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Two centuries-long dendroclimatic reconstruction based on Low Arctic *Betula pubescens* from Tromsø Region, Northern Norway

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Abstract: This study presents the results of dendrochronological and dendroclimatological research of *Betula pubescens* from four sites in northern Norway (Kvaløya Island, Tromsøya Island and Storelva Valley), which provided a 193-year chronology. Our results highlight the importance of the site selection in dendroclimatological studies. We demonstrated that activity of geomorphic processes connected with local topography could led to reduced strength of climatic signal embedded in tree-ring data. Negative pointer years, triggered mainly by unfavourable climatic conditions and insect outbreaks, were common for all site chronologies in 1945, 1955, 1965, 1975, 1986, 2004. However, some site-specific differences were also distinguished. Response function analysis confirmed that June, July and August temperatures were positively correlated with tree-ring widths. This climate-growth relationship was stable throughout the years 1925–2000. From summer temperature reconstruction back to AD 1820, two colder (*c*. 1835–1850 and 1890–1920) and two warmer (*c*. 1825–1835 and 1920–1940) periods were identified. The tree-ring record from the Tromsø Region, well correlated between series, sites and climate variables, is an important element of a large-scale reconstruction of pre-instrumental climate variation in the northeastern part of the Atlantic Ocean. Our dendroclimatic reconstruction corresponds well with other climate proxy data, like fluctuations of mountain glaciers in Scandinavia or sea ice extent.

Key words: Arctic, birch, tree-ring chronology, dendroclimatology, temperature reconstruction.

Introduction

The Arctic ecosystems are very sensitive to climate conditions. Trees, shrubs and dwarf-shrubs growing in the vicinity of the northern treeline strongly respond to changes in weather conditions and thus, they constitute an excellent archive of the global changes (Linderholm *et al.* 2010; IPCC 2013). The changes of the northern tree line, shrub expansion, increase in air temperature and more extreme precipitation events have been conspicuous in different parts of the Arctic during the last decades (*e.g.* Sturm *et al.* 2001; Forbes *et al.* 2010; Hill and Henry 2011; Tremblay *et al.* 2012). Recently, many dendroecological and dendroclimatological studies based on growth-ring variability of tree, shrub and dwarf shrub species have been carried out in polar and subpolar regions (*e.g.* Woodcock and Bradley 1994; Rayback and Henry 2006; Bär *et al.* 2007; Weijers *et al.* 2010; Blok *et al.* 2011; Buchwal *et al.* 2013; Owczarek and Opała 2016). The growth rate, ring width variability and changes in wood anatomy of polar plants can also be a source of valuable information about the activity of geomorphic processes (*e.g.* frequency of debris flows), nowadays strongly affected by climate change (Owczarek *et al.* 2013; Owczarek *et al.* 2014).

The analyses of tree rings offer to reconstruct the past climate on a timescale of centuries to millennia (Fritts 1976). This is especially important for the Arctic, where instrumental data are both temporally and spatially sparse (*e.g.* Przybylak *et al.* 2010). The information about the climate in the period 1865–1920 was recently extended by Przybylak *et al.* (2015) on the basis of early instrumental land-based measurements and proxy-information from ship logbooks. Such higher-resolution observations of the past climate are needed to place the changes of recent climate in the long-term context.

The dendrochronological data have a high potential to fill the gap between temporally high-resolution early-instrumental meteorological observations and proxy data of multi-annual to multi-centennial time scale, like laminated lake and marine sediments or ice-cores. Erlandsson (1936) and Hustich (1945) conducted the first dendroclimatological studies north of the Polar Circle. Nowadays, many studies use the living and subfossil Scots pines for completing the continuous multi-millennial chronologies at the northern timberline in Fennoscandia (*e.g.* Bartholin and Karlén 1983; Schweingruber *et al.* 1988; Briffa *et al.* 1990; Kirchhefer 2001). The Scots pine wood enabled the construction of the world's longest continuous tree-ring width chronologies, with records from Torneträsk in northern Sweden (BC 5407–AD 1997; Grudd *et al.* 2002) and Finnish Lapland (BC 5634–AD 1992; Helama *et al.* 2002). The most recent temperature reconstruction for northern Fennoscandia, based on Scots pine data, was compiled by Esper *et al.* (2012). However, little attention has been paid to the dendroclimatological potential of other tree species. Some studies have been carried out on the climate-related response of Norway spruce, which is sensitive to the growing season temperatures (*e.g.* Andreassen *et al.* 2006). The dendroclimatological potential of downy birch (*Betula pubescens*) has been investigated at a few Arctic sites: in northern Norway (Kirchhefer 1996; Opała *et al.* 2014), northern Sweden (Eckstein *et al.* 1991; Karlsson *et al.* 2004), and Iceland (Levanič and Eggertsson 2008). It should be mentioned, that so far, the influence of the topographic conditions and geomorphic processes on the variability of climatic signal strength in the Arctic environment have not been satisfactorily investigated.

The aims of this study were: (1) to develop new tree-ring chronologies of *B. pubescens* concerning different topographic conditions, (2) to identify the main climatic factors that determine the annual growth of *B. pubescens* at subarctic sites, and (3) to reconstruct the past climate variability on the basis of ring-width chronologies.

