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Stable isotope and tree-ring width variations of larch affected by larch budmoth outbreaks

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Introduction

European Larch (*Larix decidua* Mill.) possesses a high potential for dendroclimatic analyses due to its frequent occurrence at the timberline of the European Alps, due to its longevity of up to 1000 years and due to its growth sensitivity to temperature (Neuwirth, 2004). So far, European Larch is solely used for low-frequency temperature reconstructions (e.g. Büntgen et al., 2005) as medium-term variations occur in tree-ring growth curves which presently cannot be traced back to climatic factors. These variations are caused by larch budmoth (LBM; *Zeiraphera diniana* Gn) outbreaks. Normally, the population of this insect strongly multiplies at intervals of 8-9 years. Its larvae gnaw at the needles, gradually damaging them (Baltensweiler/Rubli, 1999). As a result, assimilation and tree-ring growth decrease accordingly. This causes a typical pattern in ring width which is characterised by an abrupt growth reduction in the year of the outbreak and the following year, with a slow increase of ring width afterwards. The way trees recover depends on the intensity of the previous outbreak. Obviously a number of plant physiological processes are affected such that only after several years the trees regain their normal ring growth activity. Stable isotopes usually provide better insight into plant physiological processes underlying tree growth than ring widths (Schleser, personal communication). Therefore the aim of this study was to investigate to what extent LBM outbreaks modify the signature of the stable carbon and oxygen isotopes of the corresponding tree-rings. The study area chosen is located in the Lötschental, an inner-alpine dry valley in Valais, Switzerland.

Material and Methods

For inter-annual $\delta^{13}C$ and $\delta^{18}O$ analysis we sampled 5 trees located at 2000m a.s.l. on a south exposed slope. After measuring the ring widths of the cores with a resolution of 0.01 mm, the cores were dated by synchronizing the ring widths with the corrected master-chronology of the Lötschental (Büntgen et al., 2004). The years of LBM outbreaks were identified by comparison of the tree-ring pattern with historical documentation which exists back to AD1850 (Baltensweiler and Rubli, 1999). Based on ring width data, LBM outbreaks were identified quantitatively as well as qualitatively. For each tree ring the relative width change was calculated by comparing with the mean value of the 4 previous years. The threshold for potential LBM outbreaks was fixed at 40% of growth reduction (Rolland et al., 2001). The qualitative way of detecting LBM outbreaks consisted in the visual detection of the typical pattern described above. The historical documentation confirmed these methods of identification of LBM outbreaks from ring width analyses. For stable isotope analyses each tree-ring of the time span AD1900-2004 was separated from 5mm cores.

It is usual to extract cellulose to concentrate on one chemical compound because the different components of the wood have different isotopic signatures. Nevertheless, we analysed cellulose and wood of one tree for the time span AD1950-1982, with the idea that similar results for cellulose and total wood could ease the workload considerably by concentrating on wood. The investigations resulted in a correlation coefficient between wood and cellulose of r = 0.84 for carbon and r = 0.91 for oxygen stable isotope ratios. Due to the high similarity we decided to use only wood for this study. The samples were measured by using an elemental analyser interfaced to a continuous flow isotope ratio mass spectrometer (Micromass Optima). The resulting δ-values are defined as the isotope ratio R of an element relative to the ratio of an internationally accepted reference material of this element. Thus, e.g.: $\delta^{13}C = [R_{sample}/R_{reference}-1]*1000$. Since the values are multiplied by 1000, δ-values are given as per mill (‰) deviation from the reference. The analytical error was < ±0.1‰ for carbon and < ±0.35‰ for oxygen isotope ratios.

Precipitation data covers the time span 1900-1995 and originate from the meteorological stations of Kippel (1370 m) and Ried (1480 m) in the Lötschental (Neuwirth, 1998, Neuwirth et al., 2004). The temperature data were taken from the ALPCLIM-Dataset (version 2004) (Böhm et al., 2001). The nearest climate stations to the site are Sion (482m a.s.l.) and Jungfraujoch (3572m a.s.l.). We calculated the mean adiabatic gradient from these two stations and used it to calculate the temperature at 2000m a.s.l. from the data of Sion for the time span 1900-2002.

Results and discussion

Potential outbreaks of LBM were identified for the years 1908, 1915, 1923, 1937, 1945, 1954, 1963, 1972 and 1981 on the basis of ring width. Tree-ring widths, $\delta^{13}C$ and $\delta^{18}O$ records are shown in figure 1, 2, and 3.

