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Comparison of pruning effects on tree growth, productivity and dominance of two major timber conifer species

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ABSTRACT

This study examined different pruning intensities, and the subsequent tree responses, in young trees from a network of permanent plots established in two of the most important South European timber species, maritime pine (*Pinus pinaster* Ait.) and radiata pine (*Pinus radiata* D. Don), in the Atlantic region. The experimental sites were monitored for 5 years post-pruning. The results reveal a pruning effect in terms of diameter growth, but none in terms of height growth. More specifically, a significant negative effect on diameter increment was found in both species, although *P. radiata* was more sensitive to the treatment. Furthermore, pruning affected the dominance of some trees, and hence impacted on stand structure. Dominant and codominant trees were the social positions which performed best following pruning. Individual-tree growth models for diameter and height are reported here for both species. The models adopt an explanatory approach and incorporate tree and stand variables, pruning intensity, along with a competition index which also characterizes the social position of the tree within the stand. Silvicultural implications for selection of crop trees and quality timber production are discussed. This is a first step towards the optimisation of forest management which includes pruning, and the integration of this intervention in forest growth models for maritime and radiata pines. In general, our results provide helpful information for the management of these Atlantic conifer species focused towards producing high-quality timber, for which pruning is essential, and suggest that guidelines for this practice should consider the differences between the two species in their growing response to pruning.

1. Introduction

An expected increased demand for wood products (FAO, 2009) has promoted a great deal of interest in the incorporation of intensive silvicultural practices into forestry operations (Zhai et al., 2015) in order to obtain higher quality of wood and, therefore, higher value forests. In this sense, pruning plays a key role since this operation allows knots and branch-related defects to be restricted to a central knotty core (Montagu et al., 2003) and the subsequent diameter growth results in more valuable wood (clearwood, free of knots). However, pruning may also constrain the growth, and consequently the volume of the trees, as well as impacting on their dominance, particularly under very intensive treatments (e.g. Sutton and Crowe, 1975; Gerrand et al., 1997; Courdier et al., 2002; Alcorn et al., 2008). Although the impact of this silvicultural intervention on tree growth can be limited and temporary (Amateis and Burkhart, 2011), it is essential to understand the responses of the main timber tree species to pruning in order to optimise their forest management to obtain higher quality wood.

Knot-free timber is produced as a result of investment in high-cost pruning interventions early in the rotation (Neilsen and Pinkard, 2003; Pinkard et al., 2004), although this investment will be returned at the end of the rotation (Pinkard et al., 2004). To minimise the costs, it is recommended to prune only those trees which will be selected for the final crop, i.e. future crop trees (FCTs) (Neilsen and Pinkard, 2003). The trees selected as suitable for pruning should present specific characteristics, such as stem straightness and an appropriate stem size which ensures the minimisation of the knotty core diameter (Montagu et al., 2003; Neilsen and Pinkard, 2003; Nutto and Touza, 2004; Hevia, 2013). Furthermore, it is critical that, as well as improving quality, the volume and quantity of clearwood resulting from pruned stands is maximised (Pinkard et al., 2004). To achieve this, a combination

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of pruning and thinning allows the canopy to be manipulated and thus increases the amount of high-quality clearwood produced (Forrester et al., 2010). However, if stands are left unthinned, it is important that pruned trees retain their competitiveness (Neilsen and Pinkard, 2003), since non-pruned dominant or codominant neighbours may suppress the trees selected for pruning (Sutton and Crowe, 1975), impacting on the final merchantable volume of high-quality timber in the stand.

It is reported in the literature that many factors can influence the response of trees to pruning (e.g. the tree species and genetic material, stand structure, site quality, timing and technique of pruning, other silvicultural treatments, etc.) (e.g. Sutton and Crowe, 1975; Montagu et al., 2003; Forrester et al., 2010; Forrester, 2013). The interaction of all these factors makes studying the effects of pruning intervention on tree growth rather complicated. Together with this, contradictory results are reported in the literature (see review by Forrester et al., 2010). As an example, some studies have shown a positive effect of pruning on tree growth (e.g. Davel and Sepúlveda, 2000; Schoelzke, 2003; Muñoz et al., 2005; Cyr, 2006), while others have observed negative effects (e.g. Sutton and Crowe, 1975; Långström and Hellqvist, 1991; Neilsen and Pinkard, 2003; Nutto and Touza, 2004; Amateis and Burkhart, 2010, 2011), and some even report no effects, when pruning intervention was not severe (e.g. Neilsen and Pinkard, 2003; Muñoz et al., 2005; Mäkinen et al., 2014). The variability of the factors involved in such studies (e.g. species, sites, etc.) means that there is no general optimal silviculture regime (Forrester et al., 2010), and it is thus crucial to understand the responses of trees, and the mechanisms responsible for driving growth responses (e.g. Forrester et al., 2010; Forrester, 2013), in order to design the most effective forest management strategies possible for the production of increased volumes of higher quality wood.

