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# Response of white birch (*Betula platyphylla* Sukaczev) to temperature and precipitation in the mountain forest steppe and taiga of northern Mongolia☆

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ABSTRACT

The mountain forest steppe and taiga in northern Mongolia have experienced a forest decline in area and quality since the end of the last century. Changes in land use, climate, fire frequency and pest occurrence are considered to be the main drivers of this vegetation shift and desertification. Because this region is the source for major rivers, is home to a unique flora and fauna and represents an important source of timber for Mongolia, the ability of different tree species to respond to these changes and regenerate is of increasing interest. Our contribution focuses on the climate-growth relationship of old and young birch trees from two valleys in the Mongolian province of Selenge Aimag.

The research site Bugant, located in the Western Khentey Mountains, was the most important logging centre in Mongolia during socialist times. Today, the vegetation is dominated by succession forests of light taiga. The research site Altansumber, on the border of the Sant and Khushat soum, is dominated by light taiga and mountain forest steppe. Traditional nomads who depend on these forests for different reasons inhabit this area.

Wood cores were sampled and chronologies of young and old birch trees at Bugant and Altansumber were created. Climate data were obtained from the Eroo station, which is known in the region for its long and reliable climate record. We analysed the climate-growth relationships of the chronologies from 1962 to 2009. At both sites and in both age classes, correlations with temperature were predominantly negative, particularly in April (Bugant, south- and east-facing slopes) and May (Altansumber, north-facing slopes). Precipitation of the late summer of the previous year (August/September) positively correlated with the growth of birch at Altansumber. We assume that the significant negative correlation between winter precipitation (December/January) and the growth of old birches at both sites is due to positive effects of snow cover on the survival rate of herbivorous insect populations. Our results indicate that during the early vegetation period, younger birch trees are more dependent on water availability than older ones. Negative pointer years were characterized by below-average precipitation during the current summer period and above-average spring temperatures. For the old trees, positive pointer years were characterized by above-average summer precipitation. We conclude that water availability is the most crucial factor for the growth of white birch in northern Mongolia.



## 1. Introduction

Northern Mongolia is the transition zone between the Siberian taiga and the inner Asian steppes, a transition that takes place over several hundred kilometers from north to south (Walter, 1974).

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During winter, the climate is dominated by the Asiatic anticyclone. During summer, warm air masses from the south flow into northern Mongolia, resulting in the formation of cyclones when they encounter cold air from Siberia (Dulamsuren and Hauck, 2008). The majority (85–94%) of the annual precipitation falls as rain during the vegetation period. The mean annual temperature in Mongolia increased by 2.14 °C over the last 70 years, which is higher than the global average temperature rise. Precipitation has decreased in most regions by at least 0.1 mm/year (Oyuntuya et al., 2015), and a further decrease is expected for northern Mongolia and the Khentey Mountains (Sato et al., 2007).

Current changes in climate, land use, fire frequency and pest occurrence are considered to be the main drivers of the vegetation shift in northern Mongolia. During the last decades, many forest sites became replaced by steppe vegetation and the species composition of the remaining forests changed in favor of pioneer tree species. Therefore, investigation of the response and regeneration capabilities of different tree species is of increasing interest. Studies of climate effects on the growth performance of tree species have mostly concentrated on *Larix sibirica* Ledeb. (Dulamsuren et al., 2011; Slemnev et al., 2012; Khishigjargal et al., 2014; James, 2011), *Pinus sylvestris* L. and *Pinus sibirica* Du Tour (De Grandpre et al., 2011), and to a lesser extent on *Picea obovata* Ledeb. (James, 2011). These studies have revealed predominantly negative relationships between climate warming and tree growth. Climate-growth relationships may also be useful for forecasts of species-specific distribution patterns and forest productivity.

White birch, also known as Manchurian birch, Siberian silver birch or Japanese or Asian white birch (*Betula platyphylla* Sukaczev), is one of the most common tree species in the Mongolian mountain forest steppe and taiga. It is drought-sensitive, frost-resistant and able to grow well under different environmental conditions (Puhua, 2013). *B. platyphylla* is of economic value and can reach up to 27 m in height, live for 120–140 years and is closely related to *B. pendula* Roth (Zyryanova et al., 2010; Puhua, 2013). It is a characteristic species in habitat types of the light taiga (Mühlenberg et al., 2004). In Mongolia, birch occurs frequently as a main species in pure and mixed stands with Siberian larch (*L. sibirica*) and Scots pine (*P. sylvestris*). It is also one of the pioneer species, which forms some of the southernmost forest outposts in Mongolia, such as in the Hustai National Park. In northern Mongolian forests, it dominates after disturbances such as fires and clear-cutting due to its sprouting capability (Otoda et al., 2013).

Because of its importance as both a main tree species and a pioneer species, white birch is relevant for maintaining a continuous forest cover in the region. Mongolia has a high rate of forest loss and degradation (Hansen et al., 2013). It is therefore important to identify the climatic factors that drive the growth of white birch in the region and to consider potential site-specific effects (e.g. topography). To this end, we collected wood cores of white birch on recently established research plots in the Selenge Aimag. The core collection and the assessment of the forest structure on the plots were conducted within the framework of an international cooperation for capacity development and comprehensive forest monitoring (Gradel et al., 2012). Our contribution focuses on the relationship between regional climate factors and the radial growth response of younger and older birch trees.

