Identification of macro-scale groups among 17 site chronologies from Fennoscandia

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Introduction

The Scandinavian Peninsula provides a continuous and relatively untouched boreal forest which offers an interesting area for dendroclimatic and dendroecological research through its geographical settings and the connected climatic gradients: the latitudinal temperature changes and the longitudinal Luv and Lee effects of the Scandinavian Mountains.

It is generally known that extreme climatic conditions synchronize tree growth, and thus provide a common signal in tree-ring time-series (Fritts 1976). In the boreal forest, tree growth is primarily controlled by summer temperature and direct sunlight (Boisvenue and Running 2006, Büntgen et al. 2011, Esper et al. 2014), thereby providing an ideal area for tree-ring based summer temperature reconstructions of the past centuries (e.g. Eronen et al. 2002, Grudd 2008, Esper et al. 2012). However, with decreasing latitudes the limiting effect of temperature on growth is replaced by increasing sensitivity of the trees to precipitation and water availability (Drobyshev et al. 2011). Next to the latitudinal temperature gradient, a longitudinal effect was displayed in tree-ring stable isotope studies on cloud cover and solar radiation (Young et al. 2012, Loader et al. 2013). Gouirand et al. (2008) also addresses the spatiotemporal relationships of tree-ring based temperature reconstructions in northern Europe. However, a comprehensive study analyzing common growth patterns of the most abundant conifer species Scots pine across Fennoscandia is still missing. An estimation of spatially resolved inter-site relationships would help dividing the Scandinavian Peninsula into ecological habitats with common factors influencing tree growth.

In this study we provide an overview on a comprehensive tree-ring network from Fennoscandia, located between 59°-69°N and 15°-29°E. Overall 17 sites were investigated with similar sampling design (see: Düthorn et al. 2013), allowing comparability among the chronologies. We here address inter-site relationships and expect nearby site chronologies to share variance and contain similar signals. We use multivariate analysis (principle component analysis and hierarchal cluster analysis of variables) as an objective approach to define groups and to present new representative mean chronologies. The same methods were used by Wilson and Hopfmueller (2001) to identify different elevational zones in the Bavarian Forest and by Koprowski (2013) to distinguish climate induced growth patterns in Poland.

Material & Methods

We compiled a tree-ring width network of 17 Scots pine site chronologies, distributed over northern and eastern Fennoscandia. The spatial arrangement of the sites is clustered in two North-South transects in Finland and Sweden and a longitudinal transect taking the Luv and Lee effects of the Scandinavian Mountains into account (Figure 1).

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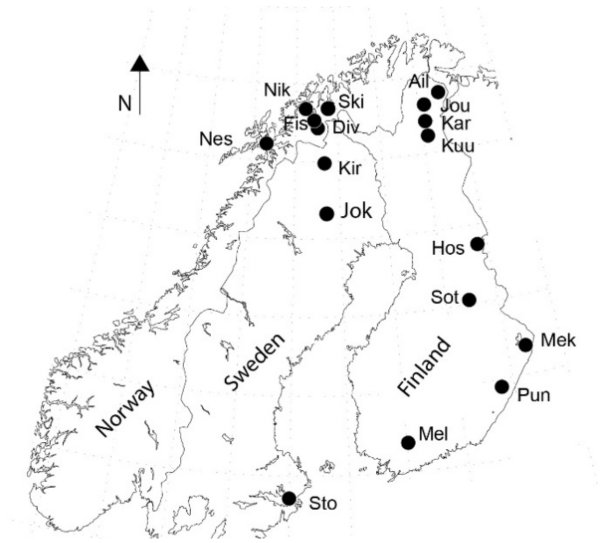

Figure 1: Map showing the 17 sampling sites in Fennoscandia

The age-effect of the tree-ring series was removed using Negative Exponential Curve Standardization after a data adaptive power transformation (Cook & Peters 1997). We calculated residual time-series and stabilized the variance using the Rbar-weighted method (Osborne et al. 1997). After truncating all series at a minimum replication of five series the common period of all site chronologies equals 1882 to 2009.

