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Is land abandonment affecting forest dynamics at high elevation in Mediterranean mountains more than climate change?

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Abstract
Global change is leaving a fingerprint on the appearance, structure and productivity of the treeline ecotone, modifying patterns of mountain ecosystems. In order to implement correct policies for managing natural resources, we examine how climate change interrelated with land-use abandonment could shape mountain forests at their upper limit in a Mediterranean environment, and how patterns of tree growth and periods of tree establishment guide the interpretation of global change effects on treeline dynamics. We reconstructed the population dynamics of mountain pine (*Pinus mugo* Turra spp. *mugo*) in the subalpine belt of the Majella National Park (Italy). In a test area of 14,440 ha, proposed as a pilot study site for long-term ecological monitoring, temporal and spatial mountain pine distribution were examined since 1954 by historical aerial ortophotos. Multitemporal maps documented the expansion upwards (1 m/year) and downwards (3 m/year) of mountain pine. Mountain pine started to expand upwards into the formerly tree-free grassland in early 1900s, in association with a decline of the local human population and livestock. Land-use change was the major driving force of vegetation dynamics at the treeline in the Majella massif.

Keywords: *Global change, forest management, national parks, Mediterranean mountains, treeline*

Foreword

One of the biggest gains of the global conference Rio+ 20 on sustainable development has been the pledge to protect mountain ecosystems. The Rio+ 20 outcome document encourages states and organizations to take concrete actions since mountains offer solutions both to kick-start a sustainable and equitable Green Economy and demonstrate inclusive development models that have reduced poverty and promoted social and gender equity in both upstream and downstream contexts (Kohler et al. 2012). The benefits deriving from mountain regions are essential for sustainable development of countries facing the Mediterranean Basin; in fact, mountain ecosystems play a crucial role in providing water resources to a large portion of the population. 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. Local communities have developed sustainable uses of mountain resources, but they are often marginalized. Pisanelli et al. (2012) in a recent study conducted in a mountain area of central Italy stress the awareness of social, cultural and environmental constraints/potentialities of the local communities. They also highlight that continued efforts would be required especially to satisfy expectation of young people concerning the territorial development. The research community is invited to boost networking with effective involvement and sharing of experience of all relevant stakeholders, by strengthening existing cooperation, as well as exploring new development strategies.

In Southern Europe, the legacy of Mediterranean civilizations have led, mainly through fire and grazing of natural vegetation, to the overexploitation and transformation of pristine ecosystems into the present human-made landscapes (Marchetti et al. 2010). The landscape in these areas was artificially modified by man for the purpose of enhancing

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agriculture, forestry and other productive activities. Such traditional techniques and practices represent a relevant value of this cultural landscape (Agnoletti 2007). Industrialization processes of Europe during the nineteenth and twentieth centuries have triggered deep socioeconomic shifts, including rural exodus and declines of traditional practices based on small-scale agriculture, pastoralism and forest resource utilization (Blondel & Aronson 1999). These changes in land use were characterized by the abandonment of marginal areas, generally situated in the mountains, where land-cover change, grazing cessation and switch from habitual forest resources to other construction material or fuel type have transformed the landscape patterns deeply (Debussche et al. 1999; Boden et al. 2010).

The principal effect in the Italian countryside has been the spontaneous return of woodlands on land previously used for agriculture and pasture. This patchy process is influenced by the presence of former agricultural structures, such as terraces or walls, and crops, including fruit trees. This secondary succession is currently accelerating in many areas of the Italian Peninsula, acutely in mountainous areas (Motta et al. 2006; Boden et al. 2010). The same is happening in the central Apennines, where 2400 m a.s.l. represent the lower border of the subalpine/alpine ecocline (Blasi et al. 2003). In this natural test site, the typical treeline with a compact frame of beech forest is certainly anthropogenic, as a result of human activities for centuries (grazing, burning and logging). The Majella massif, in particular, has a wide altitudinal range available for tree recruitment in the alpine belt; it is the only area in the Apennines with large patches above 2000 m a.s.l., consisting of gentle slopes and large plateaus (Blasi et al. 2005). The presence of woodland patches [krummholz, *sensu* Holtmeier (1981)] dominated by mountain pine (*Pinus mugo* Turra spp. *mugo*) at the treeline on dry plateaus of the Majella massif resembles the subalpine–alpine ecotone on the Alps, and suggests that in the past a real climatically induced treeline must have been occurred somewhere sporadically on the Apennines.

