Effects of nurse shrubs and tree shelters on the survival and growth of two Austrocedrus chilensis *seedling types in a forest restoration trial in semiarid Patagonia, Argentina*

María Florencia Urretavizcaya & Guillermo E. Defossé

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ORIGINAL PAPER

Effects of nurse shrubs and tree shelters on the survival and growth of two *Austrocedrus chilensis* seedling types in a forest restoration trial in semiarid Patagonia, Argentina

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Abstract
• ***Context*** Harsh environmental conditions in xeric sites of Andean Patagonia, affect the emergence, survival, and growth of either naturally grown or planted *Austrocedrus* seedlings.
• ***Aims*** We evaluated the effects of nurse shrubs and tree shelters on the survival and growth of *Austrocedrus* seedlings as compared to unprotected (control) areas and how differently produced seedling types perform under these treatments.
• ***Methods*** In 2006, two *Austrocedrus* seedling types (1+2= S1 and Plug 2+1=S2) were planted under shrub cover (C1), tree shelter (C2), and control (C3). Soil surface temperature and moisture were measured for each treatment during the first growing season, while seedling survival and height were recorded during 5 years.
• ***Results*** Survival was not affected by cover type the first year, but it was affected by seedling type (S1>S2). After an extremely dry second growing season, seedling survival significantly decreased in relation to either cover or seedling type. Five years after plantation, survival was significantly higher for C1 and C2 (40–60 %) as compared to C3-S2 (18 %). Seedling height was significantly affected by cover, but not by seedling type.
• ***Conclusions*** The use of nurse shrubs and/or tree shelters is useful in *Austrocedrus* seedling restoration trials. Seedling morphology appears as relevant for survival in semiarid environments.

Keywords Temperate forests · Xeric site · Nurse plants · Facilitation · Seedling morphology · Seedling quality

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Contribution of the co-authors The experiment was designed and conducted by M. Florencia Urretavizcaya. Both authors are responsible for statistical analyses and the data, and writing the manuscript.

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M. F. Urretavizcaya (✉) · G. E. Defossé
Área de Conservación y Manejo de Bosques, Centro de Investigación y Extensión Forestal Andino Patagónico (CIEFAPCONICET) and Universidad Nacional de la Patagonia, San Juan Bosco, Sede Esquel, Ruta 259, C.C. 14-(9200), Esquel, Chubut, Argentina
e-mail: mfurretavizcaya@ciefap.org.ar

G. E. Defossé
e-mail: gdefosse@ciefap.org.ar

1 Introduction

In ecology, the term "facilitation" has been coined to qualify the positive effects of one species on another. Facilitation has been recognized as a key factor involved in the organization of some terrestrial and aquatic communities (Bruno et al. 2003). Facilitation effects are particularly relevant in areas exposed to strong environmental stress (Bertness and Callaway 1994). For that reason, the use of facilitative interactions between a nurse plant and the species of interest has been proposed as a successful technique for restoration trials in harsh environments (Padilla and Pugnaire 2006). If the facilitator disappears due to natural or human perturbations, however, the dependent plant species will fail to be established. As a consequence, the plant community may not follow the successional path originally proposed in the restoration plan.

In semiarid sites and apart from the facilitation provided by nurse shrubs, the use of tree shelters may also have facilitative effects, by increasing the survival and the growth of the seedlings they protect (Bellot et al. 2002; Chaar et al. 2008). This effect has been attributed, in part, to the formation of a microclimate within the shelter that favors plant growth (Oliet and Jacobs 2007). This protective effect appears to be particularly important for plants growing in Mediterranean types of climates (Oliet et al. 2005), in which the growing season coincides with the dry period. However, the use of tree shelters may produce an imbalance between the aerial and belowground parts of the seedlings, increasing foliage in detriment of root biomass (Jiménez et al. 2005).

In addition, seedling performance may depend not only on the post-planting environmental conditions but also on the quality of the seedlings themselves. Nursery conditions and cultivation may affect seedling structural and functional characteristics, determining thereby their ability to survive the transplanting stress and the post-planting environmental conditions prevailing at the site (Burdett 1990). In this sense, although seedling quality is one of the key components in restoration projects, there is no standard or ideal way to assess seedling quality since a given seedling quality may perform very well in some sites but not in others (Villar Salvador 2003).