Two different statistical methods were used to identify homogeneous groups in the dataset: A Principal Component Analysis (PCA) and a hierarchical cluster analysis of variables (HCAv). With HCAv the correlation ratio between the variables(site chronologies) and the center of the cluster, represented by the first Principle Component (PC) of a PCAmix, is calculated (Chavent et al. 2012). Calculations were done with R3.1.1 (R Development Core Team 2014) and the package ClustOfVar (Chavent et al. 2012).

Results

The PCA approach results inan obvious distinction of the chronologies into two main groups (Figure 2a). Seven chronologies are positively correlated with PC1 and PC2 (group A) and ten chronologies correlate positively with PC1 and negatively with PC2 (group B). Surprisingly, these groups do not show a spatial (longitudinal or latitudinal) pattern (Figure 2b). The southernmost site (Sto), for example, is the only site below the Arctic Circle containing common variance with the northern chronologies(especially sites located in the northeast of the network).The comparison of the site chronologies of the two groups (Figure 2c) reveals that group A chronologies contain a distinct increase in tree-growth at the beginning of the 20th century (1900 to 1930), while this increase is largely missing in the group B chronologies.

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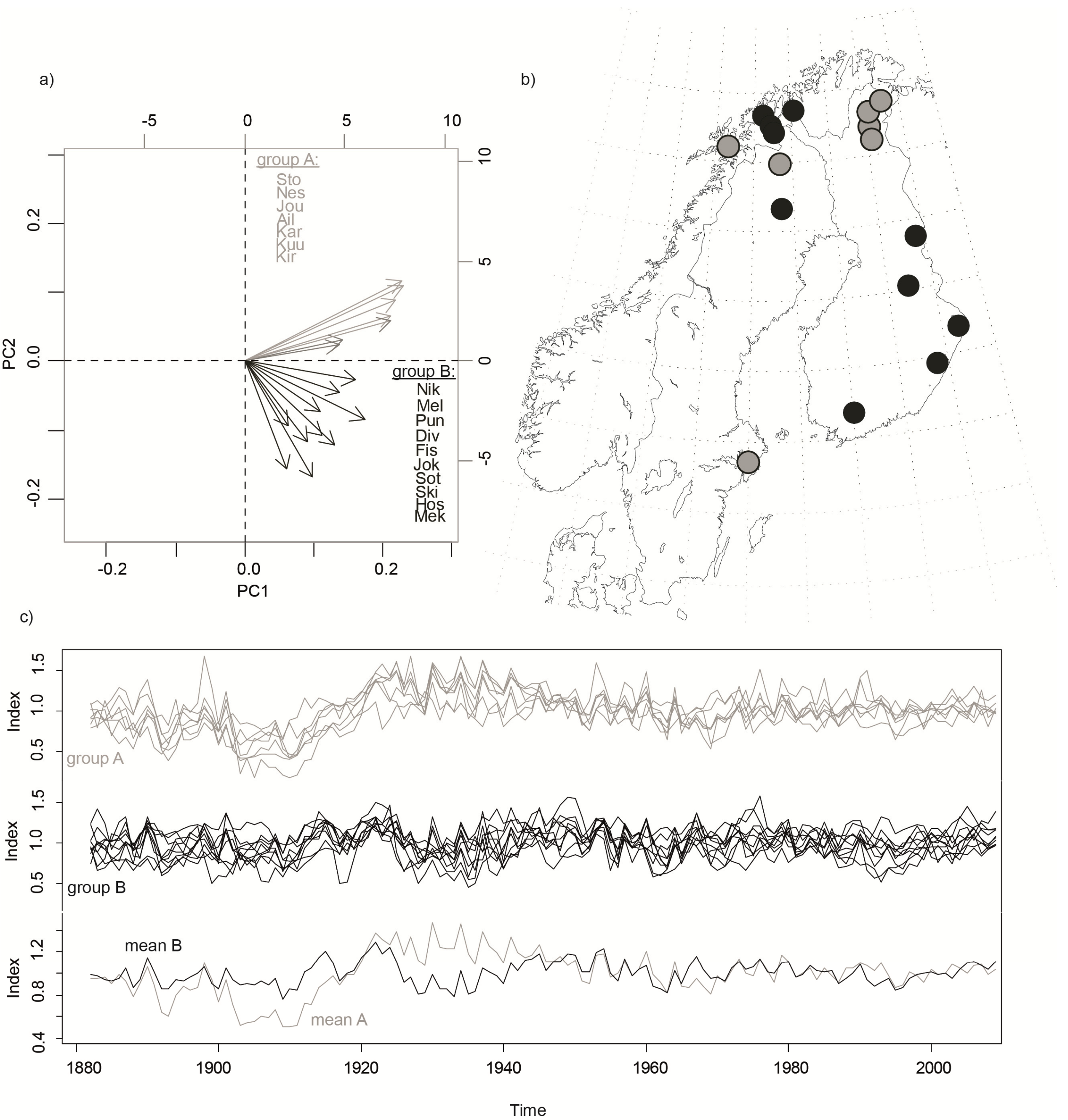

