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UNCERTAINTIES OF TREELINE ALTERATIONS DUE TO CLIMATIC CHANGE DURING THE PAST CENTURY IN THE CENTRAL NORWEGIAN SCANDES

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ABSTRACT

Treelines are widely used as an indicator for the observation of nature response to climatic change. One major difficulty in analysing treeline responses to climatic change is the global influence of non-climatic ecological variables on the ecosystems first and foremost land use. In this study we aimed to uncouple non-climatic and climatic ecological variables and to assess their influence on the treeline ecosystem. An integrative approach was used to analyse treeline alterations throughout the past century in the central Norwegian Scandes. Bitemporal aerial photo interpretation, dendrochronology, and analyses of land use and climatic change impacts were applied to enable correlation and trend statistics. Our results showed that the treeline ecotone had changed as characterised by reestablishment of forest fragments in formerly used pastures and slight upward-shifts of solitary trees. Land use decreased but we found an additional positive mean annual trend of air temperatures. Uncoupling this ecological variables revealed a differentiated picture: The temperature increase was restricted to the winter month only; but, we found neither summer temperatures nor lengths of the growing period to be changed significantly over the past decades. Direct causal response to climatic change could be neglected by our findings. Contrasting literature, our findings reveal that seasonal climate patterns did not trigger treeline alterations. Uncoupling environmental triggers is essential for understanding both current treeline alterations and future distribution patterns. As a consequence, models predicting future treeline distributions by assuming a direct climate–treeline response must fail on a regional scale.

Keywords: Global warming, climate-growth relations, *Betula pubescens* ssp. *czerepanovii*, land use changes, forest regeneration, uncoupling environmental triggers, mountain ecosystems.

INTRODUCTION

Since a drastic global warming was primary predicted, much attention was set on the discovery of nature responses to climatic change (MCCARTHY et al. 2001, WALTHER et al. 2002, PARMESAN & YOHE 2003). Due to climatic limitation of tree growth in arctic-alpine environments, treeline alterations especially in the boreal and temperate climatic zones are regarded as distinctive regional response indicators of climatic change (PAYETTE & LAVOIE 1994; KULLMAN 1998). A small temperature depression in the 60th and 70th climate warmed significantly and regionally differentiated in all parts of the world (HOUGHTON et al. 2001). Up to now, some studies proved the treeline to react on this recent change (KULLMAN 2001; MOISEEV & SHIYATOV 2003). In Norway, an increase of mean temperatures by 0.7 K (in 2020) and 1.1 K (2050) respectively, accompanied by stable precipitation was forecasted (HOUGHTON et al. 2001), causing a high potential for a drastic upward shift of the treeline.

One major difficulty in analysing nature responses to climatic change is the global and heavy influence of non-climatic ecological variables on global ecosystems. Besides the influence of climate, a variety of non-climatic ecological variables are considered to influence to treeline distribution as well (OKSANEN et al. 1995; HOFGAARD 1997a; 1997b; KÖRNER 2003; HOLTMEIER 2003). HOFGAARD (1999) i.e. emphasised the long-term and strong influence of human activity on the alpine and subalpine altitudinal belts in the Norwegian Scandes regionally or temporally overriding responses to climatic change (HOFGAARD 1997). Anthropogenic delimited treelines showed greatest altitudinal shifts after cessation of land use impact in general (HOLTMEIER & BROLL 2005) and this recovery is sometimes misinterpreted as an effect of climatic change.

Investigations dealing with responses of the treeline to climatic change must cope with the complexity of treeline ecosystems (HOLTMEIER 2003; LÖFFLER et al. 2004; DALEN & HOFGAARD 2004), demanding complex and integrative approaches (RÖSSLER et al. under review). Therefore, our study aims at analysing treeline alterations during the past century in eastern Norway. We tried to uncouple the effects of land use and climatic change. Finally, uncertainties of treeline responses to climatic change were assessed in order to improve predictions of treeline distribution in the future.

