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Stable oxygen isotopes in juniper trees from the Tibetan plateau as a proxy for monsoonal activity

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Introduction

Extracting climatic and environmental information from stable isotopes in tree rings is of growing importance for reconstructing past environments. In recent publications, several authors (Helle & Schleser 2003, Treydte 2003, Treydte et al. 2006, McCarroll & Loader 2004, Schleser et al. 1999) confirmed the high potential inherent to stable isotopes for dendroclimatological investigations. In this study we present annually resolved stable oxygen ($\delta^{18}O$) isotope series of tree ring cellulose from three upper tree-line sites on the Tibetan plateau. Our sampling sites are situated along a hydrological gradient in the south-eastern part of Tibet with increasing moisture towards the East (Fig. 1).

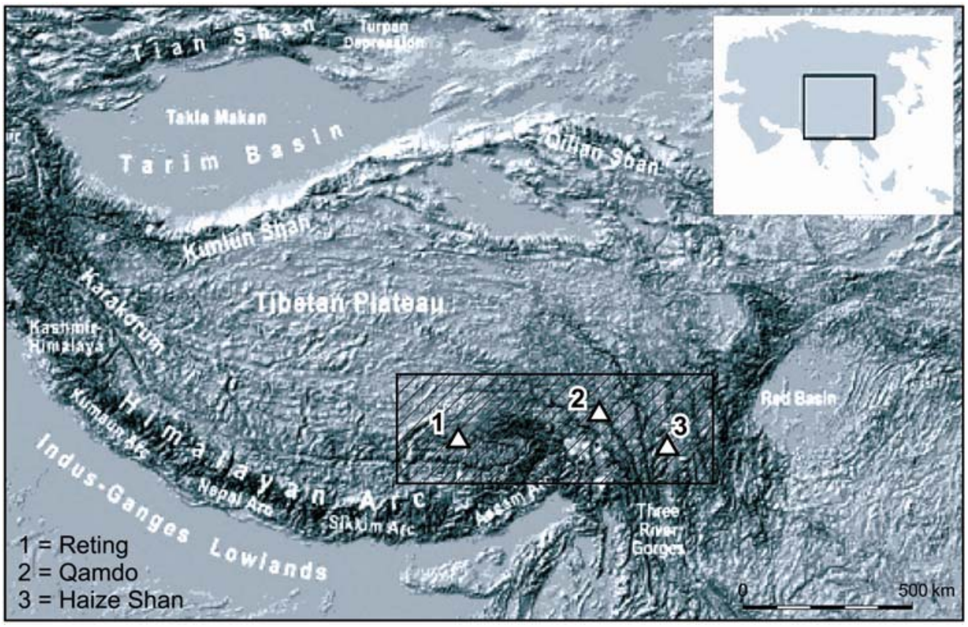


Figure 1: Main geographic units of High-Asia and location of the sample sites in Southeast-Tibet. Map: Böhner (2006).

We selected three stands of juniper trees (*Juniperus tibetica*) from southern exposed slopes. All sites are characterized by slope angles between 30 and 35°, well-drained soil conditions and are situated in the sub-alpine belt at 4300 to 4400 m.a.s.l. Former analysis of ring width showed that the trees at the study sites are very sensitive to climate variations and therefore suited for a detailed proxy-climate investigation (Bräuning 1999). The study area is influenced by a seasonal change of two major atmospheric circulation systems: during summer, humid air masses of the Indian summer monsoon and the East Asian monsoon are the prevailing factors of regional climate. In winter, cold westerly winds with small amounts of precipitation are predominant (Webster et al. 1998).

Material and Methods

For the annual isotope analysis, 4 to 6 dominant trees per sampling site were selected. For the exact dating of ring widths, each core was measured and synchronized with existing site-chronologies by Bräuning (1999, 2001). After dating, tree rings were accurately separated on an annual base using a razorblade. For each site, tree-rings of the same calendar age were pooled prior to analysis, following a method suggested by Leavitt & Long (1984) as well as Borella et al. (1998). Thereafter, cellulose was extracted adapting a standard procedure described by Kürschner & Popik (1962). For the analysis of δ^{18}O, samples are transferred into sample gas by pyrolizing them to CO at a temperature of 1080 °C. Measurement of the isotope ratios was done by using an elemental analyser interfaced to a continuous flow isotope ratio mass spectrometer (Micromass Optima) (for further details see McCarroll & Loader 2004, 2006). The resulting δ^{18}O-values are expressed as deviations from the international VSMOW-standard. Overall, we were able to establish three annually resolved δ^{18}O-isotope series with different time spans reaching from 820 (site of Haize Shan), 840 (Reting) up to 1520 years (Qamdo).