Study area and climate conditions

The study area is located in the northern Scandinavian Peninsula – on the islands of Tromsøya and Kvaløya, and in the Storelva Valley, in the Tromsø Region. Four sites were selected for detailed research (Fig. 1). The Tromsø Region has a well-developed coastline facing the Norwegian Sea with large and mountainous islands. Steep mountains with broad plateaus and narrow, flat lowland areas along the seacoast (Strandflaten) are characteristic of this region. The discontinuous permafrost occurs in the mountains and plateaus, mainly in the mainland east of Tromsøya and above the timberline (Farbrot *et al.* 2013). The study area is built of Neoarchean and Paleoproterozoic rocks: granites, gneisses and quartz-diorites (Bergh *et al.* 2012). The tree line is located at *c.* 400 m a.s.l., dominant species of the tree layer are the mountain downy birch together with some scattered aspen (*Populus tremula*). The alpine zone is occupied by mountain meadows with dwarf shrub patches, where dwarf birch (*Betula nana*) dominates (Moen 1999). Two research sites are located on the island of Tromsøya. The island is surrounded by narrow canals: Sandnes-sundet and Tromsøy-sundet within large Balsfjorden system (Fig. 1). The northern and central parts of the island (Tromsøya University research site) have hilly relief with narrow longitudinal ridges (max. elevation of 135 m a.s.l.). The southern part of the island is flatter with shallow depressions which are partly filled with water of artificial Prestvannet Lake (Tromsøya Prestvannet research site). The Kvaløya research site is located in the north-western part of the Kvaløya island, by the open sea. The samples were collected within a gentle slope with north-eastern exposure. The fourth research site, Storelva Valley, is located in the lower part of the north-western slope of a deep U-shaped glacial valley (Fig. 1). This latitudinal wide valley with steep rocky hillsides is part of the Ullsfjorden hydrographic system.

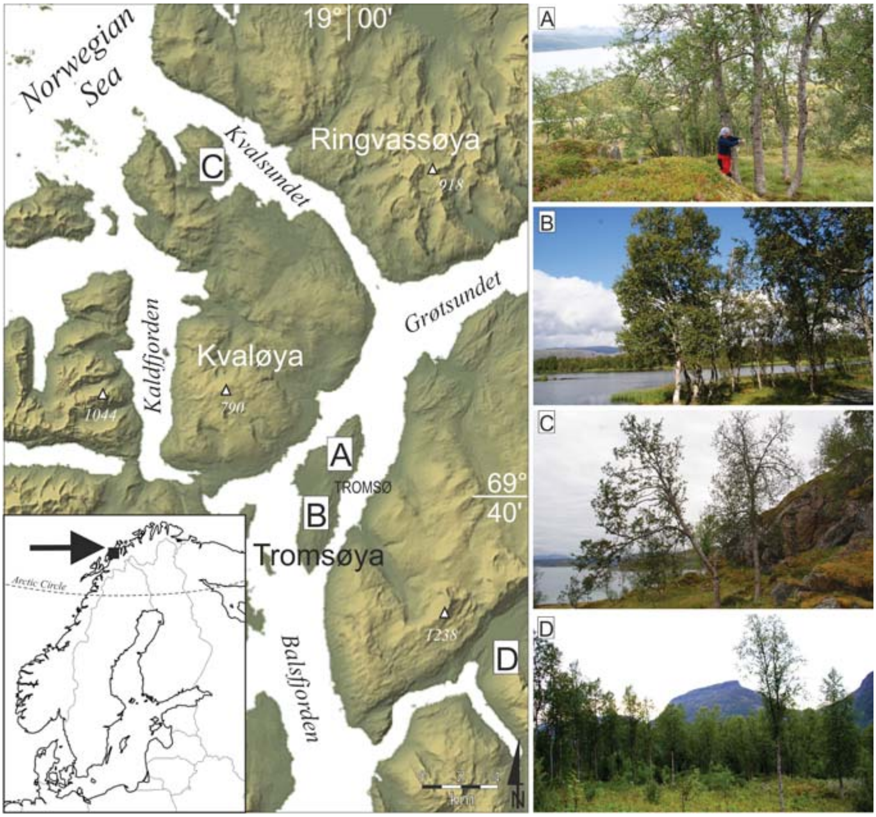


Fig. 1. Location and general view of the research sites within central part of the Tromsø Region, Northern Scandinavia: **A** – Tromsøya University, **B** – Tromsøya Prestvannet, **C** – Kvaløya and **D** – Storelva Valley.

Tromsø has a subarctic climate but, because of the effect of the Norwegian Coastal Current, this area is warmer than other places located at the same altitude. Thus, the climate is moderate oceanic, with mild snowy winters. The mean annual air temperature during 1925–2013 period was +2.9°C with the standard deviation (σ) of 0.7, but varied strongly from year to year (Fig. 2). The coldest month was February with the mean air temperature of -3.9°C (σ = 2.1), while the warmest was July with the mean air temperature of +12.8°C (σ = 1.8) (Fig. 3). The annual precipitation reached 1010.9 mm (σ = 178), with its maximum in October (124.6 mm, σ = 59) and minimum in May (54.8 mm, σ = 28).

The maximum annual snow depth varied from 100 to 140 cm and the duration of the permanent snow cover fluctuated from 185 to 220 days. The last day of a snow season, which is relevant for plant growth, can happen as late as the end of May (Vikhamar-Schuler *et al*. 2010). From 20 May to 22 July,

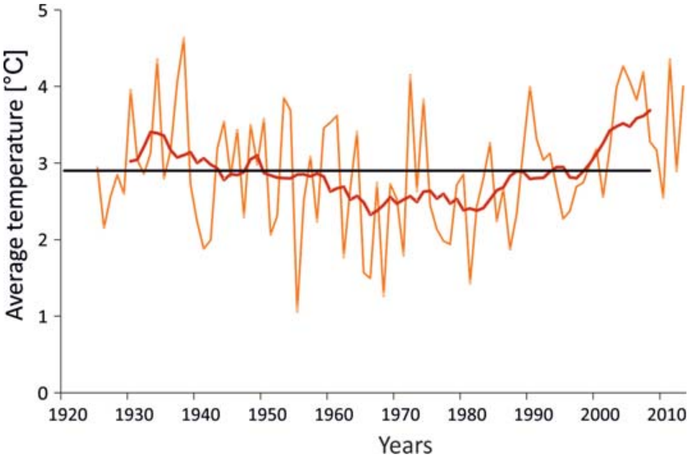


Fig. 2. Annual air temperatures, 11-year running means and long-term mean in Tromsø during the period 1925–2010 (based on data from from eKlima 2014).