Tree-ring width records (Fig. 1) show decreasing values in the years of LBM outbreaks and still lower values in the following year except for 1923 and 1981. The $\delta^{18}O$-values (Fig. 2) are characterised by a strong decrease in the years of LBM outbreaks except for 1923, i.e. both, ring width and $\delta^{18}O$ respond to LBM outbreaks with strongly decreasing values. In contrast to ring width, $\delta^{18}O$-values solely decrease in the year of an outbreak. The following year seems to be not affected. In general, carbon isotopes also show a decrease in the year of LBM outbreak as compared to $\delta^{18}O$, but it is less pronounced. In the year after an outbreak, $\delta^{13}C$ shows both, increasing and decreasing values. A detailed analysis of the isotope changes will be given elsewhere (Weidner et al. in prep.). Unlike ring width, carbon and oxygen isotopes show increasing values in 1923. Although historical documentations and the qualitative and quantitative methods identify an outbreak in 1923, the isotope signature may indicate that probably no outbreak took place.

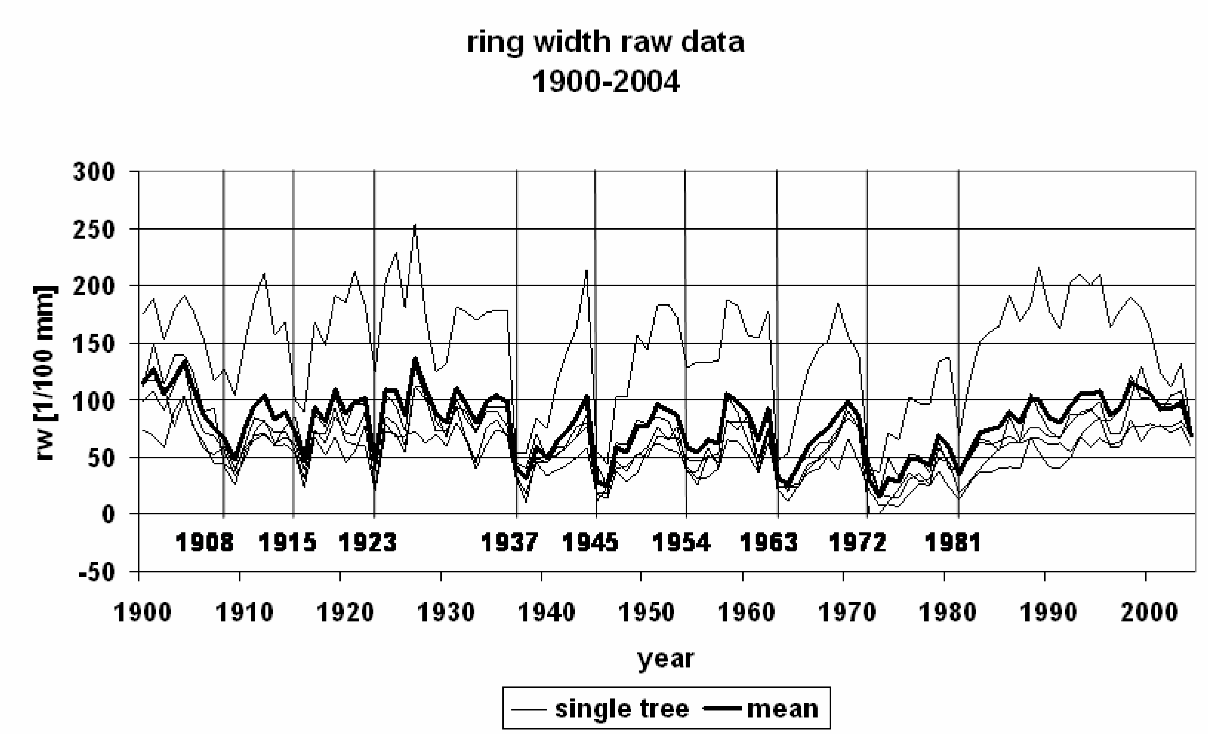

Figure 1: Records of ring widths and mean curve for the time period 1900-2004.

