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Impacts of regional climatic fluctuations on radial growth of Siberian and Scots pine at Mukhrino mire (central-western Siberia)

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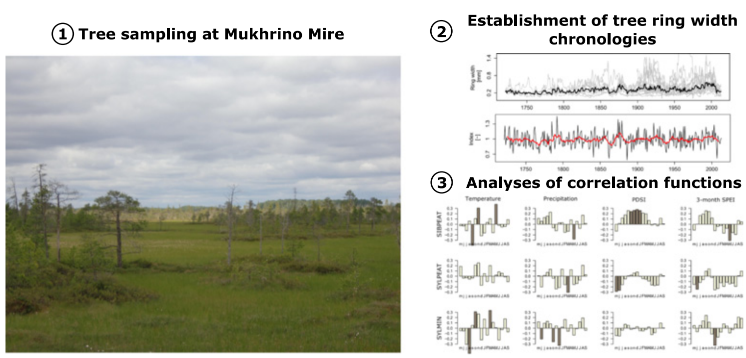
HIGHLIGHTS

- We perform a dendroclimatological study in a pristine mire in northern Eurasia.
- Tree growth of Siberian and Scots pines from peat soil is correlated with PDSI and 3-month SPEI.
- Trees establishment in Siberian peatlands occurred in the 16th and 18th centuries.
- Climate signals from Siberian pines are representative of May temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

Ring width (TRW) chronologies from Siberian (*Pinus sibirica*) and Scots (*Pinus sylvestris*) pine trees were sampled at Mukhrino – a large mire complex in central-western Siberia – to evaluate the impacts of hydroclimatic variability on tree growth over the last three centuries. For this purpose, we compared climate-growth correlation profiles from trees growing on peat soils with those growing on adjacent mineral soils. Tree growth at both peat and mineral soils was positively correlated to air temperature during the vegetation period. This finding can be explained by (i) the positive influence of temperature on plant physiological processes (i.e. growth control) during the growing season and (ii) the indirect impact of air temperatures on water table fluctuations. We observe also a strong link between TRW and the winter Palmer Drought Severity Index (PDSI), especially in Siberian pine, reflecting the isolating effect of snow and limited freezing damage in roots. Significant negative relations were, by contrast, observed between bog TRW chronologies and hydroclimatic indices during spring and summer; they are considered an expression of the negative impacts of high water levels and moist peat soils on root development. Some unusually old bog pines – exhibiting >500 growth rings – apparently colonized the site at the

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beginning of the Little Ice Age, and therefore seem to confirm that (i) peat conditions may have been drier in Siberia than in most other regions of western Europe during this period. At the same time, the bog trees also point to (ii) their strong dependence on surface conditions.

1. Introduction

Peatlands are peculiar ecosystems acting as effective long-term sinks of atmospheric carbon due to their accumulation of organic matter (MacDonald et al., 2006; Evans and Warburton, 2011). Should climate change towards warmer and drier conditions, however, peatlands could also turn from present-day sinks into future carbon sources (Gorham, 1991; Frey, 2005; Ise et al., 2008). Despite the importance of peatlands in the global carbon cycle, a more complete and, ideally, holistic understanding of interactions between carbon balance, soil moisture variability and vegetation dynamics is still critically lacking (Waddington et al., 2015). Further studies aiming to prevent precise and reliable predictions of future vegetation changes, carbon sequestration and vulnerability of northern peatlands to climate change are thus urgently needed.

Linkages between water-table fluctuations, annual tree growth, and tree population dynamics in peatlands have been studied using both living (Cedro and Lamentowicz, 2011; Smiljanić et al., 2014; Edvardsson et al., 2015a) and subfossil trees (Leuschner et al., 2002; Eckstein et al., 2009; Edvardsson et al., 2012). High water levels and moist soils in peatlands have thereby been associated with depressed radial tree growth (Boggie, 1972; Edvardsson et al., 2015a) and were found to cause widespread dying-off under unfavourable conditions (Leuschner et al., 2002). Linkages between hydroclimatic dynamics and tree growth variability are, however, not yet fully understood, mainly as a result of apparent hydrological lags and feedback effects in peatlands (Linderholm et al., 2002; Edvardsson et al., 2015a). Furthermore, the lack of natural and unmanaged peatlands have so far hampered studies of these linkages between climate, hydrology, and tree growth, at least in Western Europe. In Siberia, by contrast, large unmanaged peatland complexes still exist (Kremenetski et al., 2003), but have escaped more in-depth analyses.

In Western Siberia alone, ~900,000 km^2 are currently covered by peatlands; the region is therefore estimated to contain a terrestrial soil carbon pool which is equivalent to more than 53,800 million tons of carbon (Kremenetski et al., 2003). Dendrochronological studies in Western Siberia are rare (Vaganov and Kachaev, 1992) and were primarily aimed at reconstructing temperatures (Hantemirov and Shiyatov, 2002; Sidorova et al., 2005; Briffa et al., 2008) or, to a minor degree hydrological fluctuations (Tei et al., 2013).

Here, we present a study carried out at Mukhrino mire in central western Siberia based on *Pinus sibirica* and *Pinus sylvestris* trees sampled at the margin of a mire complex, both on mineral soils and in the central part (mire expanse) on a thick peat deposit. Specifically, the main aims of this study were (i) to relate growth responses in *P. sibirica* and *P. sylvestris* to historical records of temperature and precipitation, and (ii) to clarify the potential interactions between hydrology, tree growth, and climate in central-western Siberian peatlands.

