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The Use of Mulch and Shading Improves the Survival of Sclerophyllous Species Established in Island Plots in Central Chile

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Abstract: Climate change is threatening the restoration efforts in Mediterranean ecosystems, and there is still little knowledge about the responses of some sclerophyllous species to plant management techniques. This study assessed the effects of the planting date, use of mulch, and controlling light levels on the early survival and growth of sclerophyllous species established in island plots. A factorial design was installed in the Metropolitan Region of central Chile, with a treatment combination that included three planting dates (January: midsummer, April: autumn, and June: winter), three light levels (full sun exposed (T0), shaded at 35% (T35), and shaded at 70% (T70)), and two mulch levels (no mulch versus mulch application). Additionally, we tested the species effects within the island plot. We measured survival, as well as plant diameter and height increments, 1 year after establishment. Each island plot contained three seedlings of *Acacia caven* Mol., two of *Quillaja saponaria* Mol., two of *Maytenus boaria* Mol., one of *Schinus polygamus* (Cav.) Cabrera, and one of *Cryptocarya alba* (Mol.) Losser. We found a significant main effect for all the factors assessed. Despite the high mortality in the trial, survival was increased around fourfold by planting in winter, using mulch, or using either of the shading levels. At the species level, average survival ranged from 7% for *C. alba* to 27% for *S. polygamous*. To increase plant survival in the restoration of this ecosystem, it is necessary to intensify the management techniques and the use of these types of eco-technologies; if not, the restoration may fail.

Keywords: eco-technology; forest restoration; Mediterranean-type climate

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1. Introduction

The Mediterranean-type climate zone of central Chile is mainly dominated by the Savannah-like 'espinal' ecosystems and sclerophyllous forests with a high level of species endemism. This area has been historically degraded by anthropogenic activities, including agriculture, forestry, grazing, mining, urban development, and fires [1–6]. Currently, there are concerns about the ecological restoration of this type of Mediterranean ecosystems, especially regarding the lower water availability and higher temperatures imposed by climate change, which decrease seedling recruitment, establishment, and survival [7–10]. Moreover, this area has experienced a succession of dry years since 2010, the so-called "mega drought" [11], which highlights the necessity to identify successful establishment techniques that assure seedling survival and growth of tree species in this ecosystem.

Planting tree seedlings and direct seeding are two active restoration methods used in native species in these ecosystems [12], where the former has shown better survival [13]. In Chile, planting tree seedlings has been traditionally carried out at regular spacing and using one or a few more species, with still low survival rates after outplanting [14]. Otherwise, there is still scarce information about other restoration strategies that might mimic the natural succession processes, such as the use of heterogeneous group planting (i.e., applied nucleation or tree island planting) [15,16]. This approach might be more effective for forest restoration on small and larger scales and have positive effects, speeding up the species succession [17,18]. Nucleation by tree island planting corresponds to a nature-based restoration technique that considers both diversity of plant species and functional groups [19,20], which may reduce planting and maintenance costs [21].

Securing seedling survival during the first growing season is critical in restoring Mediterranean environments, primarily because of the biotic stresses that plants face following transplant [22]. In Chile, some studies support the use of eco-technologies (e.g., tree shelters, fertilizers, mulching, and hydrogel) and proper establishment design in planting seedlings to alleviate those stresses and increase plant survival and growth [18,23]. Tree shelters were initially designed to protect plants from animal browsing, but several studies have shown their positive effect on survival in the Mediterranean and semiarid zones by reducing the light and thermal stress at outplanting (i.e., shading effect of shelters) [24–27]. However, the effect of shading through shelters and light transmissivity is species-specific and determined by site factors such as temperature and water stress experienced by plants [28]. On the other hand, water conservation in the soils may be achieved with some type of mulching, with their permeability negatively related to their effectiveness [29]. This has increased the production of synthetic biodegradable mulch, which has been less explored in forest restoration. Mulching influences tree growth by decreasing soil evaporation, regulating the soil temperature, and preserving soil fertility [30–33], but other studies have shown low or no response [34,35].