To obtain information about climate-proxy relationship concerning the δ^{18}O-series we compared different climate parameters such as temperature, precipitation and potential evapotranspiration (PET), to incorporate a more complex climate parameter. The associated climate data originate from adjacent meteorological stations, extended by calculated PET datasets by Chen et al. (2006). At the site Qamdo, we used the nearby station for our calibration studies. For the sites of Reting and Haize Shan we had to build regional means from two adjacent stations following the methods of Jones & Hulme (1996) to ensure spatial representativeness.

Results and discussion

In a first step, all δ^{18}O series were calibrated with the common climate parameters, temperature and precipitation. With the exception of the easternmost site, which is strongly influenced by the summer monsoon, all tree stands indicate highly significant negative relationships between δ^{18}O and precipitation during the summer months. In contrast, correlations for all sites with temperature are predominantly positive, although not always highly significant (for $p<0.1$). Due to the site conditions with steep slopes and well-drained soils, influence of groundwater during water uptake can be excluded. This leads to the assumption of a distinct summer precipitation signal, recorded in the tree-ring δ^{18}O-variations. The apparent δ^{18}O-precipitation relationship is modified by site ecological differences (Fig. 2).

Reting junipers	**Qamdo junipers**	**Haize Shan junipers**
semi-arid	*temperate*	*cold-humid*

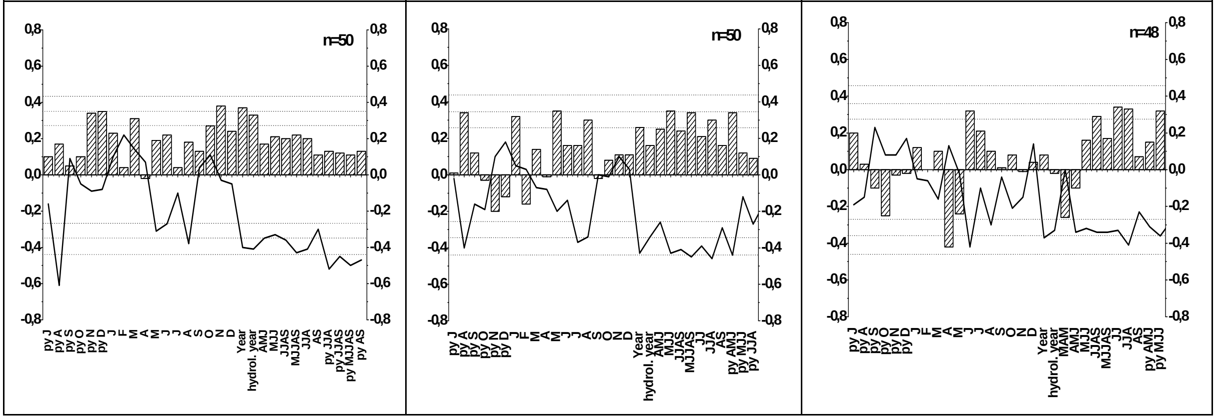


Figure 2: Site-specific climate-proxy-relationships between δ^{18}O, temperature (columns) and precipitation (lines) for monthly means of the actual and the previous year (py). Dotted lines represent levels of significance with $p<0.5$; $p<0.1$ and $p< 0.01$.

Oxygen isotopes show highest negative correlations for monthly and seasonal means of rainfall of the previous and the actual year. For the dry and warm site Reting in the western part of the investigation area, correlation is highest with previous year precipitation in August (r=-0.61). With increasing influence and intensity of the summer monsoon to the East, correlations to previous year conditions disappear. In contrast, the other juniper sites indicate highest correlations with precipitation during the actual vegetation period. For this reason, we assume that the dry and warm site is characterized by a storage effect during δ^{18}O-fixation which leads to a re-mobilization of previous years´ storage into the tree ring. Caused by the strong site-specific dependency on precipitation, this could be interpreted as a local plant physiological adaptation towards water stress during the vegetation period. This may cause site-specific water use and storage strategies during monsoonal rainfalls from May to September. Additionally, it has to be taken into account that some unexpected relationships at Reting within the calibration period could also be caused by the calculation with the regional mean climate series.

