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Temporal and spatial variability of tree growth in mountain-forest steppe in Central Asia

J. Block[1], V.N. Magda[2] & E.A. Vaganov[2]

[1]*Institute of Geography, Friedrich-Alexander-University Erlangen-Nuernberg, Kochstr. 4/4, 91054 Erlangen, Germany; e-mail: jblock@geographie.uni-erlangen.de*

[2]*Institute of Forest SB RAS, 660036, Akademgorodok, Krasnoyarsk, Russia*

Introduction

A network of 140 tree-ring sites in the mountain regions of Central Asia and the low-land regions of Flat Altai and Khakasia (Fig. 1) was established between 1994 and 2002. It is suggested that southern Siberia and Mongolia form an important region in Central Asia. Due to the extreme continental climate conditions, forest is restricted to small areas and climate changes may have a high influence on the distribution of the forest. Also several big Siberian rivers (e.g., Ob, Yenisey, and Selenge) have their headwaters in these mountain ranges.

These regions are covered by different types of forest. The low-land areas of Flat Altai and Khakasia are covered by forest steppe, the intramountainous basins of Mountain Altai, the southern part of Tannu-Ola mountains and the mountain areas of Mongolia by mountain forest steppe and the upper tree line ecotones of Mountain Altay and Sayan mountains and the northern part of Tannu-Ola mountains by light taiga (Fig. 2a-c).