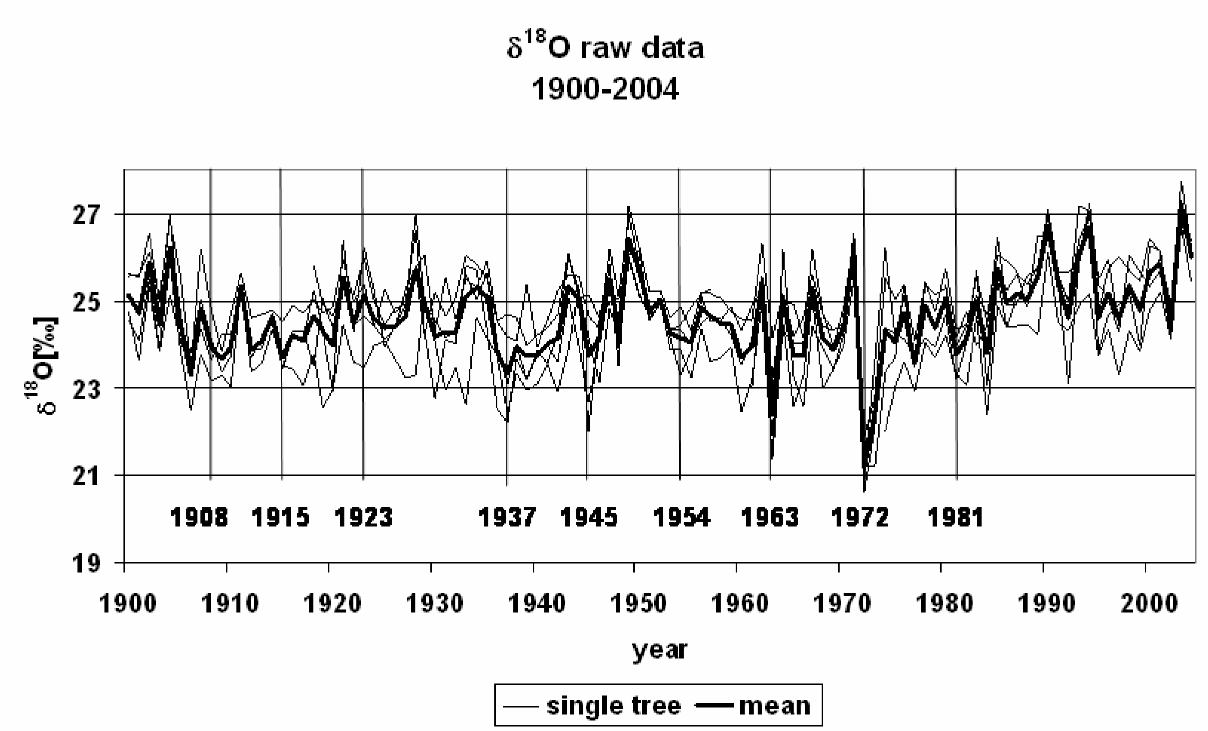

Figure 2: Records of $\delta^{18}O$ and mean curve for the time period 1900-2004.

