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Climate-growth relationships of the dwarf shrub species *Empetrum hermaphroditum* in the Norwegian Scandes

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Introduction

Dwarf shrubs present a good, but until now relatively unstudied, resource to research high alpine climate fluctuations, both between different microsites and in the greater geographic area where climate information is rare. The circumpolar abundance of the dwarf shrub *Empetrum hermaphroditum* along with the relative clarity of its rings, compared to other species, make it an ideal specimen for this study and others that may follow. By analyzing the tree-ring structure of *E. hermaphroditum* at different microsites, this study tries to determine micro-climatic differences between the sites and the factors that most significantly control the growth of the dwarf shrub. Many problems in the tree-ring record make dating synchronization difficult, however. This includes the presence of wedging rings, missing rings, frost rings, and asymmetric growth common to dwarf shrubs, largely as the result of the extreme environment which they inhabit (Kolishchuk 1990, Woodcook & Bradley 1994, Schweingruber 2001, Schweingruber & Poschlod 2005, Bär et al. 2006).

Material and Methods

Study Area

Samples were taken from the middle alpine belt in the Vågå/Oppland region (61° 53´ N; 9° 15´ E) of the Central Norwegian Scandes, which experience one of the most continental climates of Scandinavia and receive precipitation of 300 – 400 mm/yr (Moen 1999). The middle alpine belt ranges from about 1,350 m to 1,500 m a.s.l. and vegetation in the zone is scarce and scattered. The upper tree line is located at about 1,000 m a.s.l. *E. hermaphroditum* is close to its altitudinal limit at the study sites. Samples were taken from two microsite types, at ridges and north-facing slopes. Shrubs at north-facing slopes are protected by snow cover throughout winter until mid June, while at ridge positions they lack snow cover due to the presence of high winds and are therefore exposed nearly year-round.

Sampling Preparation and Analysis

Complete individuals of *E. hermaphroditum* were collected from both sites and photographed. Microtome sections of each individual were taken using a sledge microtome, with some individuals having many cross-sections for the detection of inconsistent rings along the stem applying the “serial sectioning” method (Kolishchuk, 1990; Bär et al. 2006). Ring widths were measured from digital photos of the microtome. This was done in each image along two transects (cores) that had the least complications from irregular growth. All individuals from each microsite were synchronized using the “serial sectioning” curves and prints of the digital photos as a reference. A ring width chronology from *Betula pubescens* growing at the local tree line was used for a final cross-dating check due to the lack of preexisting dwarf shrub chronologies and experience. Using the program ARSTAN (Cook 1985), the mean curves were detrended using a 32 year smoothing spline to remove age related growth trends, intra-plant variations, and long term growth trends.

Climate Analysis

Data from the closest official climate station was used in growth-climate analysis. Data was taken from the “Fokstua”/Oppland station, approximately 40 km northeast from the sampling sites at 970 m a.s.l. in the Dovre mountain range on a ridge position (Meteorologisk institutt, eklima 2006). This station provides continuous measurements over the whole time period covered by the chronologies and gives data for monthly mean temperatures and precipitation sums. Anomalies of mean monthly temperatures and precipitation sums were calculated for single years which represent wide rings in 1988 and 1997 and narrow rings in 1990 and 1993. Graphs were made for these years, where anomalies are expressed as standard deviations from the means of each single month from 1923-2004, the longest time period for which data is available (figure 1).

Results and Discussion

Chronology Characteristics

The oldest individuals of *E. hermaphroditum* found were between 80 and 85 years (Bär et al. 2006). However, we confined the chronology to only the last 54 years due to decreasing sample depth and uncertainty in dating. These are the first chronologies ever developed using standard methods of ring width analysis for dwarf shrubs, specifically *E. hermaphroditum*. The chronologies show very high inter-annual variations expressed by low and even negative autocorrelation values (table 1). Variations between the two micro-site types were small and highly correlated, with $r = 0.81$ ($p < 0.01$), however. The chronologies differ in mean annual growth increments, with the chronology for the ridge site type showing larger rings (figure 1). The ridge chronology shows average growth of 0.09 mm/yr, compared to 0.07 mm/yr at north-facing slopes.

Table 1: Statistical characteristics of the raw-chronologies of E. hermaphroditum at the ridges and north-facing slopes, (N = max. number of radii included in the chronologies; Mean = mean growth increment; SD = standard deviation; AC(1) = first-order autocorrelation; rbar = mean correlation coefficient among all growth curves; EPS = expressed population signal). Bold values are significant at p < 0.01, others at p < 0.05. Mean growth increment was calculated from the measured raw values, all other values were calculated for ARSTAN standard chronologies.

