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Effects of climate on radial growth of *Picea meyeri* in semi-arid grassland, north China

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ABSTRACT

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Dendroclimatic assessment of *Picea meyeri* Rehd. et Wils was carried out on the sandy land in semi-arid Inner Mongolian grassland. Response function analysis was performed to identify climate-growth relationships for *P. meyeri*. The growth of *P. meyeri* exhibits a positive relationships with precipitation in current February and May as well as in prior September. Furthermore, it is showed that several variables among mean monthly temperature and total monthly precipitation from September of current year to August of preceding year can explain about 70% of the variance in the tree-ring width. The results reveal a greater sensitivity of this species to climate conditions in this area, suggesting that *P. meyeri* is a suitable species for dendroclimatic studies.

Key-words—*Picea meyeri*, Dendroclimatology, Semi-arid grassland.

उत्तरी चीन के अर्द्ध शुष्क अन्तर्वर्ती मंगोलियाई घास स्थल में *पाइसिया मीयेरी* की परिधीय वृद्धि पर जलवायु के प्रभाव

एर्युआन लिआंग एवं स्यूमेई शाओ

सारांश

अर्द्धशुष्क अन्तर्वर्ती मंगोलियाई घास स्थल में बलुई स्थल पर *पाइसिया मीयरी* रेड. एट् विल्स का वृक्षजलवायुविक निर्धारण किया गया। *पी. मीयेरी* हेतु जलवायु-वृद्धि सम्बन्धों के अभिनिर्धारण के लिए सहसम्बन्धन फलन विश्लेषण किया गया। *पी. मीयेरी* की वृद्धि वर्तमान फरवरी एवं मई माह तथा सितम्बर के पूर्ववर्ती दिनों में वर्षण की सकारात्मक सम्बद्धता प्रदर्शित करती है। इसके अतिरिक्त यह भी देखा गया है कि पिछले वर्ष के अगस्त माह तथा वर्तमान वर्ष के सितम्बर माह में मासिक औसत तापमान तथा कुल वार्षिक वर्षण के मध्य प्राप्त अनेक प्रसरण वृक्ष वलय चौड़ाई में लगभग 70% प्रसरण की व्याख्या करते हैं। ये परिणाम इस क्षेत्र में इन प्रजातियों की जलवायुविक स्थितियों के प्रति अधिक संवेदनशीलता प्रदर्शित करते हैं, जिससे प्रस्तावित होता है कि *पी. मीयेरी* वृक्षजलवायुविक अध्ययन हेतु एक उपयुक्त प्रजाति है।

संकेत शब्द—*पाइसिया मीयेरी*, वृक्षजलवायुविकी, बलुई भूमि, अर्द्ध शुष्क घासस्थल.

INTRODUCTION

PICEA meyeri Rehd. et Wils is a predominant community of coniferous forest in the mountainous regions in north China. In semi-arid grassland of the Xilin River Basin, Inner Mongolia it has reached the upper latitude margin of its natural range (Zhao *et al.*, 1988). As a climatically relict species, *P. meyeri* forms a special forest landscape on sandy land in semi-arid grassland (Cui & Kong, 1992; Li *et al.*, 1988), which is dominated by perennial dry grass species, such as *Leymus chinensis* and *Stipa grandis*. Thus, small patch of *P. meyeri* forest offers a unique opportunity to conduct dendroclimatic research in the Xilin River Basin. An evaluation of cross-dating characteristics and the responses to climate of unstudied species is the first step in assessing the potentiality of such trees in dendroclimatology (Yasue *et al.*, 1996). In the present study, response function is applied to evaluate the dendroclimatic potential of *P. meyeri* in the Xilin River Basin.

MATERIAL AND METHODS

A small portion of *P. meyeri* natural pure stands (about 2 ha) is located in the north-facing slope of one sand dune (43°42'N, 116°54' E, Elevation 1400 m) (Li *et al.*, 1988). Cambial activity of *P. meyeri* at this elevation and latitude commences at the end of April or the beginning of May (Xu & Zou, 1998; Zhao *et al.*, 1988). *P. meyeri* prefers wet and cold climate in mountainous regions, as a result, spruce growth ceases in August coinciding with high temperature and strong evapotranspiration in this region (Xu & Zou, 1998). The canopy coverage of *P. meyeri* reaches 0·20-0·40 and the height ranges from 5 to 10 m. Soil is woodland sand soil including 80% SiO_2 and low organic matter.