Forest expansion in the Majella massif can be hypothetically attributed to three major (inter-related) issues: (i) cessation of grazing, burning and logging (especially after the foundation of the Majella National Park in the 1995), which influence present land use; (ii) increase in summer air temperatures, which affects tree growth at the natural boundary and (iii) changes in natural disturbances, which create opportunities for the establishment of new individuals. Dai (2010) predicted krummholz expansion on the Majella massif using a model with neighbourhood and environmental variables. Palombo (2013) reconstructed the population dynamics of mountain pine back in time by dating periods of past tree establishment, to understand tree-establishment patterns over the past 100 years, and found that tree growth of mountain pine was positively influenced by current spring temperature and summer precipitation. We aimed at investigating the population dynamics of mountain pine in the Majella National Park through a multitemporal comparison, to interpret recent treeline changes due to changes in land use. To achieve this goal, we examined: (i) the spatial patterns of tree establishment in current treeline forests, (ii) evidence for recent establishment above the treeline and (iii) the socio-economic changes in the alpine belt.

A pilot site for long-term monitoring of the treeline on the Apennines

The Majella massif (Abruzzo Region, central Italy – Figure 1), reaching 2793 m a.s.l. with Mt. Amaro, creates a ridge with a latitudinal span between 42°09′33″N and 42°00′14″N, 32 km from the Adriatic Sea. The Majella massif is composed almost exclusively by large layers of limestone, with the highest part characterized by a wide summit surface weakly sloped, of structural origin, bordered by steep inclinations, and incised by deep valleys. Karstic phenomena feature in depth the whole massif. Secondary montane grasslands, currently unutilized, prevail on south-eastern to south-western slopes. On satellite imagery (e.g. Arc Globe at 0.5 km resolution), the Majella altipiano appears as the largest (≈ 100 km^2) barrens in the Apennines. On the ground, these alpine barrens include patches of grassland and open, low vegetation, often featuring tussock and cushion growth forms (Blasi et al. 2005; van Gils et al. 2012).

The mountain pine is rare in the Apennines, and is considered the potential vegetation of the subalpine belt in central Apennines (Migliaccio 1966). The largest stands are in the Majella massif, above the beech forest limit, where mountain pine finds its ecological optimum in the north facing altitudinal range. The subalpine/alpine belt of Majella massif was subjected to the traditional summer pasturing until the 1950s and, since high-altitude pasture abandonment, upward moving of mountain pine dwarf-shrubland up to 2450 m a.s.l. has occurred. Mountain pine is a drought-tolerant species that grows successfully on carbonate-rich soils, and current climatic changes might thus be favourable to its expansion. Having slopes with prairies up to an elevation of 2400 m a.s.l., the Majella massif is probably the most suited Apennines' site for investigation on the effects of global warming and land-use change in Mediterranean mountains.

