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Temporal interactions among throughfall, type of canopy and thinning drive radial growth in an Iberian mixed pine-beech forest

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ABSTRACT

Many factors can influence tree growth over time such as different forest management practices, climate or tree-to-tree interactions, especially in mixed forests. We show in this work how the temporal growth patterns for Scots pine and European beech depend on thinning intensity (0%, 20% and 40% extraction of basal area), canopy type (pine–beech vs. pine patches), throughfall and their interactions. To fulfill this objective we monitored radial growth of both species using band dendrometers during a 6-year long period including two very dry years. Temporal growth patterns differed between both species. Whereas Scots pine showed two main peaks of growth in May–June and October, European beech mainly grew from May to early September even when throughfall was very limited. Effects of thinning on growth generally increased for both species during dry periods both at the seasonal and annual scales. The treatment with 20% of thinning intensity was the most effective at the annual scale for enhancing growth of both species. However, increases in growth due to thinning were much higher in beech than in pine and lasted longer. Thinning effects on pine were higher in mixed canopy than in pure canopy and appeared to be modulated by throughfall. Global differences in pine growth between canopy types as a function of throughfall increased during the main growing season as beech canopy developed. Growth of Scots pine, but not that of European beech, generally increased with throughfall which suggests that pine might be more dependent for its growth on water from the soil surface layer while beech would depend more on water from deeper soil layers. Our findings have implications to select the most convenient thinning treatments and canopy type under a potential climate change scenario characterized by warmer conditions, more severe droughts and less throughfall.

1. Introduction

Forest researchers and managers consider that a conversion of pure coniferous forests into a mixed conifer-hardwood forest, is greatly meaningful from an ecological and economic point of view (Knoke et al., 2005; Spiecker, 2003). Mixed conifer-hardwood woodlands may provide multiple benefits such as higher biodiversity, protection from disease or stability (resilience) to disturbances including climate extremes as droughts (Knoke et al., 2005; Pretzsch et al., 2015a). Additionally, mixed forests may increase stand productivity when inter-specific processes are not dominated by competition (Kelty, 1992). Nevertheless, empirical data on these topics is often nonexistent in mixed conifer-hardwood forests (Forrester and Tang, 2016), particularly long-term data are needed to elucidate mechanisms underlying observed patterns.

The growth dynamics in mixed conifer-hardwood forests are often difficult to predict due to a high number of interactions among coexisting tree species as well as to the fact that resource availability and climatic conditions change temporally and from site to site (Forrester and Tang, 2016). Although many studies have been carried out on the growth of Scots pine (*Pinus sylvestris* L.) or European beech (*Fagus sylvatica* L.) forests (Camarero et al., 1998; Ježík et al., 2011), relatively few scientific literature is available about inter-specific processes in mixed Scots pine and European beech forests (but see Pretzsch et al., 2015a, Pretzsch et al., 2016 and references therein). This is one of the most widespread and economically relevant mixed forest type in Europe (Pretzsch et al., 2015b), with a high ecological amplitude spanning from mesic conditions in central Europe up to drought-prone conditions in sub-Mediterranean sites (del Río et al., 2014; Primicia et al., 2016, Primicia et al., 2013). A more severe drought stress due to warmer conditions, higher evapotranspiration rates and more frequent heat waves (Cardil et al., 2014) are one of the major climatic concerns negatively impacting forest productivity and vitality, particularly in the Mediterranean Basin (Camarero et al., 2015). Indeed, temperature and

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water availability during the summer are the main climatic drivers of Scots pine (Martínez-Vilalta et al., 2008; Sánchez-Salguero et al., 2015) and European beech (Rozas et al., 2015) long-term growth in Mediterranean populations. In this respect, ongoing long-term increases in drought frequency and intensity in the Iberian Peninsula (Andreu et al., 2007; Candel-Pérez et al., 2012) are reducing the productivity and increasing the incidence of canopy dieback and mortality in Scots pine (Camarero et al., 2015; Gea-Izquierdo et al., 2014; Martínez-Vilalta and Piñol, 2002). In NE Spain increased summer drought stress is impacting negatively on Scots pine growth, although so far the magnitude of such punctual growth declines is not enough to counteract the overall increase of growth during the 20th century (Martínez-Vilalta et al., 2008). In this region, summer drought increase has even caused an upward shift (Peñuelas and Boada, 2003) and a dramatic growth decline of beech over the last half-century (Jump et al., 2006). However, the beech populations are expanding across the mostly humid and temperate areas of NW Spain, particularly in lowlands, and stand growth is expected to show similar positive trends (Sánchez de Dios et al., 2016).