2. Material and methods

2.1. Study area

The Mukhrino peatland (60°54′N, 68°42′E) is part of a wider mire complex located on the south-western bank of the Irtysh River, near its confluence with the Ob River (Fig. 1). This peatland is representative of the large pristine mires of western Siberia and has so far escaped human disturbance. As described by Bleuten and Filippov (2008), the mire complex consists of ombrotrophic raised bogs, patterned bogs with ridges and hollows, poor fens and shallow water tracks, and peat thicknesses varying between 2 and 4.5 m. Water-table depth is controlled by micro-topography; during summer, it can reach depths between 5 and 20 cm below the moss surface in poor fens and hollow habitats but up to 40–80 cm below the surface in *Sphagnum* hummocks (Bleuten and Filippov, 2008; Lamentowicz et al., 2015). The bog covers an area of ~10 km^2 and is dominated by ombrotrophic plant communities; transitional plant communities are limited to the edges of the bog and along the water courses (Filippova and Thormann, 2014). Dominant tree species found at the site consist of Scots pine (*P. sylvestris* L.) and the Siberian pine (*P. sibirica* L.); they typically present sparse populations on the mire expanse (on thick peat deposits) and denser stands on drier mineral soils at the margins of the mire complex.

The Mukhrino mire is located in the boreal climate zone, corresponding to the subarctic zone of Western Europe. Based on data from the Khanty-Mansiysk meteorological station (located ~22 km to the south-west of Mukhrino mire), annual mean temperature is −1.2 °C

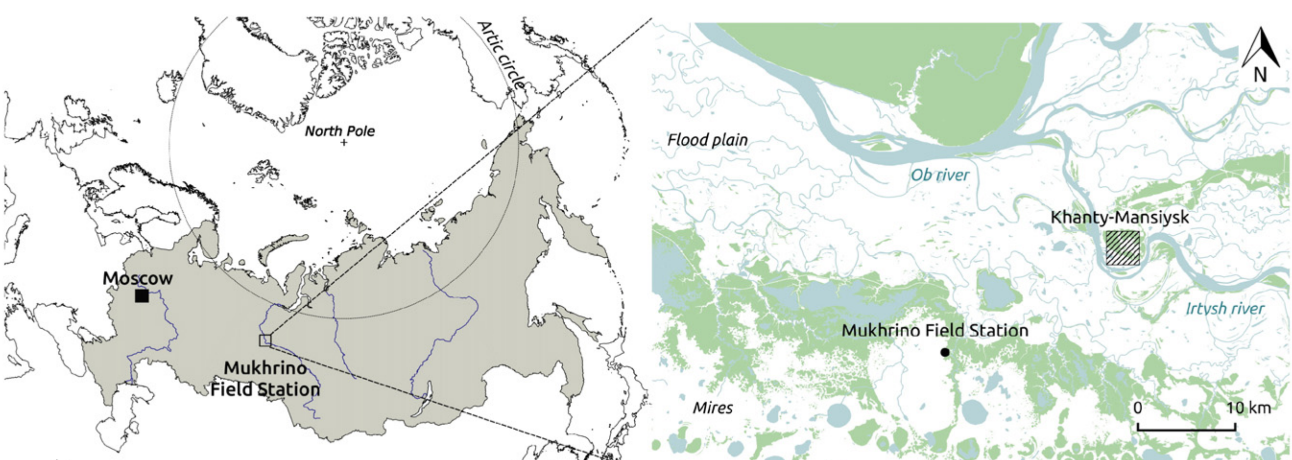

Fig. 1. Location map of the Mukhrino Field Station (60°54′N, 68°42′E).

(1950–2010; Fig. 2), with minimum and maximum mean temperatures in January (−19.6 °C) and July (17.9 °C), respectively. Mean annual precipitation is 524 mm with 40% falling in the form of snow and hail, thus leaving a consistent snowpack from October to April.

2.2. Field sampling and tree core preparation

A total of 20 *P. sibirica* and 54 *P. sylvestris* trees were sampled on peat soils (mire expanse) in 2013 and 2014, and complemented with 18 *P. sylvestris* trees from mineral soils (i.e. at the mire's margin). At least two cores were extracted per tree using a Suunto increment borer. To obtain a maximum number of rings and, at the same time, to avoid irregularities, trees were sampled at a height of 0.5 m above the peat surface. In addition, based on visual inspection (e.g., tree height and shape), we preferentially sampled the oldest trees so as to ensure a chronology reaching as far back in time as possible (Linderholm et al., 2002).

After sampling, tree cores were mounted on woody supports, air-dried in the lab and then sanded (Braker, 2002). Tree-ring widths (TRW) were measured to the nearest 0.001 mm using a digital LINTAB5 positioning table connected to a Leica stereomicroscope and TSAPWin software (Rinntech, 2016). Individual ring-width series were then cross-checked visually and statistically using Cofecha (Holmes, 1983), so as to identify potential counting errors or missing rings. In a subsequent step, individual series were created by averaging measurements from at least two cores of the same tree. Samples were discarded or truncated if too many annual rings were missing or if the growth pattern was significantly different from the other trees of the same subset of samples. In total, 3 TRW chronologies were developed according to the tree species and soil type (Table 1), and named SIBPEAT, SYLPEAT, and SYLMIN.

