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Original article

Stable oxygen isotopes in juniper and oak tree rings from northern Iran as indicators for site-specific and season-specific moisture variations

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ABSTRACT

Variations of stable isotopes ratios in tree rings are indicators of climate fluctuations. The current study examines the relationships between precipitation and temperature variations and stable oxygen isotopes ratios ($\delta^{18}O$) of the last 50 years in cellulose extracted from growth rings of *Juniperus polycarpus* and *Quercus macranthera* in northern Iran. We sampled at high-elevation sites in the Alborz Mountains, where *J. polycarpus* covers south-facing slopes and *Q. macranthera* covers north-facing slopes, respectively. $\delta^{18}O$ values of tree-ring cellulose in oak and juniper show site-specific differences in their mean and standard deviation, but temporal variations are significantly correlated, indicating a common forcing. Correlation functions of tree-ring $\delta^{18}O$ with local and modelled climate data reveal positive effects of temperature on $\delta^{18}O$ values in *J. polycarpus* during January–June, with significant correlations in January and May. Moreover, juniper $\delta^{18}O$ is influenced by winter precipitation, probably due to an influence of snow melt on the isotopic composition of soil water during spring. Negative correlations were found between juniper $\delta^{18}O$ and early vegetation period precipitation, when new xylem cells are formed. In contrast, $\delta^{18}O$ of oak contains a late summer (September) precipitation signal. Besides, $\delta^{18}O$ values in oak are positively affected by temperatures during summer and winter, with strongest connections with temperatures of September during the previous and current growing seasons. By combining stable isotope signals of species growing under different site conditions, there is a potential to reconstruct moisture variations during different seasons in the mountain areas of north Iran.

1. Introduction

Iran is located in a transition zone between different atmospheric circulation systems. While the western part is influenced by the Mediterranean climate regime, the eastern part of the country is located in the arid subtropical belt. The Alborz Mountain range in the north of Iran, however, is influenced by northerly winds bringing humid air masses blowing over the Caspian Sea that can cause serious flooding events (Rahimzadeh et al., 2009). The establishment of meteorological stations in Iran dates back to the 1950s, therefore instrumental climate records providing estimates about long-term regional climate variability are lacking. A general trend towards drier conditions has been reported from different parts of Iran during the last decades, but these trends are spatially heterogeneous and inconsistent (Nazemosadat and Ghazemi, 2004; Modarres and Sarhadi, 2009; Rahimzadeh et al., 2009; Tabari and Talaee, 2011; Kousari et al., 2011).

Tree rings are an extremely valuable archive of climate variability because they present a continuous, high-resolution archive of past growing conditions and environmental changes. In spite of this, dendroclimatological climate reconstructions for Iran are still few (e.g. Azizi et al., 2013) and restricted to the dry continental Zagros oak forests of west Iran. The Alborz Mountain range hosts lush forest resources and a high tree species biodiversity (Sagheb Talebi et al., 2014). Preliminary analyses of climate-tree growth relationships revealed that tree growth of high-elevation juniper and oak trees growing on south-facing slopes are limited by moisture conditions during spring, whereas oak trees growing on north-facing slopes are mainly controlled by temperature conditions (Pourtahmasi et al., 2009, 2012).

Beside ring width, stable isotope ratios in tree-ring cellulose may potentially contain strong palaeoenvironmental signals (McCarroll

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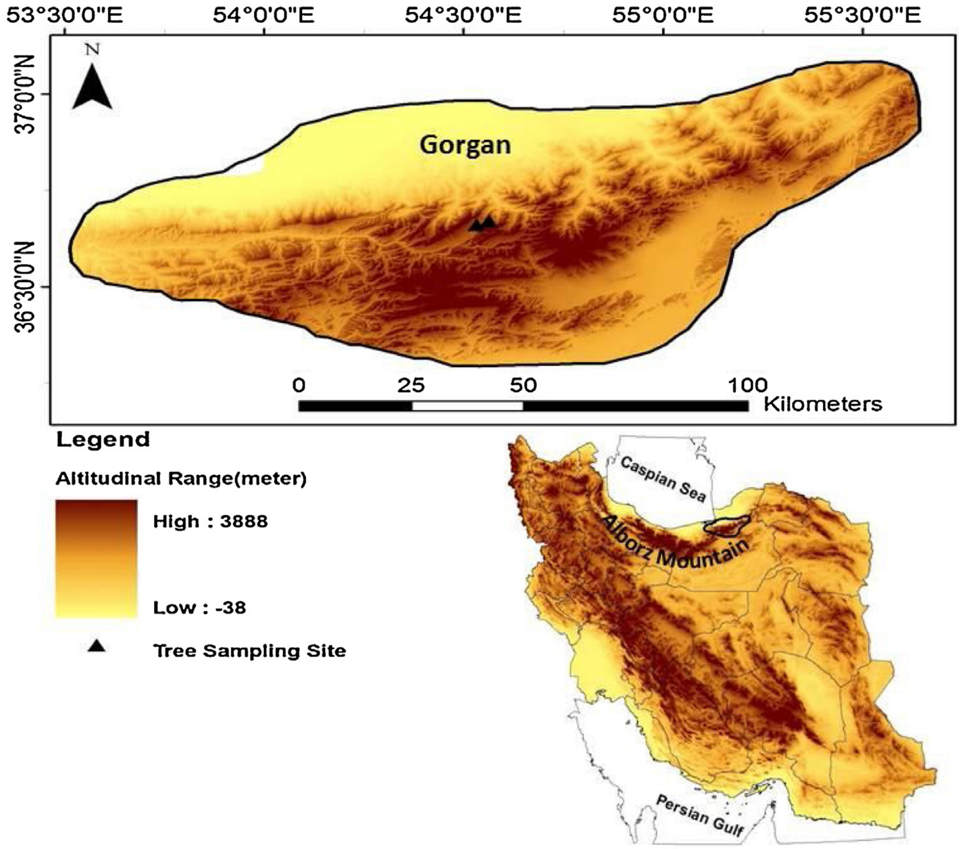