STUDY AREA

The study area *Vågå* (61°53’ N, 9°15’ E, Figure 1) is situated east of the central Norwegian mountain chain and characterised by the most continental climate found in Scandinavia with lowest annual precipitation sums of ~ 300 mm/a in the valleys (KLEMSDAL 1980). Petrography of the *Vågå* region is characterized by glacially shaped phyllitic parent rocks of moderate weathering capacity but silicate-acid chemistry (STRAND 1951). *Betula pubescens* ssp. *czerepanovii* (hereafter referred to as *Betula pubescens*) forms the subalpine belt as well as the current treeline (Figure 1, picture) at app. 1,050 m a.s.l. A patchy treeline ecotone (Figure 1, picture) transfers into low alpine vegetation dominated by dwarf shrubs (DAHL 1986). The *Betula pubescens* species line was found at 1,400 m a.s.l. The region is characterized by the lowest mean annual precipitation (300–500 mm) found in Norway (KLEIVEN 1959). Figure 1 illustrates the location of the study area in Norway and the position of the meteorological station *Fokstua* (DNMI).

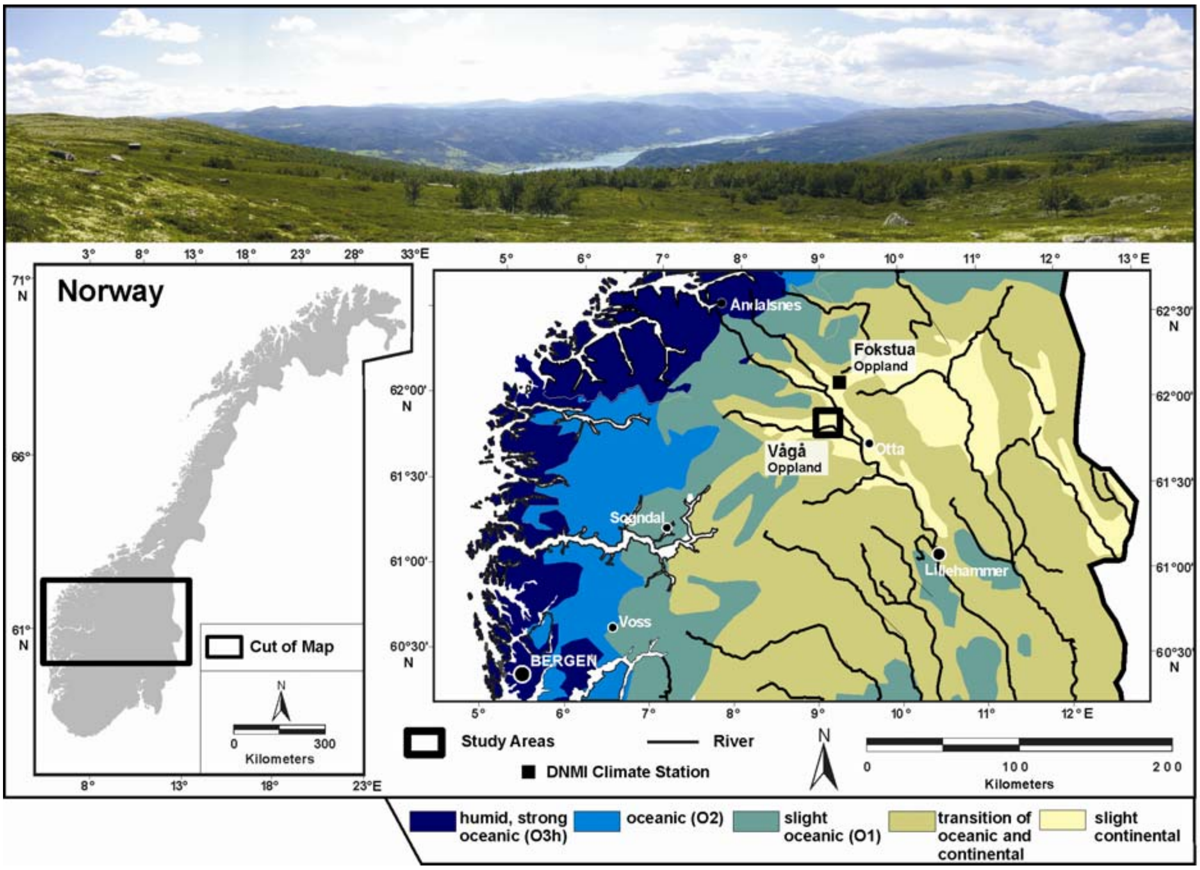

Figure 1 Location of the study area *Vågå* and the meteorological station *Fokstua* (DNMI) and their allocation to the different climatic regions in central Norway (map modified after MOEN 1999).