2.3. Chronology development and statistics

To remove non-climatic trends from the records (e.g., age-related growth trends or effects of stand dynamics) and to maximize climatic information, we standardized TRW chronologies using the ARSTAN_41d software (Cook and Krusic, 2006). As non-significant synchronism was detected between peat soil and mineral soil trees, a flexible Friedman's variable span smoother (Friedman, 1984) was used for standardization so as to preserve potential low-frequency variations in tree growth. In a second step, the standardized series were pre-whitened with low-order autoregressive models to remove any persistence which was not related to climatic variations. The standardized series were then averaged by year using a bi-weighted robust mean which in turn allowed development of chronologies representing the common high-frequency variation of the individual series (Cook, 1985). Increasing variance back in time, which is related to the decreasing number of TRW series, was stabilized in the three mean chronologies using the rbar-weighted method as described in Osborn et al. (1997). Finally, we evaluated signal strength of each chronology using running expressed population signals (EPS) computed over a 50-year window with a 25-year overlap (Wigley et al., 1984). The EPS estimates the ability of a finite sample to approximate the true, unknown, population tree-ring signal at the site. We consider TRW chronologies as reliable as soon as the EPS is above the commonly accepted threshold of 0.85 (Wigley et al., 1984).

Table 1
Main characteristics of the tree ring width (TRW) chronologies.

	Chronology		
	SIBPEAT	SYLPEAT	SYLMIN
Tree species	*P. sibirica*	*P. sylvestris*	*P. sylvestris*
Soil type	Peat	Peat	Mineral
Number of sampled trees	20	54	18
Number of trees in established chronology	17	47	16
Number of tree-cores considered	54	96	34
Mean ring width [mm]	0.302	0.366	1.311
Full chronology span	1721–2013	1760–2013	1893–2013
Correlation between trees (rbar)	0.549	0.528	0.628
Standardized chronology statistics			
Mean sensitivity	0.147	0.152	0.136
Standard deviation	0.158	0.188	0.167
First-order autocorrelation	0.361	0.478	0.443
Residual chronology statistics			
Mean sensitivity	0.169	0.165	0.159
Standard deviation	0.146	0.154	0.154
First-order autocorrelation	−0.019	0.085	0.096

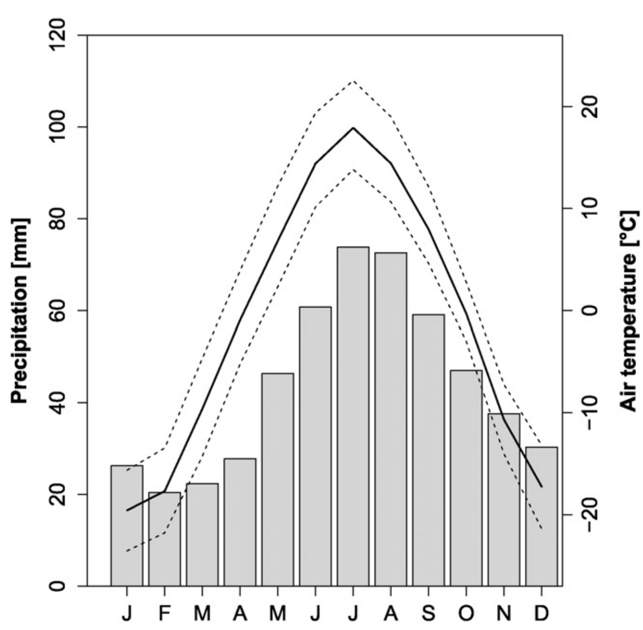

Fig. 2. Monthly meteorological records from Khanty-Mansiysk station. Black line represents mean monthly temperature, dotted lines mean monthly minimal and maximal temperatures, respectively.

2.4. Climatic data

Several discontinuities were found in local meteorological station data prior to 1950; these were essentially caused by maintenance issues or displacements of the stations. To account for these inhomogeneities, monthly temperature and precipitation records from the meteorological station of Khanty-Mansiysk were compared with the 1901–2010 monthly 0.5° × 0.5° latitude/longitude gridded dataset for the region spanning 60–61°N and 68–69°E (CRU TS 3.22, Harris et al., 2014). All monthly Pearson's correlation values were highly significant ($r = 0.98$, $p < 0.01$) for the time interval covered by both series (1950–2010) and discontinuities were clearly absent in the gridded data for the period 1950–2010. As a consequence, the CRU data was preferred over the local measurements for the climate-growth analyses. In addition to temperature and precipitation, the self-calibrated Palmer Drought Severity Index (PDSI; Palmer, 1965; Wells et al., 2004) and the 3-month Standardized Precipitation Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010) time series were tested as regressors for climate/growth analyses. Both indices give an estimation of the water balance for a given surface but differ in their computational methods and their time-scale consideration. The 3-month SPEI (1950–2010) and PDSI (1950–2010) were extracted from the Global SPEI (SPEIbase, Beguería et al., 2014) and CRU sc-PDSI 3.21 databases (van der Schrier et al., 2007) at a single location (i.e., 60–61°N, 68–69°E) corresponding to the study area.

