

Can native tree species regenerate in *Pinus radiata* plantations in Chile? Evidence from field and laboratory experiments

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Abstract

As matrices form the major component of landscapes mosaics, assessing regeneration suitability for native species within matrices is relevant for conservation and mandatory if native remnant patches are scarce, small and contain endemic species. In central Chile, we compared in two consecutive years (2001/2002–2002/2003), seed germination and seedling establishment of *Cryptocarya alba* (Mol.) Looser the most dominant specie in seedling stage, in both the native Coastal Maulino Forest and in the matrix composed of *Pinus radiata* D. Don plantations. We also tested in the laboratory, whether watering with leachate of soil extract of *P. radiata* plantations had allelopathic effects on *C. alba* seed germination, seedling growth and survival compared to leachate from native forests and to pure water. We expected a reduction in germination and seedling establishment in *P. radiata* plantations, due to documented allelopathic inhibition. We only found differences in germination probabilities during the 2001/2002 period, whereas seedling establishment did not vary. In addition, in the laboratory we found that watering with leachate from *P. radiata* plantations produced an equivalent reduction in *C. alba* seed germination when compared with watering with native forest litter leachate. We did not find allelopathic effects on seedling survival nor growth. *P. radiata* plantations might be a suitable habitat where, in some years, *C. alba* can regenerate. *P. radiata* plantations should be incorporated in the conservation scenario of the Maulino Forest plant species, introducing new procedures to reduce the impact of forest replacement on native plant dynamics.

Keywords: Chile; Seed germination; Seedling establishment; Seedling growth; Seedling survival; Allelopathy; Leachate; *Cryptocarya alba*

1. Introduction

Deforestation and fragmentation of native forests is an anthropogenic large-scale disturbance which is reducing biodiversity worldwide (Saunders et al., 1991; Turner, 1996; Whitmore, 1997). In a fragmented landscape, native species become confined inside remnant fragments, thus generating a metapopulation structure (Bender and Fahrig, 2005). It is assumed that only fragments contain the conditions and resources necessary for the regeneration of native species; the matrix at best may be used by individuals to cross from one patch to another (Bender and Fahrig, 2005). However, in plants, there exists evidence that the matrix may be sufficiently heterogeneous to contain conditions for the survival and

reproduction of native species, thus, departing from the classic metapopulation model (Murphy and Lovett-Doust, 2004). Examining the conditions under which the matrix may allow the persistence of native species is becoming a fruitful avenue of research (Murphy and Lovett-Doust, 2004).

The Monterrey pine, *Pinus radiata* (D. Don) (Pinaceae), is an exotic tree species in Chile, originating from California. Currently, it is the base of the forestry industry in different countries of the southern hemisphere (FAO, 1998). In surface area, the Chilean *P. radiata* plantations represent more than one third of the total planted in the world, reaching 1,694,194 ha forming the basis of the industrial forestry in Chile (INFOR, 1999; Toro and Gessel, 1999; FAO, 1998). In the Coastal Range of the Maule and the extreme north of the Bio Bio Regions (35°55'–36°20') exists the Coastal Maulino Forest a unique and endangered Chilean forest-type (San Martín and Donoso, 1996). This forest has a long history of human use and disturbance, which has concomitantly produced a drastic reduction of the extent of original native forest and dramatic

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fragmentation (San Martín and Donoso, 1996; Bustamante and Castor, 1998; Estades and Temple, 1999). Currently, the landscape is a mosaic of remnant forest fragments immersed in a matrix of *P. radiata* plantations (Bustamante and Castor, 1998). In fact, about 76 % of the original area covered by the Coastal Maulino Forest has been replaced by *P. radiata* plantations (Estades and Temple, 1999).