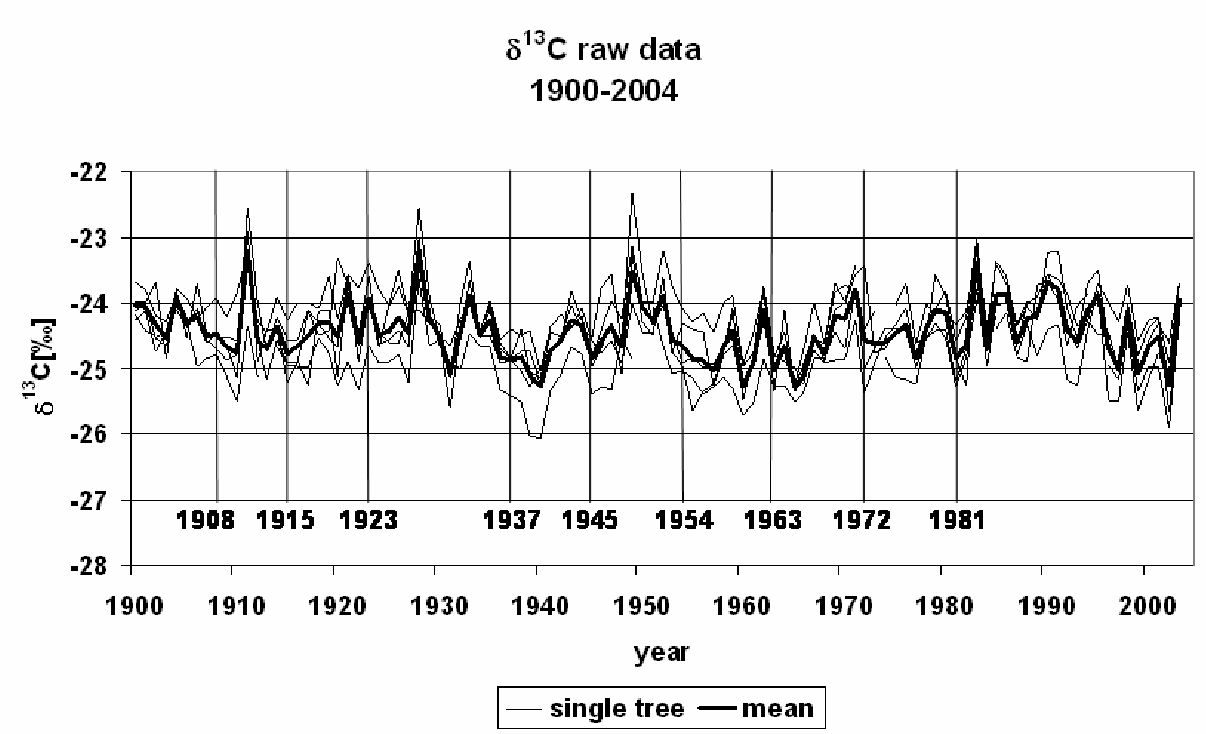

Figure 3: Records of $\delta^{13}C$ and mean curve for the time period 1900-2004.

Correlations between ring width, $\delta^{13}C$ and $\delta^{18}O$ and temperature are shown in Figure 4. Correlation between ring width and temperature is low. Just one tree exceeds the 99,9% significance level. On the contrary, correlations between oxygen and most notably between carbon isotopes and temperature are significantly positive in July and August.

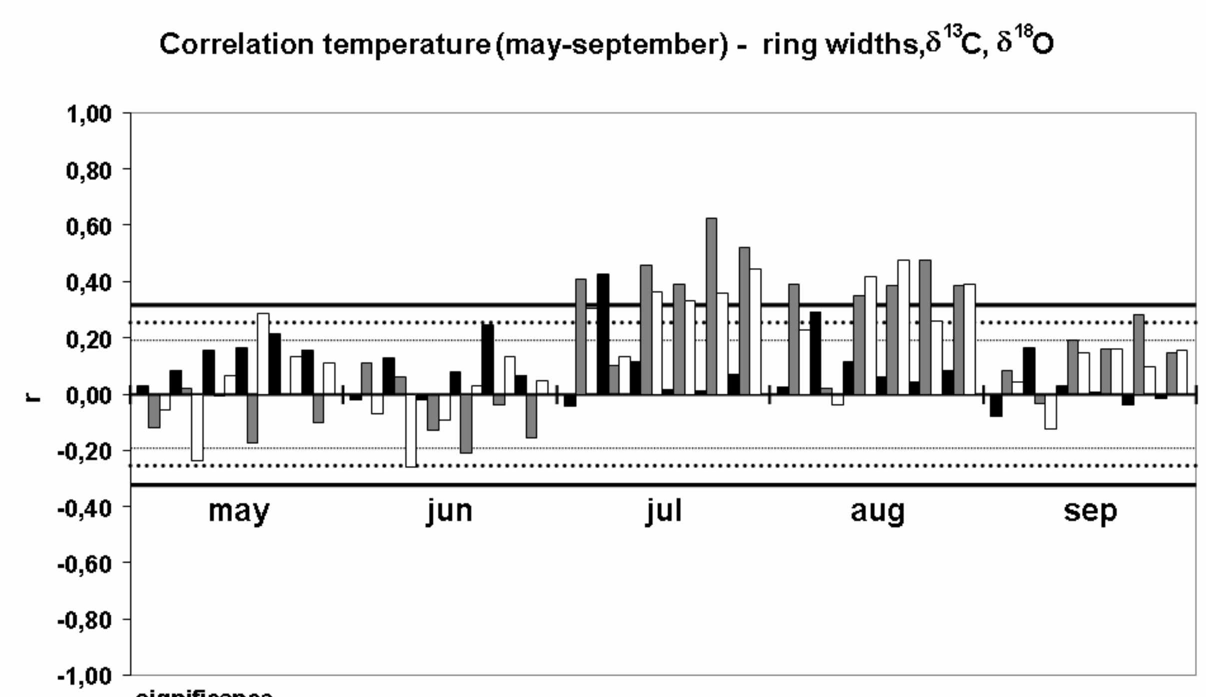

Figure 4: Correlation between ring width, $\delta^{13}C$ and $\delta^{18}O$ and temperature during the growth period.