2.5. Climate and tree growth relationships

To test for the sensitivity of the three TRW chronologies to (hydro)climatic fluctuations, climate–growth relationships were tested with response bootstrapped correlation analyses computed between each residual chronology and monthly climate predictors for the period 1950–2010 using the *BootRes* package (Zang and Biondi, 2013). For this period, the EPS was above 0.85 for each of the TRW chronologies, so that they can be considered reliable. The climatic dataset includes mean monthly air temperature (°C), total monthly precipitation (mm), PDSI and 3-month SPEI indices and was sequenced from May of the year preceding [n-1] the year of the tree-ring formation [n] to September of the year of actual tree-ring formation (17 predictors) to detect any potential lag effects. Finally, spatial correlation analyses between TRW chronologies and regional gridded climate data were performed with the KNMI Climate Explorer web application (http://www.climexp.knmi.nl), with the aim to (i) test whether the significant growth-climate relationships detected from bootstrap correlation analyses were also reliable at regional-scale climate variability and to (ii) identify potential larger-scale forcing effects on tree-growth response.

3. Results

3.1. Descriptive statistics of tree ring chronologies

The chronologies of *P. sylvestris* from the mire expanse (on peat soil, SYLPEAT) and the mire margin (on mineral soil, SYLMIN) were obtained, respectively, from 47 (rejection rate: 13%) and 16 trees (rejection rate: 11%) (Table 1). The mire expanse chronology (SYLPEAT) spans a period of 253 years (1760–2013), whereas the mire margin chronology (SYLMIN) covers a 120-year long period (1893–2013). In addition, the age distribution of mire expanse trees is characterized by rapid establishment between 1880 and 1900 (Fig. 3). The high mean inter-series correlation between individual tree radii reveals strong common signals in each TRW chronology with 0.53 and 0.63 for SYLPEAT and SYLMIN, respectively. On average, mire expanse trees are growing more slowly (0.37 mm yr^{-1}) in comparison to pines from the mire margin (1.31 mm yr^{-1}) as a result of the inclusion of older individuals (134 vs. 92 years on average) at SYLPEAT and harsher growth conditions on pure peat soil. The EPS exceeds values of 0.85 during the period 1850–2013 for SYLPEAT and from 1920 to 2013 for SYLMIN (Fig. 3).

The *P. sibirica* chronology (SIBPEAT) was obtained from 17 trees (rejection rate 15%) and spans 292 years, i.e. the period 1721–2013. On the mire expanse, Siberian pines are generally older than Scots pines (173 vs. 134 years). Mean inter-series correlation (0.549) and TRW (0.30 mm yr^{-1}) reveal growth conditions and climatic signal strength comparable to SYLPEAT. The EPS values for SIBPEAT exceed 0.85 from 1850 and remain close to 0.80 over the course of the 18th century (Fig. 4). Moreover, the two oldest trees from the site were recorded among the Siberian pines, with minimum ages of 536 and 527 years, respectively. Due to the large number of missing rings, these two trees were not, however, included in the SIBPEAT TRW chronology.

3.2. Bootstrapping correlation analysis

In the case of SYLPEAT, statistically significant correlations were missing between the TRW chronology and monthly temperatures (Fig. 5). Tree growth is negatively influenced by the precipitation amount from previous October (October $_{[n-1]}$) to current July (July $_{[n]}$). At a 5% error level, however, the only significant correlation is obtained for March $_{[n]}$ ($r = -0.3$). Correlation between TRW indices, PDSI, and 3-month SPEI exhibits a similar pattern with generally, albeit rarely significant, negative values during the previous and the current vegetation periods, i.e. from May $_{[n-1]}$ to July $_{[n-1]}$ and from February $_{[n]}$ to July $_{[n]}$, respectively.

On mineral soils, scattered significant values are observed in August $_{[n-1]}$ ($r = -0.46$), October $_{[n-1]}$ ($r = -0.31$) and March $_{[n]}$ ($r = -0.34$) for air temperature. Despite the vicinity between both Scots pine chronologies, the correlation patterns are very different for precipitation and 3-month SPEI, with SYLMIN presenting a more complex profile overall. Correlations with precipitation are significantly

