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Growth and water use performance of four co-occurring riparian tree species in a Mediterranean riparian forest

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ABSTRACT

Mediterranean riparian zones act as vegetation shelters for several deciduous tree species at the edge of their bioclimatic distribution, e.g. alder (*Alnus glutinosa*), black poplar (*Populus nigra*) or ash (*Fraxinus excelsior*). Current global warming and human induced disturbances may worsen their growing conditions. Under such circumstances, black locust (*Robinia pseudoacacia*) is outcompeting autochthonous tree species. Here, we provide evidences of black locust better growth and water use performance than alder and ash. We compare the temporal and spatial patterns of transpiration and the stem basal area increments of alder, black poplar, common ash and black locust, all of them co-occurring in a mixed riparian Mediterranean forest. Black locust presented the lowest transpiration values per basal area unit (4.0 $mm \cdot m^{-2}$·growing $season^{-1}$). Although tree transpiration was mainly driven by energy availability instead of water, ash transpiration was constrained by water availability at soil water contents below 0.08 $cm^3 \cdot cm^{-3}$. Black locust was the only tree species growing all over the water availability gradient present in the study site, and it did not present any significant difference in sap flow values across this gradient. Furthermore, black locust and black poplar were the species with higher growth-based water use efficiency (5.4 $g \cdot cm^{-1} \cdot m^{-3}$ and 3.6 $g \cdot cm^{-1} \cdot m^{-3}$, respectively); ash and alder were the less efficient ones (2.8 $g \cdot cm^{-1} \cdot m^{-3}$ and 1.9 $g \cdot cm^{-1} \cdot m^{-3}$respectively). The good performance of black locust is relevant to understand its great successful invasion of Mediterranean riparian forests, particularly after human-induced disturbances, as forest management.

1. Introduction

Mediterranean riparian forests are natural refuges for boreal and temperate origin's tree species such as alder (*Alnus glutinosa* (L.) Gaertn.), black poplar (*Populus nigra* L.) and ash (*Fraxinus excelsior* L.) (Holstein, 1984; Sanz et al., 2011). Due to their ecological interest, those habitats have been provided with a special protection status by the Natura 2000 EU strategy (Natura 2000, 91E0). However, many of them are located in the driest limit of their current bioclimatic distribution. Climate projections in the Mediterranean region show both a rainfall decrease and an atmospheric evaporative demand increase, particularly during winter and summer seasons (Ruíz-Sinoga et al., 2011; IPCC, 2013; Vautard et al., 2014). Periodical drought events, mainly in summer, are already affecting the Mediterranean ecosystems (Bréda et al., 2006; Vicente-Serrano, 2006; Lindner et al., 2010; García-Ruiz et al., 2011). Riparian tree species in Mediterranean areas might experience important changes of water availability during their lifetime (Otero et al., 2011; Singer et al., 2014; Sargeant and Singer, 2016). Those changes both in river discharge and soil saturated water table height may imply vegetation changes in riparian forests, and help invasive tree species to outcompete autochthonous vegetation (Lite and Stromberg, 2006). In addition, climate change conditions are expected to increase water stress periods in the Mediterranean area (IPCC, 2013). Consequently, it may result in a north pole-ward shift of the optimal growing conditions for broad-leaved winter deciduous tree species. This is especially applicable for riparian tree species because their biological processes require high water availability (Scott et al., 1999; Snyder and Williams, 2000; Zhou et al., 2014). Furthermore, during typical Mediterranean summers, i.e. dry and hot environmental conditions, transpiration of some of these tree species is mostly supported by their access to the riparian phreatic water table. However, if stream

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water flow decreases, the phreatic water table might descend below the rooting depth, uncoupling the riparian trees from such extra water. On the other hand, different tree species may experience drought differently, and consequently, present different thresholds of drought-tolerance. For instance, wood structural traits are important to understand tree species hydraulic conductivity. Ring-porous tree species, such as ash and black locust, are in general frost and drought avoiders, with a greater potential sap velocity than diffuse-porous ones. Conversely, diffuse-porous ones, such as alder and black poplar, are less vulnerable to freezing and support more negative xylem pressures before cavitation phenomena occurs (Sperry et al., 1994).

In addition, human-induced disturbances in riparian areas, such as wood extraction, facilitate the propagation of black locust, which is invading moist forests all over the northern Mediterranean basin area (Motta et al., 2009; Radtke et al., 2013). This tree species was introduced in Europe during the 17th century. It has been cultivated in well-watered environments for wood extraction in moist Europe (DeGomez and Wagner, 2001; Gruenewald et al., 2007; Redei et al., 2011), for energy generation (Kraszkiewicz, 2013), or soil erosion prevention (Straker et al., 2015). In spite of all such possible uses, black locust is within the group of most problematic invasive tree species in the Mediterranean. Its control is costly and difficult, and black locust populations are currently spreading over the south-eastern Mediterranean basin (Capdevila-Argüelles et al., 2006; Gassó et al., 2009; Andreu et al., 2009; Benesperi et al., 2012). Furthermore, according to climate change projections, black locust is projected to increase its invasiveness (Kleinbauer et al., 2010; Gassó et al., 2012) and it is detected as an important threat for the autochthonous Mediterranean riparian forests dominated by alder.