METHODS

To delineate treeline alterations throughout the past century we used aerial photo interpretation. More detailed and temporally explicit data concerning tree growth conditions at the treeline were sampled and tree ring widths were measured. We assumed that better growth conditions and therefore wider tree rings indicate a higher potential for the treeline to rise with altitude. Since land use and climatic change are documented to have strongest effects on treeline alterations (HOLTMEIER & BROLL 2005) we analysed both, ecological variables according to their temporal change, and to their impact on the treeline. Finally, land use and climate variables were correlated with tree ring data and treeline alteration causally and statistically. This strategy yield uncoupled values of influence for each ecological variable.

Treeline alterations were detected using bitemporal aerial photo interpretation (LÖFFLER et al. 2004; RÖSSLER et al. under review). We used earliest and latest aerial photos available (1964 and 1992). The aerial photos were orthorectified using a digital elevation model with a resolution of 25 m. Forest fragments, solitary trees and woodless areas were categorised besides structural features like rivers and roads. A threshold of 100 m^2 was used to distinguish solitary trees and forest fragments.

To obtain data of land use intensity in the study area, we accomplished interviews and inquires. Inquiries acquired information about form and intensity of past and present land use. Official statistics provided quantitative data about past and present numbers of grazing animals and numbers of mountain summer farms. Additionally, local farmers and landowners were interrogated about land use changes using a qualitative, informal and semi-structured approach (LUNDBERG 2002).

The Norwegian Meteorological Institute (DNMI) provided long-term data of monthly mean temperatures and precipitation from the climate station *Fokstua* since 1925 (DNMI 1925–2003). Moreover, daily mean temperatures were obtained within the time period of 1957–2002. *Fokstua* is located at 972 m a.s.l. app. 50 km northwest of the study area *Vågå* (figure 1). We tested the transferability of the climate data to the *Vågå* area and found significant correlations (r = 0.90–0.98) (BÄR et al. under review). Due to the operation time of the used station (earliest data from 1925) and sampling date of tree rings (2003), we analysed the maximal time frame possible for analyses (1925–2002).

We analysed both annual and monthly mean temperatures as well as precipitation sums. Furthermore, we calculated the length and the mean temperature of the growing period as defined by KÖRNER & PAULSEN (2004): Start and end point of the vegetation season are termed by 3.2° C soil temperatures equivalent to a weekly mean air temperature of 0° C. For this purpose daily mean temperatures are needed but limited by availability. In the present study, daily mean temperatures were obtained from the meteorological station *Fokstua* since 1956.

Firstly, we accomplished a linear fit to the mean annual temperature and annual precipitation sum of the analysed time period. Secondly, monthly data of temperatures and precipitation were tested as to intraannual trends. The magnitude of the trends was calculated using SEN's slope equation (SEN 1968) and the non-parametrical MANN-KENDALL tests was applied to estimate the significance (MANN 1945; KENDALL 1970). Calculations of precipitation and temperature trends were based on monthly means using MAKESENS (SALMI et al. 2002). Thirdly, to analyse climate-growth relations we calculated bivariate correlations between tree ring width (see below) and meteorological ecological variables that are known to be major controllers of the *Betula pubescens* treeline and thus were assumed to have the strongest climatic effect on tree growth:

(1) AAS (1964) found a strong correlation between treeline position and warmest months of a year. Hence, we correlated ring width with monotherm (warmest month) and bitherm (mean of two warmest months) as well as tritherm (mean of three warmest month) and tetratherm (mean of four warmest months).

