Quaternary Science Reviews 134 (2016) 100–113

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Tree and timberline shifts in the northern Romanian Carpathians during the Holocene and the responses to environmental changes

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ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form
22 December 2015
Accepted 23 December 2015
Available online 22 January 2016

Keywords:
High mountain vegetation
Alpine
Tree migration
Picea abies
Pinus mugo
Abies alba
Climate change
Land use
Fire
Forest management

ABSTRACT

High altitude environments are experiencing more rapid changes in temperature than the global average with the risk of losing essential ecosystem services in mountain environments. The Carpathians Mountains are regarded as hosting Europe's most pristine mountain ecosystems, yet the paucity of past environmental records limits our understanding of their sensitivity to the various drivers of change. A multi-proxy palaeoecological approach (plant macro-remains, pollen, charcoal) applied to three Holocene sediment sequences (between 1540 and 1810 m a.s.l.) in the Rodna Mountains documents past treeline and timberline shifts in response to climate change and human impact to anticipate the likely future responses. Our results indicate that forest reacted sensitively to past climate conditions. The timberline had exceeded an elevation of 1540 m a.s.l. by 10,200 cal. yr BP, when summers were warmer than today. The treeline remained below 1810 m a.s.l. at this time and reached its maximum elevation after 8500 cal. yr BP, when winter temperatures became milder. Cool summer conditions probably caused a lowering of the timberline and an extension of the treeline ecotone from 4900 cal. yr BP, a process accentuated by human impact from the Bronze Age (3500 cal. yr BP) onwards. The anticipated upslope tree movements as a consequence ongoing global warming are not yet clearly visible in our records, but will more probably take place in abandoned agricultural areas and be counter-balanced by re-enforced anthropogenic pressure elsewhere. *Pinus sylvestris* was the dominant tree species in the timberline under a warm and dry climate, when fires were frequent, during the early Holocene (11,250 −10,200 cal. yr BP), while *Picea abies* became dominant in the timberline and *Pinus mugo* in the treeline ecotone, respectively from 10,200 cal. yr BP to the present. *Abies alba* became a significant component of the timber over the last four millennia. The anticipated future warmer and moister climatic conditions will favour the persistence of *P. abies* as well as *A. alba*. However, *A. alba* is more sensitive to anthropogenic disturbance, which implies that in places with continuing farmland pressure, *A. alba* may be less prevalent than *P. abies* in the future. Anthropogenic pressure is expected to increase the proportion of tree species characteristic of more disturbed forests and consequently threaten biodiversity with important implications for mountain ecosystem services.

1. Introduction

There is growing evidence showing that high mountains are experiencing more rapid increased in temperature than the global average (Solomon et al., 2007). This elevation-dependent warming has important implications for ecosystems and biodiversity due to habitat fragmentation and restriction, with the threat of degrading

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http://dx.doi.org/10.1016/j.quascirev.2015.12.020
0277-3791/

mountain ecosystem services (Pauli et al., 2012). Alpine treelines or treeline ecotones are transitional zones between closed forests (timberline) and alpine communities, and are composed of a mixture of trees (higher than 3 m), shrubs and herbaceous species (Körner, 2012). Alpine treeline ecotones are often fragmented (i.e., parkland) in appearance, but can also be sharply demarcated depending on topography and disturbances factors such as clearance, pasturing and fire (Holtmeier, 2009; Körner, 2012). Its position is climatically sensitive, although topography, soil temperature and nutrients, snow and wind regimes can also be influential (Körner, 2003, 2012; Holtmeier, 2009; Czajka et al., 2015). Nevertheless, studies of contemporary treeline elevations have shown that the treeline can be accurately predicted by the minimum temperature of the growing season (Körner, 2012).

Past changes in timberline and treeline elevation have been identified through palaeoecological studies (temporal resolution typically 50–100 years) in most mountain chains around the world (Czajka et al., 2015; Di Pasquale et al., 2008; Kullman, 2007, 2002; Maher, 1972; Obidowicz, 1996; Reasoner and Tinner, 2008; Tinner and Theurillat, 2003; Tinner, 2013; Tonkov and Marinova, 2005; Schwörer et al., 2014). Results indicate that changes in the Holocene treeline and timberline tend to follow major climatic trends. However, these studies have also found that timberline and treeline depression during the Late Holocene was primary the result of land use intensification with climate playing a subordinate role (Tinner and Theurillat, 2003; Tinner, 2013; Tonkov and Marinova, 2005).

As treeline and timberline are particularly sensitive to climate, ongoing climate warming is anticipated to shift both to higher elevations consequently restricting the extent of mountain and alpine shrubs and herbs (Körner, 2012). Rising atmospheric CO_2 concentrations could also act as a fertiliser stimulating tree growth, further elevating treeline position (Hättenschwiler et al., 2011; Körner, 2012) although such effects will be species-specific (Dawes et al., 2011). However, field and remote sensing based analysis of more recent timberline and treeline shifts have produced ambiguous results. For example, some studies have shown that treeline response to the recent climate warming is likely to be delayed due to recruitment lag, slow tree growth at the treeline and competition with shrubs and alpine herbs communities (Gehrig-Fasel et al., 2007; Körner, 2012). Where the upslope movement of trees was noted, it was primarily related to the recovery of anthropogenically-depressed treelines, with only a minor proportion attributed to warmer temperatures (Amztegui et al., 2010; Gehrig-Fasel et al., 2007; Körner, 2012; Martazinova et al., 2011; Theurillat and Guisan, 2001; Tinner and Ammann, 2005).