Austrocedrus chilensis [D. Don] Pic. Serm. et Bizarri, locally known as "cypress" or "cypress de la cordillera," is a xerophyte conifer of the Cupressaceae family, endemic to the Patagonian Andean Forests. Because of the ecological, productive, and scenic characteristics of *Austrocedrus* forests, this species is considered the most important native tree of the northern Patagonian region. From the mid-1930s of the twentieth century and up to recent times, *Austrocedrus* stands have been cut for lumber and furniture production, burned to increase areas for pasture, and/or, in many cases, simply replaced by exotic conifers presenting higher growing rates (Urretavizcaya et al. 2006). As a result of those disturbances, some *Austrocedrus* forests show now several signs of structural and functional deterioration. It is therefore necessary to restore the lost biodiversity and the role this species plays in these environments. This is especially true in the more xeric areas of its distribution, in which deterioration has been so intense that the mere elimination of those disturbances appears as insufficient for *Austrocedrus* stand recovery. In those areas, the use of active restoration practices is needed to help recover former *Austrocedrus* stands.

The xeric sites of the Andean Patagonian ecotone present hot and dry summers (De Fina 1972), and these environmental conditions affect the emergence, survival, and growth of either naturally grown or planted *Austrocedrus* seedling. In these water-limited environments, *Austrocedrus* establishment may be enhanced by interactions between shrubs and *Austrocedrus* seedlings (Kitzberger et al. 2000; Urretavizcaya et al. 2012). During summer, nearby growing shrubs seem to protect *Austrocedrus* seedlings from direct radiation, and their shadow effect may improve the soil water availability around them (Kitzberger et al. 2000). The effects of vegetation cover and density, coupled to the prevailing environmental conditions, likely affect *Austrocedrus* seed germination and early emergence (Urretavizcaya et al. 2012). In these protected areas, this facilitation appears as an important factor for further *Austrocedrus* seedling establishment.

In Patagonia, information is very scarce on how tree shelters may affect microclimatic conditions (mainly temperature and soil moisture) and the survival and growth of target seedlings in restoration trials. For *Austrocedrus* seedlings, poor field performance has been generally associated with their vulnerability to abiotic stress factors, especially those occurring during the first and second summers after plantation. Furthermore, there is little information about how different commercial seedling types may perform in xeric sites of Patagonia during their early stages of establishment. One aspect that should be considered is that, in general, seedling survival in harsh Mediterranean environments requires that their root system is large enough to cope with the summer water stress (Carlson and Miller 1990; Defossé et al. 1997).

Within this context, this study was aimed at addressing the following questions: In these xeric areas of Patagonia and for *Austrocedrus* seedlings, (1) do protective nurse shrubs provide a less stressful environment and act as a facilitator, enhancing seedling survival and establishment as compared to unprotected (control) areas? (2) Do tree shelters act in a similar way to nurse shrubs, providing similar microenvironmental conditions that improve *Austrocedrus* seedling survival and establishment as compared to the control? (3) What is the performance of different commercial seedling types of *Austrocedrus* under these three dissimilar conditions?

2 Material and methods

2.1 Study site

The study site (42°55′01″ S latitude, 71°15′53″ W longitude) was located near the city of Esquel, in the northwestern Chubut province in Patagonia, Argentina. The region shows a typical Mediterranean climate, cold–temperate during the winter and mild and dry during the summer. According to data provided by the Esquel Airport Weather Station, located 15 km from the study site, the mean annual temperature is 8.4 °C and the mean yearly precipitation reaches 488 mm (SMN 2000). Seventy-three percent of the annual precipitation (354 mm) occurs during late fall and winter (from April to September in the Southern Hemisphere), in the form of either rain or snow, and freezing temperatures during this period could reach −15 °C. Spring is a windy season, and the low precipitation and high temperatures during the summer (mean maxima of 22 °C, and absolute maxima of 33 °C for January and February) determine a dry period with a high water deficit during this growing season. In this site, we selected an area of about 1 ha and a 1,750-m^2 plot (50×35 m) was set to carry out the experiment. The experimental site shows a southern exposure (180°) with a moderate slope. The soil is deep, sandy–loam, and presents rock fragments of different sizes at all soil profiles. Native vegetation covers about 50–60 % of the soil and is composed of perennial grasses of the genera *Stipa*, *Poa*, and *Bromus*, mainly intermixed with shrubs of *Berberis microphylla* and, to a lesser degree, with half-shrubs and herbs such as *Mulinum spinosum*, *Senecio patagonicus*, and *Acaena pinnatifida.*

