Climate change impacts on goods and services of European mountain forests

M. Maroschek, R. Seidl, S. Netherer and M.J. Lexer

A review of likely ecosystem sensitivities and impacts on forest products and services from expected climatic changes in European mountain forests – and possible adaptation options.

European mountainous areas, in contrast to many other mountain regions of the world, have high population densities and consequently many potentially conflicting demands on the environment. Forest ecosystems are key elements in the land-use matrix of these areas, providing a variety of goods and services to human livelihood. Expected climate change, however, could place these ecosystem services at risk because of the high exposure of European mountain ecosystems.

In the Alps, for instance, the observed total temperature increase over the second half of the twentieth century was roughly twice the global average. Regional projections from state-of-the-art climate models indicate that this trend will continue in the twenty-first century, with an expected warming of approximately 3.5 to 4°C in summer and little less in other seasons between today and 2100 (Christensen *et al.*, 2007). Changes in precipitation and windstorm patterns are still highly uncertain and will be strongly influenced by the local geomorphological heterogeneity of mountainous landscapes. In central European mountain areas precipitation patterns are expected to shift towards more moist conditions in winter and increasingly dry summers. This trend is projected to be even stronger in the Mediterranean, where distinct decreases in precipitation during the vegetation period are expected

Mountain forests provide multiple goods and services to local communities, for example in the Stubai Valley in the Central Alps, Austria


M. MAROSCHEK

Michael Maroschek, Rupert Seidl and **Manfred J. Lexer** are in the Institute of Silviculture, and **Sigrid Netherer** is in the Institute of Forest Entomology, Forest Pathology and Forest Protection, all in the Department of Forest- and Soil Sciences, University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria.

to be amplified by warming of up to 4°C by the end of the twenty-first century (Christensen *et al.*, 2007).

This article reviews ecosystem sensitivities, future impacts on goods and services and possible adaptation options in relation to expected climatic changes in temperate and Mediterranean mountain forests in Europe. It focuses on the main mountain ranges in these climatic zones – the Alps, Carpathians and Pyrenees – and covers a variety of (current) forest types, ranging from thermophilous broadleaved evergreen and dry coniferous forests to alpine coniferous forests and temperate continental deciduous forests. It is part of a recent in-depth pan-European synthesis on climate change and forestry (Lindner *et al.*, 2008).

Subalpine **Picea abies** *forest infested with the bark beetle* **Ips typographus***, which has already benefited from temperature changes and increasing drought stress, which make host trees more susceptible (inset: characteristic larval galleries of* **I. typographus***)*

FOREST ECOSYSTEM SENSITIVITIES

Changes in temperature, water availability and disturbance regimes are likely to lead to changes in productivity of forest ecosystems, particularly in those already limited by either temperature or water. An increased atmospheric CO_2 content may also influence productivity, but the effect on different tree species is not yet fully known (Körner *et al.*, 2005).

At higher elevations, warmer temperatures and less harsh environmental conditions have already resulted in higher growth rates. Continuing lengthening of the vegetation period might intensify this effect, but might also stimulate earlier budburst which could increase the susceptibility of trees to late frosts. Nevertheless, a positive growth trend is expected to continue, particularly at sites not restricted by water availability (Bolli, Rigling and Bugmann, 2007).

At low elevations and in dry inner alpine valleys, changing precipitation patterns and increasing temperatures may result in drought stress, which could decrease productivity. This has already been observed recently, for instance in the upper Rhône Valley in Switzerland (Rebetez and Dobbertin, 2004).

An increase in drought stress might also increase vulnerability of mountain forests to biotic disturbance agents, with implications ranging from increased tree mortality at the stand level to drastic consequences on a larger scale as the system's resilience is exceeded (Raffa *et al.*, 2008).

Warmer and drier conditions also make alpine forest ecosystems more prone to abiotic damage. Periods of drought, especially during winter and spring, promote forest fires, which are expected to increase not only in the already arid and fire-influenced Pyrenees but also in the Alps, where wildfires have been of only minor importance historically (Reinhard, Rebetetz and Schlaepfer, 2005; Schumacher and Bugmann, 2006). While the influence of climate change on storm frequency and severity is still uncertain, the greater number of disastrous storm events in Central Europe over the past two decades (e.g. "Viviane" in 1990, "Lothar" in 1999, "Kyrill" in 2007) underlines an increasing susceptibility.