Compared to other large mountain ranges in Europe (the Alps, Pyrennes and Scandes), very little is known about past timberline and treeline monuments in the Carpathian Mountains, an ecologically important region regarded as one of Europe's most pristine mountain areas. The existing studies in this region focus on either Lateglacial or early Holocene changes (Geantă et al., 2014; Magyari et al., 2012; Vincze et al., 2014) with only a single record documenting the Late Holocene treeline development of these high mountains (Geantă et al., 2014). Results from these studies indicate a higher-than-today position of the timberline and treeline during the early and mid Holocene, initially composed of *Larix decidua Pinus sylvestris /cembra, Pinus* spp., and from about 10,000 cal. yr BP by *Picea abies* with some *Pinus cembra*, the latter with a greater abundance in the southern Carpathians (Geantă et al., 2014; Magyari et al., 2012; Vincze et al., 2014). A lowering of tree positions was visible from about 3200 cal. yr BP (Geantă et al., 2014; Vincze et al., 2014). However, individual mountain regions can have very distinct vegetation characteristics and can be affected differently by climate and land use change, depending on their geographical position, morphological characteristics and climatic regime (Treml and Chuman, 2015). The paucity of past environmental records at high elevation greatly limits our understanding of the sensitivity of mountain and alpine plant communities to climate and land use change.

To fill these geographical and temporal gaps, a multi-proxy palaeoecological approach (pollen, stomata, plant macrofossil, macroscopic charcoal) applied to three Holocene sediment sequences located between 1540 and 1810 m a.s.l. in the Eastern Carpathians, northern Romania, was used to determine treeline and timberline sensitivity to various competing drivers (climate, fire and land use) of change. We assessed three main hypotheses that:

1. Treeline and timberline composition and elevation responded sensitively to Holocene climatic fluctuations
2. Human activity had already led to a depression in treeline and timberline elevation by the Bronze Age (ca. 3500 years ago)
3. Treeline and timberline are migrating upslope as a response to the recent climate warming

Results from our long-term ecological study document the impacts of climate warming and land use change on high mountain species composition and tree altitudinal range shifts over time. This long-term perspective is essential in quantifying the expected changes in vegetation cover and ecosystem functions in the mountains, and therefore facilitating the mitigation of the consequence for ecosystem composition and diversity.

2. Materials and methods

2.1. Modern environmental settings

The Rodna Mountains are located in the north of Romania forming part of the Eastern Carpathians (Fig. 1). The climate is moderate temperate with a mean annual temperature of 1.2 °C, mean summer temperatures of 10.6 °C and a mean annual precipitation of 1300 mm (Donita, 2005; Dragotă and Kucsicsa, 2011). Today the average upper limit of the closed forest (timberline) in this region is around 1500 m a.s.l. (ca. 56% of the timberline lies between 1400 and 1600 m with 32% at 1600–1800 m a.s.l.) with a higher elevation (1600–1650 m a.s.l.) on the northern slope and a lower position (1550–1600 m) on the southern slope of the range (Management Plan of Rodna Mountains National Park; MPRMNP, 2013 thereafter). Forests at the timberline are dominated by *P. abies* with scattered *Pinus sylvestris*, *P. cembra* and *L. decidua*. The current treeline limit ranges from 1600 to 1700 m a.s.l. and is composed of trees (mainly *P. abies*), shrubs/creeping shrubs (*Pinus mugo*, *Juniperus communis*, *Alnus viridis*, *Empetrum nigrum*, *Vaccinium myrtillus*, *Vaccinium oxycoccos*, *Vaccinium vitis-idaea*, and *Betula nana*) and alpine meadows (Kucsicsa, 2011; MPRMNP, 2013). The treeline limit is also higher on the northern and western slopes than on the southern slope. This altitude distribution is contrary to what might be expected under natural conditions and reflects the more accessible topography of the southern slopes to shepherding and forest clearance (Kucsicsa, 2011).

Poiana Ştiol peatland (1540 m a.s.l.) is located in the current treeline (Fig. 1B). It is a poor fen formed in small limestone sinkholes (Tanţău et al., 2011). The vegetation directly surrounding the site is mainly composed of *P. abies*, *P. cembra*, *P. mugo*, *Sorbus aucuparia*, *Salix silesiaca*, *J. communis ssp. nana*, and *Rhododendron myrtifolium*. Lake Ştiol (1670 m a.s.l.), located at the treeline limit (Fig. 1B), is considered to be a glacial lake (Hutchinson et al., 2015). Woody vegetation surrounding the site is composed of patches of *P. mugo* and scattered *P. abies* trees. Gărgălău peatland (1810 m a.s.l.), situated above the current treeline ecotone, is a poor fen nested in a