In this study we monitored tree transpiration and stem basal area increments over the year 2012 growing season of four co-occurring tree species (alder, poplar, ash and black locust), in a Mediterranean riparian forest. The aim of this study is to evaluate growth and water use performance of these species, to better understand how black locust succeeds in outcompeting the autochthonous tree species. The growing conditions in the riparian forest studied area covered a wide temporal and spatial range of soil water availability and atmospheric evaporative demand. Studying both tree transpiration and stem basal area increments together allows us to analyse the linkages and interdependencies of the simultaneous responses of both processes to tree species' water use strategies (Hsiao and Acevedo, 1974).

We hypothesize that, in Mediterranean riparian forests, there is no water limitation for growth and transpiration in the case of species distributed by the river side, such as alder and black poplar, well known as phreatophytic species (McVean, 1956; Allen et al., 1999; Cox et al., 2005; Singer et al., 2013). On the other hand, we expect water availability constraints on ash growth during summer drought, due its non-phreatophytic behaviour (Sánchez-Pérez et al., 2008; Singer et al., 2013). Since black locust is distributed all over the water availability gradient, we expect both no transpiration constraints and a better water use efficiency of black locust trees, compared to autochthonous tree species. Finally, we expect that alder would be less water use efficient than the other tree species given that only grows by the riverside, where no water limitations are expected to happen.

2. Material and methods

2.1. Site description

The study was conducted in Font del Regàs riparian forest, located in the Montseny Natural Park, NE Spain (41°50′N, 2°30′E, 550 m.a.s.l.). This riparian forest is growing along the Riera d'Arbúcies stream, which has a permanent flow. In the experimental area four tree species are present: alder (*Alnus glutinosa* (L.) Gaertn.), black poplar (*Populus nigra* L.), ash (*Fraxinus excelsior* L.) and black locust (*Robinia pseudoacacia* L.); hereafter referred as alder, poplar, ash and black locust. Alder and poplar are mostly distributed nearby the river, whereas ash trees are located further away, on the hill-slope zone. Black locust trees are scattered over the study area. Alder and poplar are known as phreatophytic species. They also have diffuse-porous wood ring structure. Ash and black locust are ring-porous wood species. Ash is described as a non-phreatophytic tree species. Font del Regàs site is an example of the discontinuous populations of these species, growing in the borders of fluvial streams and above wet soils that can be found in the North-Eastern Iberian peninsula (Ginés, 2007).

About 25 years ago, as usually practiced in the region for this forest type, the forest was managed by clear-cutting the riparian tree species near the riverside. According to tree-ring core analysis (unpublished data), black locust entered successfully after then. This is consistent with its shade intolerance and known difficulties to get established under closed canopies (Motta et al., 2009), as well as with its ability to proliferate in the riparian forests all over the Mediterranean basin favoured by frequent disturbances (Kleinbauer et al., 2010; Radtke et al., 2013; Straker et al., 2015). Alder individuals resprouted after management. Poplar, a fast growing tree species often human-promoted in the Mediterranean riparian zones of the area, was thereafter planted. Based on a previous botanical assessment in the area (Bernal et al., 2015), we designated this tree species as *Populus nigra*. Older individuals of ash remained uncut, farther away from the riverside. At present, no natural regeneration by seedlings has been observed for alder and poplar. The riparian understory is formed by a shrub layer of *Corylus avellana* L., *Sambucus nigra* L., and there is an important abundance of the climbing vine *Hedera helix* L. There is also an herbaceous stratum dominated by *Anemone nemorosa* L., *Lamium album* L, *Viola spp*., *Carex pendula* L., and some other common riparian forbs, as well as the opportunist plants *Urtica dioica* L., and *Clematis flammula* L.

The study plot covers about 150 m × 26 m on both sides of the Riera d'Arbúcies stream and stand characteristics are presented in Table 1. According to a gradient of soil moisture, soil slope, distance from the stream channel, and distance from the phreatic water table depth, the area was divided into three zones. The first zone was located at the first four meters from the riverside, with the presence of alder, poplar and black locust (0–4 m). The second zone, at an intermediate distance (4–7 m) from the river stream, had the presence of poplar and black locust, and the third zone, located on the hill-slope zone (>7 m), had the presence of black locust and ash (Fig. 1).

Field measurements were taken to cover the whole growing season of year 2012 (from Day Of Year (DOY)106 to 306).

During 2012 vegetative period, the distance from the soil surface to the phreatic water table level reached values of −0.62 ± 0.03 m, −1.31 ± 0.03 m, and −2.24 ± 0.04 m in the first, the second and the third zones, respectively. During the studied period, differences between maximum and minimum groundwater level were <0.2 m in all riparian zones (Poblador, unpublished data). Groundwater level oscillations were registered every 15 min using water pressure transducers (HOBO U20-001-04) installed in slotted PVC wells.

2.2. Meteorological and soil water content data

Meteorological data were recorded in a meteorological station, located at *ca*. 800 m distance from the study site. Air temperature and relative humidity, solar radiation, photosynthetic active radia-