Forest Ecology and Management 343 (2015) 34–41

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Variability in needle lifespan and foliar biomass along a gradient of soil fertility in maritime pine plantations on acid soils rich in organic matter

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ARTICLE INFO

Article history:
Received 24 November 2014
Received in revised form 27 January 2015
Accepted 29 January 2015
Available online 16 February 2015

Keywords:
Needle longevity
Biomass
Leaf area index
Site index
Nutrients
Pinus pinaster

ABSTRACT

The variability in needle lifespan, foliar biomass and leaf area index was studied in 31 *Pinus pinaster* Ait. plots in Galicia (NW Spain), established along a gradient of soil productivity in plantations of similar age (11–14 years). The soils under study were acidic (pH 3.7–5.3) and very rich in organic matter (6.9–34.3%). All needles were classified according to age class, and presence/absence of needles was recorded to evaluate survival. Specific leaf area and needle biomass were calculated for each plot. The foliage nutrient concentrations were also measured and site index was calculated. The maximum needle age was 5 years. Survival of needles older than 2 years declined rapidly. Needle longevity was positively affected by site index and foliar nutrient concentrations, particularly of Mg and K. This suggests that maritime pine responds to low soil fertility by decreasing needle lifespan at local scales. Needle biomass and leaf area index were significantly higher in 1 and 2-year-old needles. Total needle biomass and LAI values were very variable (average values of 4.89 t ha^{-1} and 1.64 m^2 m^{-2}, standard deviation 3.1 and 1.1 and CV of 64% and 69%, respectively) and were positively related to site productivity and foliar nutrients. The average litterfall rate was estimated to be 0.31 $year^{-1}$. The mean growth efficiency (0.36 kg m^{-2} $year^{-1}$) was also rather variable (CV = 50%) and was positively related to foliar K and needle longevity. The relationships between all variables associated with high levels of pine productivity and the mean shrub height were always significant and negative, indicating a reduction in the risk of ground fire.

1. Introduction

The wide range of leaf longevity of pines, both between and within species, may have contributed to the extensive distribution of the genus in diverse habitats. This factor thus depends upon resource availability, environmental conditions and the incidence of disease, as well as their interactions and relationships with morphological, physiological and life history traits (Schoettle and Fahey, 1994). Among the pine species used for timber grown in Southern Europe, *Pinus radiata* can be considered as having short-lived foliage, whereas the needle lifespan is longer in *Pinus pinaster* (Warren and Adams, 2000a). Nevertheless, it is possible that intraspecific differences produce Atlantic provenances with short needle lifespan and that support a smaller mass of foliage of higher specific leaf area.

Maritime pine is a major productive species in northwestern Spain. The species covers more than half a million ha of land in the region, with site conditions ranging from natural stands in forest areas to stands recently planted under the program for afforestation of former agricultural land (Rodríguez-Soalleiro and Madrigal, 2008). Previous studies have provided information about the limiting resources affecting site productivity in the area (Pacheco-Marques, 1991; Álvarez-Álvarez et al., 2011). Although some climatic parameters, such as mean annual temperature, have been shown to be important, the reduced intensity of summer drought and the relatively homogeneous climatic conditions in the region explain the particular importance of nutrient availability in determining maritime pine productivity (Eimil-Fraga et al., 2014).

The abovementioned studies did not explore the direct influence of nutrient status on needle longevity, needle biomass or leaf area, which are major drivers of forest productivity (Leverenz and Hinckley, 1990). The total leaf area of a tree depends on needle production and needle retention, both of which may be influenced by

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http://dx.doi.org/10.1016/j.foreco.2015.01.030
0378-1127/

edaphic or climatic factors (Reich et al., 1995) as well as by crown closure. Low supplies of soil nutrients have been shown to reduce leaf area development and growth efficiency in pines, thus leading to lower production (Fox et al., 2007). Regarding macronutrients, nitrogen availability has been considered the main limiting factor for growth, and fertilization has been shown to affect both stand-level LAI and GE (Binkley and Reid, 1984; Binkley et al., 2004).

In the study region, maritime pine plantations of age 10–20 years are located on acidic soils rich in organic matter. These areas were previously used as pasture or agricultural land, and tillage was applied at intervals of more than 10 years. The sites are mainly placed over granitic, schist, gneiss, phyllite or slate substrates. Although organic matter mineralization rates are usually low because of aluminium binding, they also depend on soil temperature and pH (Calvo and Díaz-Fierros, 1982). Previous studies in such sites have shown that the main limiting nutrients are P, K, Mg, Ca and N (Martins et al., 2009).