Figure 2: PCA on the Fennoscandian tree-ring network. a) Biplot for PC1 and PC2. Grey (black) arrows belong to group A (B). b) Map showing the spatial distribution of group A (grey) and group B (black) c) Site chronologies of group A (at top),group B (center), and mean chronologies of the respective groups (bottom).

With HCAv two main groups were classified on the first level of the dendrogram (Fig.3a), dividing the data into Northern and Central sites (Fig. 3a &b). Next to these two main groups we could define sub-regions: In the northern parts of Norway and Finland a differentiation of a western and an eastern cluster can be detected, with one cluster being located in the Scandinavian mountain range and the other in the area of Lake Inari in northeastern Finland. Within the second main region (central), two sites in Finland (Sot and Hos) could be separated from the other sites to an own cluster. The classification indicates that the division into three or four clusters offers the most robust results (Fig. 3c).

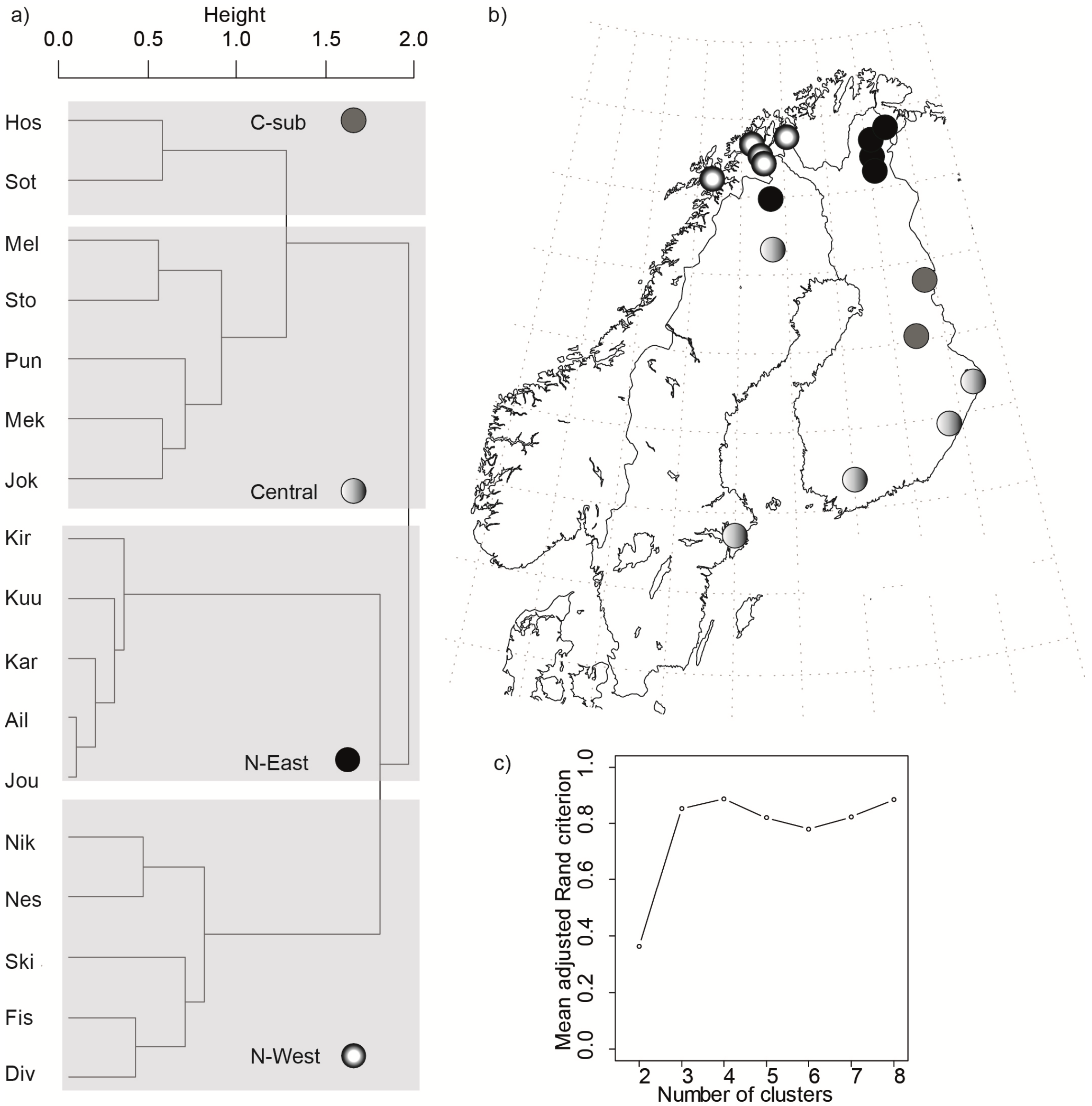

Figure 3:Cluster analysis of the Fennoscandian tree-ring network. a) Dendrogramm for the clustered sections. Grey fields mark the clusters. b) Map showing the spatial distribution of the sites with regard to the clusters.c)Stability of partitions obtained from a hierarchy of 17 variables.

Discussion

Boreal forest trees are known as being temperature sensitive (Lindholm et al. 2000, Messier et al. 1999)and we expect nearby sites to share variance as summer temperature patterns synchronize tree-growth in space. Düthorn et al. (2015) already displayed that the variance of tree-ring chronologies is related to latitude and might be a good indicator to combine different site chronologies. For assessing common variance among chronologies in more detail, PCA might be a helpful tool(Peters et al. 1981).In our study the PCA helped identifying coherent growth patterns but the method did not support the differentiation of clear spatial clusters. The sites within group A are mainly located in northern Finland but this group also includes the most western (Nes) and southernmost (Sto) sites, i.e. this group contains sites with a distance of up to 1000km in between. However, the difference between groups A and B is defined by the different relationship to PC2.