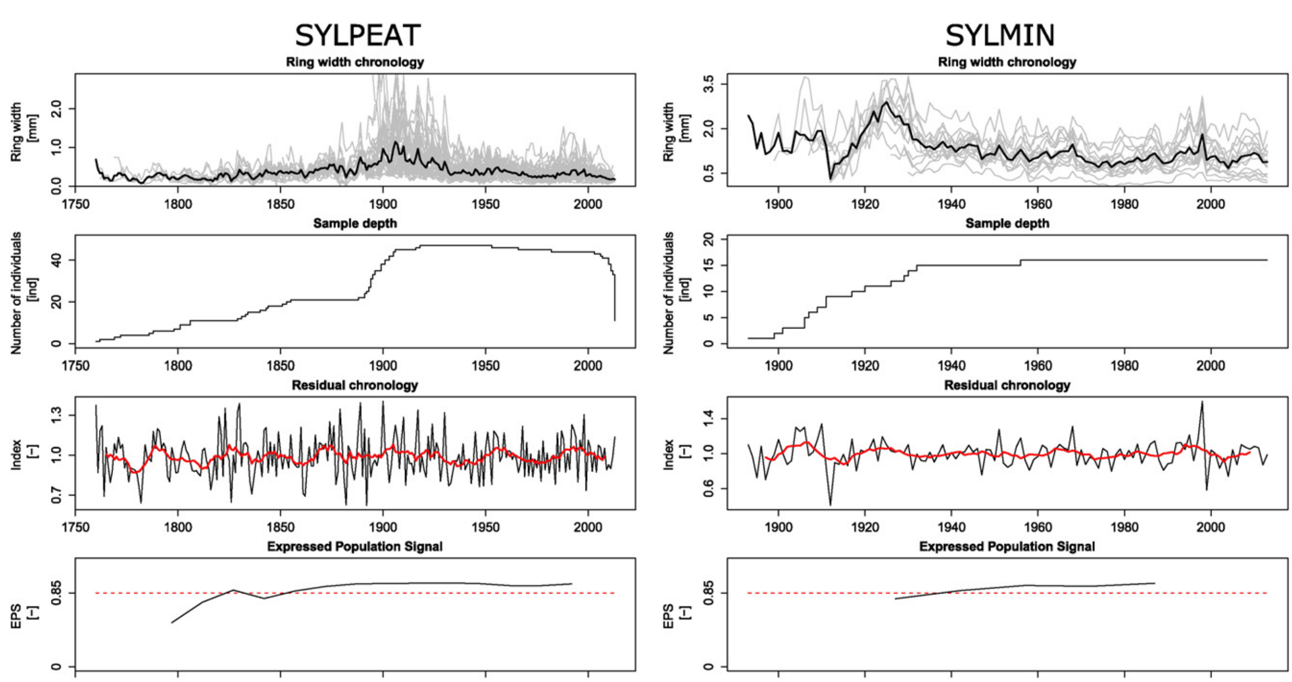

Fig. 3. Chronologies from the Scots pine trees growing on peat soil (SYLPEAT) and on mineral soil (SYLMIN). Graph of tree ring width (TRW) chronologies shows individual chronologies (grey lines) and mean TRW chronology (black line). Sample depth graph displays the number of trees included in the TRW chronology along the studied period. Residual chronology and Expressed Population Signal (EPS) were obtained according to the statistical procedure described in the "Material and Methods" section. Residual chronology is used for correlation analysis (see Fig. 5) and red line exhibits low frequency variability (9 years low-pass filter).

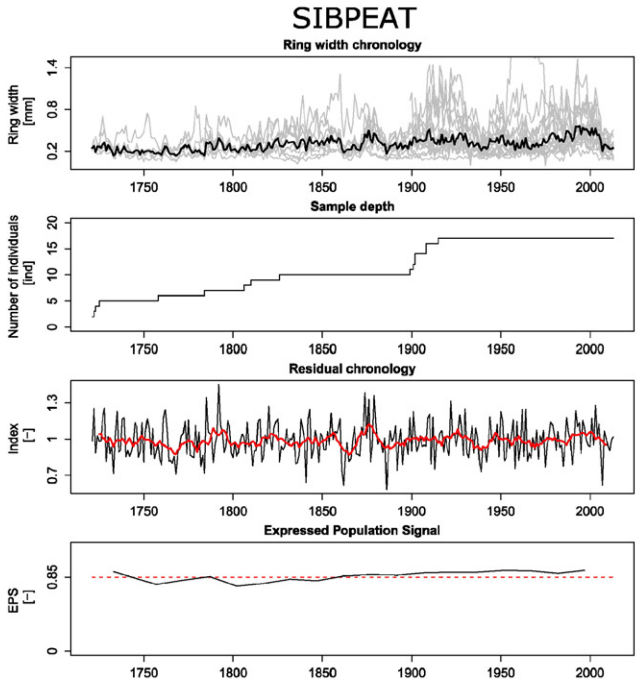

Fig. 4. Chronology from Siberian pine trees (SIBPEAT) growing on peat soil. For explanation, see Fig. 3.

negative for June $_{[n-1]}$ ($r = -0.21$), October $_{[n-1]}$ ($r = -0.26$), and December $_{[n-1]}$ ($r = -0.34$); they remain low for all other months ($-0.15 < r < 0.15$). Positive, albeit not significant, correlations between 3-month SPEI and TRW chronologies are observed during both summers [n − 1, n] whereas the SYLMIN chronology appears to be weakly and not statistically correlated to PDSI (Fig. 5).

Similarly to SYLPEAT and SYLMIN, SIBPEAT exhibits low correlations with temperature ($|r| < 0.3$) (Fig. 5). Nevertheless, three months exhibit significant values, i.e. November $_{[n-1]}$ ($r = 0.31$), May $_{[n]}$ ($r = 0.38$) and September $_{[n]}$ ($r = -0.40$). This correlation profile was similar to SYLMIN, but with a lag of one to two months over the plant growing period. Below-average precipitation between December $_{[n-1]}$ and August $_{[n]}$ tend to favor tree-ring formation. This influence is particularly significant in May $_{[n]}$ for both parameters ($r = -0.28$ and $r = -0.31$, $p < 0.05$). In the case of PDSI, a positive and almost constant correlation profile, significant from October $_{[n-1]}$ to January $_{[n]}$, is obtained between drought indices and TRW chronologies over the winter season, i.e. outside the plant growing season.