## 2. Materials and methods

### 2.1. Research area

The two research areas (RA) are located in the province of Selenge Aimag in northern Mongolia (Fig. 1). The RA Altansumber (49°29′07.29″N; 105°31′30.36″E) is characterized by mountain forest steppe in which Siberian larch and white birch are the dominant tree species. Most forest stands in this region are affected by fire and small-scale logging activities. The area is inhabited by traditional nomads, who recently united to a forest user group. The plot establishment was conducted within the framework of international cooperation (FAO-project: GCP/MON/002/NET; Gradel, 2010). The relevant plots in this study area are largely characterized by mixed and pure birch stands between 934 and 1188 m a.s.l., and north or northwest-facing slopes. The cores were collected in autumn 2012.

The RA Bugant is located in the western Khentey Mountains (49°25′9.90″N; 107°25′46.70″E) and was the most important logging centre in Mongolia during socialist times. Forest industry started there in the first half of the 20th century based on Soviet standards. Today, forestry is still an important source of income for the residents of Bugant (Gradel and Petrow, 2014). The vegetation in Bugant is characterized by dense secondary growth dominated by white birch (*B. platyphylla* Sukaczev) and Scots pine (*P. sylvestris* L.). The plots are largely characterized by mixed birch stands between 860 and 960 m a.s.l., with a low incline and a southerly or easterly aspect. The cores were collected in autumn 2013.

In both research areas, thinning experiments have been conducted since autumn 2009 (Gradel, 2010; Gradel et al., 2015c,e). Therefore, we limited our study to the period before the end of the year 2009. For more details concerning the research plots in RA Altansumber and RA Bugant, see Gradel et al. (2015a,b).

### 2.2. Climate data

Long-term climate data are rare in Mongolia. The nearest permanent meteorological station in northern Selenge Aimag with reliable data records is located at the Eroo sum centre (Station “*Eroo*”) at an elevation of ca. 900 m (49°48′N, 106°42′E) (Fig. 2). The Eroo station is also part of the CRU grid (CRU, University of East Anglia 2014), and the data have already been used for dendrochronological studies of larch trees around the research station Khonin Nuga (Dulamsuren et al., 2011). Air temperature and precipitation data are available since 1961. From 1961 to 2009, the mean annual temperature was −1.83 °C; the mean monthly temperature was $-27.1 \pm 2.7$ °C for January and $18.8 \pm 1.4$ °C for July. The mean annual precipitation was 278 mm with a maximum in summer and a minimum in winter. The RA Bugant is located approximately 66 km southeast of the Eroo station; RA Altansumber is approximately 88 km to the southwest.

### 2.3. Core sampling and processing

We collected cores from birch trees of different diameter classes and social status in the RA Altansumber and Bugant. These cores were taken with an increment borer of 5 mm in diameter at a height of 1 m above the ground, according to Dulamsuren et al. (2011). Tree rings in birch are hard to distinguish. Therefore the cores required a special processing. They were dried and mounted, and the surface was cut with a core-microtome, which is a new tool for surface preparation, resulting in a clear visibility of the annual rings (Gärtner and Nievergelt, 2010) and of anomalies such as wedging and false rings (Fig. 3). All cores were colored with basic blue 140. The tree-ring widths were measured with a precision of 10 μm on a movable object Table (Megatron) and recorded with the programme Berlin Muehle 4 1.0 (by Tobias Heussner). Data recording and first evaluations were conducted using the Time Series Analysis and Presentation TSAP-Win software 4.69 (RinnTech, 2015).