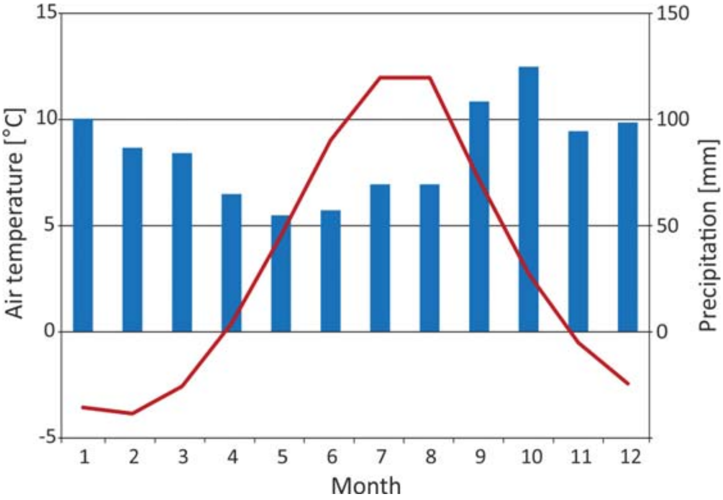


Fig. 3. Monthly mean air temperatures and mean precipitation totals in Tromsø for the reference period 1925–2010 (based on data from eKlima 2014).

with the midnight sun, shortwave solar radiation with visible light and PAR (photosynthetically active radiation) operate 24 hours a day.

Mountain ridges in the Tromsø area are about 1200–1800 m a.s.l high. Assuming the mean lapse rate of 0.6°C/100 m, the annual mean 0°C altitude will be already at 600 m a.s.l.

Materials and methods

Wood material and sampling. — Downy birch is one of the dominant species in northern Fennoscandia. In the Arctic tree line, it forms a subspecies named the mountain birch (*Betula pubescens* ssp. *czerepanovii*), which is resistant to extreme environments (Tømmervik *et al*. 2004). These trees are characterised by a low production rate (Wielgolaski 2001). At our sampling sites, they were between four and ten meters high. The low, multistemmed (polycormic) tree was a dominant growth form only at the northernmost site (Kvaløya). *Betula pubescens* is a diffuse-porous species with rather distinct growth-ring boundaries.

The samples of wood material were collected in 2013. We obtained 80 cores of *Betula pubescens* in different topoclimatic conditions: the sea coast, glacial valley, narrow ridge and plateau. At each site, 20 trees were chosen for analyses and one core per tree was extracted, using an increment borer, at about 1.3 m from the ground level.

Chronology development. — All cores were mounted and polished in order to obtain clear cross-sections and perform measurements of tree-ring widths (TRW) (at a precision of 0.01 mm). The measurements and the crossdating were made using the LINTAB 6 device with a microscope and the TSAPWin software (Rinn 2010). The quality control was performed with the program COFECHA (Holmes 1983). The program ARSTAN (Cook 1985) was used to calculate ring-width chronologies of *Betula pubescens*. The age-related growth trend was removed by fitting negative exponential functions. All site chronologies were computed applying bi-weight robust means to further remove the random signals related to local disturbances (Cook and Kairiukstis 1990). For the analysis of the climate-growth response, the residual chronologies were constructed, after removing autocorrelation in the individual series (in order to maximise the climate signal). The chronologies were evaluated using the following statistics: the mean correlation strength between each individual and the mean chronology (r), the mean sensitivity (MS), which is the relative change of ring-width for consecutive rings (Fritts 1976), and the expressed population signal (EPS), which is the relationship between an investigated chronology and a hypothetical chronology with infinite replication (Wigley *et al*. 1984). The extreme years were determined based on standard deviations of indexed ring-width measurements. In the present study, extreme years were defined as calendar years when TRW index has exceeded the threshold value of ±1 standard deviation. Finally, the outstanding negative extreme pointer years were compared with the climate data and information about insect outbreaks (Babst *et al*. 2010).

Climate data and dendroclimatological analysis. — The closest meteorological station to our study area is Tromsø (69°39’ N, 18°56’ E, 115 m a.s.l.), located from 1 to 4 km from our dendrochronological sites. The homogenized monthly temperature and monthly precipitation data from the period of 1925–present were obtained from the Norwegian Meteorological Institute (eKlima 2014). The data were homogenized by Andresen (2011).

The correlation analysis between the indexed chronologies and instrumental climate data was performed to identify the climate signal of tree-ring growth. We examined the climate variables for the successive months from the previous May to the current August to identify the best climatic variable for reconstruction. We also tested the temporal stability of climatic signals using the moving correlation analysis. The response function analysis was used for calibration, which is the procedure to find a statistical relation between the tree-ring growth and the environment. The calibration assumes the fitting of the statistical model that can be applied to one or more predictors to estimate (reconstruct) one or more predictants. The assessment of models followed cross calibration–validation procedure, where one set of predictor and predictant data, called the dependent set (first half of time interval), was used to estimate the coefficients of the calibration model, while the remaining data (second half of time interval), called independent data, was used for validation of the calibration model. The above-mentioned splitting the data into two sub-periods was utilized to assess the temporal stability of the model. To evaluate the ability of the model to reconstruct climate effectively, the following statistics were calculated: Pearson's correlation coefficient (R), explained variance (R2), standard error of estimate (SEE), reduction of error (RE) and coefficient of efficiency (CE). After the positive cross calibration–validation procedure, the instrumental climatic records from the whole time interval were regressed against the TRW chronology and the obtained new model coefficient was used to reconstruct the past climate variations (see Fritts 1976; Cook and Kairiukstis 1990; Bürger 2007).