Drought-stress release of beech may be enhanced in mixed forests or stands relative to pure ones (Mölder and Leuschner, 2014). However, mixing may not fully compensate for lower field capacities or frequent lack of precipitation as shown by Metz et al. (2016) when beech was admixed with Scots pine. Furthermore, mixing of Scots pine and European beech may result in a reduction of throughfall (Primicia et al., 2013) affecting tree growth negatively. Another strategy for minimizing forest drought vulnerability in temperate forests (D'Amato et al., 2013; Elkin et al., 2015; Sohn et al., 2016a) and also in drought-prone Mediterranean forests (Martín-Benito et al., 2010) is thinning. Thinning has been recommended as a short-term solution to reduce drought vulnerability by increasing resilience in mixed forests, albeit the initial enhancement of resilience may be reversed as stands mature and bigger trees increase water demand (D'Amato et al., 2013). Heavy thinning has been shown to improve resistance and particularly resilience of Scots pine to drought events in Germany, but these benefits diminish with time since the last intervention (Sohn et al., 2016a). In this case, progressive decreases in growth recovery apparently resulted from decreased throughfall and increased transpiration rather than from tree ageing. With regard to beech, thinning can increase its growth during wet and also in dry years (Diaconu et al., 2015; van der Maaten, 2013) but also affect growth negatively during dry periods by reducing soil water availability layer (Geβler et al., 2004). Sohn et al., (2016a) suggested that long-lasting effects on growth recovery are related to relatively larger leaf area and fine-root biomass in thinned mixed stands. Consequently, they predicted that European beech would recover faster from drought than Scots pine given its faster expansion of crown and root systems. However, to our knowledge no single study has dealt with the relationship between thinning intensity and growth response to drought in mixed pine-beech forests. This is important because synergies between pine and beech may result in different growth responses to thinning and drought relative to monospecific stands. Furthermore, growth responses to thinning are typically studied at an annual scale, but studying seasonal scales (Aldea et al., 2017; Primicia et al., 2013) may be important to elucidate the mechanisms implied and the long-term effects on growth. For instance, temporal patterns of rainfall and leaf phenology may interact and modulate the effects of thinning on tree growth.

In this work we analyse whether temporal interactions among throughfall, canopy type and thinning affected radial growth of Scots pine and European beech during a 6-year long period (2009–2014) which included two very dry years. The research site, Aspurz, is a thinned pine-beech forest located in the western Spanish Pyrenees, close to the southern European limit of Scots pine and European beech. Previous research has shown that throughfall is the most important growth limiting factor for Scots pines at this site (Primicia et al., 2013). Aspurz can be considered as a transitional site between the Eurosiberian and Mediterranean regions, respectively characterized by cool-wet and warm-dry climate conditions, in which since 1920 mean annual temperatures have risen $+0.020\,^{\circ}\mathrm{C}\ \mathrm{year}^{-1}$ and water surplus has significantly decreased (González de Andrés et al., 2017).

Linear mixed models are a valuable statistical tool for describing and predicting the radial-growth patterns in relation to different factors such as thinning and canopy type in mixed forests (Pretzsch et al., 2015a). Therefore, these models were used in this study in order to fulfill the following objectives: (1) To compare intra-annual and inter-annual basal-area growth patterns of Scots pine and European beech in a mixed forest; (2) To evaluate the effects of canopy type and thinning on Scots pine basal-area growth dynamics, and of thinning on basal area growth dynamics of European beech; and (3) To assess the effects of throughfall and its interactions with other factors (i.e., month, year, type of canopy and thinning) or combinations of these factors on basal-area growth dynamics of Scots pine and European beech.

2. Methods

2.1. Study area

The study area is located in Aspurz (42°42′31″N, 1°08′40″W), a forest situated in the western Spanish Pyrenees, Navarre. Plots are North-oriented, located at a mean altitude of 642 m, a mean slope of 7% and on a soil classified as Haplic Alisol (Blanco, 2004). The climate is considered as a cold wet Mediterranean type with water deficit usually in July and August with frequent frosts from winter to early spring. In the 1984–2014 period, mean annual precipitation was 921 mm and mean annual temperature 12.0 °C (data from Navascués weather station located at 2.7 km from the plots, 42° 43′ 06″ N, 1° 06′ 55″ W, 615 m). The forest is an even-aged mixed stand dominated by *Pinus sylvestris L.* (Scots pine), naturally regenerated in the mid-1960s after strip-like clear- cutting, with a mean dominant tree height of 20.4 m in 2014, being one of the most productive Scots pine forests in Spain (Primicia et al., 2016). *Fagus sylvatica* L. (European beech) is the second most abundant tree species, with a mean crown cover of ca. 38% and mean age of 35–40 years. Most beech trees were codominant or dominant, although they covered all strata from suppressed to dominant ones.

2.2. Experimental design

A complete randomized block design (Andrew, 1986) was used in this study, including nine plots (30 m × 40 m) installed by the Servicio Forestal del Gobierno de Navarra. The experimental design can be thus specified as a split-plot (von Ende, 2001). Three different thinning intensities (3 thinning intensities with 3 replicates) were applied in November 1999 (0%, 20% and 30% basal area removed) and March 2009 (0%, 20% and 40%) in the plots and in a buffer zone of 5–10 m around them. The first thinning was carried out removing mainly suppressed or intermediate trees, and some dominant or codominant trees with malformed stems. However, during the second thinning, mainly subdominant or dominant trees were removed. The highest thinning intensity was increased up to the 40% of the basal area during the second thinning in accordance to the silvicultural trends applied on similar surrounding stands at that moment. Similarly, following the silvicultural guidelines applied in Navarre on mixed stands with beech as secondary species, only Scots pine trees were thinned.

Within each plot, two discontinuous subplots can be distinguished: mixed beech-pine and pure pine subplots (hereafter abbreviated as MC and PC sub-plots). To establish the subplots, first we divided each plot into 300 2 m × 2 m quadrats by using banderoles. Then, we delimitated the projection on the ground of beech canopy taller than 2 m by using plastic bands. Lastly we used plot maps with georeferenced trees and a grid of 2 m × 2 m quadrats to draw the contours of each type of subplot. In each plot, we randomly selected three Scots pines in PC sub-plots, three Scots Pines and three beeches in MC subplots. Only dominant or codominant trees were selected. Six treatments are thus determined for

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