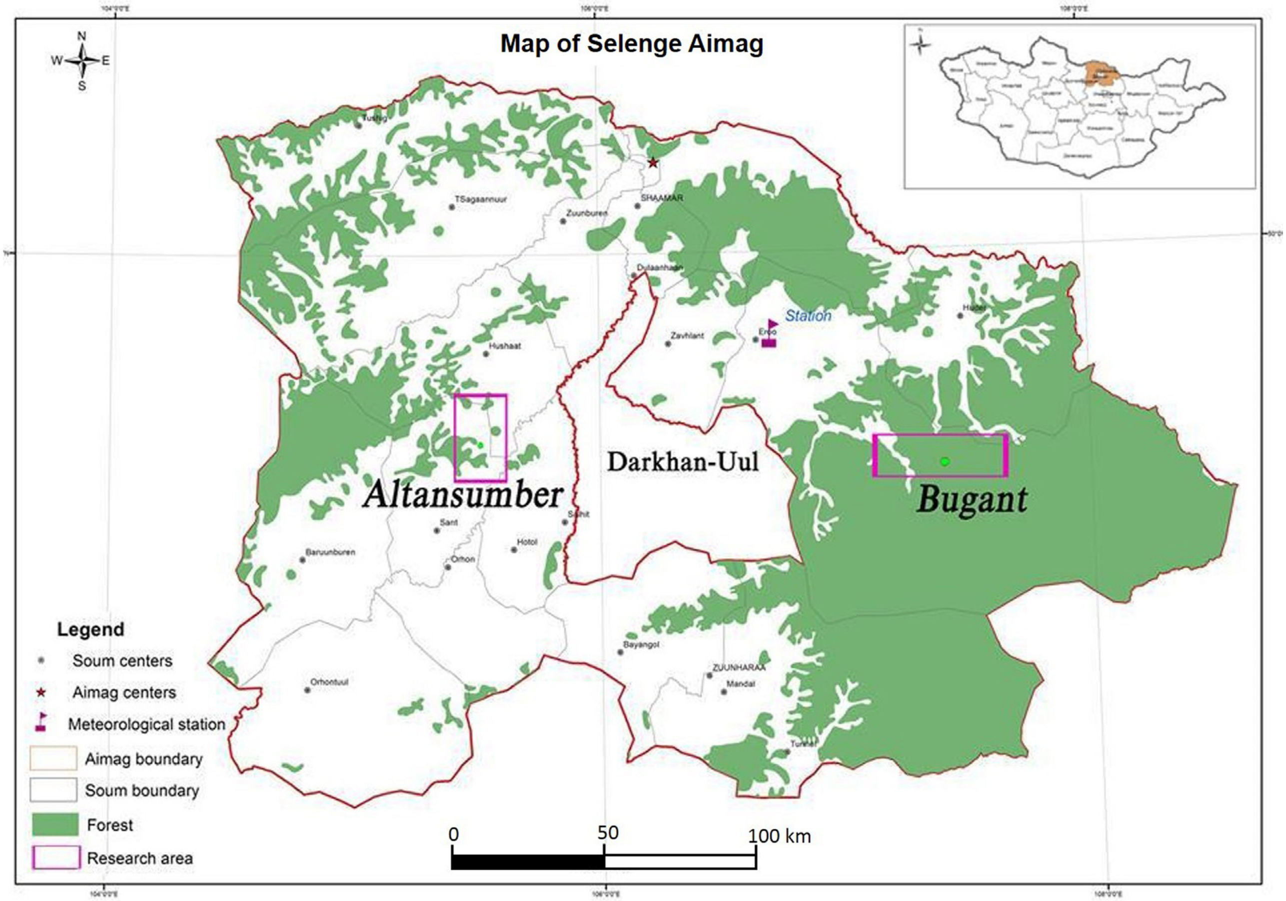


**Fig. 1.** Contour map of Mongolia (inset) and the research areas Altansumber and Bugant in the Selenge Aimag in northern Mongolia. (Map: Institute of Geography-Geoecology, MAS, Ulaanbaatar).

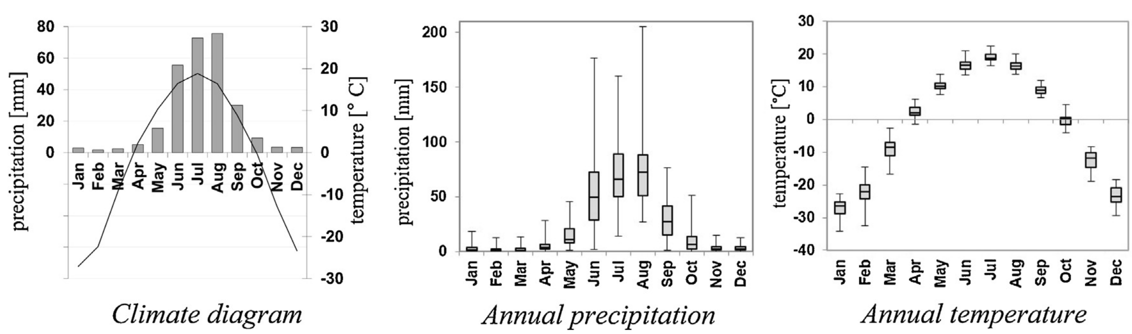


**Fig. 2.** Overview of the climate data recorded by the meteorological station Eroo for the period 1961–2009.

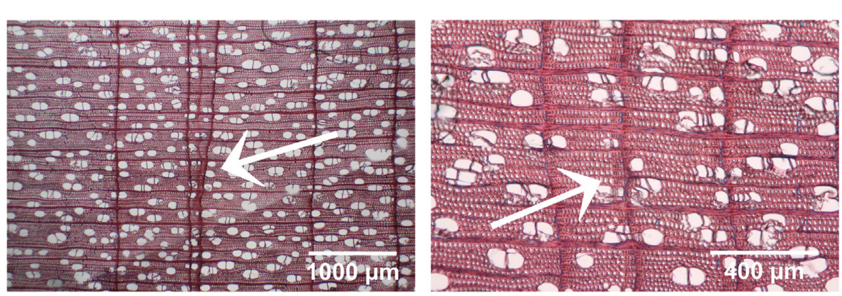


**Fig. 3.** Betula platyphylla cross sections: wedging tree ring (left), false tree ring (right).

### 2.4. Evaluation of tree-ring data

After the first crossdating between single series, the chronologies were checked using the TSAP-Win software and the program COFECHA 6.06P (Cook, 1985). The tree-ring series were processed with a segment length of 30 years lagged successively by 15 years. In order to obtain the residual version of the chronology the data were detrended by the ARSTAN program (version 44h3) using a cubic smoothing spline with a 50% cut-off (Holmes, 1983; Holmes et al., 1986). The statistical evaluation of the residual series was performed with dplR 1.6.3 (Bunn, 2008) in R (R Development Core Team, 2015). The chronologies were finally evaluated using the following dendrochronological statistics: mean coefficient of coincidence "Gleichläufigkeit" (Eckstein and Bauch, 1969); overall interseries correlation according to the description of Bunn and Korpela (2014); the mean tree-ring width and standard deviation (SD); the first-order autocorrelation (AC1) of the raw series, which measures the year-to-year persistence; the mean sensitivity of the residual series (MS), which quantifies the relative change in width among consecutive years; the mean correlation (Rbar) among all individual residual series within each site; and the expressed population signal (EPS) of the residual series, which indicates to what extent the sample size is representative of a theoretical infinite population; see also Pasho et al. (2014).