Central Chile is characterized by severe summer droughts, and water is the main limiting factor of forest productivity. For this reason, most forest plantations are established in winter and early spring when soils have sufficient moisture. However, there is an increasing need to extend the planting period to the summer months, especially in forest reclamation on mine lands. Although much of the semiarid sclerophyllous forests are dominated by drought-tolerant species, the mega drought has affected large areas of the native forests and expressed as foliage desiccation (i.e., browning) [36]. Consequently, this is affecting several of the current restoration efforts in the country. In this study, we approach the restoration of sclerophyllous species using the island planting technique on five dominant species of the Chilean sclerophyllous forest (i.e., *A. caven*, *Q. saponaria*, *M. boaria*, *S. polygamus*, and *C. alba*) and applying ecotechnologies at the island plot level. The experimental zone corresponded to a dry area beside a mine tailing. The objective of this study was to assess the effect of plantation date, mulching, and shading on the early growth and survival of the plant species established in island plots.

2. Materials and Methods

2.1. Study Site

In winter 2018, a trial was planted in a site located in the Metropolitan Region, central Chile (33°07′03.98″ S, 70°42′49.8″ W; altitude 684 m.a.s.l.). The site has a temperate mesothermal climate, Mediterranean stenothermal semiarid inland, with a mean annual temperature of 14.5 °C, and minimum and maximum monthly mean temperatures of 3.8 °C in June and 30.4 °C in January, respectively [37]. The annual precipitation is 371 mm and concentrates mainly between May and September [37], whereas winds predominate all year. Figure 1 summarizes the climatic conditions for the experimental period. The soil belongs to Rungue soil series (Vertic Haploxerolls, Mollisols), characterized by high slopes and shallow stony soils. The surrounding area is used for mining activity, and the trial was established beside a mine tailing. The dominant vegetation is sclerophyllous forest, covering approximately 67% of the area, whereas the rest is covered by exotic plant species (33%).

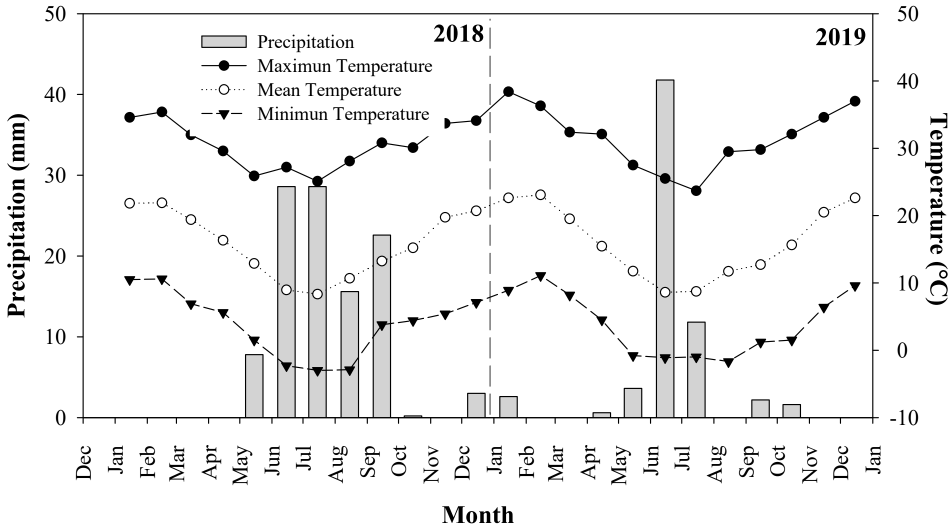

Figure 1. Monthly mean, minimum, and maximum temperatures (lines) and precipitation (bars) during the study period (2018–2019) (Source: Estación Peldehue, www.agromet.cl, accessed on 1 October 2022).