Despite the importance of examining the effect of pruning on tree growth little is actually know about this effect in the main timber conifer species in Europe (Courdier et al., 2002; Hevia, 2013; Moreno-Fernández et al., 2014). Maritime and radiata pines, two of the most important wood producing species in the Atlantic area, are commonly managed under the same silvicultural schedule, and as far as we are aware there are little or no comparative studies of their responses to pruning. However, understanding the pruning responses of the two species would throw light on the appropriateness of taking a common approach to their management and whether or not each species has specific and different requirements. In fact, at a broader level, there is a lack of information as regards how to achieve optimal benefits from pruning for these species in the Atlantic region to enable the definition of sustainable forest management strategies to improve wood quality and thus obtain higher value products. In this sense, and according to Forrester et al. (2012a), the true effect of silviculture should be estimated at the individual-tree level, which is of greater importance still with respect to FCTs and key to the optimisation of financial investment and returns. The purpose of this work is therefore to study the effect of different pruning intensities on diameter and height growth, productivity and dominance of individual trees in intensively managed young *Pinus pinaster* and *Pinus radiata* stands in the Atlantic area. We hypothesised that: (*i*) tree growth, productivity and dominance would decrease after severe pruning and (*ii*) there are species-specific growth responses to pruning across sites.

2. Material and methods

2.1. Study area

The study was carried out in a network of permanent silviculture research plots established in winter 2005–2006 in eight young stands, four of *P. pinaster* (7–11 years) and four of *P. radiata* (7–10 years), each measuring approximately 1 ha, in north-western Spain (Atlantic area) (Hevia, 2013). The characteristics of climate, soil and physiographic conditions for each of the study sites are detailed in Table 1.

2.2. Experimental design and treatments

Each of the eight research plots was divided into 64 pruning subplots, each of which was then randomly allocated to one of three pruning treatments (see Fig. 1) which were conducted in winter 2005–2006 just after the establishment of the experiments. Treatment comprised a "variable lift pruning" in all trees at one of three pruning intensities: *unpruned control* – C – (none of the live crown was removed but to facilitate fieldwork the dead branches from the lower crown were removed), *light pruning* – LP – (the percentage of live crown removed ranged from 12% to 15%), and *heavy pruning* – HP – (29–37% of live crown removed). The experimental design was such that double the number of plots were assigned to the *light pruning* treatment than to the *heavy* or *unpruned* treatment in preparation for a second phase where half the lightly pruned trees were to be subjected to one pruning intensity and the other half to a different intensity (Fig. 1).

Pruning was done using a special forestry pruning kit composed of shears especially designed for *P. radiata* (Prun-off loppers), electronic pruning shears (Electrocoup) and forestry ladders. All branches were cut close to the stem, taking care to avoid damaging

Table 1
Location, temperature data, soil conditions and physiographic characteristics of the study sites.

Experiment	Location	Climate[a]			Soil conditions			Physiographic[b]		
		Precipitation (mm)	Temperature (°C)	Evapotranspiration (mm)	Soil texture	pH	Soil depth (cm)	Elevation (m)	Aspect	Slope (%)
Pinus pinaster										
Valsera	43°33′26″N, 6°12′56″W	930	14	681	Sandy clay loam	4.20	101.25	101	O-NO	15
Barcia	43°31′02″N, 6°28′49″W	1475	12	644	Sandy clay loam	3.46	28.75	382	NE	38
Monteagudo	43°31′26″N, 6°6′19″W	1156	14	721	Sandy clay loam	3.75	33.75	248	SO	28
Uria	43°4′21″N, 6°51′55″W	1226	13	626	Sandy clay loam	4.40	23.75	536	SO-NO	22
Pinus radiata										
La Campa	43°24′57″N, 5°28′14″W	2164	11	655	Clay loam	5.08	32.50	529	E	22
Cabada	43°25′14″N, 6°33′15″W	1590	11	614	Sandy loam	3.67	33.67	548	S	28
Santa Catalina	43°31′01″N, 6°6′39″W	1274	13	731	Sandy Clay loam	4.07	27.5	324	E-NE	25
Fabal	43°12′05″N, 6°53′22″W	1272	13	626	Sandy clay loam	4.49	29.23	591	S-SE	34

[a] Annual mean values of climate data estimated using the methodology defined by Carballeira et al. (1983) and Martínez-Cortizas et al. (1997) within the climatic sector defined by Rodríguez-Guitián (2004).
[b] Physiographic values based on the Digital Elevation Model obtained using ArcGIS v9.1 (ESRI, 2006).