Fig. 1. Location of the study sites. The location of Gorgan County is indicated by the black shape in the overview map of Iran.

and Loader, 2004). With the development of rapid online measurement techniques, stable isotope analyses of tree rings have become an important tool for paleoclimate studies, providing palaeoclimate reconstructions with annual or even sub-annual resolution and stronger climate signals than ring width.

Many studies have used the δ^{18}O variations in tree rings of hardwood and softwood tree species as quantitative proxies for various climatic parameters such as temperature, precipitation, relative humidity, vapor pressure deficit, or cloudiness (Barbour et al., 2001; Saurer et al., 2002; Nakatsuka et al., 2004; Roden et al., 2005; Szczepanek et al., 2006; Treydte et al., 2006; Holzkämper et al., 2008). Variations in the stable oxygen isotope ratios (δ^{18}O) in wood cellulose are controlled by a range of external and internal factors. The oxygen isotope ratio in the soil water is primarily influenced by the isotopic composition of the meteoric (source) water and by possible enrichment of heavy isotopes by evaporation. Soil water is taken up by the trees without further fractionation and transported through the xylem to the leaves. During photosynthesis, leaf water isotopic enrichment occurs (Roden et al., 2000; McCarroll and Loader 2004; Robertson et al., 2008) which is controlled by the vapor pressure deficit of the surrounding air and related to temperature, precipitation, and relative humidity (McCarroll and Loader 2004; Liu et al., 2009; Kress et al., 2010).

However, correlation functions between δ^{18}O variations in wood cellulose and climate parameters may vary as a function of tree species, regional climatic control, and local site conditions. For example, Nakatsuka et al. (2004) found negative correlations of δ^{18}O of tree-ring cellulose in *Quercus crispula* with winter and summer precipitation amounts in Northern Japan, and suggested that their study area is influenced by multiple source regions of water vapor for local precipitation. In monsoon Asia, tree-ring δ^{18}O are sensitive to summer moisture conditions and have been used as indicators for summer monsoon strength (e.g. Liu et al., 2004; Grießinger et al., 2011; Sano et al., 2012). In subarctic Canada, Holzkämper et al. (2012) found that tree-ring oxygen isotopes correlate with summer temperature and precipitation and concluded that tree-ring oxygen isotope ratios are controlled by a combination of spring temperatures and precipitation totals. The analysis of oxygen isotopes in tree rings at cool temperate sites constitutes a potential source of proxy data for reconstructing temperatures of past centuries and even millennia (e.g. Haupt et al., 2014; Porter et al., 2014).

The present study presents the first stable isotope analysis on Iranian forest tree species. Various oak species growing in different climatic zones of Iran have been used in dendrochronological studies and respond to fluctuations in climate (humidity, temperature), site conditions (elevation, slope, soil type), and the impact of humans (Pourtahmasi et al., 2009, 2012; Azizi et al., 2013). Juniper is resistant against harsh mountain climate conditions with cold and long winters and dry summers, and forms the upper tree limit in continental parts of northern Iran, namely on the southern slopes of the Alborz mountain range (Pourtahmasi et al., 2007, 2012).

In this study we examine which climatic factors influenced stable oxygen isotope ratios in tree rings of the broadleaved deciduous *Quercus macranthera* and the evergreen conifer *Juniperus polycarpus* during the last 50 years and evaluate the potential of tree-ring δ^{18}O for climate reconstructions in northern Iran. We hypothesize that (i) isotope fractionation levels at the two study sites should be significantly different due to differences in plant functional types and microclimatic conditions due to different levels of moisture availability and resulting leaf water enrichment with ^{18}O; (ii) climate response of the tree-ring stable isotope variations are different for the two studied species due to variations in seasonal levels of moisture availability at north-facing and south-facing slopes.