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Changes in tree species composition in Mediterranean mountains under climate change: Indicators for conservation planning

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ABSTRACT

Since the last glacial–interglacial cycles, Mediterranean mountains in Southern Europe have constituted the southern refuge of numerous species of Eurosiberian and Boreal origin. Some vestiges of European Tertiary flora have also remained in this area. These mountains present one of the continent's highest plant diversity indices deriving from their geographic and historical circumstances throughout the Quaternary. Throughout this century, a change in the biogeographic characteristics of these mountains is to be expected as a result of climate change.

Based on four Intergovernmental Panel on Climate Change (IPCC) scenarios, we developed a multivariate analysis model for mountain ranges in Central Spain (Southern Europe), enabling us to adjust data on vegetation, climate, lithology and availability of soil water. With high-resolution data on species occurrences and abiotic characteristics for better accounting of micro-refugia and topographic complexity in mountain regions, we assess the future potential distribution of tree species and changes in plant communities under climate change. Our model provides the climate descriptors that most influence changes in species distribution and which lead us to consider the parameters of these changes as indicators for management.

We project for this century a significant spread of Mediterranean tree communities in detriment to temperate or cold-adapted tree communities. In mountain forests in northern Europe, limitations on plant growth are mainly thermic, and the boreal and subalpine species in high- and mid-mountain regions are therefore the ones most threatened by the predicted global warming. To the contrary, our results show that in mountains in southern Europe, the formations that will undergo the greatest changes will be at piedmonts and low-mountain levels, due to increased hydric deficit. These results suggest that nature conservation strategies currently call for new approaches that take into account the fact that climate change is a driving force of species distribution. The results can be used at the landscape scale for management of forest species and for the design of protected areas.

1. Introduction

Mountains in Southern Europe currently harbour some of the planet's highest biodiversity values (Väre et al., 2003). Among the factors explaining these high levels of biodiversity, one can highlight the alternation of cold and warm periods during the Quaternary, which restricted the geographic range of many species from the temperate regions of the Northern Hemisphere to more southern latitudes. European glacial refugia for many plant and animal species were likely located in Mediterranean mountains, where varied topography results in a variety of microclimates providing suitable habitats during both warm and cold periods (Bennett et al., 1991; Taberlet and Cheddady, 2002; Magri, 2010). In the long term, these refugia provided suitable habitats for many taxa from the Northern Hemisphere, as they constituted the location of post-glacial recolonisation when temperatures rose again at the end of the glaciations (Tzedakis et al., 2002; Médail and Diadema, 2009; Bhagwat and Willis, 2008). Thus, the Quaternary glaciations, responsible for the most recent floristic impoverishment in Central Europe, gave rise to the opposite effect in Mediterranean mountains (Sáinz and Moreno, 2002). These mountains acted as warm-wet refuge areas in climatically adverse periods and sheltered species with a cold-wet ecological optimum as from the Late-glacial warming (Franco et al., 1998). Consequently, they currently constitute the low-latitude margins of the distribution ranges of numerous central European species (rear edge populations; see Hewitt, 2000; Hampe and Petit, 2005; Gugger et al., 2011). Furthermore, the geographic isolation of these locations also caused a high concentration of endemisms (Gómez-Campo, 1985; Sáinz and Moreno, 2002; Väre et al., 2003). These mountains currently constitute wet and cool islands of biodiversity in a warm and dry area, enabling the coexistence of plants of Eurosiberian and Boreal origin together

