Forest Ecology and Management 417 (2018) 1–17

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Very large trees in a lowland old-growth beech (*Fagus sylvatica* L.) forest: Density, size, growth and spatial patterns in comparison to reference sites in Europe

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ARTICLE INFO

Keywords:
Very large trees
Old-growth forest
Fagus sylvatica
Increment
Mortality
Spatial distribution pattern

ABSTRACT

The frequent occurrence of very large trees (diameter at breast height DBH ≥ 80 cm) is a typical element of both primary and secondary old-growth forests. We analyzed the characteristics of very large trees in one of the few stands of lowland old-growth beech forest in Northwestern Europe, regenerated around 1775 and left unmanaged since 1986. We examined their density, diameter range, increment, mortality rate and spatial distribution, based on repeated full dendrometric surveys. In order to evaluate the results, we compared them to original datasets from primary and secondary old-growth beech forests in Europe, and an extensive reference table, compiled from inventories and literature.

In our study site, the density of very large trees increased from 31.5 to 34.3 trees ha^{-1} over the last 25 years, reaching a median DBH of 97 cm (mean 98.9), with the largest tree attaining a DBH of 159 cm. Although the trees were over 240 years old, they still showed an average DBH increment of 4.75 mm year^{-1} and a low mortality rate (0.89% year^{-1}), indicating that they were still vital. These figures are remarkably high compared to other old-growth beech forest reference sites, where the density of very large trees generally varies between 5 and 20 trees ha^{-1} (median value 13.1), with a median diameter of 85–90 cm and maximum DBH for beech trees rarely exceeding 100–130 cm.

The regular spatial distribution pattern of the very large trees in the studied stand clearly differed from a typical old-growth stand, in which very large trees are randomly distributed. Over the last 25 years though, because of random mortality and ingrowth, the spatial distribution gradually became more random.

The extraordinary densities and sizes of the very large trees in our study site can be explained by the favorable climate and site conditions that promote high increments, in combination with the former management interventions of tending and thinning that resulted in continuous non-suppressed growth. Although derived from a very specific case with particular conditions, our observations may be relevant to other beech forests, as they tend to reset certain baseline assumptions for tree size and longevity potential of beech in Northwestern Europe.

1. Introduction

Old-growth forests are defined as forest sites and stands that have developed a high degree of naturalness. According to Frelich and Reich (2003), old-growth forests can be subdivided in ‘primary old-growth’, being old-growth forests whose dynamics are driven exclusively by natural processes while human impacts are absent, and ‘secondary old-growth’, being previously managed forests that have developed old-growth features after decades of (intentional or non-intentional) non-intervention (Piovesan et al., 2008; Ziaco et al., 2012). Next to large quantities of dead wood, the frequent occurrence of large old trees is a prominent structural characteristic of old-growth forests (Bobiec, 2002; Burrascano et al., 2013; Greenberg et al., 1997; Ziaco et al., 2012). Very large trees are therefore among the features most frequently used as basic descriptors of natural or old-growth forests (Nilsson et al., 2002; Von Oheimb et al., 2005; Wirth et al., 2009; Ziaco et al., 2012).

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https://doi.org/10.1016/j.foreco.2018.02.033
Received 22 December 2017; Received in revised form 19 February 2018; Accepted 19 February 2018
0378-1127/

Several definitions and size thresholds are used to define very large trees. In this study, we applied the frequently used threshold of 80 cm DBH for very large trees (further shortened to 'VLT'), also called 'giant trees' or 'oversized trees' (Bílek et al., 2011; Burrascano et al., 2008; Heiri et al., 2011, 2012; Hobi et al., 2014; Kucbel et al., 2012; Meyer et al., 2003; Petritan et al., 2015; Von Oheimb et al., 2005; Zenner et al., 2015). In forestry, 70–80 cm often is the maximum target diameter (e.g. Schütz, 2006), so that larger trees are rarely occurring in commercially managed forest stands.

Already in ancient times, VLT were missing in lowland European forests managed for wood production (e.g. Vandekerkhove et al., 2009, 2011). They only occurred in hunting reserves, deer parks and wood pastures. In many regions their numbers are still declining (Lindenmayer et al., 2012) although in other areas, they are more and more protected and integrated in forest management as their recreational and ecological value is better known and appreciated (e.g. Fedrowitz et al., 2014; Gustafsson et al., 2012). Still, the numbers of VLT are low. In Germany, the density of VLT in forests was 66 per 100 ha in 2012 (Thünen-Institut, 2017), an increase of 50% compared to 2002 (Kroiher and Bolte, 2015). In northern Belgium, a similar density of 65 VLT per 100 ha was registered (Vandekerkhove et al., 2011). In Switzerland, VLT density is somewhat higher, with 120 VLT per 100 ha in the beech-dominated colline and submontane height range, twice as high as during the previous survey ten years before (Brändli et al., 2010).

