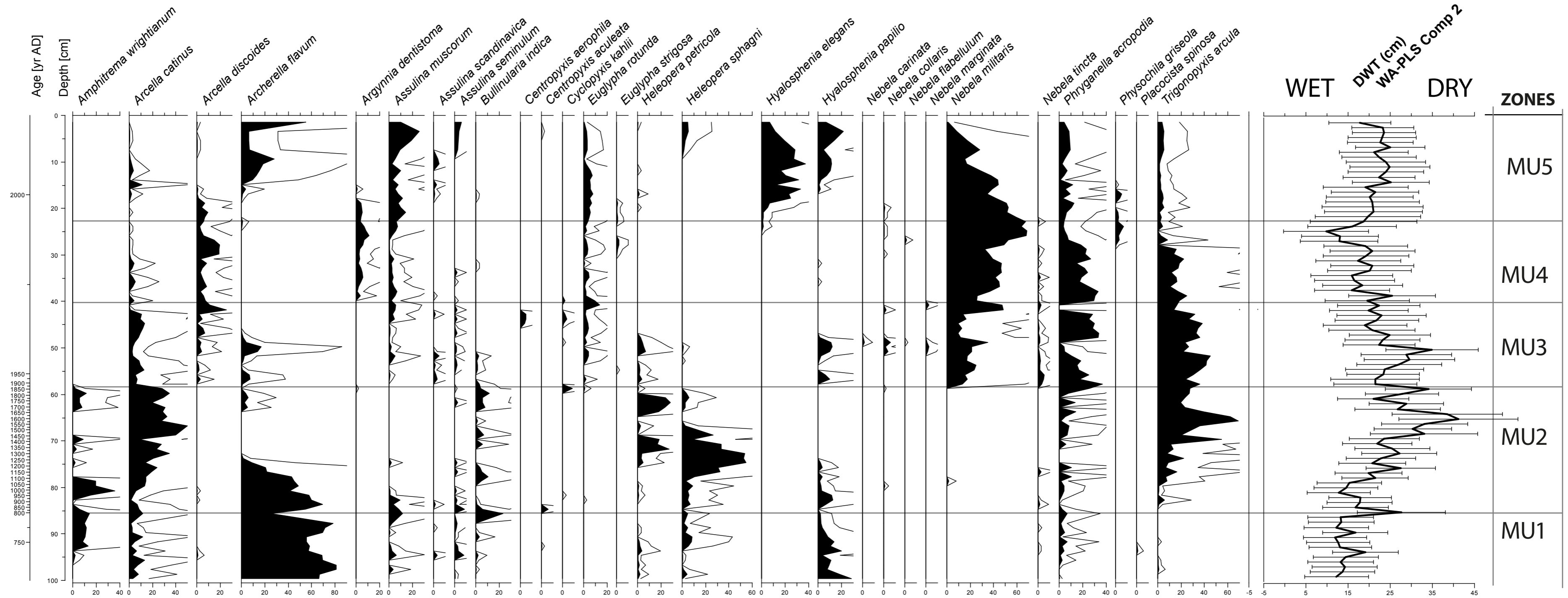


Fig.6.

