Quaternary International xxx (2017) 1–20

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Treeline and timberline dynamics on the northern and southern slopes of the Retezat Mountains (Romania) during the late glacial and the Holocene

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ARTICLE INFO

Article history:
Received 6 September 2016
Accepted 10 March 2017
Available online xxx

Keywords:
Treeline
Timberline
Macrofossil analysis
Stomata analysis
Retezat mountains
Carpathians

ABSTRACT

To investigate treeline and timberline dynamics in the Retezat Mountains (Romanian Carpathians), late glacial and Holocene sediment sequences from four lakes were studied. The south and north slopes of the mountain range were compared using two lakes from the north flank (Lake Brazi, 1740 m a.s.l. and Lake Gales, 1990 m a.s.l) and two from the south flank (Lake Lia, 1910 m a.s.l. and Lake Bucura, 2040 m a.s.l.). Macrofossil and stomata analyses were performed to assess changes in the local vegetation, supplemented by pollen, charcoal and loss-on-ignition analyses.

Our results show that treeline reached Lake Brazi on the northern side during the late glacial (ca. 14,000 cal yr BP) and then Lake Gales between 11,000 and 10,800 cal yr BP. During the early Holocene the upper limit of closed forest, the timberline, reached and passed Lake Brazi and has stayed above it since, but it has never reached Lake Gales at 1990 m a.s.l. The expansion of *Larix decidua* in the late glacialand early Holocene around Lake Brazi is unique. Stomata and macrofossils of *Abies alba* are also more abundant in the northern records.

On the southern flank, treeline reached Lake Lia at around 12,000 cal yr BP, and was either very close to or at the elevation of Lake Bucura between ca. 8600 and 3000 cal yr BP. Timberline reached Lake Lia at ca. 8000 cal yr BP, some 3000 years after Lake Brazi, only 170 m lower on the north slope. Local fire events delayed the advance of timberline around Lake Lia in the early Holocene in a dry continental climate. The surrounding forest was dominated by *Picea abies* with individuals of *Pinus cembra* and stands of *P. mugo* until about 3000 cal yr BP when timberline retreated below the lake.

Maximum elevation of timberline was attained between ca. 8000 and 3000 cal yr BP, after which it descended in response to climate cooling.

Regional climate change appears to be the main driver of treeline dynamics, but it was modified by local climatic differences due to slope aspect. The first signs of human disturbance appeared ca. 4200 cal yr BP, when naturally open areas were used as alpine pastures. Human impact in the treeline ecotone, mainly burning and grazing, was intensified after ca. 2600 cal yr BP, contributing to the widening of the ecotone and the lowering of the timberline.

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http://dx.doi.org/10.1016/j.quaint.2017.03.012
1040-6182/

1. Introduction

The alpine treeline ecotone is a climatically sensitive transitional zone between the upper limit of closed forest (timberline; see Körner, 2012) and the highest individuals of tree species showing an upright growth form (treeline). Changes in its structure, range, and elevation have been extensively studied on decadal to millennial timescales around the globe, shedding light on the complexity of this natural transition.

Climate is the overall factor affecting the elevation of treeline and timberline. On a global scale, the elevation of timberline is best correlated with the mean temperature of the warmest summer month (the 10 °C isotherm in the temperate zone, see Brockmann-Jerosch, 1919; Daubenmire, 1954; Holtmeier, 1974; Körner, 1998), and with the 5.5–7.5 °C isotherm of mean growing season temperature (Körner, 1998). On a regional scale, continentality, the amount of precipitation, and seasonality are also important drivers, while effects of local topography and aspect operate on finer scales (Holtmeier, 2009). Biotic factors, such as herbivore pressure and pathogens may also have significant effects (Holtmeier, 2009). However, even regional and global patterns can be overprinted by human transformation of the landscape by cutting or burning forests for different reasons (e.g. expanding alpine pastures).

In the light of studies suggesting significant changes in the alpine and subalpine vegetation zones of mountainous regions under recent climate change (Sætersdal et al., 1998; Klein et al., 2004; Thuiller et al., 2008; Britton et al., 2009; Harsch et al., 2009; Dirnböck et al., 2011; Gottfried et al., 2012; Grytnes et al., 2014), disentangling the effects of the various drivers of change and contributing to the knowledge on the natural variability of treelines and timberlines have become increasingly important. The reconstruction of past treelines using the toolbox of palaeoecology is vital in this process, as it provides data on decadal to millennial timescales, beyond the span of direct observation. Macrofossil and stomata analyses have proved to be especially useful in this context, as macro-remains usually indicate the local presence of species at and around the sediment archive (Birks and Birks, 2000; MacDonald, 2001; Birks and Bjune, 2010; Ammann et al., 2014) and can provide data at finer spatial resolution than pollen analysis.