### 2.5. Statistical analysis of climate-growth relationships

The four residual chronologies were used for correlation analysis with the climate data of monthly mean temperatures and monthly sum of precipitation. Correlation coefficients were computed from 1962 to 2009 for the old birch series and from 1979 to 2009 (Altansumber) and 1985 to 2009 (Bugant) for the young birch trees, using a 14-month time window from August of the previous year to September of the current year. The climate-growth relationship were analyzed via the bootstrap method by the software DENDROCLIM 2002 1.0.0.1 (Biondi and Waikul, 2004), using Pearson's correlation coefficient, $p < 0.05$ was considered statistically significant.

### 2.6. Pointer year analysis

#### 2.6.1. Selection of pointer years

Years with extreme growth conditions, so-called event years, can trigger the development of above-average wide or narrow tree rings (Schweingruber et al., 1990). The event values were detected with the software Weiser 1.0 (García-González, 2001), with a 5-year window for the indexation according to the algorithm by Cropper (1979). The indices obtained were compared against a threshold value of 0.3, which corresponds to a SD of 30%. A positive or negative event year was identified if the respective index-value exceeded the threshold value of +0.3 or −0.3, respectively. A pointer year was identified if a minimum of 80% of the cores of a chronology showed the same tendency (Schweingruber 2012). The maximum number for the analysis of pointer years for one chronology was limited to 6 (strongest negative and positive pointer years, respectively).

#### 2.6.2. Interpretation of the pointer years

We wanted to explore if the extreme positive or negative growth in the pointer years could be linked to seasonal climate conditions. Therefore, we analyzed two climate variables, temperature and precipitation, for the pointer years selected. Every month of every pointer year and of the respective previous year was evaluated with regard to the mean values of precipitation and temperature according to the classification by Z'Graggen (1992). The results were pooled and averaged according to the seasons in Mongolia (see climate diagram): winter (November-March), spring (April-May), summer (June-August), and autumn (September-October). The averaged values for each season allow an estimation to which degree the respective season deviates from the long-time trend. For the interpretation, the period from the previous year's summer to the current autumn of each particular year was considered. The pointer year analysis was conducted within the same time frames for each chronology as the analysis of the climate-growth relationships.

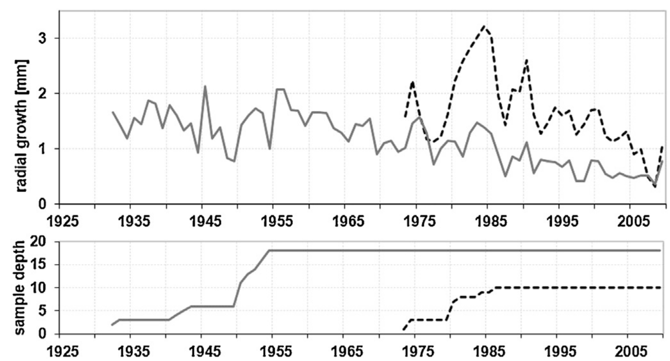


**Fig. 4.** Tree-ring chronologies of old and young birch trees (top) and sample depth (bottom) at Bugant. Solid grey line, old birch trees; dashed black line, young birch trees.

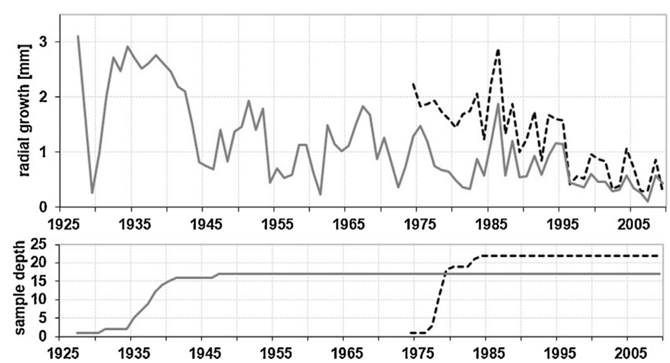


**Fig. 5.** Tree-ring chronologies of old and young birch trees (top) and sample depth (bottom) at Altansumber. Solid grey line, old birch trees; dashed black line, young birch trees.

## 3. Results

### 3.1. Statistics of the chronologies

The chronologies for Bugant showed wider tree-rings and lower sensitivity than the chronologies of the RA Altansumber (Table 1).

Mean curves and their sample depth, Figs. 4 and 5.

### 3.2. Climate-growth relationships

The month-wise analysis showed in tendency negative correlations with spring temperatures in both research areas. The young-birch chronology from Altansumber showed significant negative correlations in August of the previous year and in February and May of the current year. The young-birch chronology from Bugant showed negative correlations with temperature in December, April and August. The old-birch chronologies showed a similar but less pronounced pattern. Similar to the young-birch chronologies, the correlation was significantly negative in May in Altansumber and significantly negative in April in Bugant. It is noteworthy that both chronologies of Altansumber showed a positive correlation with June temperature (Fig. 6).

