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Quantity and dynamics of dead wood in managed and unmanaged dry-mesic oak forests in the Hungarian Carpathians

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ABSTRACT

Dead wood (DW) has great importance for many wildlife species and ecological processes. The volume of DW is considered a useful indicator of the sustainability and maintenance of biodiversity in forests. Though dry-mesic oak forests cover large areas in Hungary, little is known about DW quantities or dynamics in these forests. We investigated DW conditions in five age classes of dry-mesic *Quercus petraea* and *Q. cerris* dominated forests in the Hungarian Carpathians. Stands of the first four age classes (age class 1: 40–59, age class 2: 60–79, age class 3: 80–99, age class 4: 100–119 years old) were managed and stands at least 120 years old were unmanaged at least for 30 years (age class 5). We measured the volume, density, dominance and size distribution of standing DW and volume of downed DW. We also evaluated the decay stages of DW on an ordinal scale (I-V, intact to well-decayed). The effect of age class on the derived variables such as density, dominance, volume or proportion of DW was analysed with general linear mixed models using age class as a fixed and region as a random effect. Mean total DW volume did not reach 15 m^3/ha in age class 1, 2 and 3. A much larger volume of DW was found in age class 4 and 5, where the mean total volume of DW was 36.9 and 45.1 m^3/ha, respectively. Volume and proportion of total DW over 30 cm in diameter were markedly lower in age classes 1, 2 and 3 than in age classes 4 and 5, moreover standing and downed DW over 30 cm in diameter were totally absent in stands under 100 years old. The proportion of well-decomposed (decay stage IV and V) DW was much lower (3–18% of the volume) in all five age classes than in old-growth stands of dry-mesic oak forests. After three decades of non-intervention (age class 5), the volume of DW can approach that of old-growth forests. The 40–99-year old stands contained a similarly low percentage of DW as other managed dry-mesic oak forests in Europe. Based on the results, it is likely that stands greater than 100 years old will support much higher biodiversity of saproxylic organisms compared to younger stands.

1. Introduction

Standing and downed dead wood (DW) is an important component of forest ecosystems (Franklin et al., 1987), performing an array of functions that have been well explored by research over at least three decades (Paletto et al., 2012). DW directly or indirectly provides important habitat for a great variety of forest organisms such as invertebrates, fungi, bryophytes, lichens, birds and mammals (Harmon et al., 1986; Stokland et al., 2012). Fallen DW can provide nurse logs for some types of tree regeneration (Hofgaard, 2000; Takahashi et al., 2000), while decaying DW influences microclimate heterogeneity on the forest floor and can help retain moisture during dry periods (Harmon et al., 1986; Maser and Trappe, 1984). DW also plays an important role in nutrient and carbon storage (Edmonds, 1987; Harmon et al., 1986; Janisch and Harmon, 2002; Keenan et al., 1993) and soil development (Hyvönen and Ågren, 2001; Schaetzl et al., 1989). DW often comprises 10% or more of the aboveground carbon stored in older or primary temperate forests (Keeton et al., 2011).

The density and volume of DW is considered a useful structural indicator of the sustainability and maintenance of biodiversity in forests (Corona et al., 2003; Marchetti, 2004; Paletto et al., 2012), forest naturalness (Bartha et al., 2006; Grabherr et al., 1998) and degree of old-growthness, a term implying that structure can be

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highly variable in late-successional forests (Bauhus et al., 2009; Lombardi et al., 2010). In Europe, the volume of DW per hectare has become one of nine pan-European indicators for sustainable forest management (criterion 4: maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems) (MCPFE, 2002).

The dynamics of DW accumulation depend on recruitment rates from tree mortality and output rates as controlled by decomposition (Siitonen, 2001). The DW input is mostly influenced by site quality, competition and self-thinning (density dependent mortality) and natural disturbances (density independent mortality; Brassard and Chen, 2008; Castagneri et al., 2010; Lombardi et al., 2008). Decay rates are influenced by species-specific wood properties, size of downed dead trees, and microclimate, particularly forest floor temperature and moisture. These factors influence the activity of decomposing organisms, mainly fungi in terrestrial ecosystems (Hytteborn and Packham, 1987; Kutszegi et al., 2015).

In managed forests, the quantity of DW, particularly in its most important forms for biodiversity (i.e. well decayed, larger sized downed dead trees) are strongly reduced by forest management (Green and Peterken, 1997; Lombardi et al., 2008; Paletto et al., 2014). In many managed European forests, most of the merchantable timber is ultimately harvested, thereby reducing the potential for DW recruitment as compared to unmanaged forests (Gibb et al., 2005; Marage and Lemperiere, 2005; Vandekerkhove et al., 2009). Forest management also influences the size distribution of DW: in managed forests, DW is predominantly composed of fine woody debris (thinner than 10 cm diameter; Kruys et al., 1999; Siitonen et al., 2000).

