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The natural disturbance regime in forests of the Dinaric Mountains: A synthesis of evidence

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ABSTRACT

Quantitative descriptions of natural disturbance regimes are lacking for temperate forest regions in Europe, primarily because a long history of intensive land-use has been the overriding driver of forest structure and composition across the region. The following contribution is the first attempt to comprehensively describe the natural disturbance regime of the dominant forest communities in the Dinaric Mountain range, with an emphasis on the range of natural variability of regime components for the main disturbance agents. Compared to other forest regions in Europe, the mountain range has a history of less intensive forest exploitation and provides a suitable record of natural disturbance processes. Our synthesis is based on multiple types of evidence, including meteorological information, historical documentation, evidence from old-growth remnants, and salvage logging data from National forest inventories. Taken together, the results show that no single disturbance agent dominates the regime in the dominant forest types (i.e. beech and mixed beech-fir forests), and any given agent exhibits remarkable variation in terms of severity and spatial extent both within and among individual disturbance events. Thunderstorm winds cause the most severe damage (i.e. near stand replacement), but blowdown patches are typically limited to stand-scales (e.g. 10s of ha). Ice storms and heavy snow typically cause intermediate severity damage and affect much larger areas (e.g. 100s of km^2). A notable exception was the 2014 ice storm, which was nearly an order of magnitude larger and more severe than any other event recorded in the synthesis. Severe and prolonged periods of drought have occurred several times over the past century, and along with secondary insect damage (e.g. bark beetles), have caused episodes of forest decline. Overall, our synthesis indicates that on top of the background of relatively continuous gap dynamics, stand-scale intermediate severity events are an important part of the regime; these events likely have rotation periods that are less than the lifespan of a tree cohort (e.g. several centuries) and create canopy openings large enough to alter successional trajectories.

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1. Introduction

Forests comprised of deciduous broad-leaf and evergreen conifer species cover much of the temperate zones of the northern and southern hemispheres. They include some of the most well-studied forest systems worldwide, particularly with regard to the role of natural disturbances in driving forest dynamics. This literature demonstrates that many temperate forest regions are shaped by multiple disturbance agents, including wind (e.g. Peterson et al., 2016), ice (e.g. Lafon, 2016), pathogens (e.g. Worrall et al., 2005), drought (e.g. Pederson et al., 2014), and interactions among various agents (e.g. Papaik et al., 2005). Moreover, the regime of any given agent can exhibit remarkable variation in a region. Wind damage, for example, can cover a gradient from scattered tree fall gaps, to intermediate severity damage within stands, to catastrophic damage over large regions (Canham and Loucks, 1984; Nakashizuka and Iida, 1995; Stueve et al., 2011; Woods, 2004).

While this large body of work has been very important for improving our understanding of temperate forest dynamics, most

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studies have focused on a single agent, scale, or methodological approach. These include descriptions of small-scale tree fall gaps (Rebertus and Veblen, 1993; Runkle, 1982), observations of damage patterns following more severe abiotic disturbances (Foster and Boose, 1992; Rhoads et al., 2002), or dendroecological reconstructions (Frelich and Lorimer, 1991; Splechtna et al., 2005). Given the inherent complexity of the natural disturbance regime in many temperate forest ecosystems, understanding the regime of a given region requires a synthetical view that considers multiple agents and their respective ranges of natural variability. Such a comprehensive understanding requires various types of evidence, methodological approaches, and spatiotemporal scales related to the study of natural disturbance processes (e.g. Frelich, 2002; Greenberg and Collins, 2015).

The following contribution is the first attempt to comprehensively describe the natural disturbance regime of the dominant forest communities in the Dinaric Mountain range based on a synthesis of multiple types of available evidence. The mountain range is characterized by large contiguous regions of mature uneven-aged forests comprised of native tree species, and includes a number of remnant old-growth forests. Compared to other mountain ranges in Europe that have experienced more intensive anthropogenic land use over past millennia (Bebi et al., this issue; Vacchiano et al., this issue), forests in the Dinaric Mountains provide a suitable record of natural disturbance processes over the past century. Our goal, to the extent that was possible, was to describe the range of natural variability of disturbance regime components for the main disturbance agents in the region. Given the large scope of this contribution, we mainly focus on disturbance processes and their immediate damage patterns in forests; we do not describe the longer-term influence of disturbance on forest structure and composition. We conclude by discussing the unique features of the regime in comparison to those described for similar forest types in temperate regions worldwide.

