Forest Ecology and Management 283 (2012) 77–85

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Deadwood specific density and its influential factors: A case study from a pure Norway spruce old-growth forest in the Eastern Carpathians

Marius Teodosiu, Olivier B. Bouriaud *

Forest Research and Management Institute ICAS, Station Câmpulung Moldovenesc, Calea Bucovinei 73b, 721500 Câmpulung Moldovenesc, Suceava, Romania

ARTICLE INFO

Article history:
Received 13 April 2012
Received in revised form 27 June 2012
Accepted 28 June 2012
Available online 9 August 2012

Keywords:
Decay
Rottenness
Moisture
Mixed-effects models

ABSTRACT

Deadwood is a pivotal component of old-growth forests that plays an important role in both carbon sequestration and cycling. Deadwood carbon estimates rely on the conversion of easily measured volumes into dry masses, using decay-class conversion factors. Little is known about the specific dry density of deadwood in Norway spruce (*Picea abies* (L.) Karst) old-growth forests, especially in temperate mountainous zones. We studied specific density variations of standing and lying deadwood in an old-growth forest from the Central Eastern Carpathians. Using a balanced sampling, the piece size, rottenness percent (proportion of rotten wood within a sample) and decay, ordered in a 2-class scale for snags and an 8-class scale for logs, were recorded. For logs, the position of the sampling along piece (top, middle, bottom) and the contact with the ground were considered as additional factors. The decay classification for logs was intentionally large, aiming to test for an optimal number of decay classes. The mean density showed small variations within snag classes (322.0 kg m^{-3}/319.7 kg m^{-3}), ranging between 342.7 kg m^{-3} and 151.7 kg m^{-3} for logs. The rottenness in snags was very even (40–43%), while it increased with the decay class for logs as expected. The mean mass moisture variation was larger than in other studies, between 38.5–268.6%, with the highest variation in the higher classes (5–8), while volumetric moisture varied between 11.6% and 39.7%. The samples from the base of the log positively influenced the moisture, while the contact had only marginal effects. The relationship between the dry density and the above factors was modeled using mixed-effect models. Apart from decay class, moisture and rottenness explained more variance than any other investigated factor (position, elevation, ground contact). The best model, which explained up to 76% of the total variance, included the rottenness percent and the decay class as fixed effects and the sample piece as a random effect. The overall best performing model on a four-class decay system had the same structure. We recommend using a decay system with fewer classes to effectively estimate specific deadwood dry density.

1. Introduction

Coarse woody debris (CWD) in its different forms (snags – standing deadwood, stumps, logs – downing deadwood) is an important structural and functional component of forests (Harmon et al., 1986). Its contribution to forest biodiversity is widely acknowledged (e.g. Bütler et al., 2007), and its importance in the carbon cycle has recently been recognized (Kueppers et al., 2004; Woodall et al., 2008; Olajuyigbe et al., 2011), suggesting that forest carbon balance estimates calculated without considering CWD are inaccurate (Rice et al., 2004). The contribution of deadwood to the total forest carbon stock reported in the literature ranges between 16% and 20% (Oswalt et al., 2008; Alberti et al., 2008) depending on the species, the productivity and the stand structure.

A fundamental factor influencing both the ecological properties and the C retention of deadwood is its decomposition (Olajuyigbe et al., 2011). To account for the variability in decomposition status during field sampling, visual properties of the deadwood are used to categorize field samples into decay-stage classes. This stratification is convenient because it is fast, but it also has several disadvantages which can potentially introduce errors in the estimation of the wood density. First, measurements are subjective and are therefore likely to vary among observers. Second, the evaluation is based on external rather than internal wood characteristics, hence resulting in a discrete set of classes instead of quantitative values (Creed et al., 2004) which ignore the variability within decay classes. Moreover, the existence of different classification systems makes it difficult to compare between sites with the same forest type (Næsset, 1999).

Density is used to estimate the amount of carbon from deadwood by first converting the sampled deadwood volume into biomass and then into carbon (Sandström et al., 2007). Deadwood density has been proved to be variable and influenced by different

---

* Corresponding author. Tel./fax: +40 (0)230 314 747.
E-mail address: obouriaud@gmail.com (O.B. Bouriaud).

0378-1127/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2012.06.050

factors: (i) at large scale, by latitudinal/longitudinal gradients (Sandström et al., 2007; Yatskov et al., 2003), and (ii) at stand scale, by the degree of naturalness (higher densities in managed vs. preserved forests – Sandström et al., 2007), at tree individual level, by species, age (increasing from young to old trees – Sandström et al., 2007), microsite characteristics (although within-piece heterogeneity seems not to modify the piece value – Sandström et al., 2007), piece position (standing, lying – Harmon et al., 2011), decay class (but with less influence of the species on the values of the last classes – Yatskov et al., 2003).

Improving the accuracy and precision of carbon estimations based on inventory/measured data is an ongoing challenge (Brown, 2002) and the necessary deadwood conversion factors have been developed for a variety of species, forest types and regions (Harmon et al., 2008; Woodall et al., 2008). For Norway spruce, one of the main species at European level, the majority of the studies including conversion factors are from the boreal zone (Næsset, 1999; Sandström et al., 2007; Aakala, 2010; Yatskov et al., 2003). For the temperate zone, only a few studies exist from managed forests in Central Europe (Heunsch, 2004; Bütler et al., 2007; Paletto and Tosi, 2010) and to our knowledge, no study has been done in Eastern Europe.