Though oak forests dominate large areas in Central and Southern Europe, little is known about their DW accumulation or dynamics in these systems. Research has only recently begun to explore DW dynamics in European oak systems (Bobiec, 2002; Petritan et al., 2012; Sweeney et al., 2010) and this topic is poorly investigated in dry-mesic oak forests in particular (Lombardi et al., 2008; Rahman et al., 2008). Under-attention to the topic of DW in unmanaged and old-growth oak forests reflects the general rarity of these systems in Europe, making it difficult to find relatively untouched mixed dry-mesic sessile oak (*Quercus petraea*) dominated forests (Korpel, 1995; Rahman et al., 2008; Saniga et al., 2014). This contrasts with beech and montane beech-fir zones, for which near-natural reference sites are far more abundant in Europe and for which DW inventory data are more widely available (Christensen et al., 2005).

To address this knowledge gap, this study investigates DW in managed and unmanaged dry-mesic sessile oak and Turkey oak (*Q. cerris*) dominated forests affected by human activity of various intensity in North Hungary (i.e. the Hungarian Carpathians). We assessed the quantity and quality – distribution according to DW types (downed versus standing), size categories and decay stages – of DW in five stand age classes. Our results were compared with DW data reported by previous research from old-growth dry-mesic oak forests. The overall goals of this study are:

(1) to investigate how DW quantity and quality change with the age of dry-mesic oak forests stands in Hungary,
(2) to investigate whether and under what circumstances managed stands can sometimes develop DW characteristics similar to old-growth forests,
(3) to formulate recommendations for sustainable forest management and biodiversity conservation approaches, including DW retention practices.

In this study, significantly larger quantity of DW is hypothesized to accumulate in older as compared to younger oak-dominated stands, primarily due to decreasing impact of management activity. Silvicultural management also affects the quality of DW, hence the density of larger diameter and well-decayed DW are expected to be higher in the older age classes. We also hypothesised that in managed stands older than 120 years the volume of DW will reach the level of old-growth stands, but the proportion of well-decomposed, large sized downed dead trees will be lower due to removal of recruitment sources (i.e. harvested large standing trees).

2. Methods

2.1. Study sites

Typical habitat types in the hilly regions of the Carpathian Basin are dry-mesic oak forests dominated by *Quercus petraea*, *Q. pubescens*, *Q. robur* and *Q. cerris*, forming two characteristic Natura 2000 habitat types; 91H0 Pannonian woods with *Quercus pubescens* and 91M0 Pannonian-Balkanic turkey oak-sessile oak forests (European Commission DG Environment, 2013). They cover about 180,000 hectares in Hungary (Bölöni et al., 2008, 2011). Dry-mesic oak forests occupy a forest zone between 200 and 700 m a.s.l. in the Hungarian Carpathians (Fig. 1). The climate of the Hungarian Carpathians is temperate with an average annual precipitation of 600–700 mm and a mean annual temperature of 8.0–9.5 °C (Dövényi, 2010; Halász, 2006). The depth of the soil organic layer varies widely within this zone depending on topography. The main soil types are leptosols and cambisols (Krasilnikov et al., 2009), their physical and chemical conditions strongly specific to the bedrock because vulcanic, limestone, sandstone and loess also occur.

The upper tree layer of investigated forests is dominated by *Q. petraea* and *Q. cerris*. The second canopy layer is usually removed or formed by a small number of *Acer campestre, Sorbus torminalis, Fraxinus ornus, F. excelsior*. The shrub layer is naturally dense and consists predominantly of *Crataegus monogyna, Ligustrum vulgare, Cornus mas, Rosa canina* and saplings of associated tree species, or is often artificially removed. The herb layer is typically composed of grasses (e.g. *Poa nemoralis, Dactylis polygama, Melica uniflora*), and a mixture of light-demanding and drought-tolerant forest herbs (e.g. *Campanula persicifolia, Galium schultesii, Tanacetum corymbosum, Vincetoxicum hirundinaria*), forest generalists (e.g. *Veronica chamaedrys, Viola odorata, Fragaria vesca*), and potentially of a few species of the mesic forests (e.g. *Stellaria holostea, Viola rechenbachiana*).

In these dry-mesic oak forests the main silvicultural system historically was coppicing with intensive masting, grazing and firewood collection (Járási, 1997; Johann et al., 2011; Magyar, 1993; Szabó, 2005). Since the 19th century this has been replaced by a uniform shelterwood silvicultural system, converting these forest stands to high forests with a rotation period of 80–100 years (Danszky, 1972; Savill, 2004). The structure of these forests has been relatively uniform: in mature stands, the upper layer is dominated by oaks of circa 20 m in height and 30 cm in diameter at breast height (DBH). These relatively low productivity forests possess 300–350 m^3/ha volume of living wood in their mature state (80–100 years old).

2.2. Data collection

Managed (age class 1 to 4) and unmanaged (age class 5) dry-mesic oak forest stands were selected for the recent study. We selected the unmanaged stands based on the following criteria; (1) dry-mesic *Quercus petraea-Q. cerris* dominated site, (2) older than 120 years old, (3) has highly protected conservation status or form core area of forest reserve and (4) has not been managed for at least 30 years. In the studied regions we found 19 forest