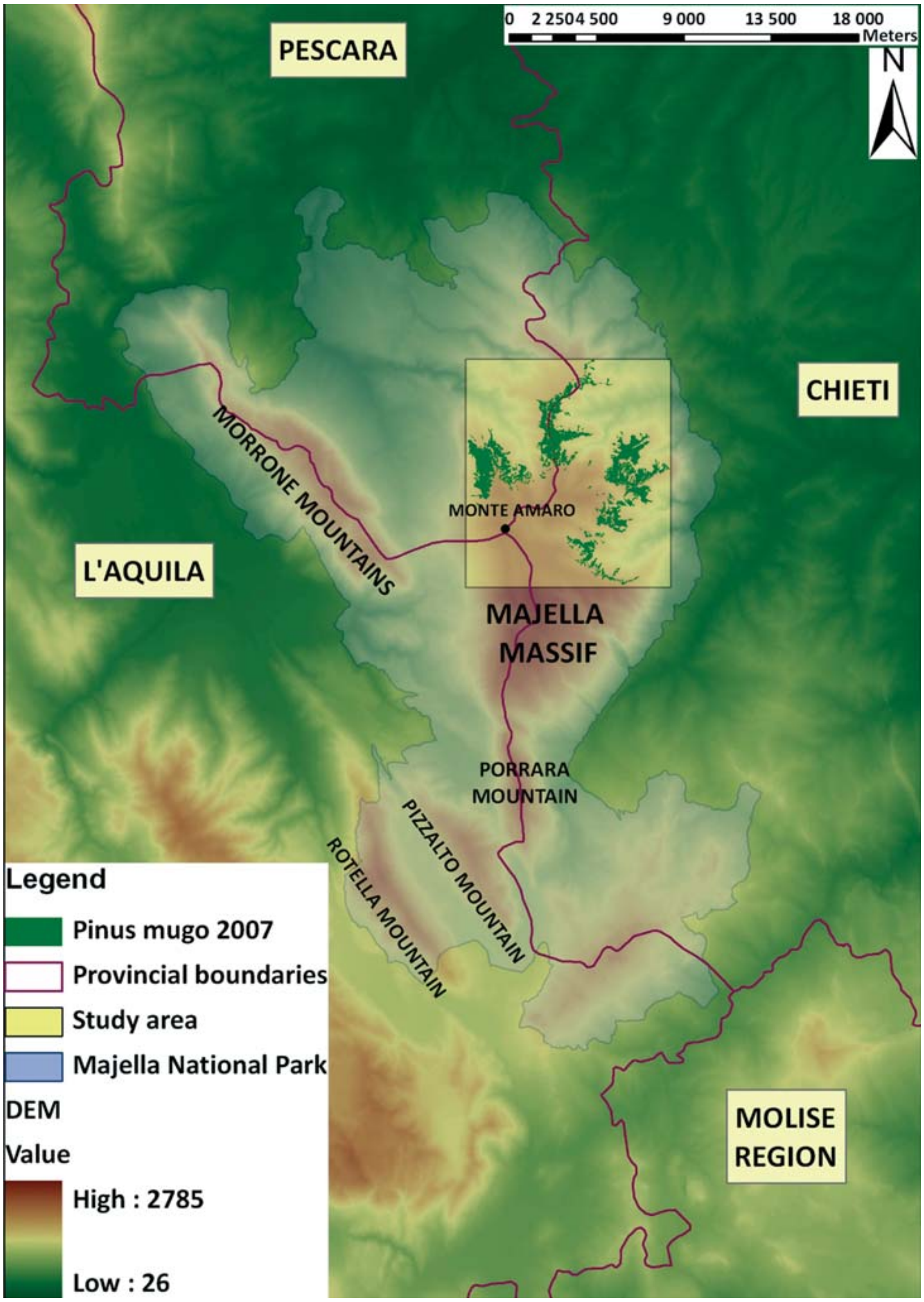

Figure 1. Location of the MNP (blue-grey) in the Abruzzo Region. In yellow the study area and in dark green the mountain pine distribution, in 2007.

The highest long-term meteorological station of central Apennines is Campo Imperatore (2125 m a.s.l.) with 3.6°C as mean annual temperature and 1613 mm as total annual precipitation (1960–1990). Stanisci et al. (2005), analysing the changes in species richness along an altitude gradient (2405–2730 m a.s.l.), found that 70% of species do not reach the highest summit and only 11% of the overall flora is shared by all summits of the massif; a drop in mean temperature was observed at soil level, along the same gradient from 3.1 to about 0°C. The study area is 14,440 ha wide and corresponds to the subalpine–alpine humid type with mountain pine woodlands as potential natural vegetation of slopes [habitat 4070 * bushes of *P. mugo* and *Rhododendron hirsutum* (*Mugo-Rhododendretum hirsuti*)], referring to the alliance *Epipactido atropurpureae-Pinion mugo* (Stanisci 1997).

Spatial patterns of treeline mountain pine forests

The analysis of recent and historical aerial-photo coverage of the area enabled us to investigate the

Table I. Technical details of the aerial photographs used in the analysis and achieved results.

Year	1954	1991	1999	2007
Scale	1:33,000	1:33,000	Pixel 1 m	Pixel 0.5 m
Format	Print 23 × 23 cm black/white	Print 23 × 23 cm black/white	Digital, real colours	Digital, real colours
Resulting mountain pine area (ha)	693	1196	1362	1423
Maximum altitude (m)	2451	2424	2462	2503
Average altitude (m)	1974	1975	1984	1973
Minimum altitude (m)	1592	1478	1469	1438

dynamics of mountain pine populations in the Majella massif (Table I). Two digital co-registered colour orthophotos were available: one of summer 1999, with a spatial resolution of 1 m, and one of summer 2007, with a spatial resolution of 0.5 m.

Historical grey scale traditional aerial photos from 1954 (seven photograms) and 1991 (four photograms) were first acquired by high-resolution scanning (1200 dpi) and then geometrically ortho-corrected and co-registered on the basis of a local high-resolution digital elevation model (DEM), having a 40 m resolution, and a number of ground control points for each photogram ranging between 46 and 80. The resulting average root mean square error of the orthorectification and co-registration was equal to 0.3 m for the photograms from 1954 and to 0.7 m for the photograms from 1991.