In the life-cycle of plants, seed germination and seedling establishment are critical stages and plant regeneration is strongly dependent on the abiotic environment (Harper, 1977; Grubb, 1977). Thus, the relation between the anthropogenic Coastal Maulino landscape and the regeneration performance of native plants comprise crucial information necessary for understanding native plant dynamics and the establishment of effective conservation actions. *Cryptocarya alba* (Mol.) Looser (Lauraceae) is one of the most dominant tree species in Maulino Coastal Forest: second during the adult stage but the first during the seedling and sapling stages (Bustamante et al., 2005; Guerrero, 2005). Although some individuals of *C. alba* can be observed growing in *P. radiata* plantations, the regeneration dynamics or limitations in the matrix has not been studied. In fact, Souto et al. (2001) revealed that the litter of *P. radiata* negatively affects seed germination and seedling growth of plants such as *Lactuca sativa* L., *Dactylis glomerata* L. and *Trifolium repens* L. The present study attempts to assess whether the germination and establishment of *C. alba* are constrained in *P. radiata* plantations compared to native forest fragments. Also, through a laboratory experiment, this study evaluated if some detrimental (allelopathic) effects of the soil of *P. radiata* plantations exist on seed germination, seedling survival and growth of *C. alba*.

2. Materials and methods

2.1. Study area

The study was conducted at both Reserva Nacional Los Queules (RNLQ), which, added to privately-owned native forests, forms the largest existing tract of Coastal Maulino Forest (over 600 ha), and two surrounding *P. radiata* plantations (35°58'S–72°42'W). The Reserve is located in the Coastal Range of central Chile, with a humid Mediterranean climate with oceanic influence (Luebert and Plissock, 2006). Precipitation is seasonal and is concentrated during winter and spring, with annual precipitation varying between 1113 and 1327 mm (Luebert and Plissock, 2006). Soils have a meta-morphic origin, characterized by high weathering and low fertility (San Martín and Donoso, 1996). The Coastal Range, including the Coastal Maulino Forest, is the most critical area for biodiversity conservation in the temperate rainforests of southern South America, because of the high species richness, concentration of narrow endemics, and the extent of direct or indirect human threat (Smith-Ramírez, 2004). The major threat to Coastal Maulino Forest is deforestation for industrial forestry purposes (mainly for *P. radiata* plantations), and this area experiences on the highest deforestation rates (8.15% per year),

producing a systematic fragmentation process (Bustamante and Castor, 1998).

The Coastal Maulino Forest is composed of 12 tree species with an approximate canopy height of 20 m. The floristic composition has a mixture of different biogeographic origins: (i) elements of matorral and sclerophyllous forest, such as *C. alba* (Mol.) Looser (Lauraceae), *Persea lingue* (R. et P.) Nees ex Kopp (Lauraceae) and *Peumus boldus* Mol. (Monimiaceae); (ii) Valdivian elements such as *Aextoxicon punctatum* R. et P. (Aextoxicaceae) and *Gevuina avellana* Mol. (Proteaceae); other elements are endemic to this forest-type such as the endangered trees species *Gomortega keule* (Mol.) Baillon (Gomortegaceae), *Nothofagus alessandrii* Esp. (Nothofagaceae) and *Pitavia punctata* Mol. (Rutaceae) (Benoit, 1989; San Martín and Donoso, 1996). The pine plantations are composed of *P. radiata*, while the understorey is mainly composed of *Aristotelia chilensis* (Mol.) Stuntz (Elaeocarpaceae), the exotic *Rubus ulmifolius* Schott (Rosaceae) and *Teline monspessulana* (L.) K. Koch (Fabaceae); occasionally native trees such as *C. alba* and *P. lingue* also grow there.

2.2. The species

Cryptocarya alba is an endemic, evergreen and shade-tolerant tree that lives in mesic habitats of central Chile. It is considered threatened in some regions of Chile, mainly due to overexploitation and habitat destruction (Benoit, 1989). Flowering of *C. alba* occurs during spring and summer (from October to January) (Hoffmann, 1997). Fruits are red, one-seeded drupes that ripen from March to July and are dispersed by birds and foxes; seed germination and seedling establishment occur from September to December (Bustamante and Simonetti, 2001). *C. alba* has many traditional uses, for example its leaves have medicinal properties, its fruits are used for food, and their wood is used for charcoal and furniture making (Hoffmann, 1997).

This species is characteristic of sclerophyllous forest (Armesto and Martínez, 1978), however, it is also dominant in the Coastal Maulino Forest and common within the northern evergreen temperate forests (32–41°S). *C. alba* is a canopy tree reaching 20 m in height.