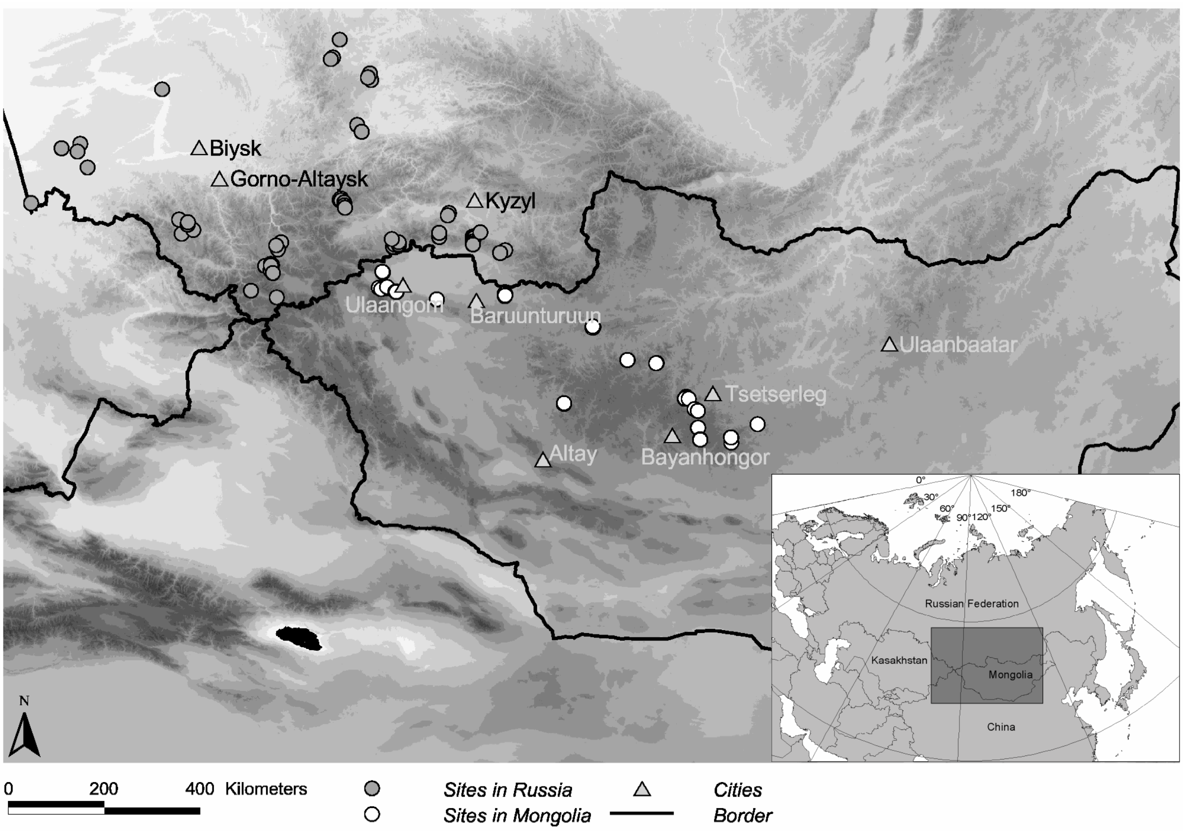

Figure 1: Overview map of sampled sites in Central Asia

The upper tree line is situated at 2200 m a.s.l. in Tannu-Ola and Sayan, at 2400 m a.s.l. in the Altai Mountains and Western Mongolia and up to 2700 m a.s.l. in Central Mongolia. In regions with mountain forest steppe in Mongolia, Tannu-Ola, Sayan and in the intramountainous basins in Mountain Altai a lower tree line is formed at an elevation of 1400 to 2100 m a.s.l. Fire is an important ecosystem factor in the whole region, with higher fire frequency in the locally more dry areas.

Figure 2: a) Landscape in central part of Mountain Altai. b) Typical landscape in Central Tannu-Ola mountains in Tuva. c) Mountain forest steppe landscape in Northwest Mongolia.

Material and Methods

Primarily typical and homogenous upper and lower timberline sites and sites in forest-steppe ecotones were selected. Cores and disks were taken from Siberian Larch (*Larix sibirica* Ledeb.), Siberian Pine (*Pinus sibirica* Du Tour) and Scots Pine (*Pinus sylvestris* L.) in Mountain Altai, Flat Altai, Khakasia, Western Sayan, Tannu-Ola (Russia), Turgen-Kharkhiraa, Khan-Khokhiyn and Khangai mountains (Mongolia).

Samples were prepared (cores and disks), tree-ring width was measured, and site and regional chronologies were built in accordance to dendrochronological methods as described by Fritts (1976), Cook and Kairiukstis (1990), Schweingruber (1996) and others, by using TSAP, COFECHA and ARSTAN.