The correlation coefficients were calculated between the birch ring-width chronology and gridded mean temperature from CRU TS3.23 dataset (Harris *et al*. 2014), at 0.5° resolution, in order to test the spatial representativeness of the newly obtained climate proxy series. The calculations were performed over the common period for tree-ring data and gridded climate records (1901–2013). The analyses were carried out using the web-based climate-data analysis tool KNMI Climate Explorer designed by the Royal Netherlands Meteorological Institute (http://climexp.knmi.nl).

Results and Discussion

Characteristics of tree-ring chronologies and extreme years. — The summary of the statistics obtained for the four constructed chronologies is presented in Table 1. Chronologies and their replications are shown in Figure 4. The life span of the collected samples ranges from 91 to 193 years. The mean ring width decreased from 1.28 mm (glacial valley site) to 0.78 mm (narrow

Table 1

Statistical characteristics of four *Betula pubescens* chronologies from Tromsø Region.

Site	Tromsøya University	Tromsøya Prestvannet	Kvaløya	Storelva Valley
Number of samples (analyzed/cored)	11/20	13/20	11/20	15/20
Chronology length	1834–2013	1820–2013	1901–2013	1923–2013
Number of years	179	193	112	91
Mean tree-ring width (mm)	0.78	0.97	1.08	1.28
Standard deviation of tree-ring width	0.51	0.65	0.62	0.62
Mean sensitivity (MS)	0.52	0.53	0.40	0.46
Mean correlation with master (r)	0.59	0.59	0.54	0.76
Express population signal (EPS)	0.90	0.85	0.80	0.95

ridge site) over the full time span of these chronologies. All chronologies have a relatively high value of the mean sensitivity (ranging from 0.40 to 0.53), which suggests that *Betula pubescens* may be useful for dendroclimatological purposes. The constructed local chronologies are characterised by the high intercorrelation (0.54–0.76) and EPS (0.80–0.95) values, indicating that the analysed trees responded quite similarly to the factors influencing the tree-ring width and the chronologies are useful for climate reconstruction. The longest chronology was constructed for the Tromsøya Prestvannet site, covering the period of 1820–2013. The good agreement between the chronologies can be observed for the two records from the Tromsøya Island ($r = 0.84$, $p < 0.01$). For the other two sites (Kvaløya Island and Storelva Valley), which are topographically more diverse and distant from each other (35 km), the correlation coefficient is considerably lower ($r = 0.26$, $p < 0.05$).

In the period of 1923–2013, all chronologies agree on eight negative extreme years: 1945, 1955, 1965, 1975, 1986, 2004, respectively. The unfavourable climatic conditions or insect outbreaks could be the reason for these extremes. The outstanding years 1955 and 1975 might be associated with cool summer periods, with temperature much below the long-term average (in 1995, the deviation from long-term average was -1.9 and in 1975, it was -2.7). However, some differences between the sites were observed in terms of insect gradations. The outbreak events are especially common in trees growing at a ridge site, which is the most exposed to external factors. The identified years, 1945, 1955, 1965, 1986 and 2004, agree with reported insect-outbreak years described for