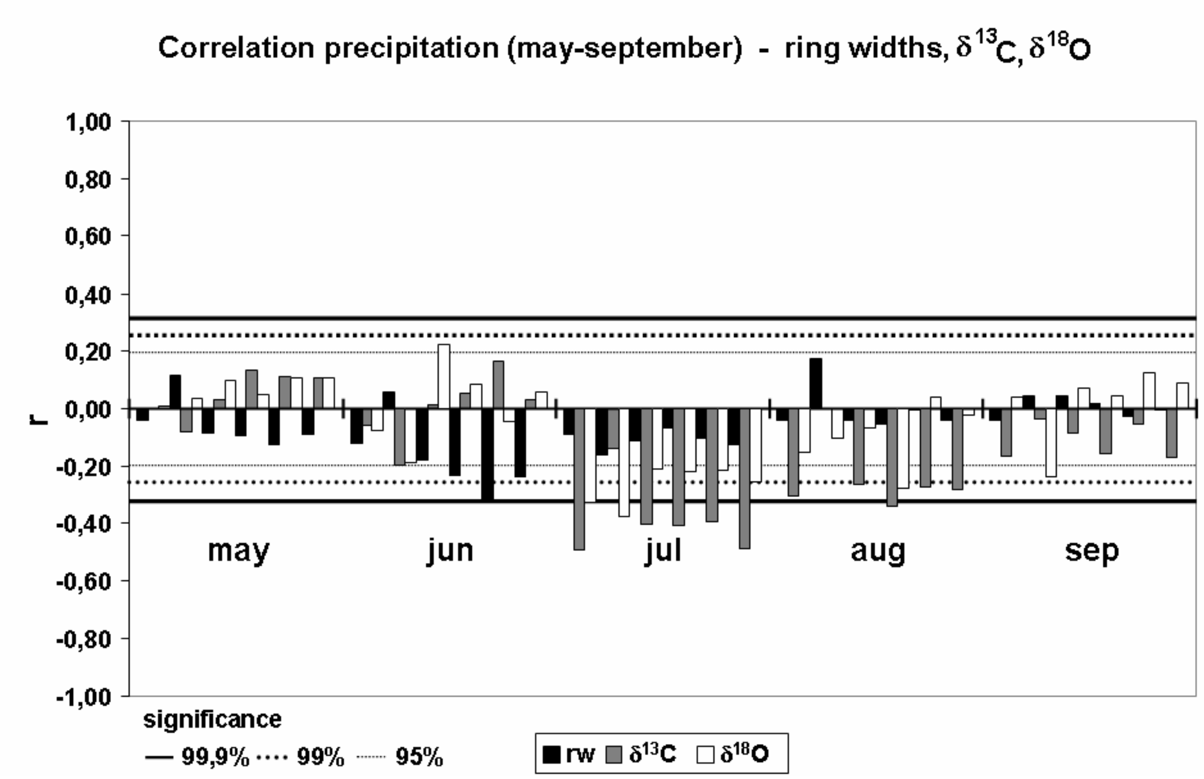

Figure 5: Correlation between ring width, $\delta^{13}C$ and $\delta^{18}O$ and precipitation during the growth period.

Correlations between ring width, $\delta^{13}C$ and $\delta^{18}O$ and precipitation (Fig. 5) are not significant in case of ring width but in case of $\delta^{13}C$ and $\delta^{18}O$ significantly negative. Effects of LBM outbreaks on ring width seem to override effects of climatic factors. The significant correlations between carbon and oxygen isotopes and climatic factors confirm the assumption that $\delta^{13}C$ and $\delta^{18}O$ are less affected by LBM outbreaks than ring width. The carbon isotope ratio is more strongly correlated to climate than the oxygen isotope ratio. Whether or not the weaker correlation of $\delta^{18}O$ is caused by a stronger influence of LBM outbreaks on $\delta^{18}O$ is currently under examination. The isotopic mechanisms underlying the tree ring $\delta^{13}C$- and $\delta^{18}O$-signatures observed during LBM outbreaks and the following years will be discussed elsewhere (Weidner et al. in prep.).

Conclusions

The results of this inter-annual analysis revealed an influence of LBM outbreaks on ring widths over several years. Oxygen isotopes seem to be influenced for only one year. Carbon isotope signatures seemed to be influenced in the year of LBM outbreak. The reaction in the following year is inconsistent. Comparisons with climate data revealed highly significant correlations between carbon and oxygen isotopes and temperature as well as precipitation. This indicates that climate signals are still to be traced during LBM outbreaks. However, it is currently not clear to what extent the signal is possibly dampened.

Further investigations, particularly on seasonal basis e.g. during the growth period during the growth period are necessary to understand the plant physiological processes. Various cores are currently prepared for intra-annual carbon and oxygen isotope analyses to investigate the seasonal behaviour. However, this study shows that multi-parameter investigations bear a great potential for studying the influence of LBM outbreaks on trees.

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