2.2. Experiment Installation

The plant material used in this study was provided by the Antumapu nursery of the Universidad de Chile, which originated from seeds collected near the planting site. This corresponded to 2 year old seedlings from five sclerophyllous species exhibiting different drought resistance. From the more to the less adapted to xeric sites, the species were *Schinus polygamus* (Cav.), *Acacia caven* Mol., *Quillaja saponaria* Mol., *Maytenus boaria* Mol., and *Cryptocarya alba* (Mol.) Losser. The trial was a factorial design with three blocks. Overall, the study site was mostly homogeneous, and blocks were defined only on the basis of small differences in slope and aspect. The treatment combinations were randomized to each of the blocks and included three planting dates in 2018 (January: midsummer, April: autumn, and June: winter), three light levels (full sun exposed (T0), shaded at 35% (T35), and shaded at 70% (T70)), and two mulch levels (no mulch versus mulch application). Shading and mulching levels correspond to current operational practices used in restoration programs in this ecosystem, addressed for shade-tolerant and intolerant species. The experimental plot (from now on referred to as island plot) included nine seedlings of the five species (*A. caven* (three seedlings), *Q. saponaria* (two), *M. boaria* (two), *S. polygamus* (one), and *C. alba* (one)). The seedling number per species represents the abundance in the surrounding area. Seedlings were established on a planting hole of 50 cm depth and in an arrangement of three rows and three columns at a spacing 0.3×0.3 m, surrounded by 16 buffer plants of *S. polygamous*. The spacing was selected to accelerate the plant interactions. Seedlings from different species were randomized within each island plot. Each of the 54 island plots was fenced (1 m height) to avoid animal damage by herbivory. The plot fence had a cuboid form and was built using metal stakes, while all the sides were covered by a chicken wire mesh. Then, a polyethylene mesh cover differing in transparency (Rachel®, Santiago, Chile) was installed over the cuboid to achieve the desired shading level. We used a LP-80 Ceptometer (Meter Environment, Pullman, WA, USA) to verify the light levels in the shading treatments. The mulch consisted of a biodegradable geomembrane GeoGreen C2 (GeoSistemas®, Santiago, Chile) composed of coconut fiber and polypropylene mesh. The geomembrane was installed to cover all the plot surface. After planting, each seedling was watered with 2.5 L of water. Afterward, the watering regime included 3 L of water every other week from October to March (growing season) and then reduced to 2 L of water before the first precipitation.

2.3. Measurements

Measurements of plant height (H, cm) and collar diameter to the base (D, mm) were recorded immediately after planting and then in June 2019 using metric tape and a digital caliper, respectively. With this information, we derived increments in D (IncD) and H (IncH). Additionally, with the inventory data we measured survival as a categorical variable (1 = alive, 0 = dead).

2.4. Statistical Analysis

To characterize the size of the planting material at establishment, we ran an analysis of variance (ANOVA) that included the effects of species, planting date, and their interaction. Growth increments were analyzed with a model that included the effect of the planting date, light level, use of mulch, and their interaction (tested against the plot-based error), plus the effect of species (tested against the pooled error). We constrained the model by discarding the interactions of species with other factors because of the low number of replicates, as well as the high mortality observed, which complicated the model convergence. Survival was analyzed at the plot level (binomial distribution) using generalized linear models (*glm*) with the log-link function, including the described factors, except the factor species. Although the number of seedlings per species was unbalanced, we ran a separate model for survival with only the species as the main factor. We checked the assumptions for data distribution and variance stability graphically. Post hoc mean comparisons were made using Šidák's method. All statistical analyses were performed using the Asreml package (VSNi, Hemel Hempstead, UK) for R software (R Core Team, r-proyect.com, accessed on 10 July 2022), using a significance level of 0.05.

3. Results

At the planting date, the means per species for diameter ranged from 3.1 mm to 4.8 mm and for height from 15.1 cm to 27.1 cm (Table 1). The preliminary analysis of variance on initial dimensions showed only a main effect of species D and H (Table 1, $p < 0.0001$). *C. alba* and *A. caven* had the highest D and H, respectively. Initial dimensions were more heterogeneous for H than D, with *A. caven* and *C. alba* being the species with higher (38.1%) and lower (20.8%) coefficients of variation, respectively.

Table 1. Number of trees, mean and coefficient of variation (CV) for initial diameter (D) and height (H) at the planting date per specie. Ca: *C. alba*, Mb: *M. boaria*, Qs: *Q. saponaria*, Ac: *A. caven*, Sp: *S. polygamous*. *p*-Values are from the analysis of variance on D and H. Different letters indicate significant differences according to Šidák's test.