2.2 Plant material

In the experiment, established in August 2006, we used two types of *Austrocedrus* seedlings, identified as S1 and S2 hereinafter. These seedlings came from two nurseries that used similar seeds but different production techniques. Seedling type S1 was grown in one of the nurseries using the traditional method of sowing *Austrocedrus* seeds in a seed bed, in which the emerged seedlings remained for a year and then were transplanted to polyethylene bags of 900 cm^3 each for two more years (3 years old, or 1+2). Seedling type S2 was grown in BCC Sideslit 40 containers (531 cavities per square meter, 120 cm^3/cavity). The growing substratum was pumice and *Sphagnum* peat (1:1), and emerged seedlings were irrigated and fertilized appropriately. The seedlings remained in the greenhouse for 2 years and then were transplanted to polyethylene bags, similar to those of S1, for another year (3 years old, or plug 2+1). *Austrocedrus* seedlings were then transported to the field and planted under different types of cover/shelters to evaluate their effects on some establishment and growth attributes. The plantation was done manually by using a shovel to make the holes where the seedlings were planted.

2.3 Morphological seedling quality parameters

Before plantation, seedlings were morphologically characterized, describing and comparing each of the two types. In a random sample of 14 seedlings per type, we determined root collar diameter and shoot height. Seedlings were oven-dried at 103±2 °C to constant weight and then the dry weight of the roots and shoot determined. The dry weight of the shoot/root ratio was calculated since it expresses the balance between losses due to transpiration and the capacity to maintain gas exchange level through the leaves, and the absorption of water and nutrients through the roots. The sturdiness ratio (=height in centimeters/diameter in millimeters ratio) was also determined (Hasse 2007).

2.4 Experimental design and treatments

The experiment was conducted on a split-plot design, with cover type as the main plot and seedling type as the subplot. The experiment was replicated (blocks) six times. The cover types were: natural cover given by nurse shrub plants of *B. microphylla* (C1); artificial cover given by tree shelters (C2), and no cover or control (C3). Seedling types (S1 and S2) were randomly assigned to each subplot. The subplots had five seedlings; the block had 30 seedlings each. One hundred and eighty seedlings were used in total, 30 per type of cover (C1, C2, and C3) and 30 per type of seedlings (S1 and S2). For C2 and C3 treatment plots, the seedlings were planted in 2-m-apart spaced rows, while in the treatment protected by *Berberis* canopies (C1), the plantation was done in the southeast corner (in the leeward side) in the exterior limit of the *Berberis* shrub canopy. This *Berberis* is a spiny shrub that can reach up to 2 m in height, reproduces either vegetatively or by seed, and has arching branches with fruits (berries) that are eaten and dispersed by birds and domestic livestock (Damascos 2011). *B. microphylla* is also a variable and widespread species that has benefited from human disturbance (Landrum 1999). In the experimental site, shrubs occupy about one third of the total area covered by the plot, while herbaceous vegetation is homogeneously distributed around it.

The tree shelters used for C2 were made of 500-μm polypropylene (produced by COTNYL Argentina). Shelters were 60 cm long, 10 cm wide, had a UV filter, were yellow colored, and had three holes for ventilation. Before installation, we cut the shelters in half (30 cm long each) to adapt them to seedling sizes. Treatments C1 and C3 were surrounded by a wide open metal sheet to protect seedlings from grazing/browsing by small herbivores. This was not necessary in the case of C2 because the tree shelter used also acted as a protector for herbivores.

2.5 Air and soil temperature and moisture

Precipitation and temperature measurements were recorded during the first two growing seasons of the study (2006–2007 and 2007–2008) for further comparison with the long-term means. This was done to determine whether the early period of seedling establishment corresponded to a dry or a humid cycle and whether temperatures were above or below the long-term mean. This information was obtained from the Esquel Airport Weather Station formerly mentioned. During the first growing season after planting (November 2006, December 2006, and February 2007), the surface temperature and moisture in the first 16 cm of the soil were measured for each treatment. For each measurement, we randomly choose three seedlings per cover and per seedling type (18 per date in total). The surface temperature was measured with an infrared thermometer (Cole Parmer SM 39650-02), while soil moisture was measured with a TDR IMKO Trime FM-3 handheld moisture meter with P3 sensors 16 cm long. This moisture meter measures the mean volumetric water content of the soil layer from the soil surface and up to 16 cm in depth. The tree shelters and metal sheet protectors were taken out during the measurements and reinstalled thereafter. At each sampling date, all measurements were systematically done from 14 to 16 h.