The relationships between site quality, GE and LAI have not been directly analyzed in maritime pine. In this species, a large amount of radiation can be transmitted through the canopy, particularly before canopy closure. The radiation is available for growth of understory species, which have been shown to account for 6.8% of the total aboveground ecosystem biomass and 27.4% of the total ecosystem root biomass (Gonzalez et al., 2013). A high leaf area index will reduce the amount of radiation reaching the understory, thus decreasing the surface fuel load but also representing an important nutrient storage component for the stand.

We hypothesized that nutrients, particularly macronutrients other than nitrogen, are the key resources that affect the productivity of maritime pine plantations and that they do so by directly influencing needle longevity, foliar biomass and leaf area. To test this hypothesis, we sampled maritime pine plantations along a gradient of soil fertility in acidic soils rich in organic matter, mainly former agricultural land, in NW Spain. Additional aims of the study included the following: (i) to determine the average needle lifespan, needle biomass and leaf area index in a network of plots before canopy closure; and (ii) to relate the aforementioned variables to site index, growth efficiency and mean shrub height.

2. Materials and methods

2.1. Sites, foliage sampling and calculation of longevity

The study was carried out in *P. pinaster* Ait. stands, of age between 11 and 14 years, located in Galicia (NW Spain). The sites were chosen to include the natural range of the species, and 31 plots (20 × 30 m) were installed in the stands in 2006 (Fig. 1). The elevation of the sites ranged between 83 and 875 m above sea level. The mean annual temperature was 12.1 °C and annual precipitation was 1392 mm. The summer precipitation accounts for on average 8.6% of the total precipitation.

The trees were measured twice, with an interval of two years between measurements. Height to the crown base, total height and breast height diameter were measured, and the values were used to calculate site index (SI, m) by applying the models proposed by Álvarez-Gónzalez et al. (2005). The stand basal area

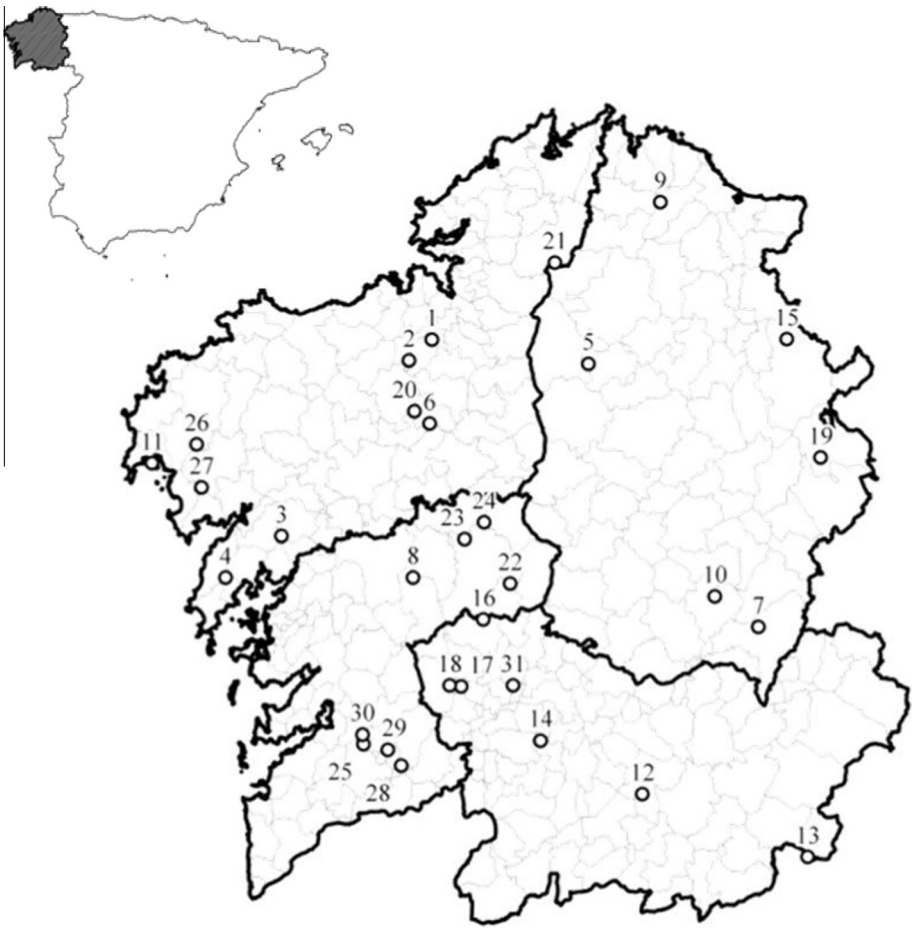

Fig. 1. Location of the 31 *Pinus pinaster* plots in Galicia (NW Spain). All plots were established under the grant program for afforestation of agricultural land.