**Table 1**
Dendrochronological statistics of the *Betula platyphylla* (Sukaczev) chronologies of young and old birch trees in the research areas Altansumber and Bugant.

| Basic information | | | | Raw chronology | | | | | Residual chronology | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Research area | Age group | Ring series (No.) | Length of chronology | Overall inters. corr. | MGL (%) | MW (mm) | SD (mm) | AC1 | MS | Rbar | EPS |
| Bugant | young | 10 | 1973–2009 | 0.58 | 64 | 1.68 | 0.84 | 0.62 | 0.27 | 0.43 | 0.86 |
| Bugant | old | 18 | 1932–2009 | 0.66 | 67 | 1.10 | 0.58 | 0.68 | 0.29 | 0.44 | 0.92 |
| Altansumber | young | 22 | 1974–2009 | 0.74 | 72 | 1.18 | 0.80 | 0.47 | 0.43 | 0.61 | 0.97 |
| Altansumber | old | 17 | 1919–2009 | 0.70 | 69 | 1.03 | 0.74 | 0.58 | 0.43 | 0.43 | 0.91 |

Statistics: overall inters. corr. = average correlation of each series with a master chronology. MGL (%) = mean coefficient of coincidence "Gleichläufigkeit". MW = mean tree-ring width. SD = standard deviation. AC1 = first-order autocorrelation. MS = mean sensitivity. Rbar = mean interseries correlation. EPS = expressed population signal.

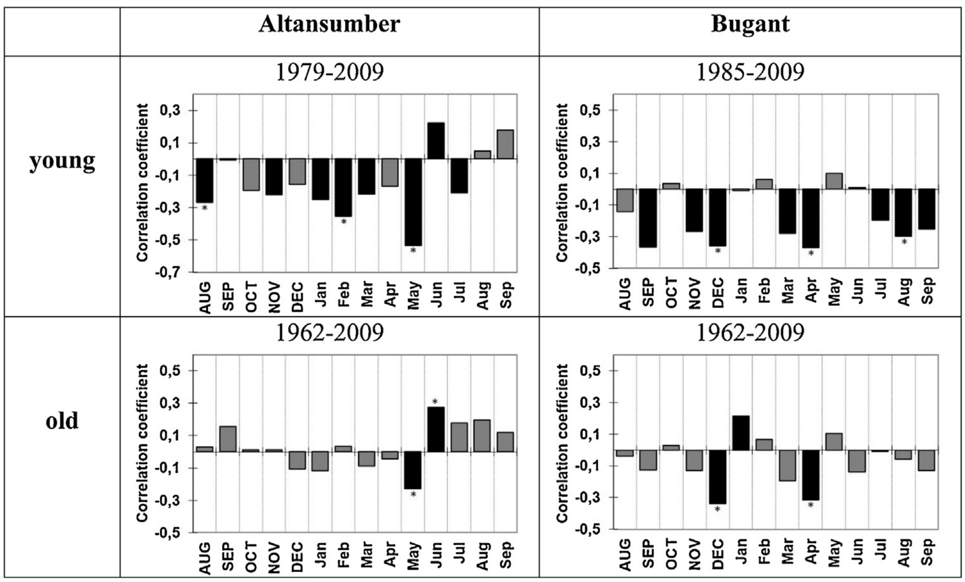


**Fig. 6.** Correlation coefficients of the temperature-growth relationship. Black bars indicate a correlation coefficient >0.2 and the asterisk (*) indicates significance with $p < 0.05$.

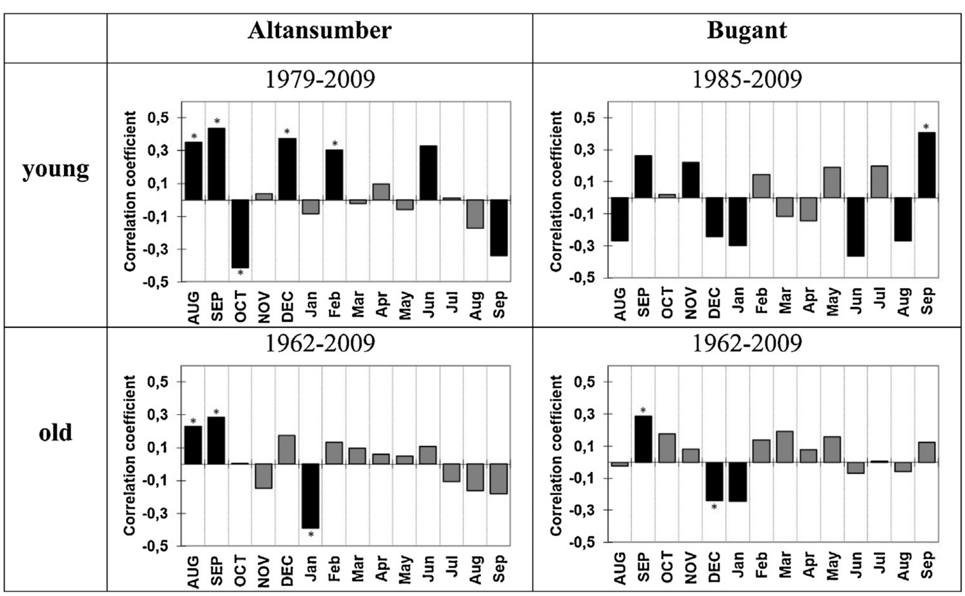


**Fig. 7.** Correlation coefficients of the precipitation-growth relationship. Black bars indicate a correlation coefficient >0.2 and the asterisk (*) indicates significance with $p < 0.05$.

For precipitation, the chronologies showed more often significant correlations. In late summer and early autumn of the previous year climate-growth relation gave positive correlations. There were no significant correlations during the main vegetation period, when both temperature and precipitation are usually high. In both research areas, the old-birch chronologies were negatively correlated with precipitation during the coldest season (January in Altansumber and December in Bugant) (Fig. 7).