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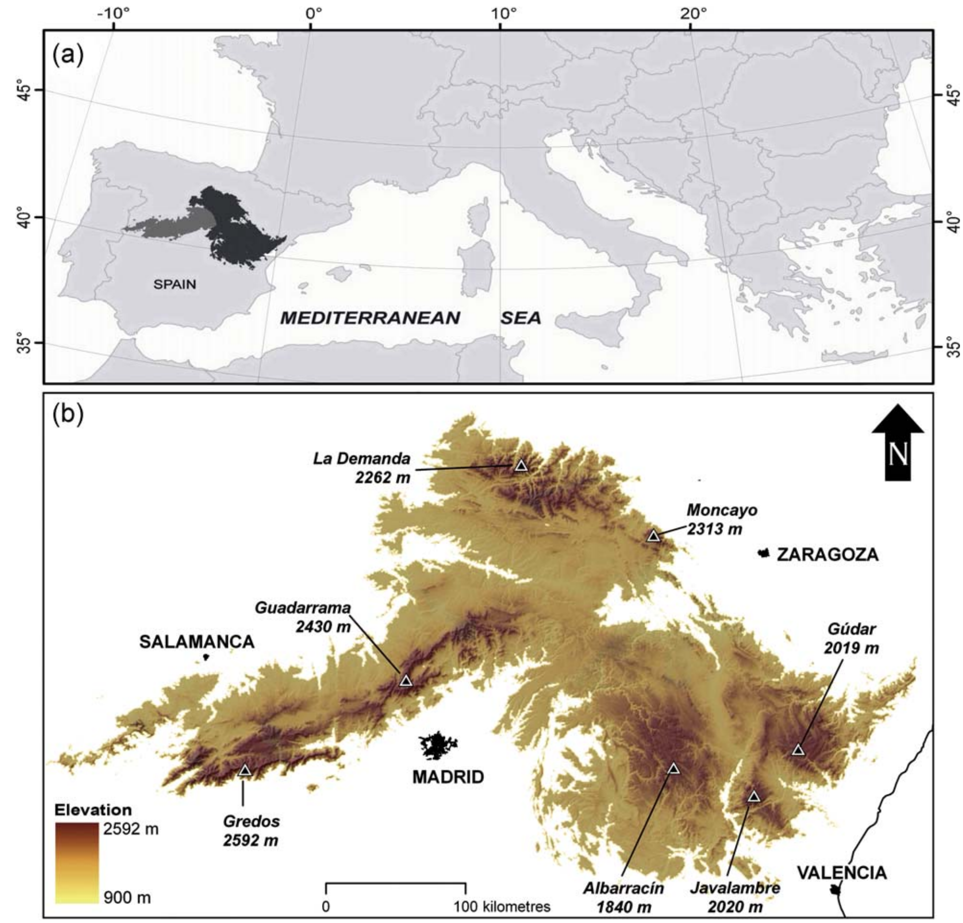

Fig. 1. (a) Location of the Central and Iberian Mountain Ranges (light and dark grey, respectively) on the Iberian Peninsula in Southern Europe. (b) The figure shows the elevations of the highest summits in these mountain ranges, together with some big cities in the area.

with other xerophyllous species, adapted to warm summers with intense hydric deficit.

Current predictions of climate change indicate serious disturbance of this high-diversity genetic heritage. The Mediterranean region lies in a transition zone between the arid climate of north Africa and the temperate and rainy one of central Europe. In this ecotone, even minor modifications can lead to substantial changes in climate, making Mediterranean mountains a potentially vulnerable region (Lionello et al., 2006). Currently it has been identified as one of the most exposed areas in future climate change projections (Giorgi, 2006) and is expected to experience disproportionately sharp increases in temperature and aridity in comparison with other regions (Cubash et al., 1996; IPCC, 2007). The predictions show that Mediterranean mountains will undergo warming, a decrease in rainfall and increased interannual variability in relation to non-Mediterranean European mountains (Morales et al., 2005; Gritti et al., 2006; Nogués-Bravo et al., 2007; Nogués-Bravo et al., 2008a,b; Giorgi and Lionello, 2008). Consequently, species losses would be higher than in the Boreal, Alpine or Atlantic regions (Thuiller et al., 2005; Bakkenes et al., 2006), due both to the more intense climate change and to their isolation within a warm, dry matrix (Petit et al., 2005) in the southern limit of their biogeographical distribution. Some predictions indicate that a change in the biogeographic characteristics of these mountains is already occurring (Granados and Toro, 2000; Goodess and Jones, 2002; Peñuelas and Boada, 2003; Sanz-Elorza et al., 2003; Sanz et al., 2003; Wilson et al., 2005; Ruiz-Labourdette et al., 2012). It is therefore of utmost importance to assess the impacts of future climate change upon the diversity of montane Mediterranean species. The information thus provided would enable us to develop dynamic conservation efforts that consider climate change in terms both of in situ conservation and of species reintroduction, as climate change can drive species out of reserves (Araújo et al., 2004).

Nogués-Bravo et al. (2007) have estimated how the evolution of the climate in the 21st century could bring about progressive aridification in forests throughout southern Europe. In this paper, we propose a quantitative method for evaluating this change, considering the variation in the distribution of the different pre-existing forest types, understood as combinations of the proportion of different species, under different climate scenarios. We develop a numerical multivariate model of potential forest distribution in mountain ranges on the Iberian Peninsula, using high-resolution climate change scenarios, lithology and water soil availability. We attempt to fit equations which enable prediction of forest distributions in this area in the 2071–2100 period, based on climate conditions predicted for this time period according to the A2 and B2 IPCC-SRES (Intergovernmental Panel on Climate Change-Special Report on Emissions Scenarios) (Nakicenovic and Swart, 2000) and General Circulation Models (GCMs) HadAM3 (Hadley Center) and ECHAM4 (Max Planck Institute). With the use of the model developed we also intend to obtain the climate indicators that most influence changes in species distribution.

2. Study area

Our study area encompasses a mountainous area in Southern Europe (c. 71,700 km^2). Its elevation ranges from 900 m to 2592 m. The area includes two large mountain ranges, the Central Mountain Range, in the centre-west of the Iberian Peninsula, and the Iberian Mountain Range, in the centre-east (Fig. 1). The western and