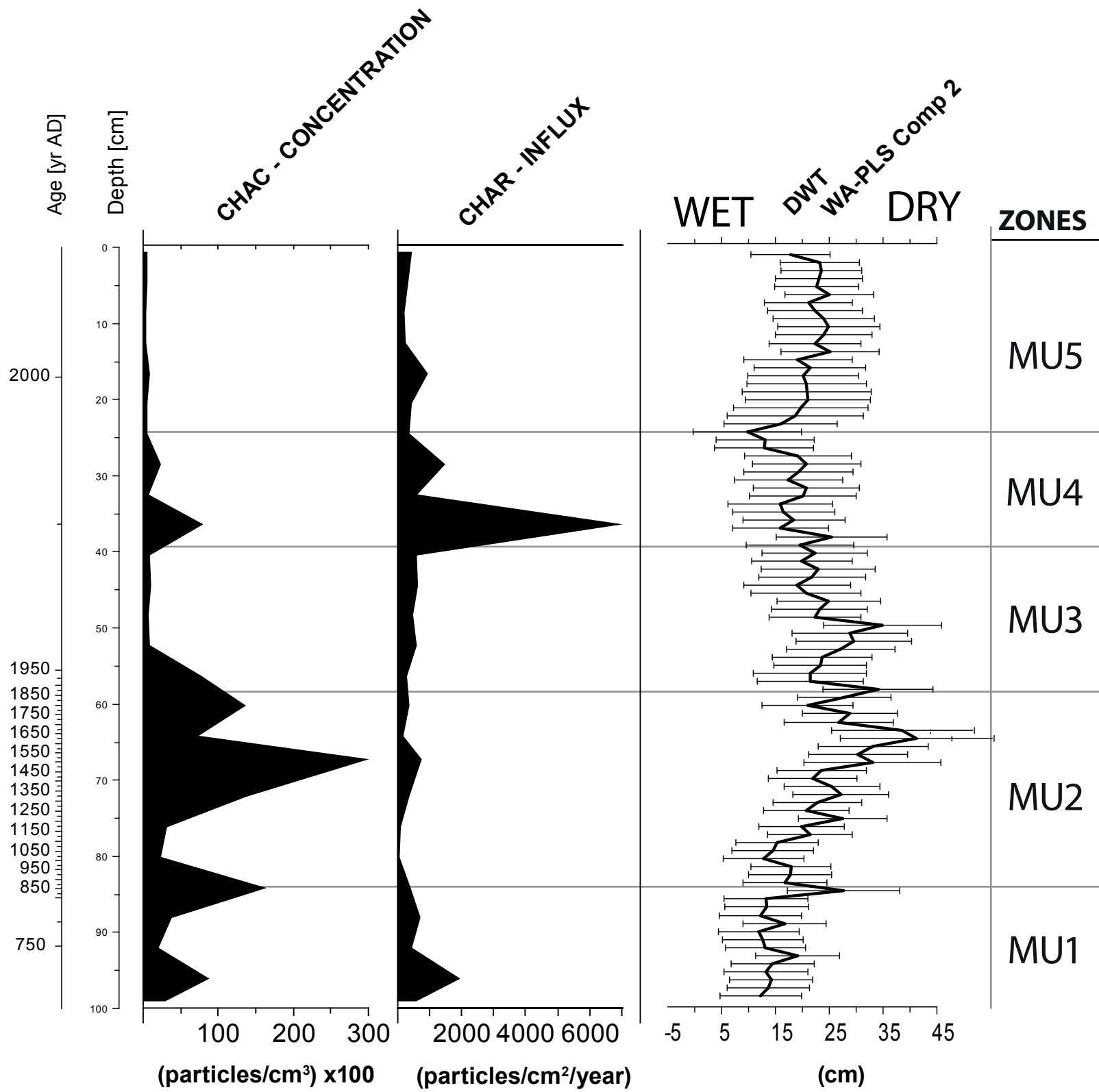


Fig. 7.

Table 1. Results of radiocarbon dating from the Mukhrino profile. Abbreviations: Poz – laboratory code of the Poznań Radiocarbon Laboratory (Poland)

Depth [cm]	Laboratory code	Age [ <sup>14</sup> C yr BP] pMC	Calibrated age, 2σ range [AD]; in brackets probability of the range of age	Material selected to date; remarks
13–14	Poz-57449	107.81 ± 0.34 pMC	1956–1957 (3.7%) 2001–2005 (91.7%)	<i>Sphagnum</i> stems
20–21	Poz-57451	110.13 ± 0.33 pMC	1957 (1.3%) 1996–2000 (94.1%)	<i>Sphagnum</i> stems
31–32	Poz-56374	130.35 ± 0.45 pMC	1961–1962 (4.9%) 1978–1980 (90.5%)	<i>Sphagnum</i> stems
40–41	Poz-56525	145.69 ± 0.4 pMC	1962–1963 (7.9%) 1972–1974 (87.5%)	<i>Sphagnum</i> stems
51–52	Poz-59502	70 ± 30	1691–1730 (24.3%) 1810–1924 (71.1%)	<i>Sphagnum</i> stems; excluded from age-depth modelling
56–57	Poz-69551	145 ± 30	1668–1710 (16.3%) 1717–1782 (29.2%) 1797–1891 (33.5%) 1909–1948 (16.4%)	<i>Sphagnum</i> stems
60–61	Poz-69552	140 ± 30	1669–1780 (43.1%) 1798–1891 (36.8%) 1909–1945 (15.5%)	<i>Sphagnum</i> stems
69–70	Poz-59503	495 ± 30	1400–1450	<i>Sphagnum</i> stems
79–80	Poz-59385	995 ± 30	986–1052 (63.8%) 1081–1158 (31.6%)	<i>Sphagnum</i> stems
90–91	Poz-59386	1270 ± 30	663–778 (92.3%) 792–804 (1.3%) 819–821 (0.2%) 842–859 (1.6%)	<i>Sphagnum</i> stems
99–100	Poz-59387	1260 ± 30	669–779 (85.3%) 791–829 (5.9%) 838–865 (4.2%)	<i>Sphagnum</i> stems

Table 2. Transfer function performance statistics. The best model is Weighted Averaging Partial Least Squares Component 2

Model	R2	Ave_Bias	Max_Bias	RMSEP
PLS				
PLS Component 1 for WT	0,51	0,33	40,51	10,34
PLS Component 2 for WT	0,64	0,23	28,31	8,90
PLS Component 3 for WT	0,68	0,07	23,67	8,49
PLS Component 4 for WT	0,67	-0,09	19,52	8,73
PLS Component 5 for WT	0,65	-0,26	16,03	9,47
WAPLS				
WAPLS Component 1 for WT	0,63	0,34	23,21	8,60
WAPLS Component 2 for WT	<b>0,74</b>	<b>-0,28</b>	<b>17,74</b>	<b>7,70</b>
WAPLS Component 3 for WT	0,73	-0,91	15,56	8,43
WAPLS Component 4 for WT	0,72	-1,08	17,39	9,06
WAPLS Component 5 for WT	0,71	-1,15	16,61	9,59
WA				
Weighted averaging model (inverse deshrinking) for WT	0,64	0,28	22,12	8,54
Weighted averaging model (classical deshrinking) for WT	0,65	0,36	16,79	9,18
Weighted averaging model (tolerance downweighted, inverse deshrinking) for WT	<b>0,75</b>	<b>0,62</b>	<b>18,12</b>	<b>7,88</b>
Weighted averaging model (tolerance downweighted, classical deshrinking) for WT	0,75	0,77	16,35	8,11