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A walk on the wild side: Disturbance dynamics and the conservation and management of European mountain forest ecosystems

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ABSTRACT

Mountain forests are among the most important ecosystems in Europe as they support numerous ecological, hydrological, climatic, social, and economic functions. They are unique relatively natural ecosystems consisting of long-lived species in an otherwise densely populated human landscape. Despite this, centuries of intensive forest management in many of these forests have eclipsed evidence of natural processes, especially the role of disturbances in long-term forest dynamics. Recent trends of land abandonment and establishment of protected forests have coincided with a growing interest in managing forests in more natural states. At the same time, the importance of past disturbances highlighted in an emerging body of literature, and recent increasing disturbances due to climate change are challenging long-held views of dynamics in these ecosystems. Here, we synthesize aspects of this *Special Issue* on the ecology of mountain forest ecosystems in Europe in the context of broader discussions in the field, to present a new perspective on these ecosystems and their natural disturbance regimes. Most mountain forests in Europe, for which long-term data are available, show a strong and long-term effect of not only human land use but also of natural disturbances that vary by orders of magnitude in size and frequency. Although these disturbances may kill many trees, the forests themselves have not been threatened. The relative importance of natural disturbances, land use, and climate change for ecosystem dynamics varies across space and time. Across the continent, changing climate and land use are altering forest cover, forest structure, tree demography, and natural disturbances, including fires, insect outbreaks, avalanches, and wind disturbances. Projected continued increases in forest area and biomass along with continued warming are likely to further promote forest disturbances. Episodic disturbances may foster ecosystem adaptation to the effects of ongoing and future climatic change. Increasing disturbances, along with trends of less intense land use, will promote further increases in coarse woody debris, with cascading positive effects on biodiversity, edaphic conditions, biogeochemical cycles, and increased heterogeneity across a range of spatial scales. Together, this may translate to disturbance-mediated resilience of forest landscapes and increased biodiversity, as long as climate and disturbance regimes remain within the tolerance of relevant species. Understanding ecological variability, even imperfectly, is integral to anticipating vulnerabilities and promoting ecological resilience, especially under growing uncertainty. Allowing some forests to be shaped by natural processes may be congruent with multiple goals of forest management, even in densely settled and developed countries.

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1. Introduction

The magnitude and direction of environmental changes vary globally with biophysical, economic, political, and sociological setting. In Europe, long-term intensive land use has been a dominant driver of ecological dynamics for centuries to millennia. However, since the nineteenth century, many European landscapes increasingly reflect abandonment of agriculture and other high-intensity land uses (Navarro and Pereira, 2012), as well as the establishment of protected areas (Motta et al., 2015), which together have contributed to an expansion of forest area (Rudel et al., 2005; Naudts et al., 2016). This recent expansion of forest has coincided with an increase in natural disturbances, partly as a result of these very changes in forest cover, structure, and composition, and partly as a result of changes in climate (Seidl et al., 2011). At the same time, an emerging body of literature highlights the historical importance of large infrequent disturbances in Europe (e.g., *articles in this issue*), even in ecosystems long thought to be shaped by fine-scale short-term processes. These changes in ecological dynamics and ecological understanding are concurrent with growing public interest in managing forests in more natural states, especially in places where other desired ecosystem services (e.g., carbon storage, nutrient cycling, water and air purification, maintenance of wildlife habitat, social and cultural benefits such as recreation, protection against natural hazards, supply of forest products, etc.) are not compromised (Meeus, 1995; Kräuchi et al., 2000). Consequently, natural disturbances and other natural processes have been increasingly allowed to shape the structure and dynamics of some forest ecosystems, but in others, the effects of natural disturbance continue to be intensively managed (Duncker et al., 2012).