(2) We tested every monthly mean temperature and seasonal temperatures to influence tree ring growth (spring: AMJ; summer: JJA; autumn: ASO) as well as last year autumn (SON) and winter temperature (DJF) and the length and mean temperature of the growing period.

(3) To accommodate with the influence of snow as well as drought on the treeline we calculated the correlation for precipitation sums of each month and season (winter, spring, summer, autumn). PEARSON correlations were accomplished using SPSS 12 (SPSS 2003).

Finally, we tested all climatic ecological variables that had significant influence on tree growth as to their internal trend using SEN's slope equation and the MANN-KENDALL-test as described above.

Within the treeline ecotone (950 and 1,050 m a.s.l.) several trees were cored twice, parallel and perpendicular to the slope. Tree ring-widths were measured using TSAPWIN (RINNTECH 2006) and mean curves of 14 tree cores were synchronized and served as the basis for a local *Betula pubescens* site chronology. Finally, the site chronology was age-detrended using a 32-year moving spline (BÄR et al. 2006; 2007). This standardized chronology was correlated with climate ecological variables as described above.

RESULTS

Regional treeline alterations

The comparison of both classified aerial photos show a slight increase, mainly within the treeline ecotone as successional stages of former pastures (Figure 2) and along infrastructures. Moreover, solitary trees within the treeline ecotone accreted and form closed forest fragments at present. Above the former treeline few solitary trees established up to app. 1,100 m a.s.l.

