Forest Ecology and Management 304 (2013) 192–203

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Which are the factors controlling tree seedling establishment in North Italian floodplain forests invaded by non-native tree species?

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A R T I C L E I N F O

Article history:
Received 5 November 2012
Received in revised form 28 April 2013
Accepted 2 May 2013
Available online 30 May 2013

Keywords:
Hurdle negative binomial model
Natural forest regeneration
Non-metric multidimensional scaling
Prunus serotina Ehrh.
Robinia pseudoacacia L.
Woody invaders

A B S T R A C T

In hardwood floodplain forests of the North Italian Po Plain the non-native and light-demanding tree species *Prunus serotina* Ehrh. and *Robinia pseudoacacia* L. coexist with the native tree species *Carpinus betulus* L., *Quercus robur* L., and *Ulmus minor* Mill. In order to identify the factors controlling the establishment of seedlings of these species, we focused on the scale of micro-plots, which provide safe sites for tree species regeneration. We used seedling and sapling counts as the response variable. For modelling the seedling regeneration in relation to a multivariate set of 15 measured soil and stand characteristics, a hurdle negative binomial model was applied and then compared with a non-metric multidimensional scaling ordination, visualising the relationships between the regenerating species and the environmental parameters. In general, it could be shown that there are species-specific differences in the requirements for seedling regeneration between the five target species, and that the most important parameters affecting seedling establishment were the availability of potential seed sources, soil humidity, and light availability. *Q. robur* and *C. betulus* showed a wide ecological range regarding soil humidity, whereas *U. minor* was restricted to moister soils, and the two non-native species only occurred on dry soils. In addition, *R. pseudoacacia* and *Q. robur* regenerated very scarcely under the closed canopy inside the stands and were highly dependent on large scale disturbance events. After a disturbance, the presence of *R. pseudoacacia* in the canopy promoted the seedling regeneration of *Q. robur*. *P. serotina* was found to regenerate frequently in the closed forest and to persist for a long time under shade, but also needs forest gaps to establish in the canopy. We believe that *P. serotina* was wrongly classified as a shade-intolerant species in the past. We suggest that it is a competitive invader in a broad range of resource availability. In conclusion, with regard to the further forest development, it could be assumed that the absence of disturbance events resulting in large openings leads to a reduction in the number of *P. serotina*, *R. pseudoacacia*, and *Q. robur* individuals during succession. Nevertheless, disturbances on wetter soils, e.g. related to the natural river dynamics, will clearly favour the seedling regeneration of *Q. robur* compared to the non-native species, which are generally limited to the drier sites of the floodplain forests.

1. Introduction

Forest remnants are often threatened in human-dominated landscapes, including floodplain forests, which are hot spots of species richness (Schnitzler, 1994; Schnitzler et al., 2007) and thus are of particular importance for the conservation of biodiversity (McKinney, 2002; Ward et al., 2002). The principal reason for higher biodiversity in floodplains is the huge number of different (micro-) habitats caused by the hydro- and morphodynamics (Schnitzler, 1994; Schneider-Binder, 2009). This leads to a shifting, steady-state habitat mosaic of species of different succession stages (Cline and McAllister, 2012) providing numerous different niches for the natural regeneration of various tree species (Grubb, 1977). Within the process of natural tree species regeneration the phase of seedling establishment is of particular importance because young seedlings are more vulnerable to stress factors, such as low or high irradiance, water shortage, which, in the long term determine community structure and composition (Ribbens et al., 1994; Zerbe, 2002; Hille Ris Lambers and Clark, 2003;

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http://dx.doi.org/10.1016/j.foreco.2013.05.003

Vanhellemont et al., 2009a) and species distribution in the landscape (Niinemets and Valladares, 2006). Consequently knowing the species requirements during their establishment phase has important implications for both community ecology as well as the management of invasive species (e.g. Liira et al., 2011; Bobiec, 2012).

According to Hall and Harcombe (1998) floodplain tree seedlings respond primarily to flooding and light. Also, Jones et al. (1994) suggest that primarily flooding and light interact to affect floodplain regeneration patterns through effects on germination, growth, and mortality. The effects vary among floodplain species depending on life-history traits such as seed size, flood tolerance, and shade tolerance (Hall and Harcombe, 1998).

However, floodplain forests are considered highly susceptible to invasions by non-native species. Invasive species are considered the second greatest threat to biodiversity worldwide, after habitat fragmentation and destruction (Walker and Steffen, 1997). The characteristic hydro- and morphodynamics of floodplain forests, along with human impacts, promote the spread of undesired exotics (Schnitzler et al., 2007; Kowarik, 2010; Mölder and Schneider, 2011). Kawaletz et al. (2013) showed that such non-native tree species (i.e. *Prunus serotina* and *Robinia pseudoacacia*) were much more competitive than the natives (in their case *Quercus robur* and *Carpinus betulus*). Mature non-native trees can form environments in their immediate neighbourhood facilitating their own seedlings' success and reduce the success of natives (Hyatt, 2008). It has been shown that invasions led to a decline in seedling regeneration rates of native species, rather than higher extinction rates (Yurkonis et al., 2005). This implies that once invasive trees are established they effectively reduce the recruitment of native species seedlings, rather than suppress existing adults (Hyatt, 2008; Annighöfer et al., 2012a).