The spatial distribution of the mountain pine at the year 2007 was created by visual interpretation and manual delineation in a geographic information system environment of the 2007 orthophoto. A nominal scale of 1:5000 was adopted; pine formations were mapped when reaching minimum crown coverage of 10% and a minimum size (minimum mapping unit) of 500 m^2. Each polygon was classified according to crown cover classes: I $<$ 40%; II between 40% and 80%; III $>$ 80%.

Following the procedure detailed in Chirici et al. (2006), the 2007 map was then modified on the basis of the 1999, 1991 and 1954 orthophotos, in order to obtain the historical mountain pine distribution maps at the different years (Figure 2). All the maps were then overlaid with the DEM in order to extract the average, minimum and maximum altitude of mountain pine distribution at the four different investigated dates.

The spatial distribution of the mountain pine forest in the test area changed from 693 ha in 1954 (4.8% of the study area) to 1423 ha in 2007 (9.8% of the study area) (Table I). At the last investigated date (2007) the altitudinal range of the mountain pine distribution ranges between 1438 and 2503 m a.s.l., with an average elevation of 1973 m. During the last 52 years, the mountain pine forest expanded 52 m

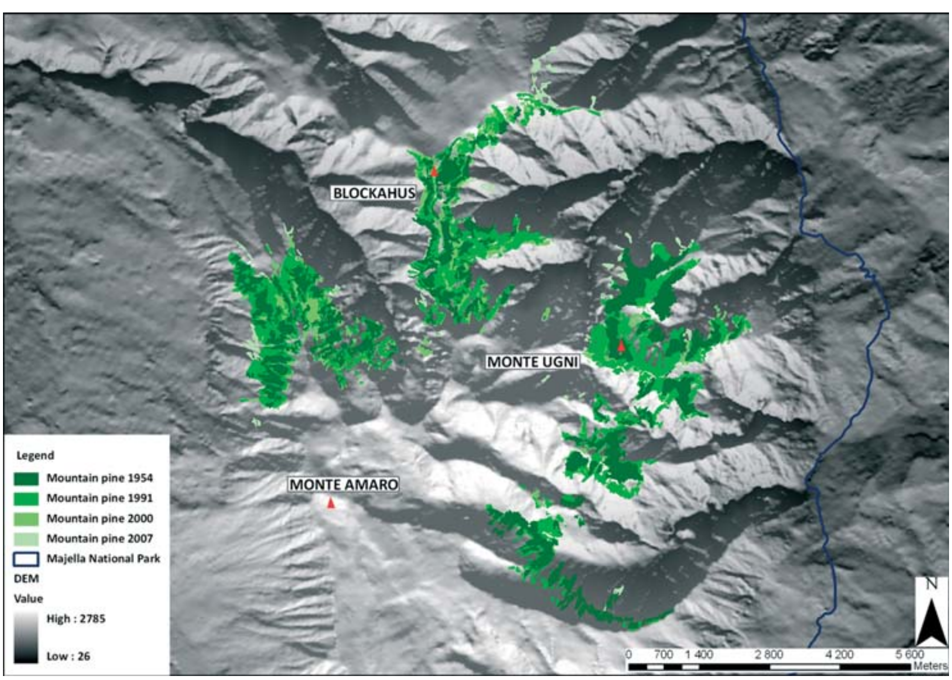

Figure 2. Multitemporal maps of the mountain pine geographical distribution on the basis of the DEM.

upwards and 154 m downwards. Maximum forest elevation changed since 1954 (2451 m), to 1991 (2424 m), to 1999 (2462 m), until 2007 (2503 m), with an overall increase of about 1 m/year (Table I). Likewise, minimum forest elevation has been constantly decreasing since 1954 (1592 m), to 1991 (1478 m), to 1999 (1469 m), until 2007 (1438 m), i. e. about 3 m/year (Table I). Overall, forest cover in the study area has increased yearly at higher rate in the period 1954–1991 (2.1%), followed by a period of partial decrease in rate, 1991–1999 (1.8%), and then a period of stable rate, 1999–2007 (0.4%) (Figure 3).

Canopy cover and grazing history in the Majella National Park

The grazing history was assessed for the last 200 years for the provinces within the borders of the Majella National Park, and for municipalities (villages) within the study area, using archival documents (official statistics, historical archives of municipalities and provinces). The forest cover versus time course provides a proxy indicator for reconstructing forest cover change, whereas the number of sheep versus time allows an indirect assessment of grazing rate changes.