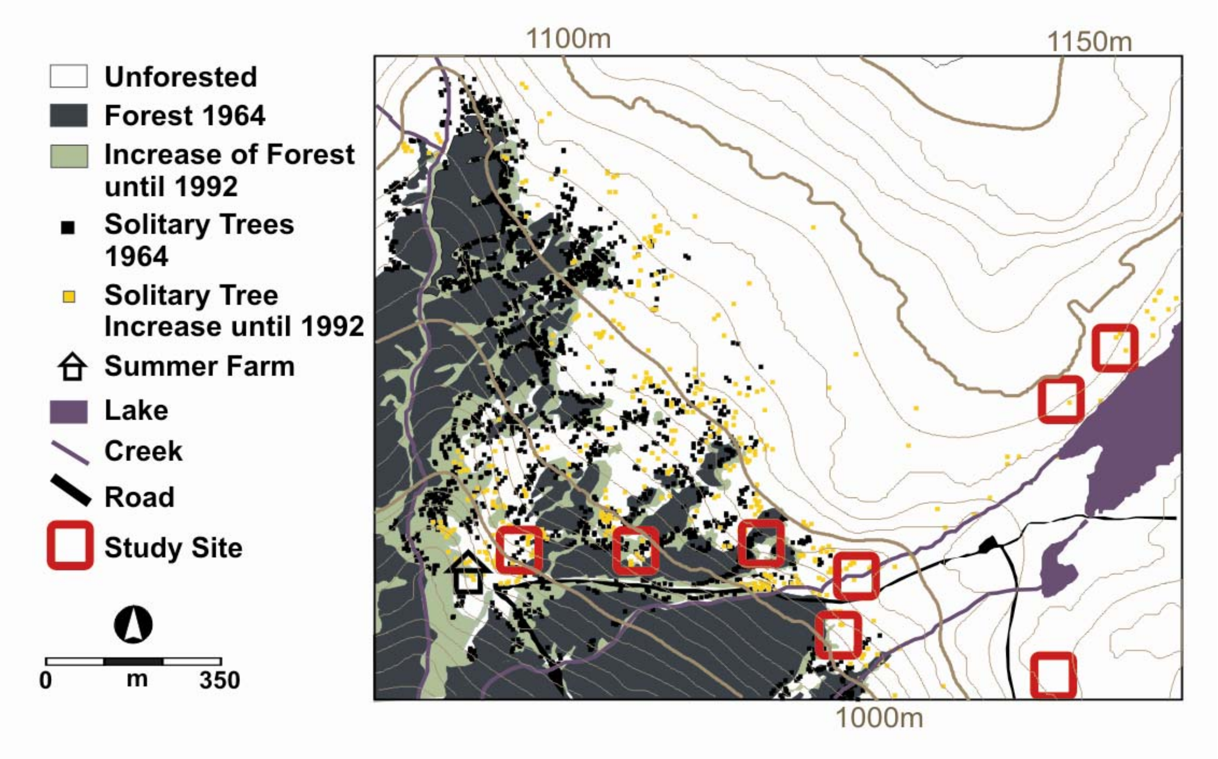

Figure 2 Patterns of treeline alterations between 1964 and 1992 are graphed revealing an reforestation of formerly open areas and a slight upward shift of solitary trees.

Land use changes

Interviews and statistical data analyses revealed changes of land use in the study area during the past century. The development of livestock in the Vågå commune is shown in Figure 3. In conjunction with the general trend of a decreased summer farm use (REINTON 1955; OLSSON et al. 2000) the number of cattle and goats diminished. In contrast, extensive pasture of sheep as part-time farming became more common, resulting in the high number of sheep. Recently, within the study area the grazing density is app. 21–25 animals per km², predominantly sheep (app. 1,400) (BEITEBRUKSPLAN 2001).

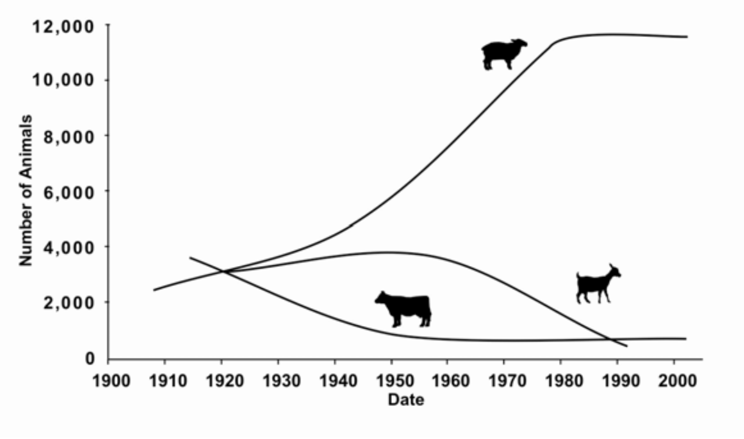

Figure 3 Land use change within the last century indicated by a decrease of goat and cattle stock and an increase of pasturing sheep.