Chronology	N	Mean [mm] ± SD	AC(1)	Mean rbar	Mean EPS
Ridge	54	0.09 ± 0.05	-0.01	**0.38**	0.87
North-facing slope	37	0.07 ± 0.03	-0.04	**0.42**	0.88

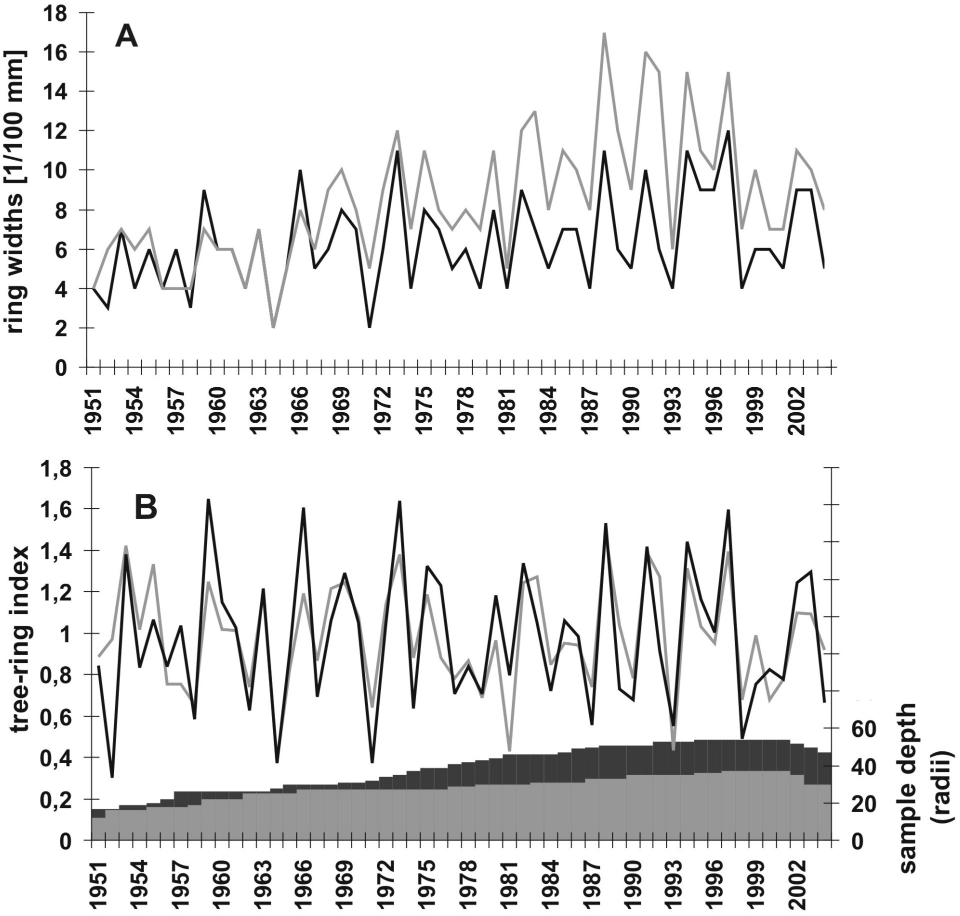

Figure 1: Growth-ring chronologies of E. hermaphroditum at the north-facing slopes (black curve) and at the ridges (grey curve). The chronologies in a) are raw values of annual growth increments whereas those in b) were standardized using a 32 year smoothing spline function.

Climate – Growth Relationships

The period from June to August, when average air temperatures exceed 5 °C, is the normal growing season in the sampling region. Temperature during the growing season seems to be the primary factor in determining growth. In 1997 tree ring growth was significantly greater than in 1993, even though the length of the growing season was much shorter due to the late snow melt in 1997 (table 2 and figure 2). Average temperatures were much greater during the growing season in 1997. This suggests that the length of the growing period must only be a secondary factor in the amount of growth occurring in a year, being outweighed by the effects of temperature. The year 1988 showed above average temperatures from June to August and the mean temperature in May exceeded 5 °C, leading to an extended growing season. As expected the growth rate for that year was above average at both sites with rates of 0.17 mm/yr at ridges and 0.11 mm/yr at north-facing slopes. In 1990 temperatures during the growing season were about average, and the growth rate at the ridge position for that year was exactly average. The north-facing slope chronology showed a slightly lower than average growth rate for that year, however. This could possibly be due to the fact that more than average snow felt in that year, which could have limited the amount of time that growth was possible if the snow lasted into the growing season. This process could explain why the ring is smaller than could be explained by temperature values alone.

High positive correlation with seasonal means of mean temperatures from June to August at ridges were found with r = 0.74 (1951-2004; p<0.01). At north-facing slopes, the correlation coefficient was r = 0.76. No significant correlations could be found between monthly precipitation sums and ring widths. Even in this continental area soil moisture availability is not a limiting growth factor throughout the year (Löffler 2005) and the plants have adequate supply with melt water during the early growing season.