2. Study area

Stretching over 650 km in length and 150 km in width, the Dinaric Mountains are one of the largest mountain regions in Europe. The mountain chain extends from the southern edge of the Eastern Alps in Slovenia to the Šar-Korab massif in Albania, and is bounded by the Adriatic Sea along its western border and the Pannonian Basin toward the east (Fig. 1). Most of the range lies over 500 m in elevation, with summits typically reaching about 1500 m, yet there are a number of rugged regions with higher summits, such as Velebit in Croatia (1758 m), the Maglič and Durmitor regions near the border of Bosnia and Herzegovina (BiH) and Montenegro (2522 m), or the Prokletije region at the Montenegro-Albania border (2656 m). The main part of the range is formed of Mesozoic rocks, the vast majority of which are limestone and dolomite. A unique feature of the region is the depth of the limestone and dolomite, which is typically 1–3 km, with considerable local variation (Gams, 1969). The pronounced altitudinal relief and exceptional depth of these sedimentary carbonate rocks are what give the region its unique geomorphological features, classically referred to as "karst". The region is globally unique in the diversity and density of these features, which include uvalas, dolinas, sink-holes, poljes, potholes, caves, and other unique features shaped by water and the chemical dissolution of carbonate rocks (Gams, 1969; Mihevc et al., 2010).

The Dinaric range is situated within the temperate climate zone. The region is characterized by a pronounced climatic gradient from the west facing slopes rising from the Adriatic coast to the interior zone of the range. Westerly winds flowing over the Adriatic sea bring large amounts of humidity to higher elevations along the western side of the range, where annual precipitation is typically above 2500 mm, and reaches up to 5000 mm in the Orjen Mountain region of Montenegro, the highest in Europe (Mihevc et al., 2010). Precipitation is much lower on the slopes facing the coast and also declines toward the interior continental region. Precipitation throughout the upper elevation zone is relatively evenly distributed during the year, with snowpack often lasting up to six months, whereas the coast experiences a Mediterranean type climate with hot dry summers and mild wet winters, and the interior a Continental climate, with hot summers and cold winters; however, there are a number of areas where the Mediterranean climate penetrates the interior of the range via river valleys that cut through the range or via lower mountain passes. The average annual temperature at the higher elevations of the mountain range is around 3 °C, but annual temperatures are substantially lower in karst depressions within the mountain zone (Mihevc et al., 2010).

Forest structure and composition in the Dinaric region is strongly influenced by the interaction of the mountain relief, karst terrain, soils, and climatic gradient. A pronounced vegetation gradient occurs from the Adriatic coast to the Dinaric plateau and east to the continental interior, which can generally be described as the following progression: Mediterranean type evergreen shrublands – sub-Mediterranean mixed thermophilous forests – beech (*Fagus sylvatica*) dominated forests – mountain forests comprised of beech, fir (*Abies alba*), and spruce (*Picea abies*) – followed by a transition to beech and mixed beech – oak (*Quercus*) dominated forests toward the lower elevations along the eastern boundary (Jovanović et al., 1986). Mountain forests in the Dinaric region, defined here as forests over 500 m in elevation, mainly include beech dominated forests and mixed forests dominated by varying amounts of beech, fir, and occasionally spruce. Within both of these forest types, a number of other less dominant canopy species can be found, such as maple (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*), and elm (*Ulmus glabra*). Several other less dominant forest communities occur within the mountain zone that are worth mentioning here, particularly because they likely support unique disturbance regimes. These include thermophilous forests on south and west facing steep slopes; these warm and dry sites are often less productive and support relatively low statured but species rich forests, which may include species of *Ostrya*, *Quercus*, *Fraxinus*, *Carpinus*, *Acer*, and *Sorbus*. Sites that are very steep and rocky often support stands of pine (*Pinus nigra*). Finally, spruce dominated stands are common in karst depressions and sink holes where temperature inversions cause significantly colder microclimates relative to the higher elevations surrounding such features. With the exception of a few cases noted in the paper (e.g. fire in pine forests), this synthesis focuses on disturbance regimes in the beech and mixed beech-fir communities that dominate the forest landscape in the Dinaric Mountains. Based on data from national inventories in Slovenia, Croatia, and BiH, the mean live tree volume across these forest types ranged from 313 m^3 ha^{-1} to 422 m^3 ha^{-1}.

Although much of the Dinaric Mountain region is heavily forested today, historical land use has had an important influence on forests. Deforestation along the coast began as early as 6500 BCE, when Neolithic culture brought stockbreeding and agriculture to the region. As population density increased during the Bronze Age, deforestation moved toward higher elevations, but the inaccessible regions in the interior were largely untouched. It was not until the Iron Age and later during the Turkish occupation that much of the interior area was deforested for charcoal production and grazing (Kranjc, 2009). Nevertheless, large forested regions in the interior range have been left relatively intact until the present. These areas have been managed with low intensity silvicultural systems for more than a century (Boncina, 2011). There are also a number of protected old-growth remnants scattered throughout

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