Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology: Official Journal of the Societa Botanica Italiana

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tplb20

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Accepted author version posted online: 13 Jan 2014.Published online: 05 Feb 2014.

To cite this article: C. Palombo, M. Marchetti & R. Tognetti (2014) Mountain vegetation at risk: Current perspectives and research reeds, Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology: Official Journal of the Societa Botanica Italiana, 148:1, 35-41, DOI: 10.1080/11263504.2013.878410

To link to this article: http://dx.doi.org/10.1080/11263504.2013.878410

Plant Biosystems, 2014
Vol. 148, No. 1, 35–41, http://dx.doi.org/10.1080/11263504.2013.878410

Mountain vegetation at risk: Current perspectives and research reeds

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Abstract
Mountain ecosystems are, however, fragile and particularly vulnerable to the adverse impacts of climate change, deforestation and forest degradation, land-use change, land degradation and natural disasters.

Keywords: *Treeline, mountain ecosystems, climate changes, land -use changes, Mediterranean Basin, alpine vegetation*

The diverse topography and altitudinal range of mountain ecosystems result in a variety of microclimates and environments along a short distance, often with sharp transitions (ecotone) in vegetation sequences. As a consequence, mountain ecosystems exhibit high biodiversity and a great number of endemic species (Camarero et al. 2006; van Gils et al. 2012; Fernández Calzado et al. 2012; Elumeeva et al. 2013). This large environmental variation within a small geographic area makes elevational gradients ideal for investigating spatial patterns in species richness (Körner 2000). Mountain ecosystems are, however, fragile and particularly vulnerable to the adverse impacts of climate change, deforestation and forest degradation, land-use change, land degradation and natural disasters (Palombo et al. 2013a, 2013b).

During the last decades, hundreds of articles and several books (e.g. Holtmeier 2009; Körner 2012a) have focused on these environments, in particular on the upper margins of the tree distribution in mountains. In all high mountains, there are environmental constraints that prevent tree growth beyond certain elevations and yield terrain to low stature alpine vegetation (Körner 2012a). This margin is called the *alpine treeline*, a dynamic ecotone that extends from the uppermost closed montane forests (*timberline*) to the treeless alpine vegetation. Alpine treeline may be determined by various factors, including abiotic factors (e.g. temperature, drought, water logging or soil nutrients) and natural (e.g. fire, insect outbreaks, pathogens) and anthropogenic (e.g. timber harvesting, logging, pastoralism) disturbances. At global scale, the current natural high elevation tree limit is associated with a growing season that is at least 90 days long (constrained by temperatures passing through a 0°C weekly mean threshold) and during which the mean air temperature is 6.4 ± 0.7°C; Körner 2012b), which points to the importance of current warming for uphill movement of the total number of species in the upper belts. The ongoing climate warming is expected to cause significant changes in the structure, dynamics and position (e.g. upward shifts) of the alpine treeline (Grace et al. 2002; Harsh et al. 2009; Batllori et al. 2012).

It has been widely demonstrated that climate and land use changes represent the main drivers affecting mountain ecosystems, particularly at high elevation (Parmesan 2006; Peñuelas et al. 2007; Resco de Dios et al. 2007; Ruiz-Labourdette et al. 2012). In most situations, these two components are likely to operate as concomitant stressors on forest ecosystems, making it difficult to disentangle their separate impacts (Peñuelas & Boada 2003; Gehrig-Fasel et al. 2007; Batllori et al. 2010; Linares et al. 2011). However, the effects of anthropogenic and geomorphic causes define regional peculiarities, which can prevent trees from growing anywhere and not directly related to high elevation. On the other hand, climatic conditions are considered responsible for the natural climatic treeline formation, helping to understand the treeline phenomenon globally

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because it is directly related to biological causes (Körner & Paulsen 2004; Holtmeier & Broll 2007; Körner 2012b). Climate warming can favour germination and growing conditions in these areas, but local topography, soil and human interference may reduce the forest expansion (Speed et al. 2010). Anthropogenic influences on treeline formation have been deeply studied in the Mediterranean Basin (Chauchard et al. 2007, 2010; Améztegui et al. 2010; Piermattei et al. 2012; Cullotta et al. 2013; Palombo, et al. 2013b), being one of the areas most vulnerable to the predicted changes (Giorgi 2006; Paušič & Čarni 2013). In this environment, forest landscape has been strongly determined by past land-use and management, which acted mainly through fire and grazing of natural vegetation (Marchetti et al. 2010; Miras et al. 2010; Catorci et al. 2012; Gargano et al. 2012). The decrease of many semi-natural open habitats in Mediterranean mountains, which had previously been maintained by traditional practices, has had a negative impact on the spatial distribution of rare or endemic species (Kiss et al. 2004; Lomba et al. 2013). Recent studies analysed also the influence of road networks in mountainous forest landscapes, due to the potential to increase the susceptibility to erosion and shallow landsliding (Grigolato et al. 2013; Tarolli et al. 2013).