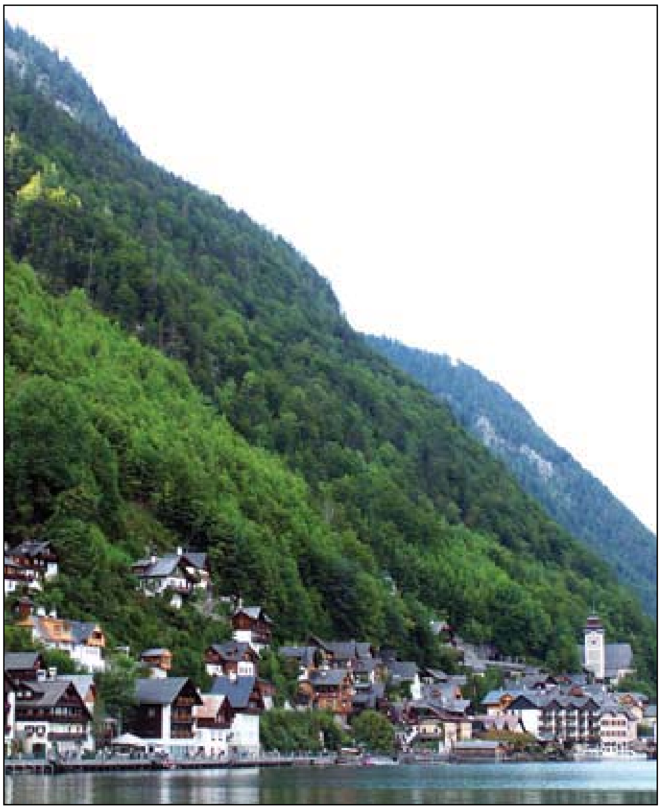
Abiotic damage is a main factor contributing to the risk of biotic disturbance, such as infestation by defoliators (e.g. Battisti, 2004) and mass outbreaks of secondary species of bark beetles (Nierhaus-Wunderwald and Forster, 2000). Norway spruce (*Picea abies*) forests impaired by drought stress or windthrow are highly predisposed to attack by the spruce bark beetles *Ips typographus* and *Pityogenes chalcographus*, which also benefit from increased summer and winter temperatures (Wermelinger, 2004). At present the spatial distribution of the host tree species extends beyond the beetles' thermal range, but the upward shift of climatic conditions that are beneficial to the insects will presumably trigger bark beetle outbreaks in coniferous forests at high elevations (Seidl *et al.*, 2009).

Although development of many poikilotherm organisms (organisms with body temperature that varies with the surrounding temperature, e.g. insects) is positively correlated with rising temperatures, negative effects are possible for certain pest species. Increased winter temperature may impair the inhibition or maintenance of diapause (a dormant state enabling arthropods to survive unfavourable conditions), raise mortality rates of overwintering stages or prevent synchrony between hosts and herbivores (Bale *et al.*, 2002; Battisti, 2004). For example, in Switzerland peak population densities and thus the incidence and intensity of severe outbreaks of the larch bud moth, *Zeiraphera diniana* (a cyclical defoliator of inner alpine larch stands) have been diminishing over the past 30 years in coincidence with the trend of climatic warming, probably owing to increased egg and larval mortality (Esper *et al.*, 2007).

Overall, simulation studies have indicated that the niches of forest tree species are highly sensitive to climatic changes; as a result species distribution and composition may be altered. In the Alps and the Carpathian Mountains the potential area of broadleaved tree species is expected to increase relative to conifers (Lexer *et al.*, 2002; Skvarenina, Krizova and Tomlain, 2004). In the Montseny Mountains in Spain, for instance, the distributions of *Quercus ilex* and *Fagus sylvatica* have already shifted towards higher elevations during recent decades (Peñuelas *et al.*, 2007). The tree line will also rise where suitable microsites become available as a result of decreased tree mortality and increased growth and reproduction where temperature is currently limiting. For example, upward movement of tree lines dominated by *Picea abies* and *Pinus cembra* in the Alps has already been observed in recent years. However, tree lines are sensitive not only to changes in climate but also to land-use changes which may either offset or amplify climatic effects (Gehrig-Fasel, Guisan and Zimmermann, 2007).

POTENTIAL IMPACTS ON FOREST GOODS AND SERVICES

The forest ecosystem sensitivities described above will have considerable impacts on mountain forest goods and services. Timber production will be altered not only by changes in productivity, but also by possible losses due to abiotic and biotic disturbance events, particularly in coniferous stands in the Alps and Carpathians (Seidl *et al.*, 2009). However, climate change will also broaden the silvicultural portfolio in many mountain forest ecosystems, relaxing eco-physiological limitations for an increasing number of broadleaved species.