3.3. Spatial correlation analysis

Spatial correlation of each residual chronology was performed with the gridded dataset of climatic variables from the area (50–75°N, 55–85°E) around the Mukhrino mire. Significant spatial correlations were obtained between the SIBPEAT TRW chronology, temperature and 3-month SPEI in May $_{[n]}$ (Fig. 6). This significant correlation between radial growth and temperature in May $_{[n]}$ at the local scale turns out to be representative of the temperature of a wider area (53–72°N, 57–81°E) covering an region stretching from Southern Russia to the Ob Gulf. Similarly, radial growth of SIBPEAT was negatively correlated ($r > -0.3$, $p < 0.05$) with 3-month SPEI gridded values for an area located to the south-east of the study area (56–64°N, 68–80°E).

4. Discussion

4.1. Radial growth rates

Mean radial tree growth on peat soil was <0.40 mm yr^{-1}, whereas the mineral soil trees showed significantly stronger growth (1.31 mm yr^{-1}). The low radial growth rates for trees growing on peat soils are indicative of stressful environmental conditions as ring widths ≤0.50 mm yr^{-1} are considered minimal in most tree species. In peatlands, narrow annual rings are usually interpreted as the consequence of persistently high water tables, soil acidity, and nutrient deficiency (Freléchoux et al., 2000, 2004; Vitas and Erlickyté, 2007).

In agreement with previous studies (Smiljanić et al., 2014; Edvardsson et al., 2015a), we experienced difficulties in cross-dating

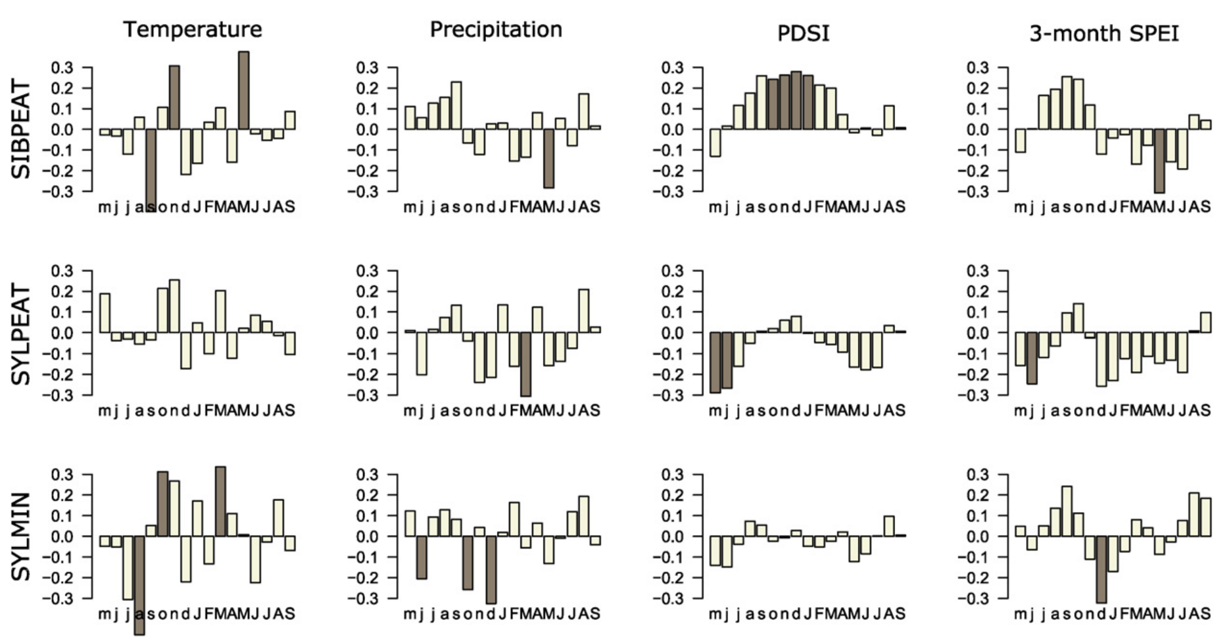

Fig. 5. Correlation function analysis between the residual chronologies and: monthly mean temperature, monthly precipitation, 3-month SPEI and PDSI monthly indices for the period 1950–2010 in Siberia trees on peat soil (SIBPEAT), Scots pines on peat soil (SYLPEAT) and mineral soil (SYLMIN). Lower case month initials refer to the previous year of tree ring growth, whereas upper case month initials to the current year. PDSI: self-calibrated Palmer Drought Severity Index; 3-month SPEI: Standardized Precipitation Evapotranspiration Index calculated over a 3-month period. Grey bars indicate significant relationships at $p < 0.05$.