To investigate the relationship between site specific transpiration rates and δ^{18}O-fixation in tree rings, we analyzed PET-values of Chen et al. (2006). The results are illustrated in Figure 3. Again, highest similarities are found for the semi-arid site Reting, where highly significant positive correlations with the previous years´ August are apparent (r=0.65).

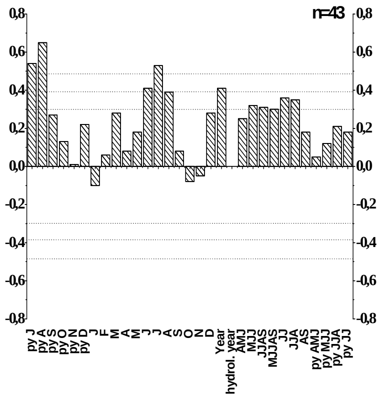
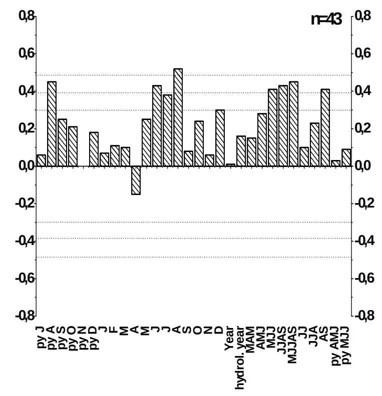
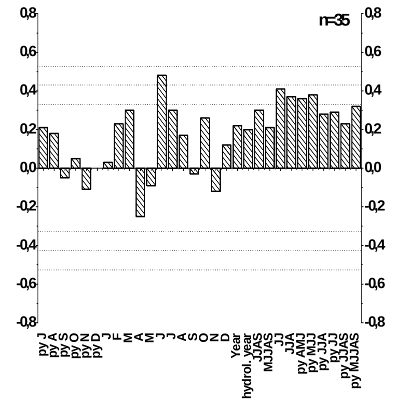
Reting junipers	**Qamdo junipers**	**Haize Shan junipers**
semi-arid	*temperate*	*cold-humid*
		

Figure 3: Site-specific climate-proxy relationships between δ^{18}O and potential evapotranspiration (PET) for monthly means of the actual and the previous year (py). Dotted lines represent levels of significance with $p<0.5$; $p<0.1$ and $p< 0.01$.

The other sample sites Qamdo (r=0.52 in August) and Haize Shan (r=0.48 in June) also indicate significantly higher results compared to precipitation datasets (Fig. 2). Similar as for calculations with precipitation, signal strength decreases with increasing influence of monsoonal activity. These results confirm the general assumptions, that increases in precipitation (in this case the summer monsoon) will lower local air temperature whereby transpiration rate is decreasing (Bendix 2004). During the summer monsoon season, water supply by precipitation combined with high temperatures leads to higher transpiration rates.

Conclusions

The results of this study of three ecological contrasting sites in Southeast-Tibet reveal a strong influence of summer precipitation for δ^{18}O isotope variations in juniper tree-rings. At all sites, oxygen isotope signatures show highly significant negative correlations with summer rainfall and highly significant positive correlation with PET-datasets. Signal strength of precipitation and PET decreases with the increasing influence of monsoonal activity from west to east. Both, δ^{18}O-relationship with precipitation as well as with PET trace obviously monsoonal signals within the tree-rings. In summary, δ^{18}O is a well-suited proxy for reconstructions of monsoonal activity and intensity for Southeast-Tibet. In contrast, ring width of Tibetan juniper shows a different behaviour: at the more humid sites Haize Shan and Qamdo, ring width is related to temperature (Bräuning 2001), whereas at the dry site Reting ring width is correlated to spring precipitation (Bräuning & Grießinger 2006).

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