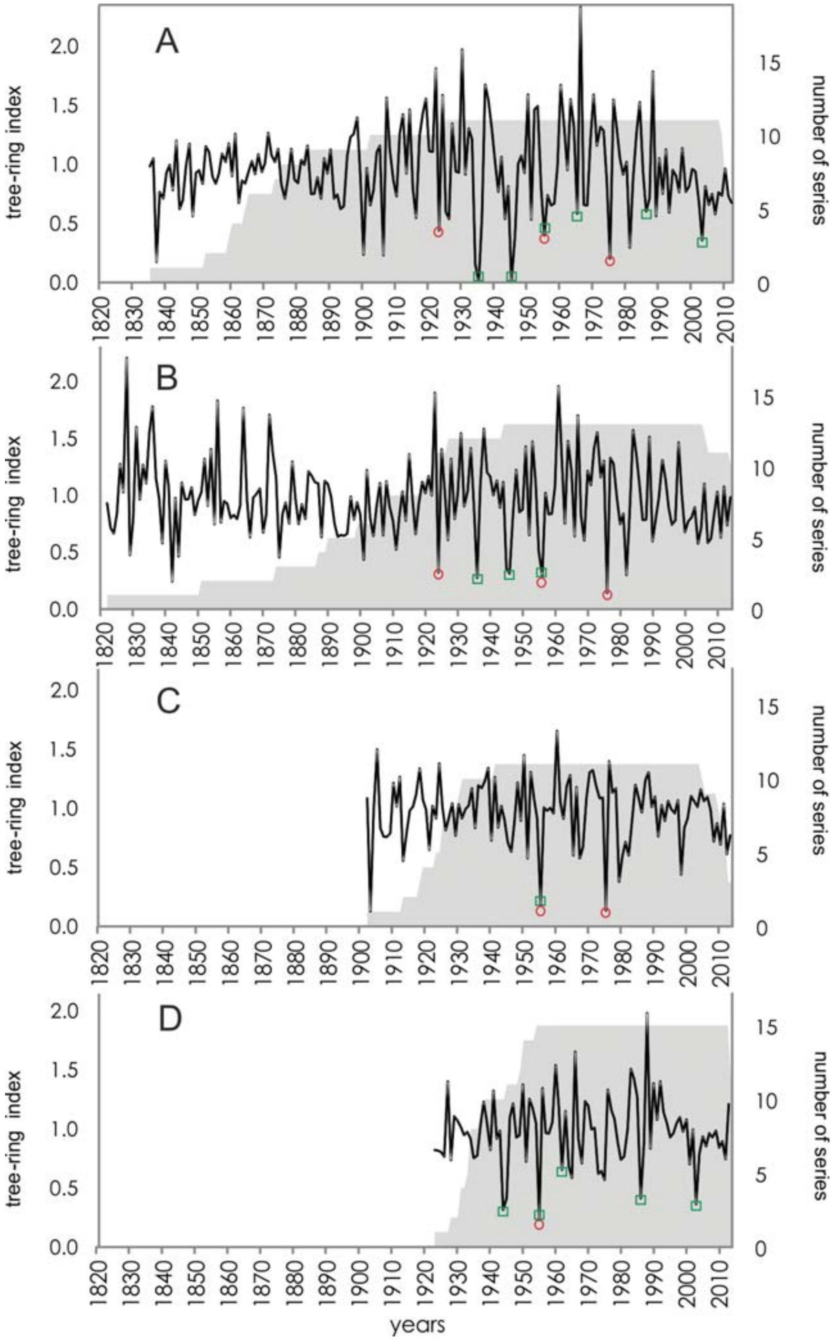


Fig. 4. Birch tree-ring chronologies from: **A** – Tromsøya University, **B** – Tromsøya Prestvannet, **C** – Kvaløya and **D** – Storelva Valley with their sample replication and extreme pointer years marked (circles for climatic extreme years and squares for outbreak years; after Bylund 1995 and Babst *et al*. 2010).

Iceland and northern Sweden by Bylund (1995) and Babst *et al*. (2010). In addition, Levanič and Eggertsson (2008) stated that insect attacks significantly affected birch wood formation in Iceland.

Climate-growth relationships. — The output of the correlation analysis indicates that for our study region tree-ring growth is most significantly impacted by the June temperature and mean summer temperature (June-August, Fig. 5). However, the signal strength reflected in tree rings of investigated birch trees is modified by topographic conditions, which differ from site to site. The effects of microsite conditions on dendroclimatological reaction were proved for other parts of the Arctic. For example, Düthorn *et al*. (2013) found stronger temperature signals in trees growing at the lakeshore compared to those from the dryer inland microsites. In the Tromsø Region, the lowest correlation between the summer temperature and tree-ring width was found for the sites characterised by the morphologically diverse terrain with features of mass movement. The lowest correlation was for the Tromsø University site, where samples were collected from a narrow ridge. The shallow landslide niches were found along the top of this ridge. The impact of geomorphic processes (slides, debris flows) could be a reason for the weaker correlation between the TRW and meteorological data. This was also noted for the Storelva Valley site (Fig. 6). The strongest correlation between the summer temperature and tree-ring width was found under geomorphologically more stable conditions: Tromsøya Prestvannet and Kvaløya Island sites. The effect of the low-energy geomorphic processes on the growth ring formation, like creeping observed in these sites, is minor. This was confirmed by the absence of reaction wood, which can develop in trees in response to gravity movements. At the Tromsøya University site, only the June temperature influences the growth considerably ($p < 0.05$). At the Tromsøya Prestvannet site, the period of high sensitivity is longer (June-July-August) than for the other sites (correlation coefficient $r_{JJA} = 0.50$). This 193-year tree-ring width chronology from the plateau site, best correlated with temperature, was chosen for further dendroclimatological analyses. No precipitation effects on tree growth can be observed at any site.

The results of our studies of birches from Tromsøya agree with those conducted in northern Sweden and Iceland, where mountain birch chronologies proved to be sensitive to June and July temperatures of the current year (Levanič and Eggertsson 2008; Young *et al*. 2011). However, the Scots pine chronologies from northern Sweden were positively related only to July temperatures. The precipitation was not correlated with the ring width at these sites (Young *et al*. 2011). The Scots pines from the coast of northern Norway reflected the July-August temperatures (Kirchhefer 2001).

The observed climate-growth responses are not stable over time, and decreasing correlation has been observed in recent decades (Fig. 7). In the last