Climate-growth response

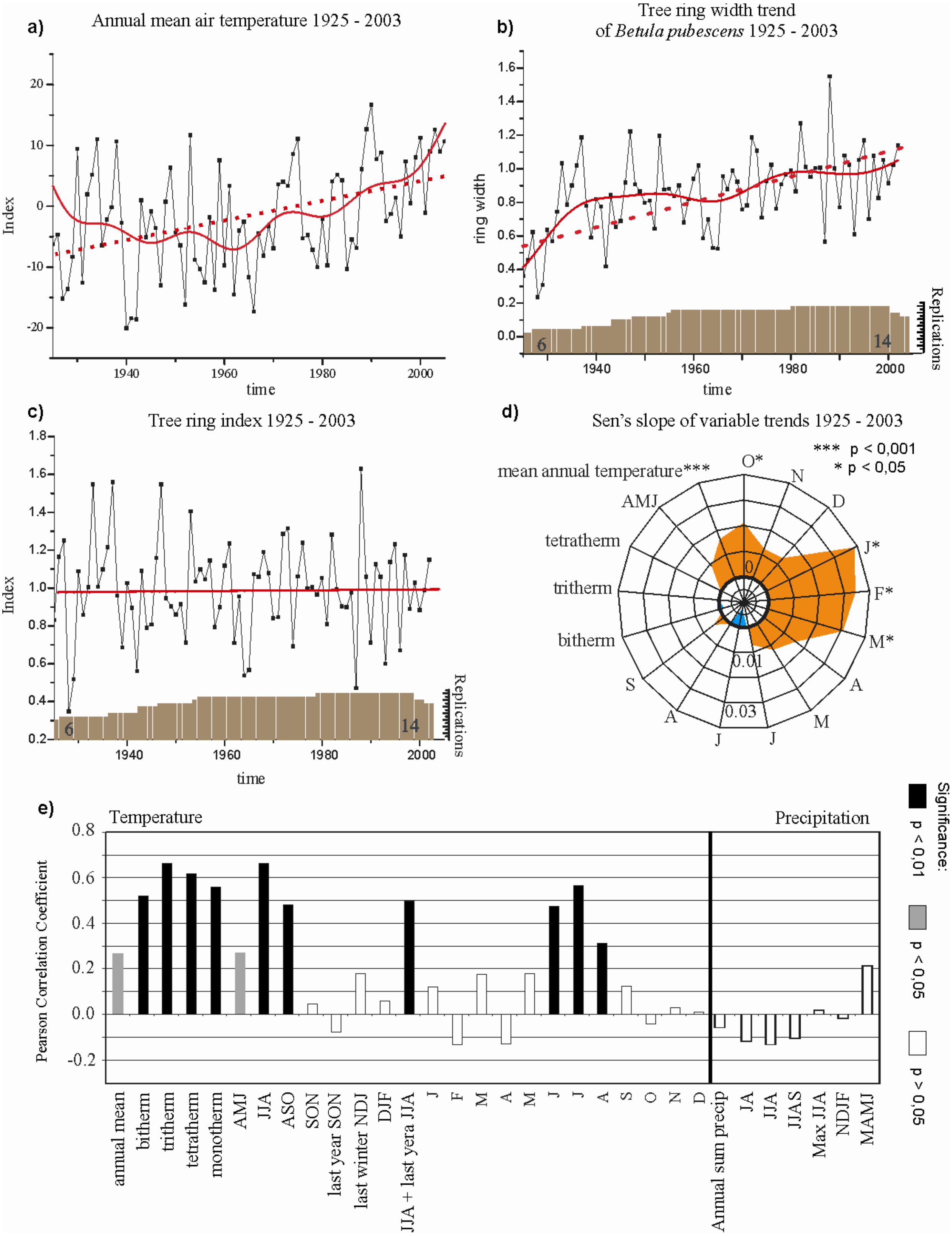

Figure 4 Climate-growth correlations of *Betula pubescens* at the current treeline ecotone: a) Time series of temperatures graphed with FFT-smoothing (9-years, red curve) and overall linear trend (dashed red line). Correlations with *Betula pubescens* tree ring width chronology; b) raw data (FFT-smoothing: red curve; linear fit (dashed red line), and c) age-detrended data (FFT-smoothing: red curve; linear fit (dashed red line); d) SEN's slope trends of best correlating variables between 1925–2005; e) PEARSON correlation coefficients of tested climatic ecological variables and level of significance (black: $p < 0.01$; grey: $p < 0.05$; white: $p > 0.05$).

The key findings of our climate-growth analyses are summarised in Figure 4 consisting of the temperature dynamic chart since 1925 plotted with a linear fitted trend (Figure 4a), the raw tree ring chronology with numbers of replicants (Figure 4b), an age-detrended, standardized tree ring chronology (Figure 4c) with number of replicants that was correlated with several climatic ecological variables (Figure 4e), as well as a amoeba diagram of most important parameter trends (Figure 4d). The linear fit shows a slightly positive trend for both annual mean temperature (+0.016*y^{-1}) and tree ring width (+0.008*y^{-1}, Figure 4a, 4b). Bivariate correlation of mean annual temperature with standardized tree ring data (Figure 4c) was significant by means of PEARSON correlation coefficients (r^2 = 0.264, p = 0.05). Further correlations of the tree ring data with climatic ecological variables are presented in the bar chart in Figure 4e: summer temperatures strongly affect tree ring increment, especially the bitherm and the JJA mean. In contrast, we found only slight effects of spring temperatures and neither any effect of winter and autumn temperatures nor of all precipitation parameter tested. These results are in accordance with literature, but since tree ring data show a positive trend (Figure 4b) we also expected a trend in the determining ecological variables. As illustrated by Figure 4d, we found no trend in the most influencing parameter like bitherm and JJA. Moreover, the temperature trend of July is slightly decreasing (-0.008°C*y^{-1}). In contrast, winter and autumn temperatures possess a strong, significant positive trend, i.e. January +0.039 °C*y^{-1}, but no significant correlation to tree ring increments. So, annual mean temperature is likely to improve tree growth, but we found no physio-ecological explanation for this correlation.