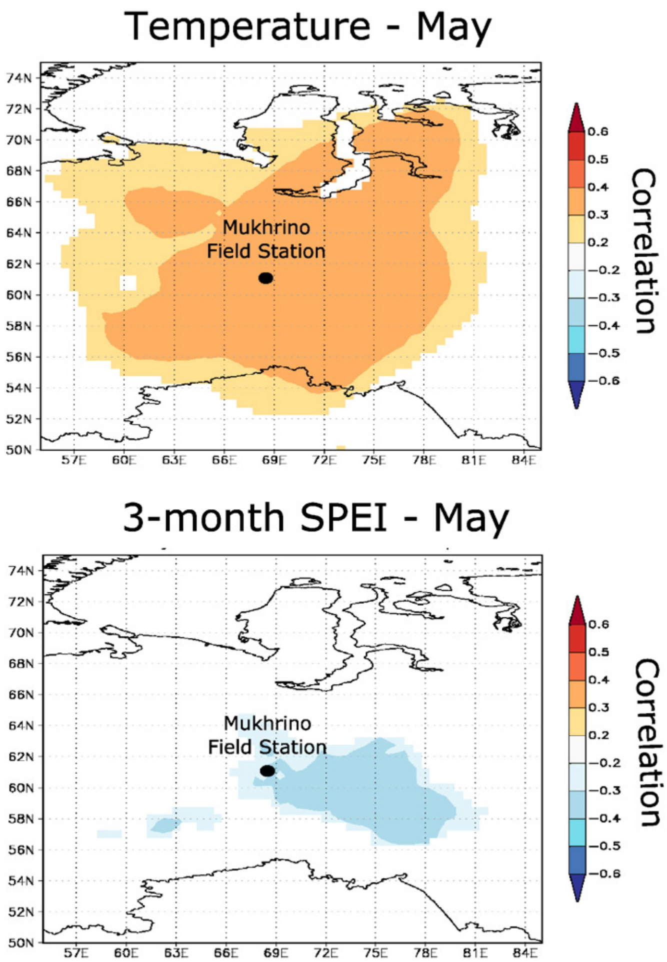

Fig. 6. Spatial correlation maps between SIBPEAT residual chronology, May monthly gridded climatic temperatures and 3-month SPEI for the period 1950–2010. Only significant correlation values ($p < 0.05$) are displayed.

peatland pine trees, not only among trees from one specific site, but also between different radii of the same tree. The rbar values (Table 1) obtained from SYLPEAT and SIBPEAT trees (respectively 0.53 and 0.55) show a weaker common signal compared to trees from the mineral soils (0.63), but values are comparable to those obtained from peatland trees in Sweden (Linderholm, 2001; Linderholm et al., 2002) or Lithuania (Edvardsson et al., 2015a). Such signals have commonly been attributed to (i) specific morphological characteristics (Vitas and Erlickytė, 2007), (ii) long periods of reduced tree growth (Cedro and Lamentowicz, 2011), or to (iii) the presence of compression wood (Stoffel and Corona, 2014) as a result of surface subsidence after flooding or strong wind, for instance (Linderholm et al., 2002). Despite this possible drawback, pine trees from the mire expanse have yielded valuable data on environmental changes as shown by the significant values of mean sensitivity (Linderholm et al., 2002; Vitas and Erlickytė, 2007; Cedro and Lamentowicz, 2008).

4.2. Existence of temperature signals in the chronologies

Although we observe different degrees of significance, SIBPEAT, SYLMIN and, to a lesser extent, SYLPEAT show comparable growth response patterns to temperature, in particular a negative correlation with late summer temperature in the year preceding tree-ring formation (September $_{[n-1]}$) and a positive correlation with monthly temperatures of preceding fall and early spring of the current year (March to May $_{[n]}$). The negative correlation observed in September, i.e. at the end of the previous vegetation period, is rather unusual and hitherto remains unexplained. On the other hand, the observed positive relations with monthly temperatures of previous fall and early current spring have already been reported for Poland (Cedro and Lamentowicz, 2008), Northern Sweden (Linderholm et al., 2002) and Scotland (Moir et al., 2011). Such correlations are attributed to (i) the direct influence of temperature on physiological processes controlling tree growth, and (ii) to the indirect impact of high temperatures on water table levels through evaporation (Linderholm, 2001; Linderholm et al., 2002). In addition, mild temperatures during current fall could favor radial growth through (iii) an extent of cambial activity and hence vegetation period (Moir et al., 2011), and (iv) a lower exposure to nighttime temperatures below 0 °C which would limit radial growth by causing damage to photosystems (Bigras and Colombo, 2001). In the case of SIBPEAT, significant correlations between TRW indices and May temperatures seem to exclude an impact of microclimatic conditions on tree growth (Fig. 6), at least during the beginning of the vegetation period.

4.3. Relations between tree-ring growth and hydroclimatic indices

Growth patterns in relation to monthly precipitation and climatic indices (PDSI, 3-month SPEI) differ between trees growing on peat soil and on close mineral soil. On mineral soil, SYLMIN shows a weak growth response to precipitation during the vegetative period and significant negative correlations with precipitation and 3-month SPEI at the end of fall (October $_{[n-1]}$) and during the dormancy period (December $_{[n-1]}$). The association between limited rainfall at the end of the previous vegetative period and increased radial growth is therefore likely to be an indirect effect considering that less rainfall could potentially correspond to increased sunshine and therefore enhanced formation of growth reserves (Fritts, 1976; Moir et al., 2011).

On peat soils, growth of SYLPEAT trees is driven by hydroclimatic variables (Fig. 5), and thus corroborates observations of others studies (Boggie, 1972). This negative correlation is being interpreted as the consequent of persistently moist soils which are in fact adverse to the radial growth of Scots pine. Usually, the underlying reasons for this reaction are twofold: (i) high water tables restrict growth of the tree root system to the upper aerobic peat layers, and thus reduce the possibility of roots to expand the space for nutrient absorption (Coutts and Philipson, 1978a, 1978b) in a soil which is already nutrient-deficient (Ohlson, 1995; Smiljanić et al., 2014); (ii) low oxygen levels in soils with high water tables induce a direct inhibition of plant growth (Boggie, 1977).