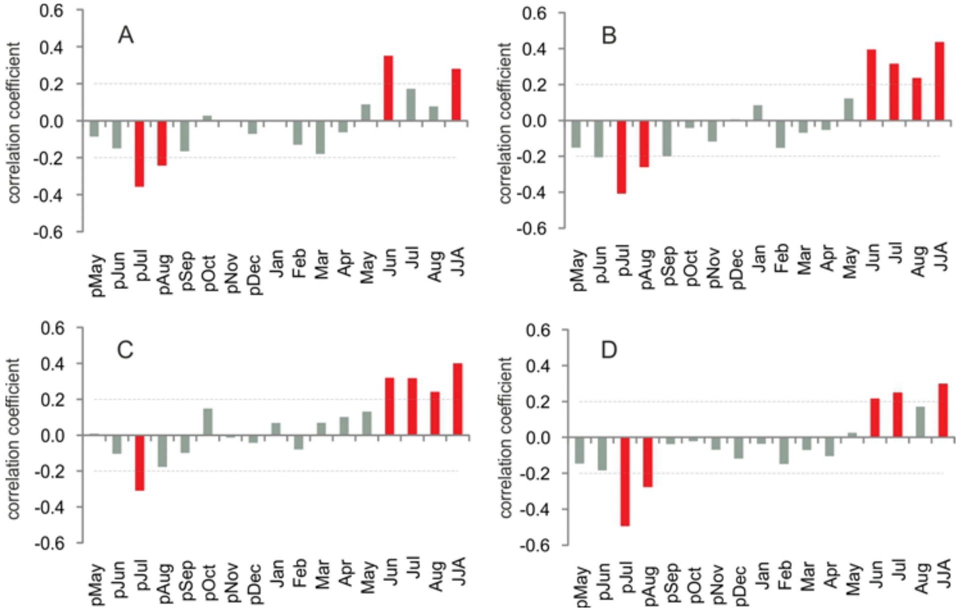
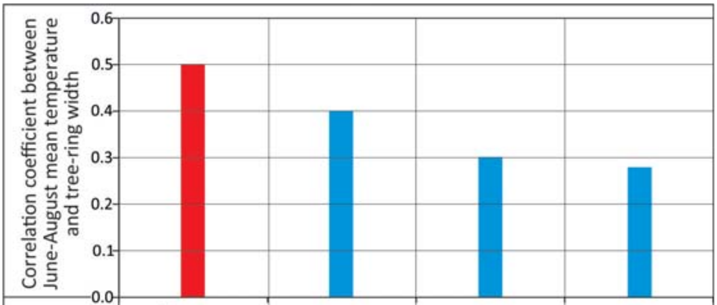


Fig. 5. Correlation between four residual chronologies (**A** – Tromsøya University, **B** – Tromsøya Prestvannet, **C** – Kvaløya, **D** – Storelva Valley) and monthly mean temperatures from previous May (pMay) to current August (Aug) and summer temperatures (JJA). Statistically significant correlation coefficient values were marked in red ($p < 0.05$).



Site	Tromsø Prestvannet	Kvaløya	Storelva Valley	Tromsø University
General location	Plateau 95 m a.s.l.	Sea coast 20-35 m a.s.l.	Glacial valley 90-125 m a.s.l.	Ridge 120-135 m a.s.l.
Remarks	Stable area within flat plateau, central part of the Tromsøya Island	Gentle slope without clearly visible high-energy mass movment activity	Morphologically diverse slope of deep U-shape valey with traces of slides and flows	Upper parts of narrow ridge with steep slopes and tarces of sliedes

Fig. 6. Influence of different topographic and geomorphic conditions on the strength of summer (JJA) temperature signal embedded in tree-ring width of *Betula pubescens* at various sites in the Tromsø Region.

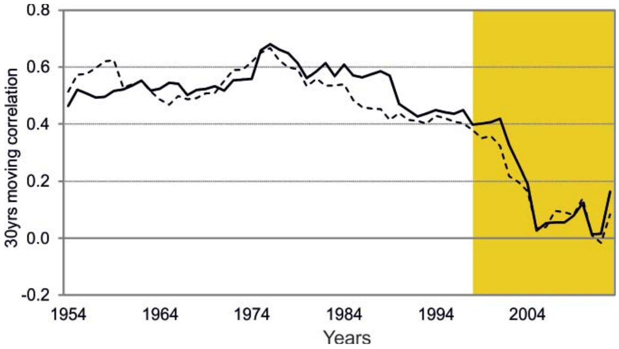


Fig. 7. 30-year moving correlation between index chronology of downy birch and June temperature (dashed line) and summer temperature (solid line) for Tromsøya Prestvannet site.

two decades, despite the increase in temperature, such a trend was not observed for growth-ring widths. This so-called divergence phenomenon between tree-ring data and temperature records can be found in both the large-scale and local northern hemispheric dendroclimatological studies and has been associated with the warming-induced drought stress that had forced a shift in the tree growth response to climate (D'Arrigo *et al*. 2008).

Temperature reconstruction. — Tree-ring series (TRI *Betula pubescens*) and the monthly Tromsø temperatures show a statistically significant, moderately strong, positive correlation ($r = 0.5$, $p < 0.001$) for the current year summer temperature over the period of 1925–2000. Therefore, the data for the 1925–2000 period was used for calibration/validation, while the data for the 2001–2013 period were excluded from the further dendroclimatological analyses (Fig. 8), due to weakening of the dendroclimatic signal (Fig. 7). Following the standard dendroclimatological approach, the split calibration-verification method was used for an assessment of the reconstruction models (Fig. 9). The results of the calibration (1925–1962) and verification (1963–2000) tests followed by a repetition of the trials with the 'reversed' calibration (1963–2000) and verification (1925–1962) periods, indicated that the correlation coefficients between the observed and reconstructed JJA temperature in all calibration and verification periods were moderately high ($r = 0.57$ and $r = 0.46$, respectively) and, importantly, significant at the 0.01 level. The RE and CE values in both verification periods were positive, indicating that the regression models had reconstructive value. The final transfer model for estimating mean June–August temperature from TRI in the past was derived from the linear regression of the instrumental data on the proxy data, over the full period of overlap. The calibration over the 1925–2000 period gave the following regression equation ($r = 0.450$, $r^2 = 0.25$, $SEE = 1.10$, $p < 0.001$):

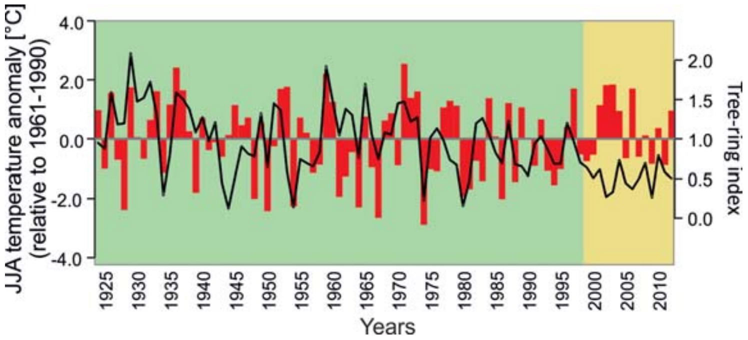


Fig. 8. Downy birch ring-width chronology (solid line) compared with normalised June-July-August temperature from the Tromsø meteorological station (bars).

