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Quantifying decay progression of deadwood in Mediterranean mountain forests

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ABSTRACT

Forests contribute to the sequestration of organic carbon (C). A key role in forest C cycling is played by deadwood. While a broad range of literature on deadwood decay (above-ground) exists, the mechanisms occurring in the transition zone from deadwood to the humus are poorly understood. In particular, scarce information is available on the temporal patterns of wood compounds (such as lignin and cellulose) during decay processes.

Our objective was to provide a deeper understanding on deadwood decay in a Mediterranean montane environment by focussing on semi-natural forests of *Fagus sylvatica* L. (beech). The decay process was studied in a field experiment (in the Majella mountains, Apennine Mountains, Italy) among an altitudinal transect at different climatic conditions. Beech wood blocks (mass, cellulose, lignin) having all an equal in size (5 cm × 5 cm × 2 cm) were placed in soil mesocosms to investigate over one year changes in the overall mass, cellulose and lignin content. The sites were along an altitudinal gradient, reflecting different climatic conditions. The effect of exposure (north- vs. south-facing slopes) was also considered. Deadwood, cellulose and lignin dynamics were related to soil parameters (pH, grain size, moisture, temperature) and climate data. Deadwood decayed very fast and followed an exponential trend. The decay rate constants of the deadwood mass significantly (positively) correlated with air temperature and soil moisture: the lower the temperature, the lower the evapotranspiration, the higher the moisture availability, and the higher the decay rates. Lignin decayed more slowly than cellulose, resulting in average decay rate constants (k) between 0.368 and 0.382 y^{-1}. Soil properties and topographic traits (slope and exposure) strongly influenced the decay processes. At south-facing sites (having an altitude < 1300 m a.s.l., above sea level), decay processes were lower owing, most likely, to drier conditions. The climosequence revealed slower beech deadwood decay processes in south- than north-facing sites of these Mediterranean mountains, owing to the drier conditions. In-field mesocosms were useful to define meaningful indicators of warming-induced changes on the linkages between C storage in beech deadwood and decomposition processes as a function of altitude and exposure.

1. Introduction

The importance of deadwood in forest ecosystems is undeniable, not only in terms of biodiversity it provides, but also in terms of carbon sequestration and emission. Within this context, deadwood is recognised as one of the most important functional and structural components of forest ecosystems (Harmon et al., 1986; Paletto et al., 2012; Marzano et al., 2013), and is considered an indicator of biodiversity conservation (Lassauce et al., 2011) and long-term carbon (C) storage, especially in temperate-cold climate environments (Ravindranath and Ostwald, 2008).

Structural characteristics of standing or downed deadwood provide habitats for different species. Habitat provision for organisms such as nesting birds, refuge for rodent species from predation and safe sites for

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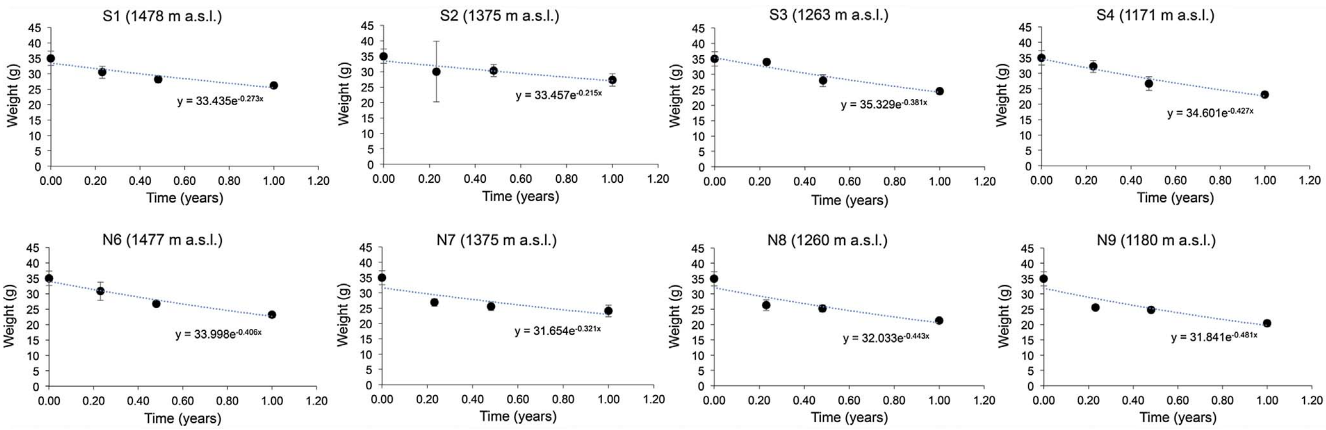

Fig. 1. Amount of dry mass (weight ± standard error) of the wood blocks (placed into mesocosms) as a function of time (0 ÷ 52 weeks), site (altitude) and exposure (north vs. south).

overstory tree regeneration (Harmon and Franklin, 1989; Heinemann and Kitzberger, 2006) have all been revealed as important roles of deadwood in natural temperate forests (Gonzalez et al., 2013). Due to its slow decomposition and persistence on the forest floor (Beets et al., 2008), deadwood represents a substantial reservoir of organic C and nutrients in many forest ecosystems (Carmona et al., 2002; Ganjegunte et al., 2004).