**Table 2**
Overview of pointer years between 1962 and 1991. Circles—positive pointer years; crosses—negative pointer years.

| | | pointer year | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1962 | 1965 | 1969 | 1972 | 1975 | 1977 | 1981 | 1982 | 1984 | 1986 | 1987 | 1990 | 1991 |
| Bugant | young | | | | | | | | | | | | o | |
| Bugant | old | | x | x | | o | x | x | | | | x | o | x |
| Altansumber | young | | | | | | | | | x | o | x | | |
| Altansumber | old | o | | x | x | o | | | x | | o | x | | |

**Table 3**
Overview of pointer years between 1992 and 2009. Circles—positive pointer years; crosses—negative pointer years.

| | | pointer year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1992 | 1995 | 1996 | 1997 | 1999 | 2002 | 2003 | 2004 | 2006 | 2007 | 2008 | 2009 |
| Bugant | young | x | | | x | | | | | | x | x | o |
| Bugant | old | | | o | | | | | | | | | o |
| Altansumber | young | | | x | | | x | x | o | x | | o | |
| Altansumber | old | x | o | | | o | | | | | x | o | |

### 3.3. *Pointer years*

Based on the common selection criteria we identified fewer positive than negative pointer years (Tables 2 and 3).

Season-related analyses gave the most meaningful results for negative pointer years, especially for spring and summer of the current year. The summers in negative pointer years were often above-average dry. The young-birch chronology in Bugant showed a clear relation between negative pointer years and a warm spring (Fig. 8). The relation to the previous year and winter was largely indifferent. However, negative pointer years showed a relation to a rather dry autumn of the previous year (young birches in Bugant and old birches in Altansumber) and, partly, to a warm summer in the previous year (young birches, Bugant) (not shown). The summers of the positive pointer years of some chronologies were largely above-average humid (old birches, Bugant and Altansumber).

The year 1987 occured in three of the four chronologies as a negative pointer year (old birches in Bugant and Altansumber, and young birches in Altansumber). It is obvious that the precipitation, especially during the previous year's late summer and autumn and during the early time of the vegetation period of 1987 was below the long-time average (Fig. 9). The temperature, however largely followed the long-time average.

The year 2009 was identified as a positive pointer year in Bugant. Precipitation was above average during the early vegetation season (May-June) (Fig. 10).

## 4. Discussion

### 4.1. *Climate-growth relationships: moisture is the main factor*

Although birch is of special interest for ecological research in forest-steppe ecotones, only a few dendrochronological studies exist to date for Northern and Central Asia (e.g., Yu et al., 2007; Dawadi et al., 2013; Otoda et al., 2013; Liang et al., 2014). The present study is the first to explore the relationship between climate and the growth of birch in Mongolia.

Climate-growth relationships cannot be generalized but always need to be interpreted based on the regional conditions. In our study, precipitation in late summer and early autumn of the previous year resulted in positive growth correlations. This was especially the case in Altansumber. A significant relationship between growth and precipitation of the previous late summer and autumn has also been reported for larch chronologies in northern Mongolia (Dulamsuren et al., 2011; Khishigjargal et al., 2014). We found that this relationship was more pronounced in the chronologies of Altansumber. These chronologies also showed higher sensitivity, which may be related to less favourable conditions for forest growth in Altansumber compared to the more densely forested Bugant region. In contrast to our results, which focus on a continental region, Levanic and Eggertsson (2008) found that a positive growth response of birch (*Betula pubescens* Ehrh.) on cool, humid Iceland was particularly related to higher temperatures in June and July.

The growth of the younger trees in Altansumber was positively correlated with late winter precipitation (February). Snowfall during this time may also have a relatively strong influence on the water content in the upper soil layer in spring compared to snowfall in early winter, as wind drift and especially sublimation have a high impact on snow depth and distribution in Mongolia (Zhang et al., 2008). The amount of snowfall before the end of the winter season may therefore be more important than early winter snowfall. Because of their less developed root systems, sufficient water availability in the beginning of the growing season may be more important for younger trees than for older ones. A positive correlation between birch growth and early-year moisture was also reported for mountainous regions of northeast and inner Asia (Takahashi et al., 2003; Yu et al., 2007; Liang et al., 2014). Similarly, positive correlations were found in the forest steppe of southern Siberia between the growth of Scots pine and Siberian larch and precipitation directly before and at the beginning of the vegetation period (Babushkina and Belokopytova, 2014).

We did not find a clear, significant effect of precipitation changes on tree growth during the current growing season. However, young trees showed a pronounced positive precipitation-growth relationship in May (Bugant) or June (Altansumber). Interestingly, the pointer year analysis did not correspond exactly with the analyses of the climate-growth relationships, but instead complemented the data on the growth response of trees to climate variations. The pointer-year analysis showed that for the most extreme negative and positive growth reactions, precipitation during the current vegetation period is especially important. It also supports the assumption that water availability is the limiting factor for tree growth. The negative pointer years frequently showed below-average summer precipitation, as well as dry, previous-year autumns. Some positive pointer years showed predominantly higher values of precipitation, especially during the summer of the current year. Summer is also the season with the highest variations in the amount of precipitation levels (see Fig. 2).