Sheep comprised more than 80% of the total livestock in the municipalities of the study area (such a percentage decreasing more recently), with land use widely dedicated to livestock rearing, according to historical records. Archival data, though discontinuous, are available from these municipalities (and local sources) to historically document livestock variation. Grazing intensity peaked in the middle of the nineteenth century, decreasing over the last century (Table II). A first sharp reduction in grazing intensity took place in the first half of the twentieth century and a second one in the last 30 years. During the first decade of present century, pasturing

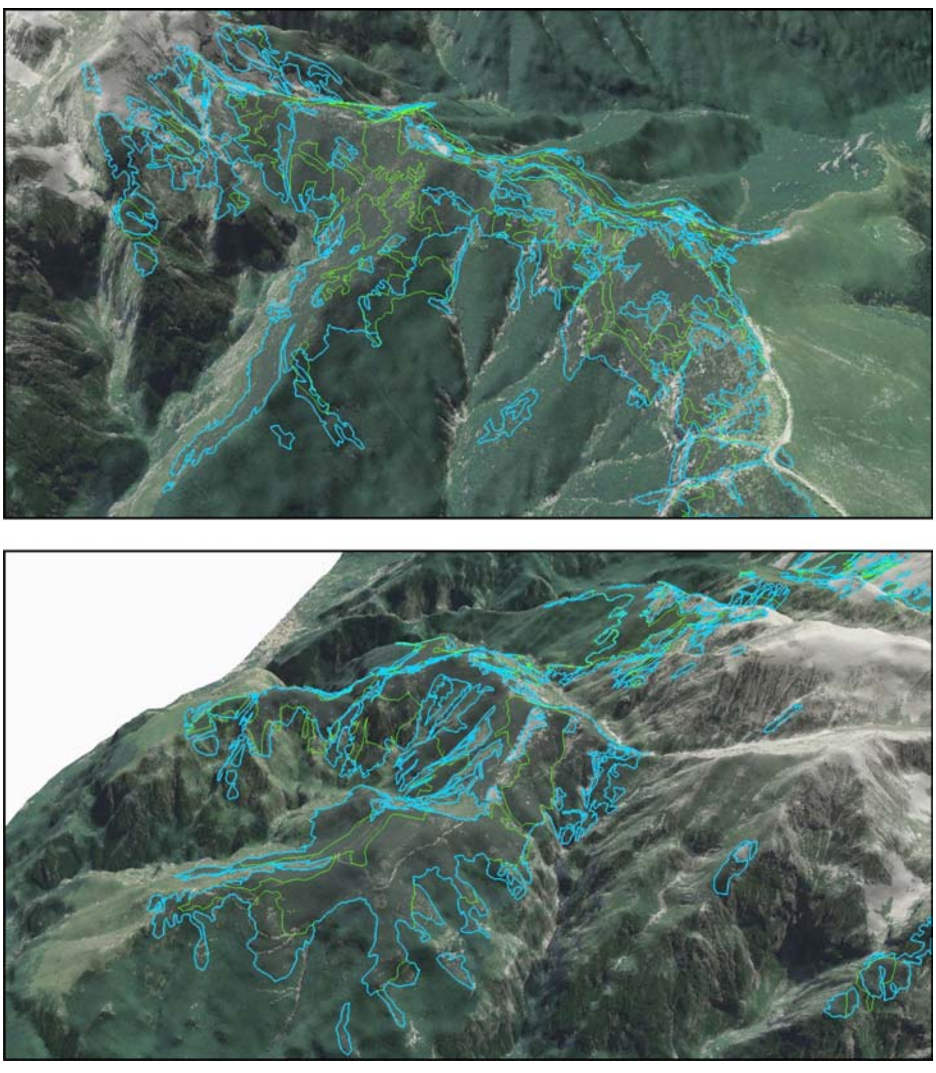

Figure 3. 3D ortophotos taken in 2007; mountain pine forest contour in 1954 (green) and 2007 (blue). View of M. Blockhaus (upper picture) and of M. Ugni (lower picture).

Table II. Tree establishment at the treeline and main land-use changes in the study area.