At the ecosystem scale, variations in the deadwood amount are suggested to occur in relation to forest type, species composition, disturbance regime (natural and anthropogenic) and successional stage (Gonzalez et al., 2013). In particular, coarse woody debris (CWD), considered as standing dead trees, downed woody debris, and stumps, is a critical component of forest ecosystems since it retains essential nutrients, stores water, contributes to soil development and conservation, and provides habitat for plants and animals, insects, fungi and bacteria (Harmon et al., 1986). CWD decay and the related nutrient mineralisation create unique conditions of microsite heterogeneity (Campbell and Laroque, 2007; Fravolini et al., 2016). However, the dynamics of C exchange and storage of the CWD pool remain poorly understood (Harmon et al., 1986; Scheller and Mladenoff, 2002).

The decomposition process of CWD can take up decades to several centuries (Lombardi et al., 2012; Petrillo et al., 2016), depending on wood characteristics (tree species, dimensions), climate (temperature and moisture; Woodall and Liknes, 2008) and the position on the ground (i.e., contact with the soil; Radtke and Bolstad, 2004). Most of the available information on decay processes refers to CWD as mass (Russell et al., 2015), and almost no data exists on the temporal behaviour of its chemical components such as lignin or cellulose, especially for Mediterranean mountain forests (Fravolini et al., 2016; Lombardi et al., 2012).

Contrasting results in CWD decay rates can be explained in part by the methodologies employed or by the different climates in which the studies were performed (Forrester et al., 2012). In moisture-limited regions, decay progression would be expected to be slow, whereas, in relatively wet forests and environments, climate conditions should promote higher decomposition rates (Progar et al., 2000; Chambers et al., 2001). In Alpine forests, Fravolini et al. (2016) have shown an interactive effect of temperature and moisture on decay dynamics. A number of other variables, including wood density, debris size, nutrient content and the contact with the soil surface, may influence decomposition dynamics (Mackensen and Bauhus, 2003; Shorohova et al., 2008), as much as micro-environmental factors surrounding the wood.

Wood density, that tells how much C the plant allocates into construction costs (Chave et al., 2006), has often been used to describe decay processes (Schwarze et al., 1999; Schäfer, 2002), as being easily measurable (Sollins et al., 1987; Mackensen and Bauhus, 2003). This procedure, however, may underestimate decay dynamics (Petrillo et al., 2016) and does not provide quantitative information on the transition phases of chemical components from woody debris to humus form. As proposed by several authors (Lombardi et al., 2012), lignin and cellulose concentrations may be used to better assess decay patterns of CWD associated with specific site characteristics, such as the microclimatic conditions of topsoil and boundary layer.

Among broadleaved species, *Fagus sylvatica* L. (beech) is a dominant or co-dominant tree in European deciduous forests. However, the process of decomposition and the changes in deadwood properties for beech over several stages of decomposition has been rarely addressed (Christensen et al., 2005; Kahl, 2008; Müller-Using and Bartsch, 2009; Herrmann et al., 2015). These studies indicate small differences in wood density between decay classes, and attribute variation in decomposition rates of beech deadwood to the uncertainty over the cause of death. In central European beech forests, decomposition time and debris dimension (and species) are considered the most important information needed to develop regional decomposition model (Herrmann et al., 2015). Although beech represents a major forest type also in Mediterranean mountain ecosystems (Nocentini, 2009), decomposition processes of deadwood in these forests have been poorly addressed so far (Lombardi et al., 2012).

We focused on early dynamics of deadwood decay in Mediterranean montane beech forests, characterised by a temperate climate. Our principal aims were: i) to determine early decomposition stages in wood blocks of beech under controlled conditions in the forest toposoil, and ii) to quantify the decay rates of its main chemical constituents, i.e., lignin and cellulose. In addition, we related deadwood decay progression to major environmental drivers, i.e., climatic conditions (temperature and precipitation), slope aspects (north- vs. south-facing sites) and soil characteristics (chemical and physical traits). We expected that climate forcing was more effective, accelerating decomposition processes of wood blocks, on south- than north-exposed slopes and at lower than higher altitudes.

2. Material and methods

2.1. Study area

The investigation area is located in the Majella National Park (Abruzzo, central Italy; Fig. 1, Table 1). The National Park, extending approximately 740 km^2, was established in 1991. Four study sites were selected along two climosequences (north vs. south-facing slopes). The altitudinal range of both slopes was between 1170 and about 1480 m above sea level (Table 1).

The climate of the study area ranges mostly from temperate-oceanic to temperate-oceanic with submediterranean characteristics; the mean annual temperature varies from 14 °C at the valley bottom (around 130 m a.s.l.) to about 3 °C above 2000 m a.s.l., with mean annual precipitation ranging from approximately 700 to 1600 mm (CFS meteo