2.6 Survival and growth measurements

The day after plantation (August 2006), all seedlings were identified and their height determined. Seedling survival was recorded in December 2006; February, July, and December 2007; October 2008; and April 2011. In July 2007 and again in April 2011, the heights of all living seedlings were also recorded.

2.7 Data analyses

Significant differences among seedling morphological parameters, and also for soil temperature and soil moisture, were evaluated using one-way analysis of variance (ANOVA). The analyses of soil temperature and soil moisture were done independently for each sampling date since they were taken nearby different seedlings every time. Statistically significant differences ($p \leq 0.05$) among means were identified using the least square difference (LSD) test.

The experiment was set up based on a split-plot design, with cover type (C1, C2, and C3) as the main plot and seedling type (S1 and S2) as the subplot. Survival was measured six times during the experiment (December 12, 2006; February 26, 2007; July 27, 2007; January 5, 2008; October 19, 2008; and April 10, 2011). Survival analysis was made with repeated measures analysis of variance. We used a mixed-model method because it allows the estimation of the standard errors more adequately for the different comparisons. In our case, since the measurements were made on unequal time intervals, we used one kind of time series covariance structure appropriate for this sort of data, like the spatial lower law (Littell et al. 2006). We analyzed the effect of cover, seedling, and time (fixed factors) and block (random factor) on percent survival; we included all three individual factors and two- and three-way interactions in the model. Simple effects of cover and seedling type factors on seedling survival were evaluated for each date, and comparisons of the treatment means with the LSD test were performed. Treatment effects on seedling height were evaluated 1 and 5 years after plantation with analysis of variance in a split-plot design. Statistically significant differences ($p \leq 0.05$) among means and between treatment levels were also identified with the LSD test.

3 Results

3.1 Seedling morphology

Both seedling types (S1 and S2) presented values in diameter (4.0 and 3.7 mm) and height (≈23 and 29 cm) that based on previous experiences could be considered as adequate for further use in restoration trials (Urretavizcaya, unpublished results). Significant differences ($p<0.05$) were found in four morphological parameters (Table 1) and were noticeable in sturdiness (S1<S2) and in the shoot/root dry weight ratio, ADW/RDW (S1<S2). For the first parameter, a high ratio indicates a relatively spindly seedling, while a lower ratio indicates a stouter seedling (Hasse 2007). For the second parameter, different studies showed that plants with low values of this ratio survive much better than those which have high values since they present a greater development of the absorption system with reference to transpiration structures (Jiménez et al. 2005). It is worth noting that seedling type S1 presented a significantly higher root biomass at the beginning of the experiment than seedlings S2 (Fig. 1).

3.2 Air and soil temperature and moisture

As a general environmental effect for all treatments, during the first growing season (October 2006–March 2007), precipitation

Table 1 Morphological parameters (average±1 standard error) of the two types of *Austrocedrus* seedlings used

	Austrocedrus 1 (S1)	*Austrocedrus* 2 (S2)	*p* values
Seedling age	3 (1+2)	3 (Plug 2+1)	–
Root collar diameter (mm)	4.0±0.2 a	3.7±0.2 a	0.2075
Shoot height (cm)	22.8±1.0 b	27.9±1.3 a	0.0063
Shoot dry weight (SDW, g)	4.6±0.4 a	3.7±0.4 a	0.2119
Root dry weight (RDW, g)	3.1±0.4 a	1.6±0.2 b	0.0037
SDW/RDW ratio	1.5 a	2.4 b	0.0002
Sturdiness	56.4 a	76.0 b	0.0007
N	14	14	–

Different letters indicate statistically significant differences for the variable at $p<0.05$