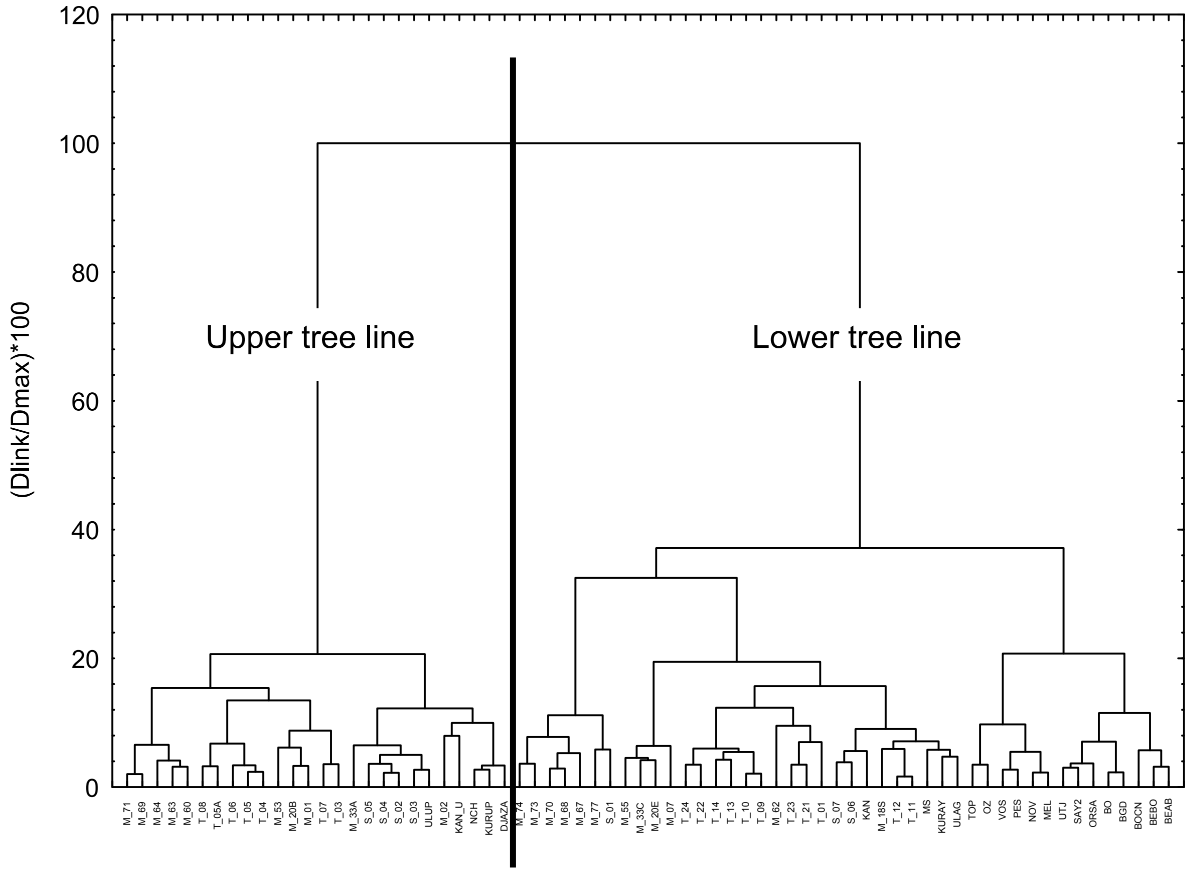

Figure 3: Tree Diagram (Ward's method, 1-Pearson r) for the last 100 years for selected sites, shown in the map in Fig 1. Upper timberline sites (left) and lower timberline sites (right) fall to two different groups.

Cluster analysis was used for the analyses of spatial patterns (Fig. 3), stepwise cluster analysis (Fig. 6) and moving correlations (Fig. 4) were used to define temporal patterns, and response functions, factor analysis (Fig. 7) and other statistical methods were used to understand the reactions of the trees to the environmental factors.

Results

The results of cluster analysis for the last 100 years show two well defined groups for the upper and lower tree-line sites (Fig. 3), but clear groups become weaker if the whole chronologies are used for clustering. In many periods pointer years of upper and lower tree line sites are inverse, so a negative pointer year at upper sites coincides with a positive pointer year at lower tree line sites, and vice-versa. But in some cases during some periods, pointer years at upper and lower tree line sites coincide.

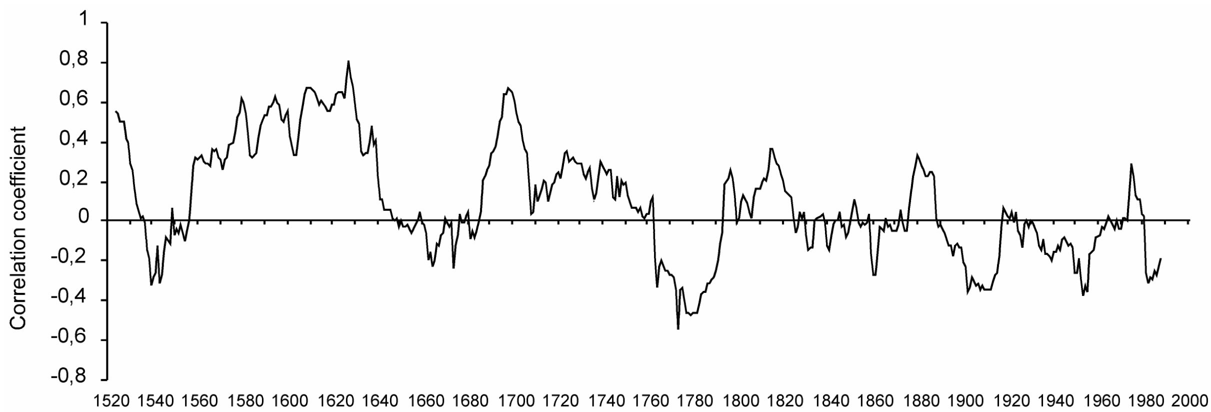

Figure 4: Moving correlations between upper and lower tree-line sites in the Mountain Altai region.