	N	D		H	
		Mean (mm)	**CV (%)**	**Mean (cm)**	**CV (%)**
Ca	54	4.8 a	18.2	15.1 d	20.8
Mb	108	3.1 c	20.8	23.1 b	25.4
Qs	108	3.9 b	16.3	19.5 c	23.7
Ac	162	3.2 c	18.1	27.1 a	38.1
Sp	54	3.8 b	13.1	23.6 ab	32.5
January	162	3.4 a	24.8	24.2 a	42.6
April	162	3.6 a	25.7	21.2 a	30.8
June	162	3.6 a	21.5	22.8 a	32.5
ANOVA					
Date (PD)		0.1501		0.2823	
Species (Sp)		<0.0001		<0.0001	
PD × Sp		0.4881		0.2538	

There was high plant mortality at the island plot level; 56% of the island plots did not present any surviving seedlings, and only 15% overcame a survival level of over 50%. None of the interactions tested were significant for survival ($p > 0.05$) (Table 2). However, we found a significant main effect for all the factors in this trait (Table 2). Survival was increased around fourfold when (1) planted in June relative to the other months (Figure 2A), (2) applying mulch (Figure 2B), and (3) shading seedlings with either level (T35 or T70) (Figure 2C).

Table 2. *p*-Values from the analyses of variance for survival (Surv), increments in Height (IncH) and diameter (IncD). Significant values at 0.05 are shown in bold type.

Source of Variation	Surv	IncD	IncH
Date	**0.0003**	0.2515	0.3763
Mulch	**<0.0001**	0.1734	0.1329
Light	**0.0003**	0.8712	0.5673
Date × mulch	0.3106	0.8906	0.6049
Date × light	0.3012	0.4164	0.5966
Mulch × light	0.4402	0.56037	0.9335
Date × mulch × light	0.9991	0.9989	0.9986
Species		**0.0085**	**0.0123**

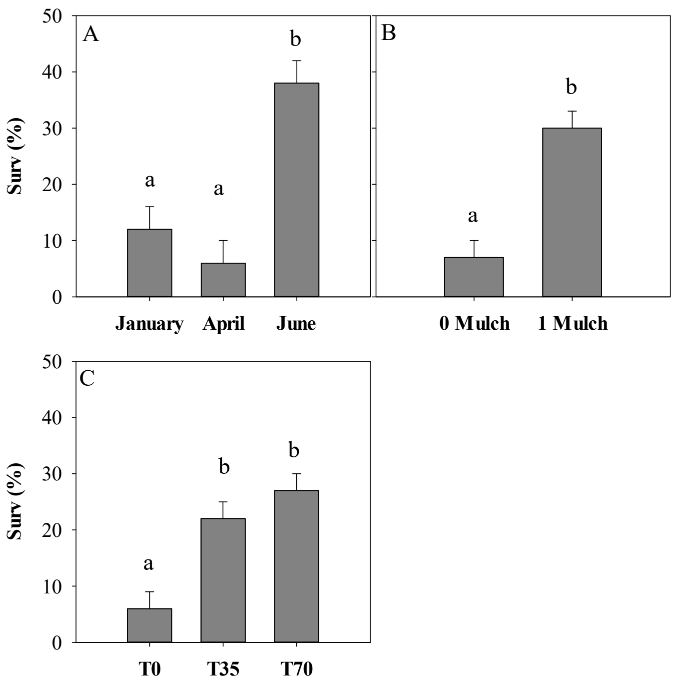

Figure 2. Mean survival per planting month (**A**), mull application (**B**), and shading level (**C**). 0 Mulch: no mulch application; 1 Mulch: mulch application. T0: full sun, T35: shade at 35%, T70: shade at 70%. Different letters indicate significant differences according to Šidák's test.

On the other hand, the island plots planted in June, with mulch and shading, averaged 82% survival. We found significant differences in survival among species ($p = 0.0005$), which were mainly explained by the high survival in *S. polygamous* (27%) relative to *C. alba* (7%), with the other species having intermediate values (Figure 3). One year after outplanting, there were significant differences among species for increments in diameter and height, but these traits were not affected by the other experimental factors (Table 2, Figure 4). *S. polygamous* had the highest survival but also the highest growth increments, whereas the lowest growth increments were observed in *Q. saponaria*.