Year	Heavy grazing (transhumance and pastoralism) and cutting	Moderate grazing (pastoralism) and cutting	Low grazing (pastoralism) and cutting	Mountain pine forest cover (ha)	Forest cover class (% of total)
			Provinces of Pescara – Chieti – L'Aquila		
1880					
1890	Sheep nos > 500,000				
1900	Inhabitant nos				
1910	800,000 (126,620[a])				
1920					
1930					
1940					
1950		300,000 < sheep nos		685 (1954)	I, 24%; II, 37%; III, 39%
1960		<500,000 Inhabitant nos			
1970		943,000 (125,585[a])			
1980					
1990			300,000 < sheep nos	1196	I, 6%; II, 7%; III, 87%
2000			< 500,000 Inhabitant nos	1327	I, 13%; II, 22%; III, 65%
2010			943,000 (125,585[a])	1409 (2006)	I, 13%; II, 23%; III, 64%
			Municipalities of the Majella National Park		
1982			30,116		
1990			41,143		
2000			31,352		
2005			17,769		
2008			23,081		
2009			14,715		

Note: Forest cover classes are: I, <40%; II, between 40% and 80%; III, >80%. Transhumance, long-distance movement; pastoralism, short-distance migration. [a] Averaged population for the municipalities of the Majella National Park.

livestock has become less and less important. Mountain pine forest cover has increased during the past 50 years with a mean annual increment of 13.7 ha. Forest cover was almost proportionally distributed across the three crown cover classes, when grazing was moderately intense, from early 1920s to late 1950s (Table II). More recently, forest cover has become increasingly skewed towards class III. The highest number of inhabitants in the municipalities of the Majella National Park was in the beginning of the twentieth century. Afterwards, the number of inhabitants began to decrease gradually up to the beginning of present century, when the population statistics recorded a plateau. The population of the larger area (provinces of Pescara, Chieti, L'Aquila), instead, has increased gradually through the last 100 years, following a shift from agriculturally based to tertiary sector economy.

Land-use change and mountain pine forest dynamics

The increase of approximately 1 K in average annual air temperature in the last 100 years all over Italy (Brunetti et al. 2006) would point to tree recruitment above the present forest limit. Our results show that the forest–pasture ecotone of the Majella massif has changed fundamentally during the last 50 years, involving encroachment processes, which is consistent with the substantial changes in land use in those ecosystems. Neither increasing growth trends nor decreasing ages in mountain pine along an elevation transect were observed by Palombo (2013), pointing to a minor role played by climate in shaping the current treeline on the Majella massif.

In an analysis of recent forest dynamics along an altitudinal gradient in the upper Susa Valley (western Italian Alps), Motta et al. (2006) argued that tree establishment was mainly controlled by land use, while tree growth was for the most part controlled by climate. Nevertheless, recent establishment above current treelines in response to climate warming has been found in many regions of the Northern Hemisphere (e.g. Daly & Shankman 1985; Kullman 1991; Luckman & Kavanagh 1998). Studies in the Swiss Alps showed a dramatic increase in the growth of *Picea* and *Pinus* at the treeline (Paulsen et al. 2000) and a dramatic increase of Scots pine at its southern distribution limits (Giuggiola et al. 2010). Čarni et al. (2011) studied gradients in several case studies across Europe and Turkey (successional, altitudinal, anthropic, phenological, macroecological or phytogeographical gradients), and found that in most cases the turnover of species composition along a gradient was due to species interactions. Yet, rising temperatures have increased the productivity and survival of trees in mountain environments (Paulsen et al. 2000; Motta & Nola 2001), with a resulting expansion of woodland mosaic in the Alps (Chauchard et al. 2007). In Mediterranean mountains, instead, patterns of land abandonment and livestock grazing superimpose to the effect of climate change, and therefore these observations have to be reframed in a context of land-use change (Poyatos et al. 2003; Boden et al. 2010).

On the Majella massif, abundant mountain pine regeneration was observed during the past 50 years (Figure 4), simultaneously with abandonment of summer pastoralism above the beech treeline (van Gils et al. 2012) and climate becoming drier during the growing season (Palombo 2013). The interpretation of historic photographs indicates that areas that are now covered by closed mountain pine forest were covered by scattered vegetation in the mid of the twentieth century. The considerable expansion of mountain pine in large areas of the Majella plateau, which have been grazed or cut until recently, is probably due to the abandonment of human activities in these marginal lands. At these treelines, cessation of grazing has been relatively gradual and marked by a staggered pattern, and forest expansion has not occurred homogeneously at the local scale. More interesting, however, are the even larger intrusion and colonization of mountain pine downhill in crop systems and beech forests. These results agree with several studies carried out recently in different European mountains (Mind'áš et al. 2004; Jodłowski 2006; Mihai et al. 2007; Švajda et al. 2011), in which the authors attribute the recent expansion of mountain pine krummholz to its ability to recolonize site from previous periods. In addition, Gerigh-Fasel et al. (2007) establish that the altitude of the potential regional treeline derived from the highest forest patches identified by a moving window algorithm, as a reference to discern which is the main factor influencing the upward expansion of the treeline. Upward shifts above the potential regional treeline were considered to be influenced primarily by climate change, while upward shifts below the potential regional treeline were interpreted as primarily influenced by land abandonment. If we consider these claims and that mountain pine could reach the summit of the Majella massif (Migliaccio 1966), we could affirm that land-use change was the main factor that led to the rapid expansion of mountain pine forest, through the re-colonization of abandoned pastures. This expansion occurred in the altitudinal range of mountain pine distribution and towards both higher and lower altitudes. However, climate variables also may affect tree growth at the high mountain pine limit, by reacting areas close to the local treeline in subalpine pastures grasslands, which are very resistant against invasion of tree species (Gerigh-Fasel et al. 2007).