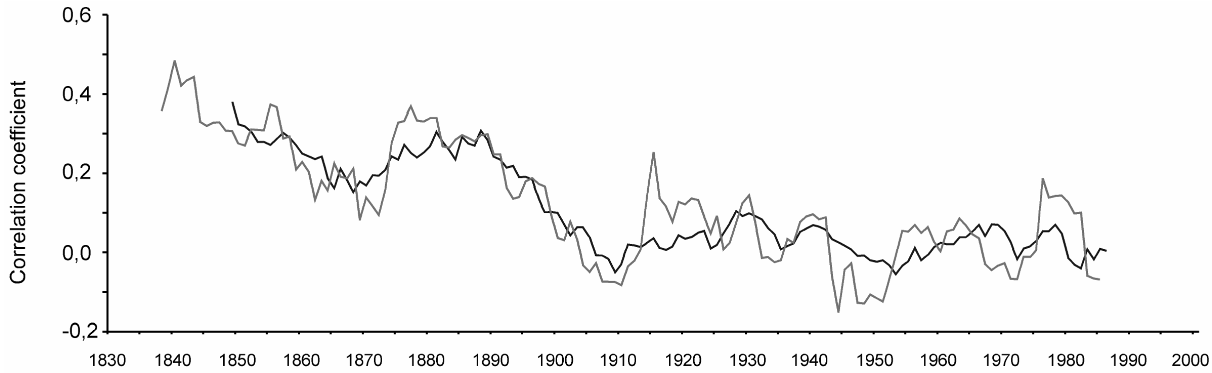

Figure 5: Moving correlations between upper and lower tree-line sites from Fig. 4 (grey) and reconstructed moving correlations, calculated by the summer temperature of the Barnaul meteo station (black line).