For SIBPEAT, hydroclimatic indices present similar correlation profiles when as those seen in SYLPEAT during the growth season (March–July, Fig. 5), but the positive response of Siberian pine to PDSI is exacerbated during the winter prior to the vegetation period. Cold winters with late or thin snow cover can cause freezing damage to roots with subsequent needle loss and growth reduction in adult pines (Kullman, 1991; Jalkanen, 1998). We interpret the sensitivity of Siberian pine to positive water balance in winter as a result of the protective effect of a thick snowpack which reduces the penetration of frost into the peat and protect the root system from freezing and cell embolism (Linderholm et al., 2002; Kershaw and McCulloch, 2007).

The minimum age of the oldest living Siberian and Scots pine trees observed in Mukhrino mire are respectively 536 and 281 years. These trees were excluded from the TRW chronologies due to several missing growth rings. Despite this limitation, the trees considered in our chronologies point to soil moisture conditions which have been dry enough for an establishment of trees in the Mukhrino mire complex during the 16th and 18th centuries. By assessing water table fluctuations at Muckhrino mire with testate amoebae and by defining the transition between *Sphagnum magellanicum* and *Sphagnum fuscum* – the later being indicative of relatively dry conditions – Lamentowicz et al. (2015) concluded that the 16th and 18th centuries were characterized by low water levels, and thus confirm indirectly the impacts of hydrological fluctuations on tree establishment in peatlands (Edvardsson et al., 2015b).

Living peatland trees older than 200 years are much scarcer in Scandinavia (Linderholm et al., 2002; Edvardsson and Hansson, 2015) or the Baltic region (Smiljanić et al., 2014; Edvardsson et al., 2015b) than in Siberia, which might in fact indicate that peat surface conditions were substantially dryer in Siberia during the Little Ice Age, which in turn would have allowed earlier colonization than elsewhere in Europe. Furthermore, in agreement with Lamentowicz et al. (2015), both SYLPEAT and SIBPEAT replication records suggest another rapid phase of tree establishment around the beginning of the 20th century, which again was characterized by drier conditions in the Mukhrino mire.

4.4. Suitability of Mukhrino trees for hydroclimatic reconstructions

While our analyses suggest that peat moisture variability is a limiting factor controlling growth of Mukhrino mire trees, correlations between hydroclimatic parameters (precipitation, PDSI and SPEI) and annual tree-ring widths (SYLPEAT, SIBPEAT) are too weak ($r < 0.3$) to allow for a statistically robust dendroclimatological reconstruction to be realized. This finding is in line with other studies carried out on peatlands of the Northern Hemisphere and further confirms the shortcomings of trees growing on peatlands for the development of highly-resolved series of past moisture or hydrological variations (Vaganov and Kachaev, 1992; Linderholm, 2001; Linderholm et al., 2002; Edvardsson et al., 2015a).

The absence of a stronger climatic signal in SYLPEAT and SYBPEAT may be explained partly by the nature of the instrumental data (i.e., precipitation, temperature, PDSI, 3-month SPEI) which have been used to perform bootstrapped correlation functions. The parameters used here indeed chiefly regulate – but only imperfectly reflect – water table depth. The latter has, however, been demonstrated to be the main driver of tree growth in peatlands (Boggie, 1972). In addition, several studies have highlighted that hydrological response of peatlands is slow and that the water table of peatlands does not react instantaneously to short-term climatic variations (Ingram, 1983; Almendinger et al., 1986; Charman et al., 2004). Shifts in water table level presumably reflect multiple years of precipitation or evaporation as well as poorly understood feedback mechanisms and lags between tree-growth and hydrological variability in peatlands (Linderholm et al., 2002; Edvardsson et al., 2015a), but are not necessarily detectable in correlation analyses. For this reason, one can reasonably assume that correlating water table fluctuation records (instead of precipitation or temperature series) with tree-ring series would yield much better results. Yet, instrumental records of hydrological changes are not currently available for peatlands. We therefore suggest to start analyses by deriving long water-table fluctuations series from locally-calibrated, process based hydrological models (see Gong et al., 2012 for a review on the topic) driven by local climatic parameters (temperature, precipitation).

5. Conclusions

In this study, we analyzed tree ring widths (TRW) of Siberian (*P. sibirica*) and Scots pine (*P. sylvestris*) trees growing on peat and mineral soils at Mukhrino mire in central-western Siberia. Some of the TRW chronologies covered the last three centuries and were analyzed to evaluate the impacts of regional climate variability on radial tree growth. *Pinus* spp. growing on peatlands in Siberia are mainly influenced by growth season temperature and precipitation but also by varying water table levels caused by climate integrated over several years. Significant negative relationships obtained between bog TRW chronologies and hydroclimatic indices during spring and summer are considered as an expression of the negative impacts of high water levels and moist peat soils on root development. This result is further corroborated by successive colonization phases revealed by tree-ring chronologies, during the Little Ice Age and at the beginning of the 20th century, that coincide with dry peatland conditions detected in other proxies (testate amoebae and *Sphagnum* spp.). For future studies, long records of water-table fluctuations could be very helpful to assess the relationships between tree growth and peatland hydrology. In this sense, the retrospective simulations based on hydrological models (see e.g. Shi et al., 2015 for a review) parameterized with short hydro-meteorological series resulting from on-going monitoring (Bleuten and Filippov, 2008) can be of great interest.

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