VLT fulfill a wide range of ecosystem services. They occupy a revered position in the human psyche (Lindenmayer, 2016), and specific aesthetic, social and cultural values are assigned to them (Blicharska and Mikusinski, 2014). Several studies indicated that the general public has a clear preference for forest landscapes and stands containing large trees and this preference increases with increasing tree size and advancing stage of stand development, thus representing a higher recreational value (e.g. Edwards et al., 2012; Gundersen and Frivold, 2008; Ribe, 1989). VLT have also been identified as essential elements for biodiversity conservation (e.g. Lindenmayer et al., 2012; Moning and Müller, 2009; Nilsson et al., 2002). They show a higher incidence and diversity of tree-related microhabitats than smaller trees (Larrieu and Cabanettes, 2012; Larrieu et al., 2014, 2018; Paillet et al., 2017; Regnery et al., 2013; Vuidot et al., 2011; Winter and Möller, 2008), and these microhabitats provide specific microclimatic conditions and substrates to a wide range of specialized species or species assemblages (Larrieu et al., 2014, 2018; Paillet et al., 2017). Large old trees also show a higher incidence of rare epiphytic bryophytes and lichens (Brunet et al., 2010; Fritz et al., 2009; Moning and Müller, 2009). Finally, VLT also have a major influence on hydrological regimes, nutrient cycles (Lindenmayer, 2016) and carbon sequestration. For instance, old-growth forests are important carbon sinks (Knohl et al., 2003; Luyssaert et al., 2008), and a large proportion of the aboveground biomass in old-growth forests is concentrated in VLT (Brown et al., 1997).

Several studies have been published on old-growth beech forests in the submontane regions of Central and Southern Europe, including information on the size range, density and longevity of beech trees in these old-growth stands (e.g. Di Filippo et al., 2015; Hobi et al., 2014; Meyer et al., 2003; Piovesan et al., 2005a). However, little is known about the performance of VLT in lowland beech forests. We analyzed the presence and characteristics (density, diameter range and increment, mortality rate and spatial distribution) of VLT in one of the rare old-growth beech forest stands in the lowlands of Northwestern Europe, over a time period of 25 years. As reference values for lowland beech forests are scarce (e.g. Von Oheimb et al., 2005), we compared our data to a set of primary and secondary, lowland and submontane old-growth stands in Central and Southeastern Europe for which equivalent datasets were available. Finally, we supplemented the study and comparison sites with literature data in a comprehensive reference table on VLT in old-growth beech forests in Europe.

2. Material and methods

2.1. Study site

The study site is located in the center of the Sonian forest (50°75′N, 4°39′E). This forest complex covers an area of 4400 ha and is located 10 km south of Brussels, Belgium. It contains over 400 ha of old beech stands (> 200 years old) and more than 25,000 VLT, mainly beech (Vandekerkhove et al., 2011). It can therefore be considered one of the most important hotspots for VLT in Northwestern Europe. Many of the VLT are located in patchy remnants of old stands or in avenues. The study site contains one of the largest remaining old stands (17 ha), known as 'Kersselaerspleyn'. It originates from a beech stand that was regenerated around 1775 and then regularly thinned with final fellings only performed in two small patches in the east and upper northwest corner of the stand (replanted with beech in 1921 and 1967). The 10.06 ha study area was selected in the central area of Kersselaerspleyn, excluding a 50 m buffer zone near the stand borders and the two artificially regenerated patches. The stand has been left unmanaged since 1983 and became an official strict forest reserve in 1995, enlarged to its current size of 230 ha in 2010 ('Forest Reserve Joseph Zwaenepoel'). In July 2017, this forest reserve was included in the UNESCO World Heritage site '*Primeval Beech Forests of the Carpathians and Other Regions of Europe*'.

The study site is located on a slightly undulating flat area, with an altitude ranging from 100 to 120 m asl. The soil consists of tertiary calcium-rich sandstone and flint stone, covered with a 3–4 m thick layer of quaternary niveo-aeolic loess deposits of the Weichselian glaciation. (FAO classification: Luvisols and Podzoluvisols). The upper layer of the loess deposit is lessivated and moderately acidic (pH H_2O 4.0–4.5); deeper soil layers are more saturated with base cations. This results in productive forests soils, which is reflected in the canopy height of the tree layer; old beech stands reach canopy heights of 45 m and more. The climate is characterized by a mean annual temperature of 10.5 °C and an annual precipitation of 852 mm. Mean temperatures in January and July are 3.3 °C and 18.4 °C. The vegetation consists of Atlantic acidophilous beech forest (*Milio-Fagetum* sensu Noirfalise, 1984; European habitat type 9120, EUNIS-code G1.62). The ground vegetation is scarce and dominated by *Pteridium aquilinum* and *Milium effusum. Oxalis acetosella, Convallaria majalis* and *Anemone nemorosa* scarcely occur.

2.2. Data collection and processing

Full dendrometric surveys of all trees in the study area were made in 1986, 2001 and 2011. The positions of all trees relative to reference points were registered using a total station in 1986 and 2001 and a Laser Rangefinder and Mapstar Digital Compass incorporated in the Fieldmap hardware configuration (http://www.fieldmap.cz) in the 2011 survey. For every tree, tree status (alive/dead), species and diameter at breast height (DBH) were recorded. In 1986, all trees with a DBH ≥ 30 cm were included in the inventory, in 2001 and 2011 the minimum DBH was 10 cm, but for comparative reasons the diameter threshold of 30 cm was also implemented to the other surveys in the data analysis. During the first interval, two heavy windstorms occurred in February 1990, with an important impact on mortality at the site. Therefore the trees that died during and within 6 months after the heavy windstorms were additionally registered in 1991.

First, for the VLT (DBH ≥ 80 cm), we calculated the density, diameter distribution and share in the total basal area for each of the three surveys. The basal area share of VLT is often applied as an important indicator of old-growth (e.g. Brown et al., 1997). As all trees have been positioned and can be identified over time, we could also asses the diameter increment and mortality of the individual trees over the subsequent surveys, and calculate the basal area increment (BAI) and decadal mortality and relate them to original tree size at the first survey.