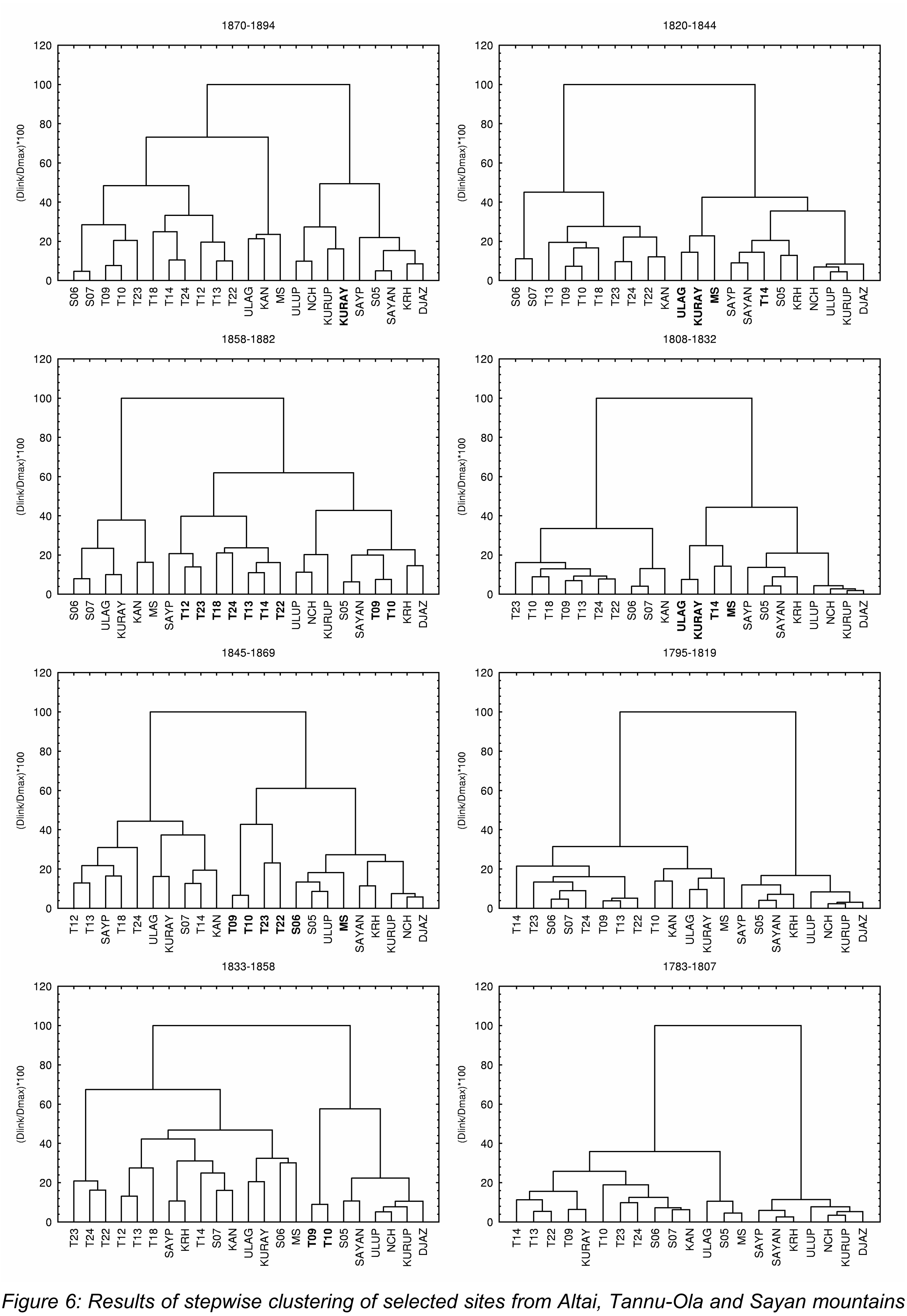

Figure 6: Results of stepwise clustering of selected sites from Altai, Tannu-Ola and Sayan mountains for 25-year periods with an overlap of 12 years. "Jumping" sites are marked.

Moving correlations in a 25-year window were calculated to study temporal variability. These moving correlations show different periods with positive, negative and approximately zero correlations (Fig. 4).
In addition to cluster analyses based on the entire chronologies, stepwise cluster analysis with a 25-year window and 12-year overlap were calculated for the last 300 years. Stepwise clustering shows periods when some sites from the group of lower tree line switch to the group of upper tree line ("jumping" sites in Fig. 6).

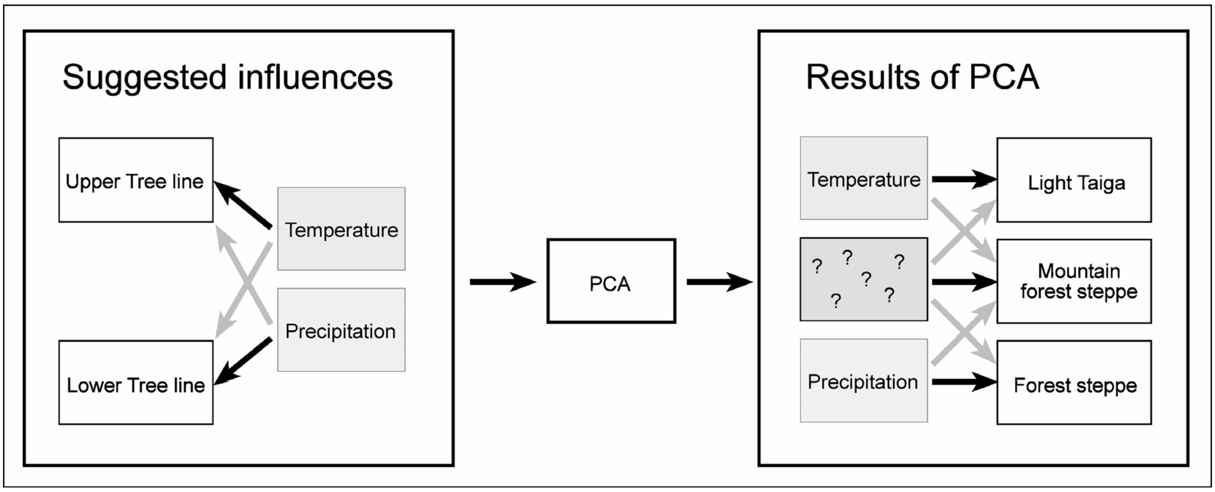

Figure 7: Suggested influences of environmental factors to tree growth and results of factor analysis (black arrows = primary factors, grey arrows = secondary factors).

Conclusion

We considered results from moving correlations as well as from stepwise cluster analysis and examination of extreme values as evidence of changing climatic conditions. We hypothesize that at the lower tree line during cooler periods the influence of temperature on tree growth increases. This means that upper and lower tree line-sites are reacting synchronously during such time periods, which leads to higher correlations. Distributions of extreme values and moving correlations support this hypothesis. The variance of moving correlations explained by summer temperature is quite high. As proof for dependence of moving correlations from temperature, we reconstructed moving correlations with the summer temperatures of Barnaul meteo station, using regression models. The good agreement is evident in Figure 5. Moving correlations as well as extreme values clearly show the known cool period in the middle of 19th century.