Several studies report on dendroclimatic elements on mountain pine at treeline (Schueller & Rolland 1995; Rolland et al. 1998). Pelfini et al. (2006), for mountain pine in Central Italian Alps, found that the climate of the summer months has the strongest influence on tree-ring growth. Correlations between ring widths and climatic conditions on mountain pine populations of the Majella massif (Di Cosmo 2003; Palombo 2013) suggest that warmer spring temperatures would be helpful to expand the vegetation period. Low temperature and abundant snowfall during spring delay bud burst, reducing growth time span, while warmer air induces prompt shoot development.

In Mediterranean mountains, constraints on treeline dynamics probably include processes more contingent on local environmental conditions than on the recent disturbance history (Batllori et al. 2010); indeed recruitment has not been episodic in the studied mountain pine stands. A small change in

Figure 4. Mountain pine dominated treeline at the Majella National Park (Mt. Cavallo), Central Apennines, Italy; left photo taken in 1940, right photo taken in 2005.The most evident change is the increase in tree density across the treeline ecotone together with an upward shift of several meters in some areas. (by courtesy of R. Motta)

site-specific water availability could have a profound influence on stand composition, structure and function in Mediterranean climate (Joffre & Rambal 2002; Vitale et al. 2012). Despite the relatively high annual precipitation in the study area, regular and prolonged summer droughts point to the Mediterranean mark of this forest ecosystem. The high solar radiation coupled with high soil permeability due to karst and fissuring of limestone may result in high evaporative water loss and low water-holding capacity (Anfodillo et al. 1998; Boden et al. 2010). Dirnböck et al. (2003) suggested a considerable range expansion of mountain pine at only moderate levels of temperature increase, throughout most of the north-eastern calcareous Alps. Overall, our results indicate that, on the Majella massif, past seasonal livestock residence due to shepherds' tracks and transhumance might be stimulating growth more than rising temperature.

The recent beech forest regeneration and expansion at the lower limit of mountain pine forests would depend on canopy openings and temperature trends (Vitale et al. 2012), and would be delayed only in the presence of disturbance (i.e. forest fire). The rare beech forest fire in Majella can be attributed to a combination of the several conditions, including summer drought and abandoned farmland management (van Gils et al. 2010). Instead, on the Majella massif, van Gils et al. (2008) observed that from 1975 to 2003 beech advanced into abandoned farmland and subalpine pastures from the contiguous, mid-altitudinal beech forest and from beech outliers, at a rate of 1.2%/year. The same applies to the mountain pine ecotone in other European mountains, where the on-going reduction of krummholz surface is the result of the upward shift of spruce forest (Mind'áš et al. 2004; Mihai et al. 2007). Mediterranean mountains will probably present shifts and replacements in response to climate and land-use changes, as a result of interfering mechanisms between different species (Lingua et al. 2008).

Conclusions and perspectives

The forest–pasture ecotone of the Majella massif has changed markedly during the last 50 years. A major role was played by changes in land use, i.e. decreasing human pressure (animal husbandry and tree cutting). The expansion towards lower altitude of mountain pine and the possible interaction with beech forest remain to be investigated. Evidence of rapid alterations due to land-use modifications in the treeline of Majella massif provides additional indication of complex effects of global change on mountain ecosystems facing the Mediterranean Basin (cf. Améztegui et al. 2010; Chauchard et al. 2010), and shows how difficult it is to disentangle complex processes, such as the impact of global change on mountain ecosystems. Climate change is altering biological processes and having important impacts on biodiversity at multiple scales. However, the responses of species and biological communities to climate change can also be influenced by the additive or synergistic effects of other components of global change, such as land-use changes or biological invasions. In fact, the magnitude of the impacts of each one of the different components of global change, and therefore their interactions, is subjected to variation among systems and biomes (Sala et al. 2000; Parmesan 2006; Clavero et al. 2011).