In high elevation forests, climate has been considered the main limiting factor for tree growth, reproduction and establishment (e.g. Tranquillini 1979; Körner 1998; Ettinger et al. 2011). For this reason, alpine treeline would result very sensitive to climatic variability (Stevens & Fox 1991; Nicolussi & Patzelt 2006), and the altitudinal zonation of mountain vegetation and biodiversity of these zones are considered sensors that indicate climatic and environmental changes (Hamilton 1999; Beniston 2000; Grace et al. 2002; Camarero et al. 2013). Currently, there is much interest in the rate at which the treeline may advance in response to environmental change, especially global warming. In fact, upper treelines could respond to climate warming with increases in recruitment or tree-density as well as upward advances (Camarero & Gutiérrez 2002, 2004; Gamache & Payette 2005; Kullman 2005; Camarero & Gutiérrez 2007; Danby & Hik 2007; Peñuelas et al. 2007; Batllori & Gutiérrez 2008; Caccianiga et al. 2008; Batllori et al. 2009; Fang et al. 2009; Kharuk et al. 2010; Liang et al. 2011).

The upward shift of forest tree species, as a function of climate scenarios, could be accompanied by a potential loss of biodiversity and ecosystem function as alpine grasslands, replaced by woody species (Thomas et al. 2004; Thuiller et al. 2005; Lenoir et al. 2008; Randin et al. 2009) or a modification of tree-climate correlation (Carrer et al. 2007, 2010). A lengthening of the growing season at mid- to high latitudes (Menzel et al. 2006; Way 2011) and a variation of plant phenology (Cleland et al. 2007) represent other possible responses to current climate change. All these changes could affect the shifts in ecosystem productivity, with implications for global carbon cycling (Dean & Wardell-Johnson 2010; Marchetti et al. 2012). Furthermore, the readiness and the amplitude of the response of treeline to climate variation change significantly considering the spatial scale (Holtmeier & Broll 2005); the present treeline position may reflect past climates rather than the current one (Paulsen et al. 2000), although a fast response of treeline position, even to extremely rapid climatic change, has been reported at least for the early Holocene (Tinner & Kaltenrieder 2005).

During the last years, the number of studies about treeline dynamics has increased, as well as the knowledge of the mechanisms driving treeline formation. Recent studies have focused on the dynamics of tree species living at high elevation and located at the edge of their potential geographical distribution (Camarero et al. 2013; Palombo et al. 2013a). These populations are considered more sensitive to climate warming and, in Mediterranean ecosystems, to aridification (Hampe & Petit 2005; Macias et al. 2006; Peñuelas et al. 2008; Linares et al. 2009; Carrer et al. 2010). Dry conditions, predicted for the southern European mountains, will cause less rainfall and more inter-annual variability in temperature and rainfall than other mountains in Europe (Nogués-Bravo et al. 2007, 2008; Giorgi & Lionello 2008). As a consequence, more species could be lost in the Mediterranean mountains or will shift along the entire elevational gradient (Ruiz-Labourdette et al. 2012), isolating most of the species within a warm, dry matrix at the southern limit of their biogeographical distribution (Petit et al. 2005). In this direction, Sardans and Peñuelas (2013) found that although many species in the Mediterranean ecosystem developed evolutionary mechanisms to overcome the drought, without significant losses of production and survival, some others have proved to be more sensitive decreasing their growth and increasing their mortality under moderate rising of drought. All these increases contribute to species composition shifts.

In a scenario of desertification for the Mediterranean Basin, the current knowledge suggests that plant–soil feedbacks can play an outstanding role in the capacity of these ecosystems to adapt to future global change (Sardans & Peñuelas 2013). This new knowledge requires an in-depth analysis in order to identify the processes involved in Mediterranean plant–soil feedbacks, which warrants further research. These mechanisms could also provide for a better understanding of the influence of climatic variables on tree growth. Many studies on conifer species, in fact, have demonstrated high correlation between tree ring width of 1 year (t) and precipitation and/or temperature of the previous fall ($t-1$) (Oberhuber 2004; Savva et al. 2006; Carrer et al. 2007; Camarero et al. 2013; Palombo et al. 2013a). In addition, satellite remote sensing data could represent a new tool for monitoring ecosystem dynamics, especially in areas strongly affected by desertification (Alberti et al. 2013; Schucknecht et al. 2013).

Where areas above the treeline are limited in size, owing to relatively low summit altitudes, endemic-species hotspots might be affected disproportionally by a rising treeline (Dirnböck et al. 2011; Engler et al. 2011). In fact, the effects of warming temperature and anthropogenic factors are visible also on the herbaceous plants, in particular at high elevation, where alpine floras have a high proportion of endemic species restricted to open microsites (Blasi et al. 2003, 2005; van Gils et al. 2012). For this reason, several scientists have analysed the influence of global change on the alpine vegetation distribution (Theurillat & Guisan 2001; Dirnböck et al. 2003; Poldini et al. 2004; Camarero et al. 2006; Nogués-Bravo 2006; Lorite et al. 2007; Caccianiga et al. 2008; Csecserits et al. 2011; Engler et al. 2011; Carasso et al. 2012; Vashistha et al. 2012; Elumeeva et al. 2013), demonstrating a loss of cold-adapted species from mountains not high enough to offer escape routes in the case of upward shifts of taxa less adapted to low temperature (Theurillat & Guisan 2001; Becker et al. 2007; Scherrer et al. 2011; Gottfried et al. 2012).