The analyses of the temperature-growth relationships revealed that white birch reacted in a largely negative way to

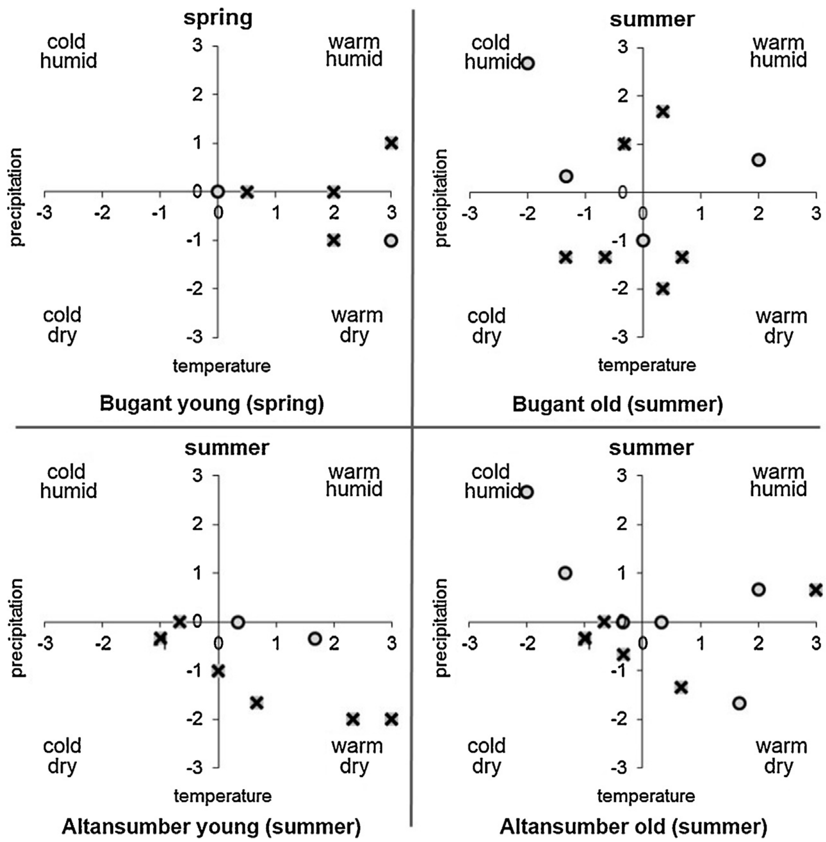


**Fig. 8.** Examples of the most meaningful, season-related pointer years of the chronologies. The values on the x- and y-axes are based on the classification of Z'Graggen (1992). Circles—positive pointer years; crosses—negative pointer years. From top left to bottom right: Bugant young, Bugant old, Altansumber young, Altansumber old.

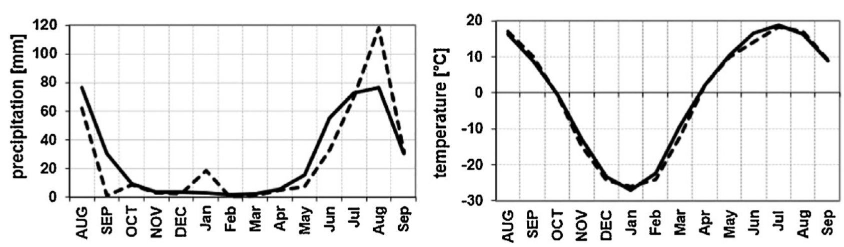


**Fig. 9.** The year 1987 was identified as a negative pointer year in both research areas. Dashed line, values from late summer 1986–early autumn 1987; solid line, mean values for the period 1961–2009.

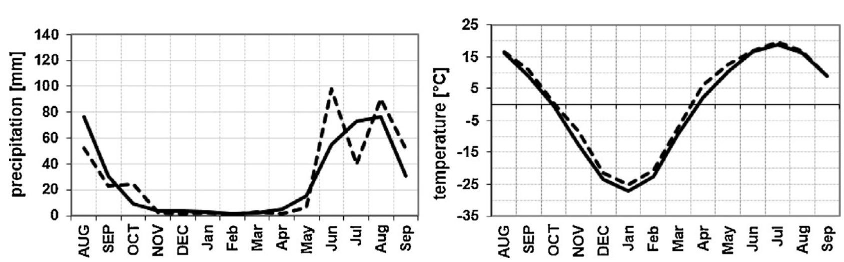


**Fig. 10.** The year 2009 was identified as a positive pointer year in the research area Bugant. Dashed line, values from late summer 2008–early autumn 2009; solid line, mean values for the period of 1961–2009.

above-average temperature. This was especially the case for the young birch chronologies. All chronologies showed a significant negative reaction to warm spring temperatures, but there was a 1-month difference in timing. Both chronologies from Bugant showed significant negative correlations during April, whereas the chronologies from Altansumber showed negative correlations in May. The sample sites in Bugant have south- and east-facing aspects, whereas the sample sites in Altansumber have northerly aspects. The exact timing of the inverse relation may therefore depend on site conditions (Leonelli et al., 2009; Liang et al., 2014). The negative correlation with above-average temperatures in May was especially strong in the young-birch chronology from Altansumber ($r = -0.54$, $p < 0.05$). Inverse relationships with spring temperatures were also found in a study on Himalayan birch

(*Betula utilis* D. Don) in Nepal. This relationship may be due to a water deficiency in spring (Dawadi et al., 2013). We assume that the largely negative correlations with temperature reflect water deficits, particularly in spring, but they may additionally also hint at the indirect effects of higher spring temperatures, for example, on ignition of forest fires, as on all plots signs of fire impact were recorded (Gradel et al., 2015e).