Sandström et al. (2007) found differences in the wood density between managed and protected Norway spruce forests and recommend separate surveys for each category. This is unsurprising given that old-growth forests often exhibit larger quantities of deadwood biomass which cover the entire spectrum of decay classes, including the last stages. Until recently (Carey et al., 2001; Knohl et al., 2003; Luyssaert et al., 2008; Wirth, 2009), the role of old-growth forests as carbon sink was considered neutral (after Odum, 1969), but some studies have proved that these forests store 60% more carbon than the plantation forest (Mackey, 2008), a considerable fraction of which being in the deadwood. Although old-growth forests are rare in temperate Europe (i.e. Western, Central Europe), due to past cuttings, south-eastern Europe – an area long time recognized for its old-growth forests – still seems to accommodate such areas (Veen et al., 2010). The paucity of data on deadwood in old-growth forests prompted a specific and detailed study.

This paper aims to provide values of densities for Norway spruce standing and downing deadwood and analyze the main factors that influence them.

2. Material and methods

2.1. Site description

The study area is located in a Norway spruce forest reserve covering 309 ha (Giumalău, 47°26′39″N, 25°27′42″, elevation ranges between 1200–1650 m), in the northern part of the Romanian Eastern Carpathians (Giumalău Mountains). The main species is *Picea abies,* with a few individuals of *Sorbus aucuparia* occurring in some big windthrow gaps being identified during the last extended inventory. The substrate is crystalline schist, with brown acid soils, on a steep topography. Mean annual temperature is 7.92 °C, while mean precipitation is about 677 mm (FAO Local Climate Estimator 2.0 software) (FAO, 2005). The research was conducted inside the core area of the reserve (about 163 ha), declared as strict protection forest reserve since 1941. No human intervention is known for this part, except for resin collection in a small area (during ‘50) at the lower margin of the reserve.

2.2. Field works

The data were collected in three previously installed, fully mapped plots (two of 0.5 ha located at 1200 m a.s.l. and one of 1 ha, at 1400 m a.s.l.), in an area with no visible signs of past large-scale disturbances. The dbh and height of all the snags above 5 cm dbh were measured during the initial survey. Their decomposition stage was associated with two classes, based on the visual examination of the bark and branches (the classes 3–4 from Maser et al., 1979). For coarse woody debris, we recorded the diameters and the length of the pieces, the apparent cause of death (broken, uprooted) and visually estimated the decomposition stage, according to a classification into eight classes (modified after Liu and Hytteborn, 1991) (Table 1). This detailed 8-class system further permitted us to test the optimum (non-overlapping) number of classes.

For the deadwood density analysis, we used a balanced random sampling with 15 snags/pieces per decay class, a number previously documented as being acceptable for this purpose in other studies (e.g. Paletto and Tosi, 2010) as well as for our modeling purposes. When it was not possible to find enough pieces inside the plots, the sampling was completed with pieces taken at a maximum distance of 50 m from the plot. One cylindrical core was extracted at breast height from each snag, from the upper slope position, while three sampling points were used in case of downed deadwood (the logs slightly decomposed, classes 1–5): at the base, middle and top (i.e., the thinnest) part of the piece. We used an increment borer of 12 mm diameter (Haglöf, Sweden), as an acceptable compromise with the local regulations that prevent any destructive sampling inside the forest reserve. Core volume was estimated as the product of its constant volume, determined by the corer diameter, and its length. Due to the consistent presence of rotten parts in the cores, a problem that was noticed at the start of the survey and which could potentially lead to a compression of the core during its extraction, the core length was best estimated as the difference between the rod length and the total borer length. Samples of decay classes 6–8 were sawn rather than extracted with a borer or a cylinder as used in other studies (e.g. Aakala, 2010), as portions of relatively hard wood that hampered a clean punching were frequently present even in these pieces. Samples were further cut into small parallelepipeds (long side <15 cm), the sample volume being estimated also in the laboratory by three side measurements (Harmon et al., 2008). The rottenness percent was estimated for all samples, defined as the percentage of decayed wood observed along the increment core or on the sawed samples. Ground contact was recorded separately for each of the three sample positions along the logs.

As rain events may have an influence on the deadwood moisture and past analyses recommended to have at least two days without rain before sampling (Fraver et al., 2002; Paletto and Tosi, 2010), all the samples were collected accordingly (in our case, 1 week after the last rain). To avoid the influence of fluctuating atmospheric humidity (Paletto and Tosi, 2010), all samples were placed in hermetic plastic bags. Until final processing, the samples were stored in laboratory in a deep freezer.

The volume of the lying deadwood samples was determined using the formula of the cone frustum volume, based on the diameter of the piece at both ends and its length.

2.3. Laboratory work

Fresh weight measurements were made within 24 h of sampling. All mass measurements were done with an analytical scale (Kern ABT, Kern & Sohn GmbH, Balingen, Germany) with a precision of 0.0001 g. Samples were oven-dried at 105 °C for 48 h to obtain the dry mass. They were placed in a desiccator during the weighing process to avoid re-humidification after they were removed from the oven.

For each sample, we calculated fresh, dry and relative density, the rottenness percent and the moisture. The fresh density was