2.3. Germination and establishment in field

Seeds of *C. alba* used in the germination experiments were obtained from the Centro de Semillas, Facultad de Ciencias Forestales, Universidad de Chile. We conducted experiments during two consecutive periods from June 2001 (at the beginning of winter) to March 2002 (at the end of summer), and subsequently from June 2002 to March 2003. For each period, we used 28 experimental units (replicates), randomly distributed in the interior of the native forest and 14 in each of the two *P. radiata* plantations. Thus, we obtained a total sample size of 56 replicates. A spatial Mantel test allowed us to conclude that there is no spatial dependence among replicates either at *P. radiata* plantations ($r = 0.04$; $p > 0.05$) and at the Reserve ($r = 0.11$; $p > 0.05$). Each experimental unit comprised 10 seeds sown on

the surface of the soil and covered with leaf litter, inside buried transparent circular plastics cups (10 cm diameter) with holes in the bottom, to allow water drainage. This seed density is equivalent to the natural *C. alba* seed densities found in some years in the field (Celis-Diez et al., 2004). Seed consumers (birds, foxes and rodents) were excluded with a wire mesh. Experimental units were located exactly at the same sites during two consecutive experimental periods, and seed germination was monitored every two months. A seed was considered as germinated when the cotyledons were visible without removing the litter. Germination proportion $P(G)$ was defined as the total number of germinated seeds, divided by the total number of seeds initially disposed in plastic cup (i.e. 10 seeds). Also seedling establishment $P(E)$ was defined as the total number of seedling that survived by March 2003, divided by the total number of germinated seeds. Finally, to verify the recruitment proportion $P(R)$ we multiplied the proportion of germinated seeds with the proportion of established seedlings.

2.4. Laboratory assay

During July 2002 we collected seeds of *C. alba* from a population located at La Campana National Park, an area with no *P. radiata* plantations in the vicinity. Seeds were collected from more than 15 individuals and then they were pooled to homogenize individual variations. This assay was carried under laboratory conditions but under natural sunlight. Seeds were individually sown in pots in August into a substrate composed of a 50:50 mixture of commercial compost (i.e. organic matter) and sterile sand. In order to test the presence of allelopathic effects of *P. radiata* plantation or native forest litter and soil, we sowed 112 seeds of *C. alba* in each of the following three treatments: (i) watered with leachate extract from litter and soil originating from *P. radiata* plantations, (ii) watered with leachate extract of litter and soil from the native forest of the RNLQ, and (iii) watered with pure water.

The leachate extracts were prepared using litter samples and soil collected randomly in the field at RNLQ for the native forest condition and from the two surrounding *P. radiata* plantations (near the experimental unit assay). Litter samplings were made every month. The leached extract was obtained following similar procedures to that used in other studies (Al-Humaid and Warrag, 1998; Cavieres et al., 2007). Briefly, 100 g of leaf litter were gently crushed and mixed with 1000 ml of water, and then all extracts (including the pure water control) were stored at 6 °C for 3 days to allow chemical compounds to be released into water. Finally, we percolated liquids with a strainer to separate them from the litter and irrigated seeds with extracts *ad libitum* two times per week, seed germination was monitored two times per week with vertical height growth of seedlings assessed once a week with a digital caliper to the nearest 0.1 mm.

2.5. Statistical analysis

In the field assay, we evaluated seed germination $P(G)$ and seedling establishment $P(E)$ using repeated measures ANOVA,

with habitat as a fixed factor and year as a repeated measure. In the laboratory assay, we assessed seed germination, assigning a 1 if a seed germinated and 0 if it did not. To evaluate the effect of the different watering treatments (categorical factors) on both seed germination and seedling survival we used a logistic regression analysis (see Visual GLIM procedure in StatSoft, Inc. 2001. STATISTICA version 6, <http://www.statsoft.com>). This procedure allowed us to consider individual seeds and seedlings as independent replicates. In the seed germination analysis, the number of replicates was 112 (the total number of seed initially sowed). For the seedling establishment analysis we considered the proportion between the number of germinated seeds and the number of seedlings that survived to the end of the experiment. In the seedling height analysis (growth) we considered the seedlings that survived at the end of the experiment, corresponding to 5, 4 and 19 ($n = 28$) for native forest, *P. radiata* plantations and water treatments, respectively. To assess seedling height we used a repeated measure ANOVA using watering treatments as a fixed factor and time as a repeated measure. The proportions of germination and establishment were arcsine transformed and height data were $\log(x + 1)$ transformed to fit ANOVA assumptions (Zar, 1999).