Concerning the loss of biodiversity and alpine habitats, many species distribution models have been formulated to predict the effect of climate changes (Guisan & Zimmermann 2000; Guisan & Thuiller 2005; Pagel & Shurr 2012; Peterson & Soberón 2012), and the turnover of species composition along the gradient was analysed (Čarni et al. 2011). However, the effects of human disturbance on the variability in biotic communities, i.e. the relation between temporal variability of species richness (or diversity) and gradients of human disturbance (Bartha et al. 2008; Sadori et al. 2010; Lomba et al. 2013), are still unknown. In both cases, one of the effects most recently considered has been the colonization of alpine belt by exotic species (Gritti et al. 2006; Thuiller et al. 2006; Csecserits et al. 2011; Concilio et al. 2013), or the different response of native and alien plant species richness to anthropic impacts along alpine elevation gradients (Marini et al. 2009). Nevertheless, how to disentangle the effects of climate change from those of human disturbance in the evolutionary dynamics of treeline ecosystems remains a matter of debate.

Protected areas have recently increased globally in mountain systems. Climate change may further increase the pressure for more conservation, as well as for more intensive resource use at high elevations. In the Mediterranean area, as well as other centres of agro-biodiversity, innovative concepts and

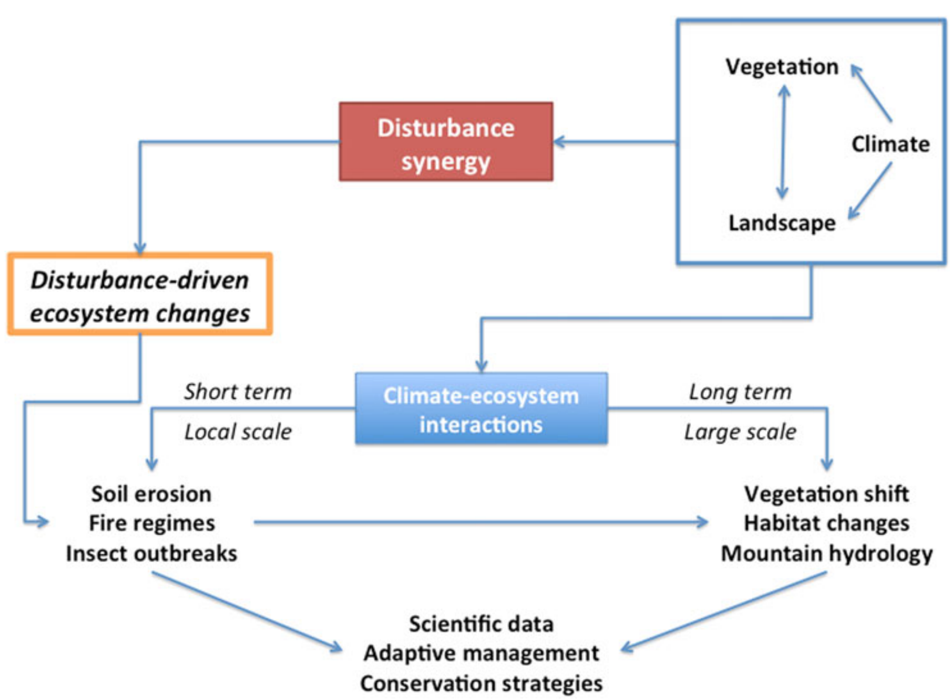

Figure 1. Conceptual model pointing to research needs: landscape focus, integration of disturbances, hydrological cycles and vegetation processes. Delivery of research findings that span a broad range of spatial and temporal scales in the form of adaptation options should be the focus of restoration initiative in mountainous ecosystems.

approaches are thus required to reconcile biodiversity conservation with development. Indeed, local communities may have conflicting goals in regional setting. One way of reconciling conservation and development is by engaging local stakeholders in the stewardship of their territory (e.g. natural and cultural heritages, agroforestry landscapes and biodiversity reserves within a common framework; see Cantiani 2012).

Conservation landscapes in mountain regions are increasingly recognized for their potential to maintain high levels of biodiversity in combination with diversified small-scale farming even in highly developed regions (e.g. Alps), where the creation and maintenance of protected areas and the connectivity across altitudinal gradients should also support the livelihoods of mountain communities and provide basic environmental services for the urbanized lowland populations. Disturbances interact with each other in ways that are complex and often difficult to predict, particularly at high elevation, which would indicate proactive risk management and ecosystem restoration initiative in high mountain environments. The nature of future treeline landscapes – given process interactions, threshold cross and cumulative effects – will likely depend upon the overlay of disturbance regimes on ecosystem processes (increased stress from drought and pests, for instance, may have significant effects on growth, regeneration, long-term distribution and abundance of forest vegetation, and carbon sequestration) (Figure 1).

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