The increasing spread of invasive tree species is also one of the main threats to the native forest communities in the hardwood floodplain forests of the North Italian biosphere reserve "Valle del Ticino" (hereinafter 'Ticino Park'), the study area of this work. Large areas of the park, originally consisting mainly of the native species pedunculate oak (*Q. robur* L.), European hornbeam (*C. betulus* L.), and field elm (*Ulmus minor* Mill.), are today heavily invaded by the two non-native tree species black locust (*R.pseudoacacia* L.) and black cherry (*P. serotina* Ehrh.) (Boschetti et al., 2007; Caronni, 2010; Annighöfer et al., 2012a).

As one of the main objectives for forest reserves is the maintenance, development and conservation of near-natural forests consisting of native species, it is important to identify and better understand the factors controlling the natural performance of seedling and sapling of different tree species in these forests. Since our study is analysing the seedlings of native and non-native species in the Mediterranean area, it may be of even greater importance with regard to prospective climate change and decreasing precipitation in other parts of Europe, where climate warming may not only drive endangered species out of reserves but might also foster the invasion of alien species into reserve networks (Kleinbauer et al., 2010).

Focusing on the scale of micro-plots, which provide safe sites (Urbanska, 1997) for tree establishment, and using seedling and sapling (hereinafter summarised by 'seedling') counts as the response variable, we addressed the following questions:

(i) Which are the important factors controlling the seedling establishment of three native (*C. betulus, Q. robur, and U. minor*) and two non-native (*P. serotina* and *R. pseudoacacia*) tree species?
(ii) Which possible scenarios for future forest development and conservation management can be drawn from identifying these factors, considering the massive presence of *P. serotina* and *R. pseudoacacia*?

2. Materials and methods

2.1. Study site

The study area is located in the North Italian UNESCO MAB Biosphere Reserve "Valle del Ticino" (Ticino Park). Being the largest continuous remnant of woodlands in the Po Plain, and an important ecological corridor between the Alps and the Apennines, the biosphere reserve was created in 2002 in order to conserve the remaining mosaic of alluvial forests (UNESCO, 2005). Situated on the border of the regions Lombardy and Piedmont, the Ticino Park is approximately 100 km long and between 10 and 20 km wide, reaching from the Lago Maggiore in the north-west (45°06′ 21″N, 08°34′53″E) with an elevation of about 195 m a.s.l. to the confluence of the Ticino river with the Po river in the south-east (45°46′38″N, 09°16′19″E) with an elevation of about 57 m a.s.l. (Fig. 1). The climate is moderate with average temperatures in January and July of 1.7 °C and 22.2 °C respectively, and an average annual precipitation of 1212 mm (meteorological station Milan Malpensa Airport, Fig. 1; CNMCA, 2009), and is characterised by long drought periods at irregular intervals, especially during summer. The forest soil is a fluvic soil (FAO, 1998) showing transitions from pale sandy soil to darker sand with higher amounts of loam and gravel.

Before becoming a biosphere reserve, most of the Ticino forests were managed for wood production and used as a hunting reserve (Motta et al., 2009). As the objective of the biosphere reserve is to develop near-natural forests in the future, consisting of native species, at present all silvicultural measures have been stopped and only sporadic measures to combat *P. serotina* are conducted, e.g. to prevent its spreading further south (pers. comm. Caronni, 2011). In general, the forests are not older than approximately 65 years because almost all forests in the Ticino Valley had been completely cut down during the strong winters following the World War II (pers. comm. Caronni, 2011). The typical native phytosociological forest association of the Ticino valley is the *Polygonato multiflori-Quercetum roboris* (Sartori, 1980), a hardwood floodplain forest consisting mainly of pedunculate oak (*Q. robur* L.), European hornbeam (*C. betulus* L.), and field elm (*U. minor* Mill.) (Sartori, 1980; UNESCO, 2005) mixed with different sub-dominant tree species. This association is subject to periodic flooding from the Ticino river and its tributaries.

2.2. Tree species studied

In the beginning of the twentieth century the two tree species black cherry (*P. serotina* Ehrh.) and black locust (*R. pseudoacacia* L.), both native to North-East America (Auclair and Cottam, 1971; Boring and Swank, 1984), were introduced to the area (Motta et al., 2009; Caronni, 2010). Presumably, they have migrated from the gardens of nearby cities such as Gallarate (Fig. 1) in the north of the park in the case of *P. serotina* (Caronni, 2010), or from outside the floodplain in the case of *R. pseudoacacia* (Annighöfer et al., 2012a). Since then the abundance of these species has greatly increased.

With regard to forest structure and forest composition *P. serotina* and *R. pseudoacacia* constitute a major threat to the biodiversity conservation and stability of the native ecosystem (Motta et al., 2009; Caronni, 2010). For example, *P. serotina,* considered a semi-shade-tolerant, opportunistic gap-phase species (Auclair and Cottam, 1971), can change abiotic soil conditions, affect biodiversity, and influence succession (Starfinger et al., 2003; Verheyen et al., 2007; Chabrerie et al., 2008). According to Royo and Carson (2006), dense shrub layers such as those formed by *P. serotina* might act as a 'recalcitrant layer' that hinders the regeneration of