Forest Ecology and Management 343 (2015) 42–52

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Regeneration dynamics of *Quercus pyrenaica* Willd. in the Central System (Spain)

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ARTICLE INFO

Article history:
Received 18 November 2014
Received in revised form 20 January 2015
Accepted 22 January 2015
Available online 16 February 2015

Keywords:
Oak recruitment
Forest dynamics
Seedling abundance
Castanea sativa
Pinus reforestations

ABSTRACT

In the Mediterranean region, over the past few centuries human activity has modeled the landscape, leading to forest degradation. However, as in many parts of the European continent since the second half of the twentieth century, the Iberian Peninsula has been subject to a substantial degree of land abandonment that has led to the expansion of important secondary forests. One of the dominant tree species in the transitional forests of mountain areas between the Mediterranean and Euro-Siberian regions of the Iberian Peninsula is the deciduous oak, *Quercus pyrenaica* Willd. The main objectives of the present work were to study the mode of regeneration and forest dynamics of *Q. pyrenaica* in several types of stands: young forests, mature and previously perturbed forests, and abandoned *Pinus* reforestations. With this in mind we established eight plots in the mountain range of the Sierra de Francia–Quilamas, in the west subdivision of the Spanish Central System. We analyzed the age and dbh distributions, regeneration density, and the spatial structure of trees and saplings. Young *Q. pyrenaica* stands were seen to show episodic recruitment after land abandonment consistent with a 'catastrophic' mode of regeneration. These stands were characterized by unimodal age-cohorts, with tree recruitment dropping drastically as the canopy developed and closed in, except at some study sites where the more shade-tolerant *Castanea sativa* was found. Older and previously disturbed *Q. pyrenaica* stands showed bimodal age cohorts, the young ones exhibiting a clumped pattern associated with canopy gaps and/or a lower tree density of the older cohort. In abandoned *Pinus* reforestations, the recruitment of *Q. pyrenaica* was also associated with canopy openings. These findings show that *Q. pyrenica* also undergoes a gap-phase mode of regeneration. An abundant regeneration of *Q. pyrenaica* could be found at all the stands, guaranteeing the persistence of seedling banks (but a scarcity or lack of saplings) under closed forests, until canopy gaps may allow some *Q. pyrenaica* individuals to grow and reach the main canopy.

1. Introduction

The structure and dynamics of forests are profoundly influenced by changes in land management (Scarascia-Mugnozza et al., 2000; Chauchard et al., 2007). This is especially true of historically disturbed areas such as the Mediterranean region, where over time traditional human activity has modeled the current landscape (Barbero et al., 1990). During the past few centuries land clearing for agriculture, livestock grazing, wood cutting for fuel, and coniferous plantations have been the main drivers of forest degradation (Barbero et al., 1990; Terradas, 1999; Scarascia-Mugnozza et al., 2000). However, as in many parts of Europe since the second half of the twentieth century, the Iberian Peninsula has been subject to substantial land abandonment and this has led to the expansion of important secondary forests dominated by the two main tree genera: *Pinus* and *Quercus* (Blanco et al., 1997; Pons and Pausas, 2006; DeSoto et al., 2010; Kouba and Alados, 2012; Kouba et al., 2012).

Quercus pyrenaica Willd. is an abundant deciduous tree species present in the western Mediterranean region, extending through southwest France, the Iberian Peninsula and northern Morocco (Blanco et al., 1997). In the Iberian Peninsula it is considered the deciduous oak that is best able to cope with the summer droughts typical of the Mediterranean climate (Aranda et al., 1996; Sisó et al., 2001; Corcuera et al., 2002), which allows it to dominate the transitional areas between the Mediterranean

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http://dx.doi.org/10.1016/j.foreco.2015.01.023
0378-1127/

and Euro-Siberian regions of the northwest of the Iberian Peninsula (Sánchez de Dios et al., 2009). Although it can be found in flat areas above an altitude of 400 m, it typically occurs in mountainous areas up to 1600–1800 m a.s.l., and occasionally up to 2000 m a.s.l. (Blanco et al., 1997). It is often found as a dominant tree species that forms almost pure stands, although it also coexists with evergreen (*P. sylvestris*, *P. pinaster*, *Q. ilex*) and/or deciduous species (*Q. robur*, *Q. petraea*, *C. sativa*) in mixed stands (Blanco et al., 1997). As in the case of many forests, mature *Q. pyrenaica* stands have been dramatically reduced and degraded by recurrent human intervention, such as felling for firewood, and clearing and burning for grazing. In some areas, *Q. pyrenaica* has been replaced by the sclerophyllous *Q. ilex* and *Q. suber*, owing to the change to degraded soils and drier conditions after the elimination of the original forest (Valladares et al., 2004). Despite this, in recent decades there has been a considerable regeneration and regrowth of young *Q. pyrenaica* forests in northwest Spain (Blanco et al., 1997), mainly due to the migration of rural populations to urban areas and the resulting abandonment of the land.