R. SEIDL

Protective forests shelter the Austrian village of Hallstatt in the Northern Calcareous Alps against rockfall, avalanche and debris flow – functions that could be influenced by increased forest disturbance under climate change

The service of carbon sequestration is partly related to changes in productivity. Forests in the Alps are expected to maintain their role as a carbon sink for approximately the first half of the twenty-first century. Later in the century increasing respiration rates and more frequent disturbances may lead to a decrease in carbon sink strength, and forests might eventually even become a source of atmospheric carbon. Ultimately, the socio-economic environment – including the demand for forest biomass, market prices for carbon sequestration and changes in land use – will determine whether European mountain forests will remain a carbon sink (Zierl and Bugmann, 2007).

An important forest service for mountainous regions as well as for adjacent metropolitan areas is the provision of drinking-water. Large-scale disturbances may lead to increased runoff and consequently reduced water storage in catchments. This may result in decreasing water security as well as increased soil erosion, flooding and debris flow activity. Furthermore, accelerated decomposition of organic matter as a result of canopy openings (from disturbances) and increased temperatures may stimulate the leaching of nitrates and other nutrients, diminishing water quality (Jandl *et al.*, 2008). Climate-induced glacier shrinkage could threaten the water balance of some inner alpine regions. Retreating glaciers may no longer be able to balance the river discharge during hot and dry summer months, with reduced water availability as a result (Zappa and Kan, 2007).

Protection against natural hazards such as flooding, debris flow, landslide, rockfall and avalanche is an ecosystem service of high importance in densely populated mountain areas. Net impacts of climate change on this forest function will be a result of the combined effects on forest dynamics and on the magnitude and frequency of such hazardous processes. In general, increasing disturbances such

Tree line dominated by* Picea abies *on Mount Speikkogel, Austria is highly sensitive to climatic changes; a rising tree line can be expected to provide stability for greater protection against hazards, but may also influence biodiversity

as bark beetle infestations, windthrow and fire will have a strong negative impact on protective functions of forests (Schumacher and Bugmann, 2006). Conversely, a rising tree line might support protection against hazards by stabilizing erodible masses, reducing avalanche starting zones, dampening runoff because of increased interception and water consumption, and stabilizing soils through deeper and more intense rooting.

A rising tree line may also influence the conservation of biodiversity. Plant species diversity in the alpine and nival zones is likely to be adversely affected by upward shifts of subalpine forest and shrubland communities, for example the *Pinus mugo* belt in the Alps (Theurillat *et al.,* 1998). In managed forests, however, where biodiversity is strongly influenced by forest management interventions, the increasing competitiveness of species-rich deciduous forest communities at higher elevations may promote overall biodiversity.

OUTLOOK: NEEDS AND OPTIONS FOR ADAPTATION

In many European mountain forest ecosystems, adaptation measures will be required to counteract adverse climate change impacts and maintain ecosystem goods and services. Local biophysical and socio-economic conditions need to be considered in the development of these measures. Thus only a broad set of general options for adapting forest management to climatic changes is discussed here.

The choice of suitable forest reproductive material (i.e. provenances and genotypes) and species adapted to expected future conditions is of paramount importance for sustainable forestry. Expected drought effects can be mitigated by establishing stands with wider spacing and adapting suitable tending and thinning schemes (Spiecker, 2003). In times of changing disturbance regimes, preventive (e.g. pest monitoring) and remedial (e.g. sanitation felling, pest control) forest protection routines are essential to minimize adverse effects of disturbances on the provision of forest goods and services. To sustain the protective function continuous forest cover is important; this requires tending and thinning practices aimed at achieving maximum stability of forest stands and enhancing regeneration. In addition, maintaining structured and continuous forest canopies supports the provision of drinking-water. The implementation of required measures in complex alpine terrain can be supported by improved forest infrastructure (e.g. road network planning). Furthermore, adaptive management options can be supported by reducing other pressures on mountain forest ecosystems such as ruminant browsing and deposition of pollutants. In general, integrated environmental management is necessary in European mountain regions, especially where land-use changes (e.g. the abandonment of high alpine pastures) strongly alter landscape structure.

Implementation of effective adaptation measures is heavily contingent on the availability of human resources and expertise. Yet the knowledge base with regard to European mountain forests is asymmetrical in terms of subject and location. More research has been done on the Alps than, for instance, the Carpathians and Pyrenees. Timber production is the service studied most frequently, while few studies have explicitly addressed impacts of climate change on the provision of high-quality drinking-water, recreation or non-wood forest products. Successful adaptive management will depend on addressing considerable gaps in understanding of climate change impacts on multipurpose mountain forests.

Furthermore, targeted research on the implementation of adaptation strategies is strongly needed. The development and application of climate-smart decision support systems and the involvement of stakeholders can facilitate this process and support the transfer of research to operational adaptation measures. Scientists, policy-makers and practitioners are called to join forces to build the capacity required to face the challenge of sustainable management of mountain forests under changing climatic conditions. ◆

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