Climatically, this area belongs to continental middle temperate semi-arid zone (Chen, 1988). Winter is cold and dry, while summer is warm and wet. The mean annual temperature is about -0.4°C; the mean of the coldest month, January, is -19.5°C; and one of the warmest month, July, is 20.8°C. On average, the area has 5 months with mean temperature 35°C, May through September, which approximates the length of the growing season. The annual precipitation is about 350 mm and 60–80% of the rainfall occurs in June, July and August. Moreover, this region is characterized by very wide fluctuations in precipitation between year ranging from 150 to 560 mm per year. The annual evaporation is about 4-5 times greater than the total annual precipitation.

Total 42 cores from 21 trees were taken with an increment borer at breast height in opposite directions. All cores were mounted, sanded, and visually cross-dated (Stokes & Smiley, 1968). The ring widths were measured to the nearest 0·01 mm using a linear digitizing tablet coupled to a computer. Then the absolute dating was subsequently verified statistically using COFECHA program (Holmes, 1983). All cores with potential errors were rechecked and corrected if possible. Finally, 3 Cores that showed low correction values with the master chronology were excluded from the site chronology. The measurement series were individually detrended with a cubic smoothing spline (30-years 50% frequency response) to remove tree specific growth trend that resulted from age and size difference, and competition effects of tree growing in closed canopy conditions. The ring-width measurements of each core were divided by the fitted spline values to produce a standardized tree ring series for each core. These individual dimensionless index series were then averaged together using a biweight robust mean to construct a mean standardized chronology (Holmes, 1983; Cook & Kairiukstis, 1990).

Response function analysis was performed to identify the months in which the strongest relation between climatic variables (monthly precipitation and temperature) and growth occurs (Fritts, 1976). For the final analysis, we modelled *P. meyeri* index chronology with the most influential climate variables using multiple regression (Grissino-Mayer & Butler, 1993). The climatic data were from the nearby Xilin Hot Meteorological Station (43°57' N° 116° 04' E), including total monthly rainfall (in mm), average monthly temperature (°C). 5 months of the prior year were used in addition to the data of January through September during the current year. The analyzed period was 1954 to 1994, which was the length in common between the climate record and the chronology. The significantly influenced months were determined at the 95% confidence level.

RESULTS AND DISCUSSION

Primary assessment of chronological characters

One 65-year standardized chronology ranging from 1930 to 1994 was developed and no missing ring was observed in all cores (Fig. 1). The analysis of variance of standard chronology for the period from 1955 to 1994 AD indicated that mean correlation between trees 0·46 and Mean sensitivity 0·18, which is enough to obtain accurate results with response function methods (Rolland, 1993). Relatively high signal-to-noise ratio and percentage of variance accounted for by the first principal component of tree ring index further suggested the suitability of *P. meyeri* standard chronology for climate analysis.

Response function analysis

Response function analysis shows that the precipitations in both February, May of the current year and September of preceeding year are significantly correlated with *P. meyeri*

	Actual	Standardized
Samples Cores/Trees	42/20	39/19
Mean ring width mm	2·500	—
Standard deviation	0·749	0·160
Mean sensitivity	0·245	0·180
First order autocorrelation*	—	-0·019
Mean correlation among all radii*	—	0·474
Mean correlation between trees*	—	0·466
Agreement with population chronology*	—	0·933
Signal-to-noise ratio*	—	13·981
Variance due to first eigenvector (%)*	—	50·12

Fig. 1—General statistics for actual and standardized chronology of *Picea meyeri*. Calculation for the common interval from 1955 to 1994 is indicated by an asterisk.

growth (Fig. 2B). However, no significant relationship can be observed between radial growth and mean monthly temperatures (Fig. 2A).

February precipitation appears to impose a positive effect on radial growth. There are some reports that spring snowfall is close linked to radial growth (Payette *et al.*, 1996; Peterson & Peterson, 1994). However, the significant effect of February snowfall cannot be physiologically explained, since the amount of February precipitation is negligible in the Xilin River Basin.

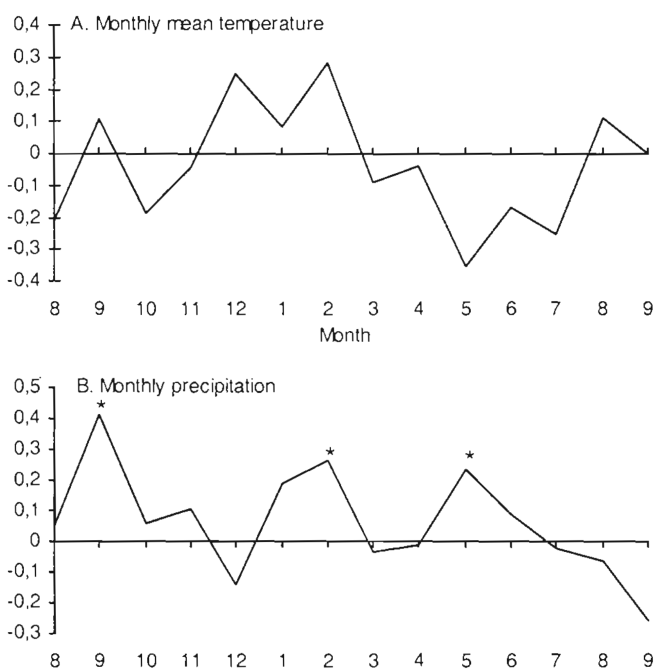

Fig. 2—Response functions for annual tree-ring growth in response to monthly mean temperature (A) and total monthly precipitation (B) from August of the previous year to September of the current year. Vertical scales are dimensionless standardized units.