In a recent study, Bracchetti et al. (2012) confirmed the crucial role of the abandonment of rural and mountain areas, which induced changes both at landscape level and at plant community level. The most common and widespread effect has been either the expansion of shrublands or forests, or both, as observed on the Mediterranean mountains. They also highlighted that the disappearance of Mediterranean cultural landscapes is a relevant problem for biodiversity conservation, causing the disappearance of a large number of species, habitats and landscapes in the Mediterranean Basin. The cultural landscape of the Mediterranean region is the result of the millenarian integration between land use and natural processes (cf. Finck et al. 2002; Mazzoleni et al. 2004).

Others studies conducted within the Mediterranean Basin, however, analysed the effect of climate changes on mountain biodiversity, and forecasted their effects on the distribution and community composition of tree species. The main conclusions were that areas with climatic conditions suitable for cold-adapted species will decrease significantly under climate change (cf. Gottfried et al. 2012) and that Mediterranean mountains might lose their key role as refugia for cold-adapted species and thus an important part of their genetic heritage (Alkemade et al. 2011; Ruiz-Labourdette et al. 2012). The locations of refugia are determined by complex historical and environmental factors. Refugia represent climatically stable areas and significant reservoirs of genetic diversity, constituting a high conservation priority in forest ecosystems and agroforestry systems of Mediterranean mountain landscapes, especially given the threat posed by the extensive environmental change processes operating in the Mediterranean region (Médail & Diadema 2009; Lombardi et al. 2012).

In this contest, Resco de Dios et al. (2007) suggested an active forest management to curb global warming effects, divided into three approaches: (i) conservation management strategy, which aims to prevent emissions and conserve current forest carbon pools through diminishing deforestation, increasing rotation period, reducing thinning intensity and restricting many harvesting activities; (ii) storage management strategy, which aims to increase the amount of carbon stored in vegetation and soil through an increase in forested areas and/or carbon stored per unit area in natural and plantation forests and (iii) substitution management strategy, which includes the transfer of carbon biomass into furnishings, construction and other. Priorities of these management strategies are the promotion and conservation of biological diversity. This is achieved by: (i) sustainable forest management for a preservation of the pool of natural species and genetic variability of forests and (ii) networking protected areas or natural ecosystems by creating ecological corridors or by maintaining appropriate ecological components in associated areas to allow natural migration of ecosystem elements.

In protected areas such a national park, it is fundamental to describe the best management practices that will maintain or enhance adaptive capacity or resilience of ecosystems. In some cases, the authorities may need to reconsider the current position, which encourages the decline of traditional practices (e.g. seasonal grazing), to avoid the risk of losing very rare ecosystems (Bartolomé et al. 2008). The elaboration of techniques for reading the landscape and its assets that can help in identifying and cataloguing landscape units, as well as in recognizing their ecologic values, and in creating models inspired to a sustainable territorial development should be reconsidered. Indeed, national park zonation considers, in general, various areas with different levels of protection, including core areas, buffer zones and transition zones. Restriction in land-use systems is relatively clear for core areas and transition zone, while many definitions of buffer zones can be provided. Zonation on national parks in mountain areas of the Mediterranean region, for instance, should be designed to help achieve the conservation needs of the park, basing the analysis of buffer zones (e.g. the contiguous area between beech and mountain pine forests on the Majella massif) on the accomplishment of conservation needs.

Marchetti et al. (2012) analysed biomass data from forests in the national parks of Italy and found that the average forest carbon stock and sink per unit area is relatively higher within national parks than on the overall national territory. They also concluded that increasing the productivity of forests, while minimizing the disturbance to stand structure and composition, would allow the restoration of carbon sequestration potential, where unsustainable management practices have degraded relatively large stocks of biomass. The question of how to meet wood demand at the least cost to forest biodiversity in rural landscapes of Mediterranean mountains could require the evaluation of two contrasting alternatives: sustainable forest management, which integrates both objectives on the same area; and strict forest conservation, in which high-impact forestry is combined with protecting high-value forest stands. While separating land for forest conservation from land for forest management could be fundamental to reducing emissions from deforestation and forest degradation, requiring the sustainable intensification of forestry, sustainable forest management is often an aim of certification schemes, and can result from some forms of agroforestry.

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