Since we expected a more pronounced spatial pattern and a grouping of nearby sites, we considered a HCAv which finally provides a clear latitudinal and longitudinal differentiation of the chronologies. The 3-4 clusters from HCAv seem to support the existence of spatially coherent climatic patterns in Fennoscandia. These settings represent the synchronizing aspect of climate ontree-growth. It is generally known that tree growth depends on a variety of external influences

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but that these factors can be reduced to one main limiting factor, especially at the altitudinal and latitudinal edge of a species distribution (Fritts 1976). In Scandinavia, we can relate the common influencing factors for the clusters to the latitudinal climate gradient. In the northern area we expect summer temperature as synchronizing factor for tree-growth, while the differentiation in eastern and western chronologies can be associated to the longitudinal position with respect to the Scandinavian Mountains. The sites provide a relatively strict division into Luv (west) and Lee (east) sites. The structure of the central cluster is also very robust and all sites below the Arctic Cycle are combined. The outsourcing of two sites (Hos and Sot) to a fourth group displays that mainly spatially close sites are combined with a higher number of clusters as they should experience similar environmental conditions.

Conclusion

Cluster analysis of variables is a reasonable tool to emphasize coherency and spatial patterns, and subsequently reduce the dimension and the number of site chronologies as tree-ring series can be averaged to macro-scale chronologies. The approach is also statistically unbiased as the analysis combines different independent methods as inter-site correlations and PCA. This enables a structuring of chronologies in space and can help identifying common influences at the macro-scale.

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