3. Results

3.1. Field experiment

We found a significant reduction in seed germination ($P(G)$) of *C. alba* within *P. radiata* plantations relative to native forest ($F = 31.23, p < 0.0001$) (Table 1). We also found that $P(G)$ was significantly higher during the period 2001–2002 than the period 2002–2003 ($F = 14.45, p = 0.0004$; Table 1). We observed a significant interaction between habitat and years ($F = 14.59, p = 0.0003$), resulting from the differences in germination between habitats being greater in 2001–2002 than in 2002–2003 (Table 1).

We did not detect significant differences in seedling establishment ($P(E)$) between habitats ($F = 0.39, p = 0.53$), but we found that $P(E)$ was significantly higher during the period 2002–2003 ($F = 18.59, p < 0.0001$) (Table 1). In

Table 1

Germination, establishment and recruitment proportion of *Cryptocarya alba* in the Coastal Maulino Forest and *Pinus radiata* plantations during two consecutive years

	Period	
	2001–2002 (mean ± S.E.)	2002–2003 (mean ± S.E.)
<i>P(G)</i> = seed germination probability		
Native forest	0.59 ± 0.06	0.22 ± 0.04
<i>P. radiata</i> plantations	0.19 ± 0.06	0.17 ± 0.04
<i>P(E)</i> = seedling establishment probability		
Native forest	0.01 ± 0.01	0.26 ± 0.08
<i>P. radiata</i> plantations	0.01 ± 0.01	0.20 ± 0.08
Recruitment probability $P(R) = P(G) \times P(E)$		
Native forest	0.00 ± 0.01	0.06 ± 0.02
<i>P. radiata</i> plantations	0.00 ± 0.01	0.05 ± 0.03

Table 2

Percentage of germinated seeds and survival seedlings of *Cryptocarya alba* with three different watering treatments

Leachate extract	Seed germination (%)	Survival seedlings (%)
Native forest	13.4	33.3
<i>Pinus radiata</i> plantations	9.8	36.4
Water	33.0	51.4

addition, there was no interaction between habitat and years ($F = 0.31$, $p = 0.58$). In terms of recruitment proportion ($P(R)$), we observed that *C. alba* displayed low values with minimal variation between habitat and years (Table 1).

3.2. Laboratory experiments

We found that leachate extracts significantly reduced seed germination compared to the pure water treatment ($\chi^2 = 22.04$, $p < 0.0001$) (Table 2), with the *P. radiata* plantation and native forest leachates having similar effects (Table 2). In addition, we did not detect significant variation in either seedling survival ($\chi^2 = 1.78$, $p = 0.41$) (Table 2) or height among treatments ($F = 1.16$, $p = 0.33$) (Fig. 1).

4. Discussion

The majority of ecological studies within *P. radiata* plantations have evaluated ecosystem function (e.g. Arneth et al., 1999; Lusk et al., 2001; Halliday et al., 2003; Bustamante-Sánchez et al., 2004). Other studies have illustrated the potential of *P. radiata* as an invasive species (Richardson et al., 1994; Rejmanek and Richardson, 1996; Bustamante and Simonetti, 2005). However, studies addressing the role of *P. radiata* plantations as habitat reservoirs for native tree species have received much less attention. Our results demonstrate the existence of subtle effects of *P. radiata* plantations on the regeneration of *C. alba*: (i) seed germination but not seedling survival was negatively affected by *P. radiata* plantations, (ii) the intensity of these detrimental effects varied between years and (iii) allelopathy may not explain these detrimental effects on seed germination.