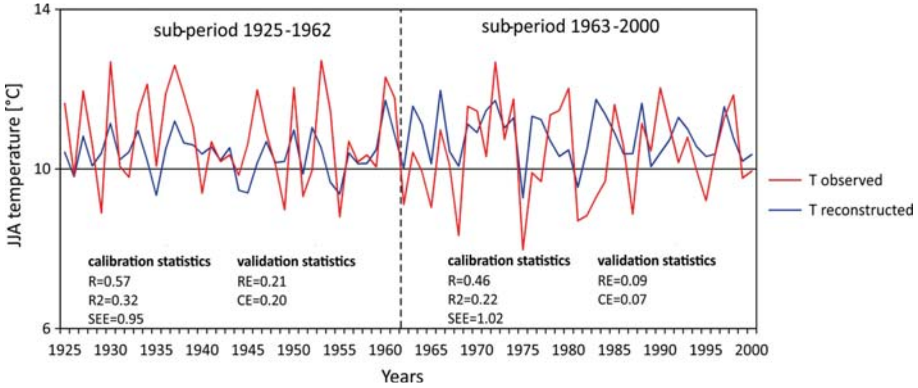


Fig. 9. Results of cross calibration/validation of the birch ring-width-based temperature estimates performed using a split period (1925–1962 and 1963–2000) approach. Explanations: R – correlation coefficient, R2 – explained variance, SEE – standard error of estimate, RE – reduction of error, CE – coefficient of efficiency.

$$\mathrm{TempJJA} = 9.034 + 1.858 \times \mathrm{TRI}\ \textit{Betula pubescens}$$

The above model and measured dendrochronological data enabled to reconstruct the temperature back to 1820 (Fig. 10). From this tree-ring based reconstruction, two major cold periods can be identified, centred on the 1840s and at the turn of the 19th and 20th centuries (1890–1920), followed by (relatively) recent cold decades of the 1960s and 1980s. In our reconstructed record, there are few warm periods: 1825–1835, 1920–1940, 1970s, and the more recent warm interval of 2001–2006.

Our results correspond well with other climatic reconstructions for the Arctic area, where the first warm period in the 20th century started rapidly, preceded by cold decades of the second part of the 19th century. The reconstructed warm period in the first half of the 19th century was also noted in other parts of Northern

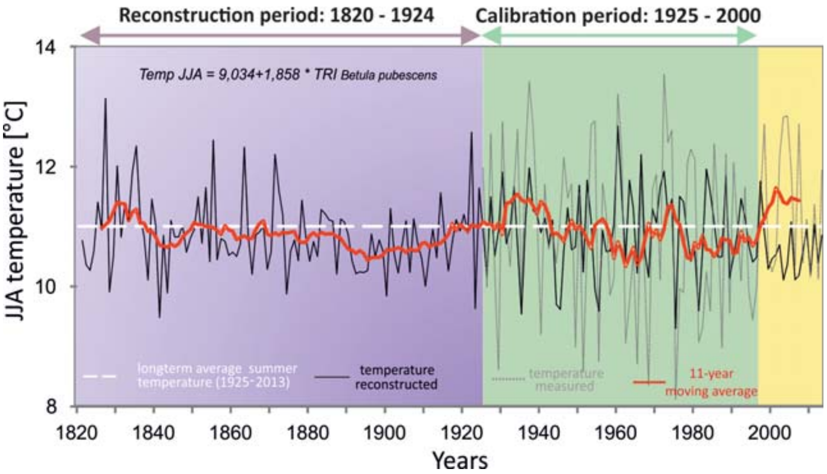


Fig. 10. Tree-ring-based reconstruction of summer temperature for the Tromsø Region and 11-year running mean compared to long-term average temperature from the instrumental records.

Europe and Northern America, but not in all parts of the Arctic (Overpeck *et al*. 1997; Shi *et al*. 2012). The proxy data, like mountain glacial fluctuation, are in agreement with our dendroclimatic reconstruction. The glaciers in northern Scandinavia have been in more or less continuously retreat since their Little Ice Age (LIA) maximum position at the end of the 18th and early 19th century (Ballantyne 1990; Andreassen *et al*. 2005). This glacial retreat was, however, interrupted by several phases of glacial readvances (Chinn *et al*. 2005). One of them had its culmination around AD 1910 (Nesje *et al*. 2008), what corresponds with the relatively cold period at the turn of the 19th and 20th century. Jansen *et al*. (2016) showed a general retreat of the maritime ice cap Høgtuvbreen (northern Norway) between the LIA glacier maximum and the present on the basis of lichenometric studies and lake sediment cores. They demonstrated that the first signal of glacier retreat had taken place in the first half of the 19th century. This process was accelerated in the (around) 1920s and 1970s. These warm periods are represented by relatively wide growth-rings of *Betula* in the Tromsø Region. Since the beginning of the 21st century, most of the observed Norwegian mountain glaciers have retreated remarkably fast (Nesje *et al*. 2008). The cold and warm periods identified on the basis of the growth-ring variability corresponded with ice extent in the Western Nordic Seas. For example, the relatively large sea-ice extent about 1910, its minimum in the 1920s and 1930s and its recovery in 1960s, coinciding with cooling in the region (Vinje 2001).