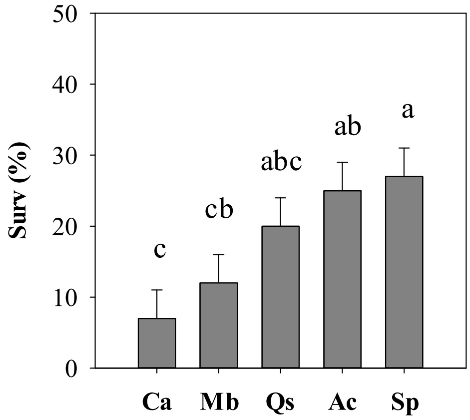

Figure 3. Mean survival per species. Ca: *C. alba*, Mb: *M. boaria*, Qs: *Q. saponaria*, Ac: *A. caven*, and Sp: *S. polygamous*. Different letters indicate significant differences according to Šidák's test.

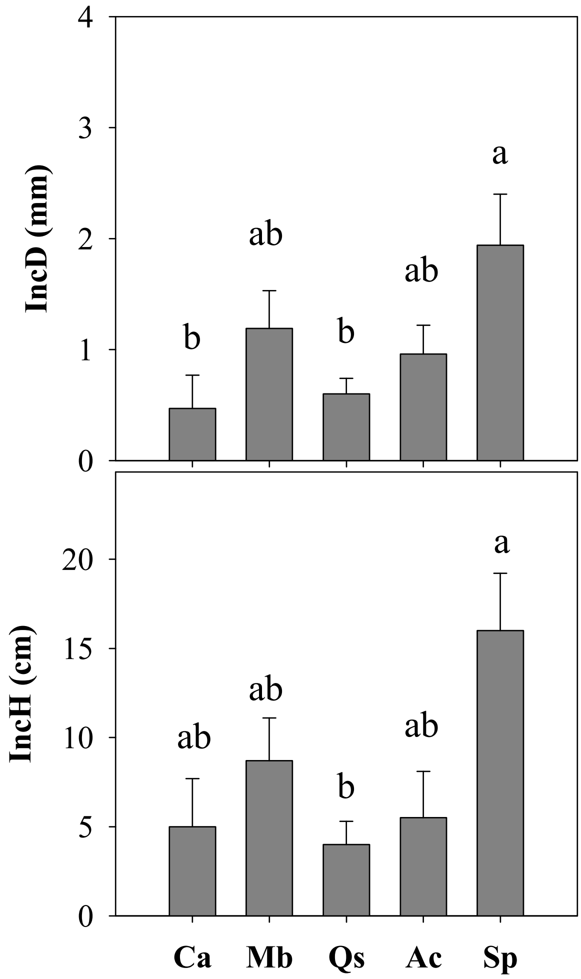

Figure 4. Mean increment for diameter (IncD) and height (IncH) per species (main effect). Ca: *C. alba*, Mb: *M. boaria*, Qs: *Q. saponaria*, Ac: *A. caven*, and Sp: *S. polygamous*. Different letters indicate significant differences according to Šidák's test.

4. Discussion

Restoring the degraded forest of the Mediterranean-type climate zone of Chile is becoming very challenging under the current climatic conditions. Most restoration efforts have been approached using active strategies [18], including eco-technologies and planting seedlings at a regular configuration. As an alternative, in our study, we tried to improve the seedling performance of sclerophyllous species, planting in island plots and applying some eco-technologies addressed to reduce the light levels and maintain soil moisture. Overall, we found an additive main effect of all the assessed factors on survival but not on plant growth. Survival was increased almost fourfold by planting in the winter months and using mulch and either of the shading levels. Island plots that included all these factors had an average survival of 82%. This survival was in the range found in a similar study with some of the same species and within the geographical area but using traditional planting instead of island plots [27]. Our results highlight the importance of intensifying the management techniques and the use of eco-technologies in the restoration programs; otherwise, the restoration may fail.