Q. pyrenaica has two well established regeneration mechanisms: (1) vegetative propagation and (2) seedling establishment through acorns. *Q. pyrenaica* shows one of the most vigorous resprouting responses of the genus *Quercus*, producing numerous sprouts from shallow lateral roots, even in absence of perturbations (Blanco et al., 1997; Calvo et al., 1999, 2003; Plieninger et al., 2010). By contrast, sexual reproduction is strongly limited by several factors, resulting in poorly effective seedling establishment (Serrada et al., 1994; Jiménez et al., 1998; Gómez et al., 2003; Castro et al., 2006). *Q. pyrenaica* has a low acorn production (Jiménez et al., 1998) and shows the typical high rates of acorn predation of *Quercus* species by invertebrates and vertebrates (Gómez et al., 2003). Additionally, it undergoes high seedling mortality during the summer stress typical of Mediterranean areas (Fernández-Abascal et al., 2004; Castro et al., 2006; Silla and Escudero, 2006), which strongly constrains its establishment under nursing plants in more open areas (Castro et al., 2006). Finally, herbivore defoliation and trampling are also important factors of reduced seedling growth and high mortality during the first years of establishment (Baraza et al., 2004; Silla and Escudero, 2006), and some studies have reported them to be the main cause of seedling death (Gómez et al., 2003). These limiting factors over recruitment from seeds are common to other Mediterranean *Quercus* species as *Q. ilex* and *Q. suber* (Plieninger et al., 2004, 2010; Pausas et al., 2006; Rossetti and Bagella, 2014). However, despite these restrictions acorn dispersion by the Eurasian jay (*Garrulus glandarius*) is considered a key process in the regeneration of *Quercus* forests after land abandonment (Pausas et al., 2006, 2009), and high genetic diversity has been found in *Q. pyrenaica* coppices and woodlands (Valbuena-Carabaña et al., 2008).

Regarding its shade-tolerance, *Q. pyrenaica* is considered to be an intolerant-intermediate species (class 3 in a nine-class classification from lowest to highest shade tolerance; Sevilla, 2008). However, the regeneration mode of *Q. pyrenaica* has been little studied. The regeneration mode is defined as regenerative behavior in relation to disturbances, and emphasizes the temporal and spatial scale at which regeneration occurs (Veblen, 1992). Veblen (1992) recognized three modes of regeneration: (1) a catastrophic regeneration mode, (2) a gap-phase regeneration mode, and (3) a continuous regeneration mode. One strong caveat in the study of regeneration modes is the lack of truly mature forests of *Q. pyrenaica* on the Iberian Peninsula due to the long history of human intervention in the Mediterranean landscape (Barbero et al., 1990; Scarascia-Mugnozza et al., 2000). Mature or old-growth forests are complex and heterogeneous systems in which non-competitive tree mortality generates gaps of different sizes that will be filled by ensuing generations of trees (Oliver and Larson, 1996; Franklin et al., 2002). In our study region, *Q. pyrenaica* forests are commonly mixed with *Pinus* reforestations planted during the 50–70s of the twentieth century, and also with *C. sativa* stands, managed for wood and food, some of them showing varying degrees of abandonment. Owing to the importance of such knowledge for ecological forestry (Franklin et al., 2007), our aim here is to take advantage of the heterogeneity of the landscape generated by human use to set up two main objectives: (1) to establish the mode of regeneration of *Q. pyrenaica* in the study area, and (2) to analyze the forest dynamics of mixed and *Q. pyrenaica*-dominated stands in relation to human intervention.

2. Material and methods

2.1. Study area

The study region is located in the mountain range of the Sierra de Francia–Quilamas, in the west subdivision of the Spanish Central System. Two areas, located in public forests under institutional management (Junta de Castilla y León) were selected: (a) the slopes of the Peña de Francia (a peak at an altitude of 1727 m), and (b) the Quilamas range (900–1423 m in altitude) (Fig. 1). The Peña de Francia is a geologically complex syncline made of quartzite, sandstone and slates, with leptosols as the dominant soils. The Quilamas range forms part of the Tamames syncline, which is dominated by quartzite, slate and limestone lithologies, with leptosols and cambisols as the dominant soils. Annual precipitation varies between 1800 and 1900 mm at the Peña de Francia, and between 1000 and 1600 mm in the Quilamas range, both with a typical Mediterranean period of low precipitation during July and August. The mean annual temperature is 7.5 °C for the Peña de Francia, and between 10 and 12.5 °C for the Quilamas range.

The slopes of the Peña de Francia are characterized by a mosaic of *Q. pyrenaica* stands and *P. sylvestris* plantations, which have been replaced by shrublands dominated by *Cytisus oromediterraneus*, and talus deposits with increasing altitude. The Quilamas range is characterized by a variety of land covers, with *Q. pyrenaica* stands, plantations of *P. sylvestris* and *P. pinaster*, *C. sativa* groves (for fruit) and coppices (for wood) in different stages of abandonment; shrublands dominated by *Erica* and *Cytisus* species, small farms, and pastures. Forestry activity in the area (Municipality of Linares) selected in the Quilamas range has been under the regulation of a forestry management plan since 1967 (Dirección General de Montes, Caza y Pesca Fluvial, 1967), while the Peña de Francia area has been managed under the general forestry regulations of the Junta de Castilla y León.

2.2. Establishment of plots and data collection

Eight *Q. pyrenaica* stands representative of different situations encountered in the study were selected and a plot was established at each, six were selected in the Quilamas range (LIN sites) and two in the slopes of the Peña de Francia (PFR sites). Six were *Q. pyrenaica*-dominated plots that included from the abundant secondary forests (LIN1-4) to the scarce remnants of mature forests (LIN5 and PFR1). The remaining ones were two reforestations of *P. pinaster* (LIN6) and *P. sylvestris* (PFR2). Plot size was variable in the areas, ranging between 400 and 3000 m^2, because of differences in tree density between sites (Table 1). All plots were regular in shape and their sides were oriented in the directions of the cardinal points.

Domestic cattle is regulated under forestry management plans and was absent in the selected stands. Main ungulates in both areas were roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*).