The map of spatial representativeness over the time period of 1901–2000 shows that the reconstruction represents the June-August temperature variability over large area of northern Fennoscandia, with particular emphasis ($r > 0.6$,

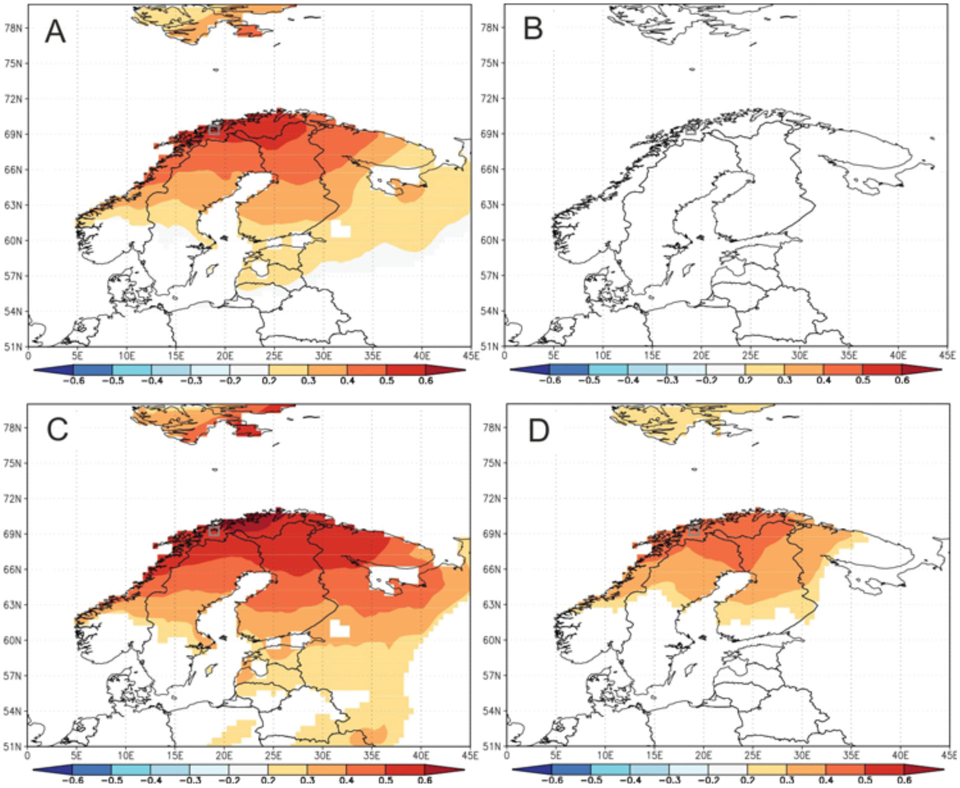


Fig. 11. The correlation between birch ring-width chronology and gridded (0.5° × 0.5°) June – August mean temperature from CRU TS3.22 over different time periods: (**A**) 1901–2000, (**B**) 1990–2013, (**C**) 1901–1950 and (**D**) 1951–2000. Grey square indicates sampling area. Orange and red colours indicate positive, significant correlations ($p < 0.05$).

$p < 0.001$) on the Tromsø Region, Finnmark Region and Finnish Lapland (Fig. 11A). It also confirms that the correlation between the birch tree-ring index and JJA temperature for the period of the last two decades, not included in the final transfer function model, is statistically insignificant (Fig. 11B). The reduced sensitivity of the tree growth to temperature, observed in our study, has been already reported from multiple sites and described in the literature as the "divergence phenomenon" between the tree-ring width and climatic data. D'Arrigo *et al*. (2008) stated that causes of this problem were not well understood due to the existence of many environmental factors that might simultaneously impacted the recent tree growth. Apart from the last two decades, the temporal stability of the dendroclimatic signal in our tree-ring record can be confirmed by the relatively high values of correlation between the tree-ring and climate data for two sub-periods, 1901–1950 and 1951–2000, over the large area of

Northern Scandinavia (Fig. 11C, D). The strongest signal can be observed in the 1901–1950 period. The obtained results indicate the reliability of the earliest part of the temperature reconstruction, which covers the 19th century.

Conclusions

- The development of new downy birch chronologies, created for morphologically diverse areas, highlighted the importance of appropriate site selection for dendroclimatological research. The relief, micro-topography, activity of geomorphic processes and insects outbreaks influence the climate-growth relationships. Thus, the constructed local chronologies recorded the varied strength of climatic signal.
- The downy birch tree-ring widths from Tromsø Region proved to be a reliable source of climatic information for the June-August temperature. It is similar to the findings of studies from other sites located north of the Arctic Circle, however, the obtained new record is based on a species which has rarely been used to study the paleoclimatic variability. Therefore, it constitutes a valuable comparative material and fills the gap in the proxy data network for the northern Scandinavia.
- The 193-year-long reconstructed series shows clearly colder and warmer periods, indicated also in other parts of the Arctic. The comparison at a regional scale suggests that the new birch tree-ring-based reconstruction has a fairly good agreement with previously published reconstructions from various natural proxies, like mountain glacial fluctuation, lake sediment cores and maritime ice cap. This implies that the birch tree-ring data can be included in future multi-proxy reconstructions.
- The dendrochronological record from Tromsø is an important element for a broader reconstruction of the pre-instrumental climate variation in the north-eastern part of the Atlantic Ocean. It may also be a valuable reference material for comparisons with trees and shrubs from the Low Arctic and dwarf shrubs chronologies from the High Arctic.

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