Since there were slightly positive temperature trends in May and September we tested the tree ring increment as a function of the length and the mean temperature of the growing period. Correlations were significant ($p < 0.05$) between the Vågå tree ring chronology and both growing period variables. But again, we found no significant positive linear trend of the variables. Table 1 summarises the correlation coefficient and the trend analyses.

Table 1 Results of trend analysis of length and mean temperature of the growing period in 1957–2002 as well as the correlation with the standardized *Betula pubescens* chronology.

	Analysed trend	Level of significance	Correlation coefficient to tree ring chronology
Length of growing period	0.000 d/y	0.05	-0.371
Mean temperature of growing period	0.001 d/y	0.01	0.688

DISCUSSION

Our results show that treeline alterations are characterised by a reestablishment of forest fragments in formerly used pastures and by a slight upward-shift of solitary trees. Regarding the potential treeline position as calculated by AAS & FAARLUND (2000) (~ 1,150m a.s.l.) even the slight upward trend of few solitary trees have to be interpreted as a recovery of formerly forested areas. This development is in line with results from several other regions in Norway (AAS & FAARLUND 1995; 1996; HOFGAARD 1997; 1999; OLSSON et al. 2000). During the 1960th Norway has been facing a strong transformational process characterised by land use change from subsistence farming including summer farms towards a high intensity, modern farming concentrating in the valleys (STATISTIKK SENTRALBYRÅ 2007). Both processes led to a decrease of land use intensity in marginal areas like alpine mountain areas that is likely to trigger an upward-shift of treelines (AAS & FAARLUND 1996).

Parallel to the observed treeline reestablishment annual mean temperatures increased, questioning the influence of climate. Seasonal temperature trends showed that the increase of mean annual temperatures was restricted to the winter months only. Our climatic analyses are in line with analyses done by FØRLAND et al. (2000) for entire Norway since 1879, who found also a positive annual trend, but decreasing and insignificant changes of summer temperatures and a strong positive winter temperature trend. Regarding the physio-ecology of deciduous *Betula pubescens* trees we found no significant correlation of ring widths to winter month temperatures. Nor did we find any correlation to winter precipitation as reported by VAGANOV et al. (1999) for subarctic Eurasian conifers.

Commonly known, *Betula pubescens* is mainly influenced by summer air temperatures and means of growing period temperatures at the alpine treeline (i.e. AAS 1964; TUHKANEN 1980; ODLAND 1996). For pine treelines in the Swedish Scandes KULLMAN (2007) concluded that seasonal temperature patterns have to be considered to explain treeline alterations. Our study strongly supports these investigations. But, we found neither summer temperatures nor growing periods to change significantly over the past decades being responsible for tree ring-widths increase and upward shifts of the treeline. Thus, we question how the observed positive trend in tree ring data and the slight upward-shift of the studied treeline might be explained. Direct causal response to climatic change could be neglected by our findings. Moreover, in our study area land use change and site history superposed the impact of climate. Both of our findings are in general accordance with current literature (i.e. DALEN & HOFGAARD 2005). Contrasting literature, our findings revealed that seasonal climate patterns do not trigger current treeline alterations in central Norway.

To conclude, uncoupling environmental triggers is essential for understanding both current treeline alterations and future distribution patterns. The impact of climatic change on treeline alterations might be obvious regarding mean annual temperature trends. Seasonal climate patterns must be considered but cannot explain current treeline alterations. As a consequence, models predicting future treeline distributions (i.e. MOEN et al. 2004) by assuming a direct climate–treeline response must fail on a regional scale.

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