Table 2: Ring width values of E. hermaphroditum at the ridge and north facing slope micro-sites, temperature, and snow characteristics, for selected years. Temperature values are averages for the normal growing period from June to August (JJA).

Year	**1988**	**1990**	**1993**	**1997**
Ridge ring width [mm]	0.17	0.09	0.06	0.15
Slope ring width [mm]	0.11	0.05	0.04	0.12
Temperature JJA [°C]	10.6	9.5	7.2	11.7
Snow melt date	May 21	Apr 25	May 10	Jun 06

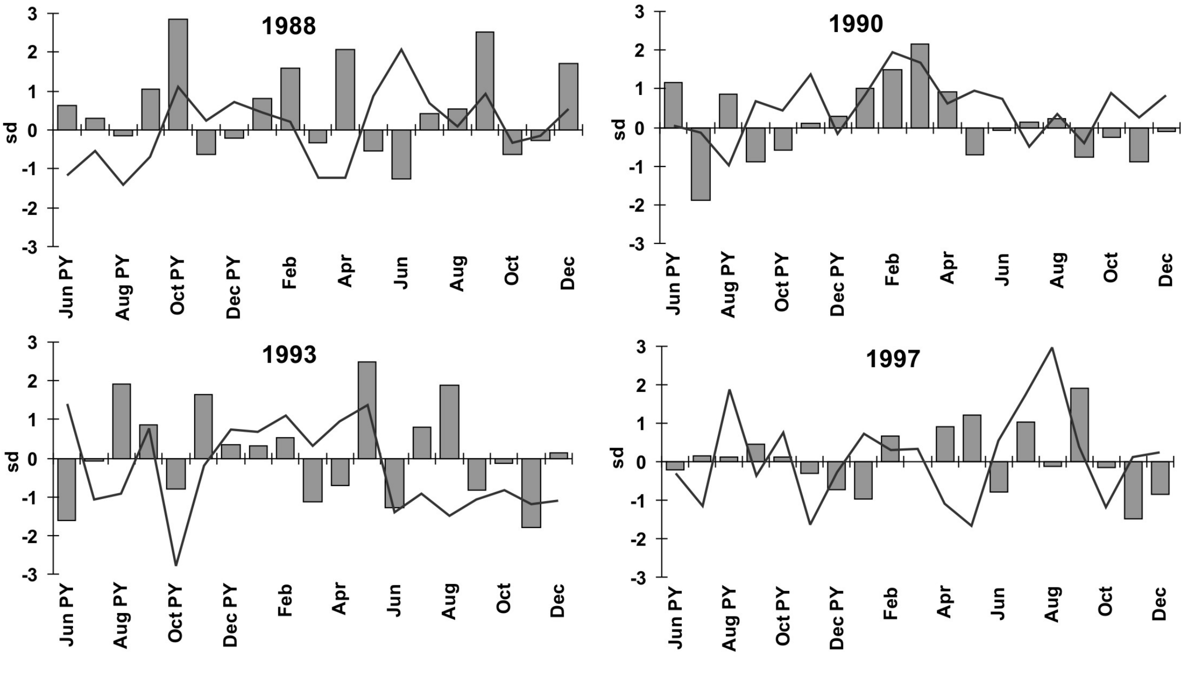

Figure 2: Anomalies of mean monthly temperatures and precipitation sums (grey bars) calculated for single years which represent wide rings in 1988 and 1997 and narrow rings in 1990 and 1993. Anomalies are expressed as standard deviations (sd) from the means of each single month from 1923-2004. Anomalies are given for single months of the previous year (PY) from June – December and January – October of the current year.

Conclusions

This study highlights the possibilities of using the growth rings of dwarf shrubs to analyze changes in the growing conditions of alpine environments. The results implicate that micro-climatic differences do not cause contrasting annual growth ring variations but lead to differences in the mean annual growth increments between north-facing slopes and ridges. Greater snow cover accumulation and duration might modify the length of the growing period and thus lead to lower annual increments at the north-facing slopes compared with those at the ridges. To determine the impact of temperature and snow cover duration resulting from micro-site differences more precisely, fine-scale analysis of micro-climate measurements within the sampling area will be carried out. Studying *E. hermaphroditum* growth rates at other micro-site types such as depressions, south facing slopes, and at different altitudes along with increasing the number of individuals analyzed will give a more comprehensive picture of how dwarf shrubs respond to different climatic factors due to micro-site differences. In large areas of alpine and arctic regions globally, dwarf shrubs provide the only information about climate and changes in growth over time, giving them a high potential for dendrochronological studies. Studies of this kind might help to expand approved dendroecological techniques into new climatic zones and contribute to a deeper knowledge of how alpine and arctic ecosystems are affected by expected future environmental changes.

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