The fact that seed germination and seedling establishment differed in two consecutive years suggests that in some years *P. radiata* plantations may be a lower quality habitat for germination than native forests, while in other years they may be equivalent. These contrasting effects on germination between vegetation types may be related to differences in vegetation structure (i.e. canopy and understory cover) which have been documented to vary between years in *P. radiata* plantations (Guerrero, 2005). Also, *P. radiata* plantations are more open habitats and drier than the old-growth Maulino Forest (Henríquez, 2002; Guerrero, 2005; Vergara and Simonetti, 2006). However, the relationship between vegetation structure and soil moisture is not completely understood and may vary spatially and temporally due to forest dynamics, human perturbations and climate oscillation (Clark et al., 1996; Breshears et al., 1997; Laurance et al., 1998;

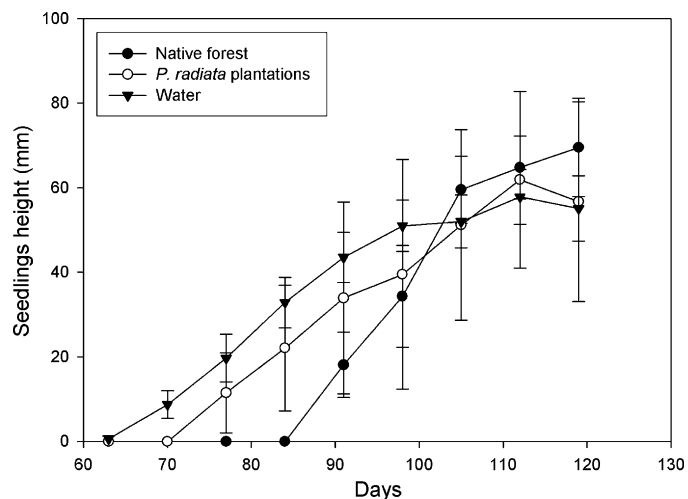


Fig. 1. Seedling growth of *Cryptocarya alba* measured as vertical height with three different watering treatments: leachate of litter and soil originating from native forest, *P. radiata* plantations and water. Vertical lines show mean \pm S.E.

Sterck et al., 1999; Clark and Clark, 2000; Daws et al., 2002a,b).

Our laboratory experiment showed a reduction in seed germination of *C. alba* seeds watered with an extract of leachate from *P. radiata* plantations compared to pure water, which suggests allelopathic effects of *P. radiata* plantation litter (Souto et al., 2001). However this negative effect is not severe and is equivalent to that detected for the native forest litter. The presence of allelopathic biochemicals in some native species, as in *Kageneckia angustifolia*, may explain the equivalent inhibitory results on seed germination of native forest and *P. radiata* plantation litter extract (Fuentes et al., 1987; Mongelli et al., 1997; Cavieres et al., 2007). However, we did not detect effects of *P. radiata* plantation or native forest litter extract on the survival and growth of *C. alba* seedlings, suggesting that germination is more sensitive than later stages to allelopathic inhibitors.

The Coastal Maulino Forest will remain fragmented and mainly surrounded by *P. radiata* plantations in the long term. Our results showed that *C. alba*, one of the most representative species in the Coastal Maulino Forest can regenerate in *P. radiata* plantations. We propose a parallel conservation strategy for the protection of the few native forest patches and the cessation of native forest replacement. Our data suggest that, at least in some years, native tree species may be able to regenerate in *P. radiata* plantations. Therefore, we recommend modifying the forestry management of native understory allowing native cover in selected points within *P. radiata* plantations, particularly of endemic and threatened species, providing more regeneration area than in the small protected areas. Although this management strategy will cause a slight reduction in the total planted area, it might also produce beneficial effects for the forestry industry. Firstly, this conservation plan is important for the approval of green certification relevant for cellulose and wood exportation. Secondly, organic matter levels and soil water content increase, which in turn, produce higher rates of growth in forestry plantations, thus increasing nutrient cycling and reducing fire

risk (Bonilla et al., 2002; Flores and Allen, 2004). Taking into account biodiversity aspects into forestry management represent an opportunity for the enhancement of conservation success, particularly because *P. radiata* represent the dominant landscape component and this study reinforced the idea that native species utilize *P. radiata* plantations (Estades and Temple, 1999; Acosta-Jamett and Simonetti, 2004; Vergara and Simonetti, 2006).

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