Monsoon rain does not occur in May. Moreover, the prevailing northern and northwestern winds in May probably increase the desiccating effects of the summer heat, resulting in the lowest air humidity in whole year in the Xilin River Basin (Chen, 1988). Soil dryness inversely affects plant growth at all habitats (Oberhuber *et al.*, 1998). In this region with a temperate climate, cell division is usually greater at the beginning of cell distribution phase (early summer) (Hughes *et al.*, 1994), and this is probably the period in which more earlywood is formed. Thus strong moisture stress in May might limit earlywood formation and hence total ring width reflecting the positive influence of the rainfall in May on ring width.

Positive correlation is also evident between spruce growth and precipitation from prior August to prior October, particularly the precipitation in previous year's September. However, other dendroclimatic studies in north China (Hughes *et al.*, 1994; Kang *et al.*, 1997; Liu & Ma, 1999; Shao & Wu, 1994 a, b, 1997 ; Zhang & Wu, 1992, 1997) failed to reveal this phenomenon, which suggests that it is mainly related to sandy substrate in this stand and phenological characters of *P. meyeri* as well as semi-arid climate in the Xilin River Basin. The evapotranspiration decreases obviously in August (Xu & Zou, 1998), while the rainfalls during these 3 months still account for 1/3 of the total annual rainfall. Hence the sandy land forms less surface runoff and can effectively prevent soil water from evaporation relative to grassland chestnut soil (Li *et al.*, 1988). Higher precipitation during this period might likewise control water availability in early spring (Bhattacharyya & Yadav, 1990). The water reservation is crucial for early cambial activity because low rainfall prevails in spring in the Xilin River Basin.

Multiple regression analysis

Because growth of *P. meyeri* is closely associated with climate, we try to describe ring width variation of *P. meyeri* with linear multiple regression. The best model includes 7 climate variables, which produces an R^2 of 0·707. The F-

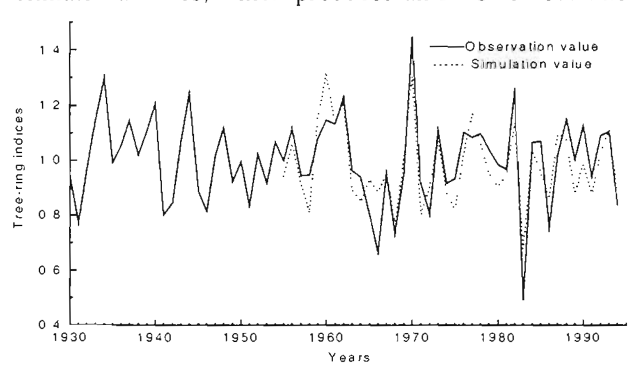

Fig. 3—Time series analysis of tree-ring indices of *Picea meyeri*.

statistic for the model is 11·00 ($P<0·05$). The model is: $I = 0·743 + 0·00406 R9 + 0·00441 P5 + 0·00277 P6 + 0·0124 T2 - 0·000847 R7 - 0·0323 T5 + 0·0321 T6$.

P5, P6, T5, T6: Total precipitation and mean temperature in current May and June;

R7, R9: total precipitation in prior July and September;

T2: mean temperature in current February.

Predicted tree-ring width index series from 1955 to 1994 against the actual observed values is plotted in Fig. 3. The dotted line representing the simulated values is quite similar to the observed values, which indicates that *P. meyeri* standardized chronology bears a high potential for climate reconstruction in semi-arid grassland of the Xilin River Basin, Inner Mongolia.

CONCLUSION

The present study suggests that *P. meyeri* is a promising species for dendroclimatic studies and a suitable source for the reconstruction of climate-tree growth relationships because of good cross-dating characters and its high sensitivity to the precipitation. The development of *P. meyeri* chronology filled the gap of dendroclimatic investigation in semi-arid grassland, north China. A forthcoming study will identify the linkage between *P. meyeri* chronology in the Xilin River Basin with other chronologies from semi-arid sites in north China, and investigate their spatial response to climate.

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