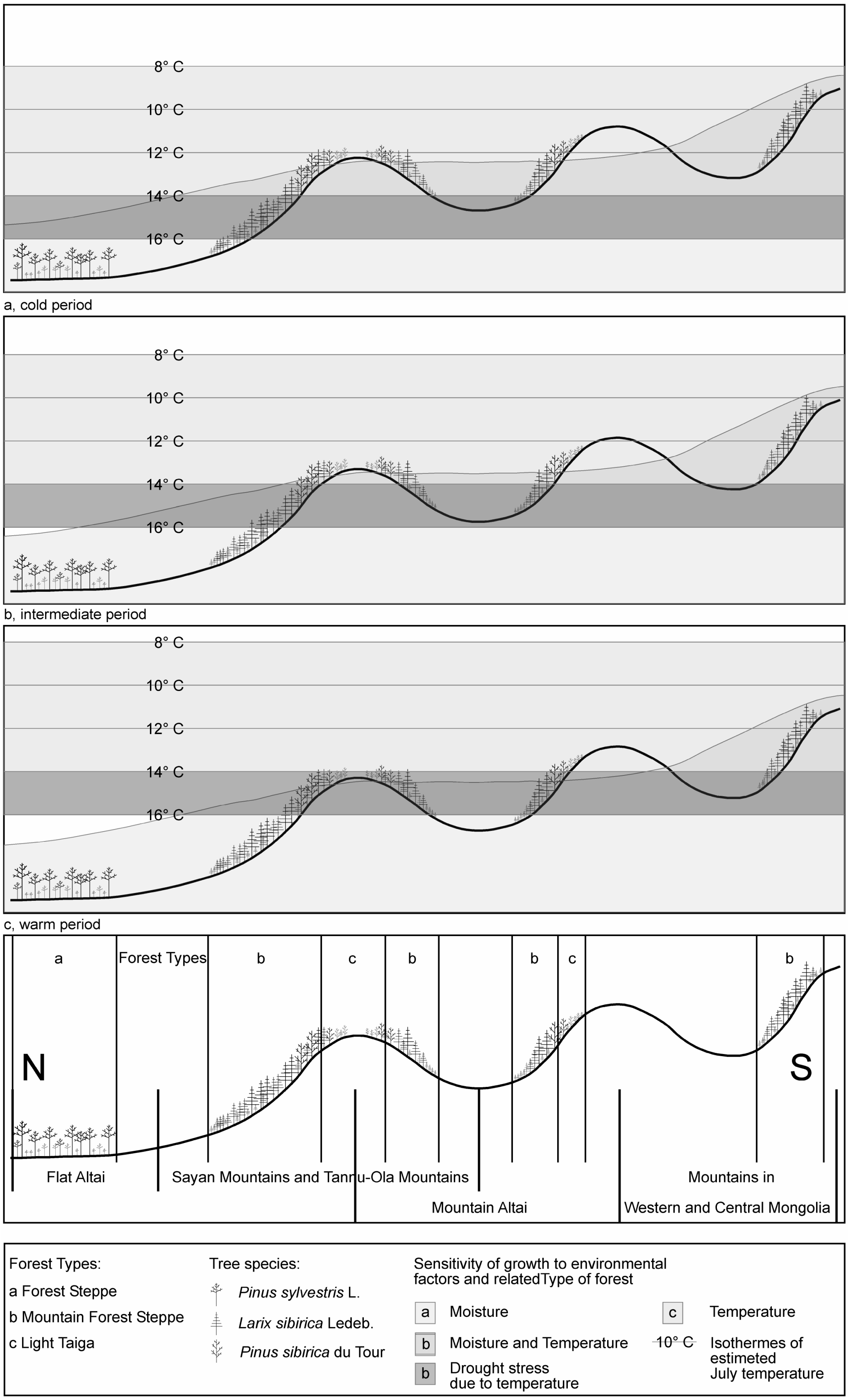

Figure 8: Forest types and forest distribution in the northern part of Central Asia and the influence of temperature and precipitation on tree growth in (a) cold, (b) intermediate and (c) warm periods.

Trees of the mountain forest steppe always have a mixed signal of temperature and precipitation; even trees of the upper tree line sites react to precipitation. Using factor analysis, we found another - still unknown – factor that explains a very high percentage of the chronologies variance (Fig. 7). These results explain why response function analyses using climate data do not always give satisfactory results.

On the basis of this study we were able to develop a classification for the forests in Central Asia using dendrochronological methods, yielding the same results as geobotanical studies. The light taiga shows a temperature signal, the forest steppe a precipitation signal and the mountain forest steppe a mixed signal. The schematic profile across the mountains in Fig. 8 shows these results. The model can also explain the temporal variability of temperature influence.

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