In order to inform adaptive management strategies and science-based scenarios of future forest development, important priorities for forest ecology and management in Europe include contextualizing recent ecological dynamics within what can be expected to be a normal range of variation; recognizing spatiotemporal patterns and trends; and understanding the ecological, social, and economic consequences of recent trajectories. Here we synthesize aspects of this *Special Issue* on the ecology of mountain forest ecosystems in Europe in the context of other relevant literature to present a new perspective on European mountain forests and their natural disturbance regimes. We especially focus on mountain forests of the Balkan Peninsula (Panayotov et al., this issue; Nagel et al., this issue), the Apennines (Vacchiano et al., this issue), the Alps (Bebi et al., this issue; Conedera et al., this issue; Seidl et al., this issue), Bavaria (Thorn et al., this issue), the Carpathians (Holeksa et al., this issue; Janda et al., this issue), and the North Fennoscandian Mountains (Kuuluvainen et al., this issue) (Fig. 1). We explore ecological factors that underlie variability, resilience, and vulnerabilities of mountain forest ecosystems in Europe. We also compare similarities and differences of forest dynamics and disturbance regimes across these ecosystems, discuss future scenarios of an emerging new ecological reality of altered climate and altered disturbance regimes, and suggest ways of accommodating natural ecological dynamics in the management of Europe's mountain forests.

Mountain forest ecosystems in Europe are in a relatively natural state compared with the more developed matrix in which they occur (EEA, 2010) (Fig. 1). Although the landscape structure of these mountain forests is heterogeneous, that mosaic is often less fragmented by human activity in comparison to lowland forests. Therefore, mountain forests serve as important refugia for genetic, species, habitat, and ecosystem diversity. The long-term history of European mountain forests varies across regions and is largely contingent on patterns of human settlement, land use, and socioeconomic development. In many forests near dense human settlements, land use has been more important than climate in determining forest extent and dynamics, in some cases even for the past 6000–8000 years (Conedera et al., this issue; Bebi et al., this issue; Vacchiano et al., this issue). The paleoecological record from central Europe shows a history of deforestation, deliberate burning and selective forest management since Neolithic times, with the most intense land use during the Medieval Period. Brief periods of forest recovery occurred as a result of land abandonment at the end of the Roman Period and during the last century. In some areas, such as those of the Alps and the Apennine Mountains, intensive agriculture, grazing, and logging were widespread also at high elevations until the mid-19th century, which reduced forest extent and forest density below topographically and climatically-determined limits (e.g., Bebi et al., this issue; Vacchiano et al., this issue). In contrast, land use history has been shorter and less intense in the forests of eastern Europe (Kaplan et al., 2009), including the Carpathian Mountains (Janda et al., this issue; Holeksa et al., this issue), southeastern Europe, including the Balkan Peninsula (Nagel et al., this issue; Panayotov et al., this issue), and northern Europe, including the North Fennoscandian Mountains (Kuuluvainen et al., this issue). Since the onset of industrialization in the mid-19th century, reduced agriculture, and secondarily reduced demand for wood, active reforestation, and active afforestation, have resulted in expanded forest cover in many regions across Europe (Table 1).

Much research on European mountain forests has focused on understanding the dynamics of the last decades to century and relatively few studies have examined the longer history of these forests (but see Section 4). Although forest dynamics of the recent past are important, many dominant species (e.g., Norway spruce, European larch, stone pine, etc.) have longevities of 200–500 years and forest dynamics are likely to fluctuate over many centuries. Present-day 100 to 150-year-old forests can actually be considered young relative to their maximum lifespan, and a perspective of a century is short for describing a natural range of variability. Understanding natural system dynamics is a key prerequisite of ecosystem management, yet the full spectrum of system dynamics cannot be understood without a longer perspective.

2. Concepts of variability

The benefits of understanding and using concepts of variability in ecosystem management have been reviewed extensively (e.g., Landres et al., 1999). They provide operational flexibility for management actions and protocols (Landres et al., 1999) and allow a coarse filter approach for sustaining a wide range of taxa with diverse and often poorly understood species requirements (Lindenmayer and Franklin, 2002). Managing within the boundaries of natural variability is also often easier and less expensive than trying to manage outside of natural system boundaries (Allen and Hoekstra, 1992; Landres et al., 1999). For example, retaining windthrow in avalanche or rockfall protection forests utilizes the protective capacity of increased surface roughness (due to increased logs and pit and mound topography), is easier and less expensive than active management, and often maintains adequate protection against rockfall or avalanches (Schönenberger et al., 2005). Incorporating natural variability into management strategies ensures that ecosystem processes that sustain ecosystems are more likely to be maintained, even if not all their respective drivers are perfectly understood. Dendroecology, paleoecology, documentary sources, and other data can help describe key components of past variability, and remote sensing and simulation modeling can describe important ecosystem processes and

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