In this study, irrigation was performed every other week during the growing season and at a dose used in other restoration studies [38]. The establishment year of the experiment (2018) was particularly dry (Figure 1), with a rainfall of 106 mm (normal year, 371 mm). Therefore, it might be possible that the frequency and amount of water applied were insufficient to compensate for the losses by evapotranspiration, which would explain the overall high mortality in our trial. However, this watering regime is already prohibited at the operational scale because of the high costs. Thus, according to the results, the eco-technologies used in our study will not likely be able to compensate for the plant stress due to lower water supply, which needs further research. Overall, most of the mortality recorded in restoration programs is attributed to environmental and site conditions (i.e., drought and desiccation mainly) [13], which explains the better survival when outplanting in June (winter). On the contrary, a plantation established in January is directly exposed to the high temperatures of the summer months, while, in April, with no precipitation events in summer, the temperature is milder, but the soil moisture reaches a minimum.

The results also showed the effectiveness of shading on survival when protecting the entire island plot. Although we did not find a comparable study of shading plants at the plot level, the use of shelters has shown contrasting results in Mediterranean species (i.e., species-specific). Rojas-Arévalo et al. [27] found that shelters improved the survival of only the more drought-tolerant *Q. saponaria*, whereas the low survival of the drought-sensitive *M. boaria* was attributed to the insufficient water supply. Similarly, Puértolas et al. [24] found a significant interaction between the shelter treatment and species, but a positive effect on growth was observed only in the shade-tolerant *Quercus ilex* L., with negative effects on the shade-intolerant *Pinus halepensis* Mill. The latter species reduced its root growth, likely affecting the water uptake, which agrees with Coutand et al. [39], who stated that this effect might be due to a reduced mechanical stimulus by wind within the tube shelters, which reduced the need for anchorage and root penetration. Unfortunately, because of the complexity of the experimental design in our study and the low replication, we could not test such types of interactions. Otherwise, Padilla et al. [22] found no effect of using shelter in eight Mediterranean species grown in an arid environment, except one (*Q. coccifera*) whose survival was still low. In our study, shading favored the survival of the whole plot and, thus, the performance of all species.

Survival was also considerably improved by mulching. The only partial permeability of the mulch used in our study likely influenced this performance. The study by Ma et al. [29] suggests that the positive effect of mulching on soil water storage was related to mulch permeability. Mulching has been shown to influence tree growth by decreasing soil evaporation, regulating soil temperature, and preserving soil fertility [30–33]. This again emphasizes that most of the success in restoration in our study area depends primarily on water supply and its conservation within the soil.

None of the factors influenced plant growth, and growth increments were very low. We argued that plants in the experiment were highly stressed by water, and the carbon assimilated by photosynthesis was more invested in the belowground than aboveground. However, we observed some differences in survival and growth increments at the species level. There was low survival in the less drought-tolerant *C. alba* and *M. boaria*, as reported in other studies [38,40]. Contrarily, survival and growth were higher in the more drought-tolerant *S. polygamous*. This agrees with Becerra et al. [41], who found a lower response of *S. polygamous* relative to *M. boaria* to irrigation, which is related to the species drought tolerance. In our study, the seedlings were planted at a close spacing to assess some early potential interaction (e.g., facilitation) among the species that might improve the performance in the survival of the whole island plot. The species in the study represent the diversity of dominant species found in the Mediterranean-type climate zone of Chile, *C. alba* and *M. boaria* from sclerophyllous forest, *Q. saponaria* and *S. polygamous* from the matorral, and *A. caven* from the Espinal. A potential successional pathway is that the matorral triggers ecosystem processes (i.e., soil quality) that favor the recruiting of Espinal, followed by sclerophyllous forest [42]. We expected interaction among the species because, for instance, *A. caven* is a drought-tolerant legume whose higher growth in these conditions might nurse the more sensitive species such as *C. alba* and *M. boaria*. However, because of the low growth experienced by plants during this first growing period, we could not observe these types of facilitation interactions, which needs additional investigation. Despite the complexities of the experimental design, the low survival in the trial by the environmental pressure likely reduced the degrees of freedom and, consequently, the precision of the model. Thus, the extrapolations of the results must be considered with care. However, this study provides interesting insights for the design of future studies in the topics.

5. Conclusions

Regarding the harsh growing conditions at our study site, planting in winter and using mulch and shading considerably improved survival but without an apparent effect on plant growth during the first year. Growth increments and survival differed among species, but survival was more related to the drought sensitivity of the species than growth increments. Further research is needed to assess the effects of these eco-technologies and the potential interaction among the species within the island plots.

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