### *4.2. Potential impact of secondary factors (fire and insects) as indicated by the climate variables*

The dry period between April and May is the peak season for forest fires in northern Mongolia (Valendik et al., 1998). High air temperature, low air humidity, direct solar radiation and wind are generally considered the most important natural factors facilitating fire ignition and expansion (Tanskanen and Venalainen, 2008; Onderka and Melichercik, 2010). Surface fires often cause long-lasting damage to the bark and cambium of birch trees, as has been reported for the birch-pine plots in Bugant. Due to their thicker bark, pine trees showed less intensive damages. On some plots, more than 20% of the birch trees exhibited visible fire damage near the base of the tree (Gradel et al., 2015a). Mechanical damage to the bark can mean substantial damage to the tree, which hampers the transport of glucose and water (Lüttge et al., 2005). Fire can also directly destroy the cambium, which is responsible for the radial growth. Such chronic damages may affect the growth performance of a tree for several years. A recently published dendrochronological study estimated that the average return interval for fire in the pine forests of the north-western Khentey Mountains in Mongolia is 11.6 years on average (Oyunsanaa, 2011). Such fires are usually of low intensity and are not stand-replacing. Signs of fire damage were reported for all sites in Bugant and Altansumber (Gradel et al., 2015e) and have become a common feature in the accessible forests of northern Mongolia.

The negative correlations with higher temperature in December in Bugant and in January in Altansumber (old trees) may be related to the impact of temperature on insect populations. Such a relationship has frequently been reported in some recent studies of larch, and it has been suggested that this is due to the influence of temperature on insect populations (Dulamsuren et al., 2011; Khishigjargal et al., 2014). The same explanation also holds for the significant negative correlation with winter precipitation during the coldest time, also confirmed in studies of larch (Dulamsuren et al., 2011). High snow cover during the coldest time of the year protects herbivorous insects, which may negatively affect tree growth in the upcoming growing season (Dulamsuren et al., 2011). Insect outbreaks are very common in the region and seem to especially affect older trees. For example, winter survival rates of eggs of one of the most important herbivorous insects in the region, the gypsy moth (*Lymantria dispar*), are directly related to threshold values of the surrounding air temperature (Waggoner, 1985). Other important herbivorous insects in the region are *Erannis jacobsoni* and *Dendrolimus superans sibiricus*. We have no specific statistical information about insect infestations and fire events in the two research areas, but the interpretation of the climate-growth relationships, field visits and literature studies support the assumption that these non-climatic factors also play an important role in the growth of birch in this region.

## 5. Conclusions

Based on the climate-growth relationships and the pointer year analyses, and considering different site factors and conditions specific to northern Mongolia, water availability seems to be the most critical factor for white birch growth, especially in the RA Altansumber. Our results indicate that in the beginning of the vegetation period, the growth performance of younger birch trees is more dependent on water availability than of older trees. There is also evidence that the seasonal impact of climate variables on growth is related to aspect. The results support the assumption that tree growth is influenced not only by climate, but also by factors such as insect populations and fire outbreaks, which are themselves influenced by climate and weather. Damage marks from surface fires on the bark of the trees (Gradel et al., 2015a) and negative correlations with temperature during the peak of the fire season indicate that fire disturbances may have negatively affected tree growth. The negative correlations with higher temperature and with snow cover during the peak of the winter season can be linked to better survival rates of herbivorous insects. In this context, the increase in mean annual temperatures as forecasted by the Intergovernmental Panel on Climate Change (IPCC, 2014) would likely have a negative impact on the growth performance of birch trees. This impact is likely to be especially severe if winter and spring temperatures increase significantly. The pointer years indicated that deviations in precipitation during the summer months and during the previous autumn affect the growth response of birch in northern Mongolia. Our results may have practical implications for land-use management and forestry in northern Mongolia and neighboring regions, particularly when compared with regional data on other tree species. For example, a comparison of our results with results from the main coniferous species from the same stands would allow for an evaluation of which tree species may be most promising for forestry under certain future climatic conditions.

**Some practical recommendations for increasing the climate signals of birch trees from the taiga and mountain forest steppe**

- The sampling of trees should focus on small-scale sites, preferably single forest stands with very similar conditions (e.g. competition situation, slope, aspect).
- Secondary factors (e.g. fire) should be taken into account. Even in a homogenous stand, it is likely that previous surface fire events affected individual trees differently. Some trees may have been spared, whereas others may have been strongly affected. This can lead to different growth response signals or variation in the expression of growth response. For studies of climate-growth relationships, only trees without visible fire damage should be selected.
- Age may play a role in a tree's sensitivity and resilience to climate effects. On average, the chronologies of the younger trees showed higher sensitivities to temperature and precipitation effects and had more significant correlations with climate factors. However, younger trees provide only relatively short chronologies.
- Based on the relative dominance, as assessed by the *measure of surround* $U_i$ (Gadow and Hui, 2002 according to the classification of Gradel and Mühlenberg, 2011), suppressed birch trees in Bugant exhibited higher sensitivity values than dominant trees (Haensch, 2015). Similar dominance-dependent relationships have also been reported for *Fagus sylvatica* L. and *Picea abies* (L.) H.Karst in northern Germany by Grundmann (2009). The relative social status of the sample trees should therefore be considered during sampling.
- It could be useful to consider time series of wood anatomical features such as vessel size and vessel density for further investigations. Vessel features have been used to describe the physiological relationship between tree growth and environmental conditions (e.g., Bryukhanova and Fonti, 2013; García-González and Fonti, 2006; Sass and Eckstein, 1995).

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