Several treeline studies have been carried out in the alpine areas of Europe, especially in the Alps (e.g. Wick and Tinner, 1997; Haas et al., 1998; Lotter and Birks, 2003; Gobet et al., 2005; Tinner and Ammann, 2005; Tinner and Kaltenrieder, 2005; Schwörer et al., 2014) and in the Fennoscandinavian Mountains (e.g. Barnekow, 1999; Bergman et al., 2005; Eide et al., 2006; Kullman and Kjällgren, 2006). In contrast, the treeline and timberline history of the Carpathians is less extensively studied. Pollen analysis has been used to describe changes in the alpine and subalpine vegetation belts in Romania (Farcas et al., 1999; Feurdean et al., 2007, 2009, 2010, 2012; Tanţău et al., 2011), but only a few studies combine the use of macrofossil, stomata, and pollen analysis, making the spatial resolution of their inferences finer (Magyari et al., 2012; Geantă et al., 2014; Feurdean et al., 2016).

Here we present the results of macrofossil and stomata analyses from four lakes from the Retezat Mountains (Southern Carpathians), augmenting them with results of other proxies analyzed within the PROLONG Project (Magyari, this issue). The distribution of lakes in the Retezat Mountains not only enables us to look at vegetation history and treeline and timberline change within the area, but also makes it possible to investigate the effects of factors that act on finer scales (e.g. microclimate, aspect, difference in land use, local fires). Although several treeline studies use data from multiple archives (e.g. Wick and Tinner, 1997; Tinner and Theurillat, 2003), few of them address questions related to the effects of local factors or attempt to reconstruct changes on fine spatio-temporal scales using local proxies of vegetation change (Jackson and Whitehead, 1991; Tinner and Theurillat, 2003; Eide et al., 2006).

Using results from sediment cores from two lakes in the north-facing Gales valley (Lake Brazi and Lake Gales) and two lakes in the south-facing Bucura valley (Lake Lia and Lake Bucura, see Fig. 1), this study aims to (1) reconstruct treeline and timberline changes on the northern and southern flanks of the main ridge, (2) assess any difference between the long-term dynamics of treeline and timberline (elevation and species composition) in these two contrasting valleys, and (3) contribute to a better understanding of the role of humans in shaping the vegetation of the treeline ecotone in the Retezat Mountains.

2. Regional setting

The Retezat Mountains are one of the westernmost massifs in the Southern Carpathians in Romania. Situated between the valley of the Jiu River and the Haţeg basin, the massif covers nearly 500 km^2 of which more than 380 km^2 are within the Retezat National Park (Fig. 1). Traditional alpine pasturing is still maintained under the control of park authorities, allowing sheep, horses, and cattle to graze on the alpine meadows (Galland, 2013).

The area has a diverse flora with a high proportion of endemic species, mostly alpine meadow herbs (e.g. *Draba dorneri, Hieracium borzae, Hieracium nigrilacus, Barbarea lepuznica, Pedicularis baumgarteni*). Mixed oak forests occur at low elevations (550–700 m a.s.l), while mid-elevations (700–1200 m a.s.l.) harbour forests of beech (*Fagus sylvatica*). Silver fir (*Abies alba*) and Norway spruce (*Picea abies*) increase in frequency between 1200 and 1350 m a.s.l., eventually forming a forest dominated by *P. abies* between ca. 1350–1800 m (Nyárády, 1958). Near the treeline ecotone, from around 1700 m a.s.l., Swiss stone pine (*Pinus cembra*) becomes increasingly common. Timberline is formed by these two species around 1850 m a.s.l. on the northern slopes, but higher, at 1900 m a.s.l., on certain southern slopes according to Nyárády (1958). Grodzińska et al. (2004) remark that on some of the southernmost slopes outside the national park, deciduous forest stretches right to the timberline due to large scale deforestation in the spruce belt by shepherds and herdsmen who still graze relatively large flocks and herds in some valleys (Radu, 2004).

The treeline is formed by individuals of *Picea abies* and *Pinus cembra* between 1900 and 2000 m a.s.l. Dwarf pine (*Pinus mugo*) becomes increasingly dominant (from 1800 m a.s.l. upwards) as the forest opens up and it covers vast areas between 1900 and 2200 m a.s.l (often referred to as the "krummholz" zone). Since individuals of this species often do not fulfill the requirements of the tree growth form (see Körner, 2012), we consider them shrubs that do not take part in forming the treeline.

Two varieties of juniper commonly occur in the Retezat Mountains. *Juniperus communis* subsp. *communis* is found at lower elevations and *J. communis* subsp. *nana* occupies a similar elevation zone to *Pinus mugo*. Ericaceous shrubs (*Vaccinium myrtillus, V. vitis-idaea* and *Rhododendron kotschii*) are also abundant in this zone. *Juniperus* thickets become less dense higher up, and they give way to alpine meadows above 2250 m a.s.l.

The area lies in the temperate-continental climatic belt, but has a distinctively different mountain mesoclimate with a mean annual temperature of 6 °C at 800 m a.s.l. decreasing to 2 °C at the highest peaks (Spinoni et al., 2015). Due to moist air masses coming from the Mediterranean and the Atlantic regions, and the topography of the area, the higher altitudes of the massif (above 1800 m a.s.l.) are particularly wet, receiving 1600–1800 mm of precipitation annually.

Due to the moist climate and the extensive ice-cover during the last glacial period (Reuther et al., 2007; Ruszkiczay-Rüdiger et al.,