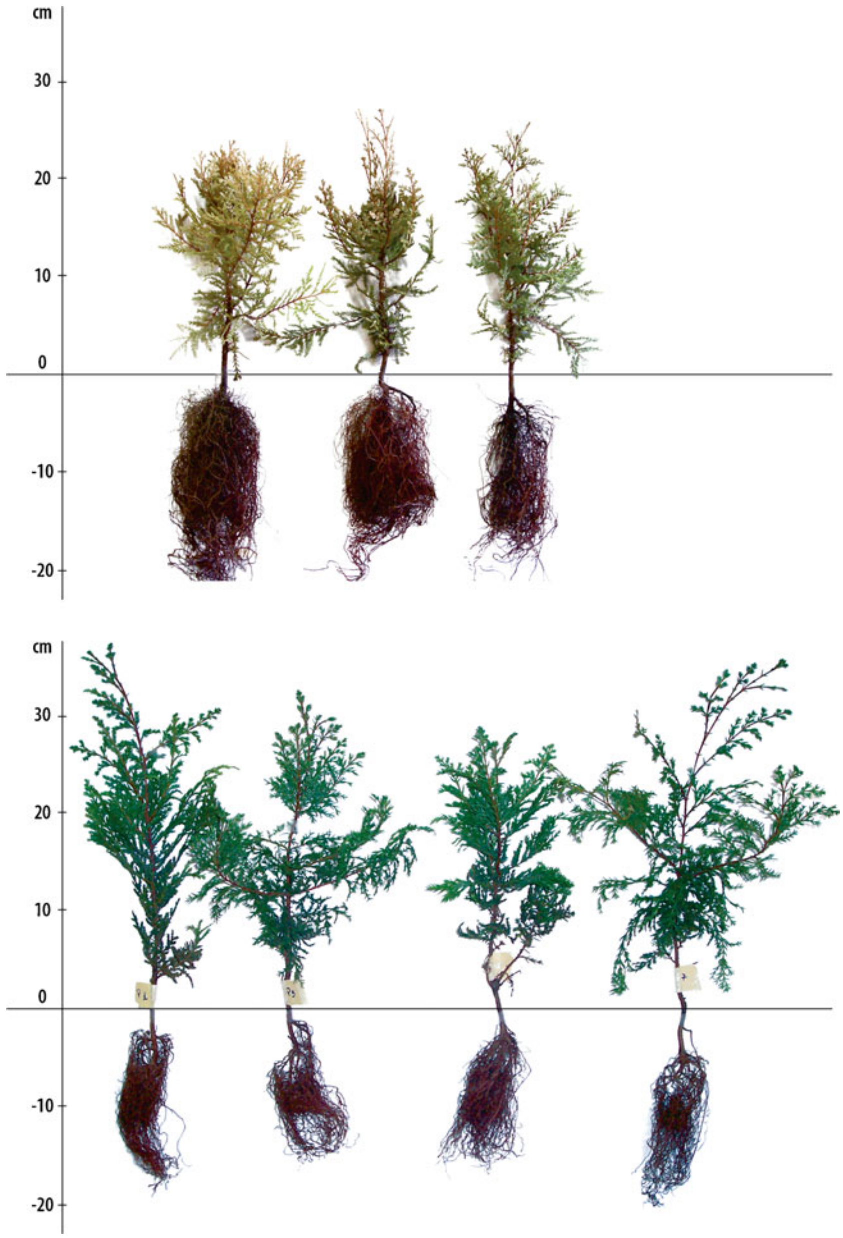

Fig. 1 Types of cypress seedlings used: S1 (*top*) and S2 (*bottom*)

reached 155 mm, 18 % higher than the historical mean of 132 mm. For the same period, the mean temperature was 11.9 °C, 1.5 °C below the respective historical mean of 12.4 °C. During the second growing season (October 2007–March 2008), in contrast, the site only received 56 mm (or 42 % less precipitation) and presented a mean temperature of 13.6 °C, 1.2 °C higher than the respective long-term mean. The first period could be considered then as a normal or above-normal period related to precipitation, while the second was markedly dry.

The soil temperature measured at mid-spring of the first growing season showed similar values for all treatments. After that period and at the beginning and mid-summer of the first growing season (December 2006 and February 2007), soil temperature showed significant differences ($p<0.05$) among treatments (C3>C2>C1, Fig. 2a). In the control treatment (C3), soil temperature values showed an upward trend during the whole growing season, reaching an average of 40 °C during the month of February. The other two treatments, in contrast, showed a downward trend, going from 34 to 27 °C in C2 and from 38 to 19 °C in C1 at the beginning and at the end of the summer, respectively (Fig. 2a).

Soil moisture in the first 16 cm of the soil showed significant differences ($p<0.05$) among treatments only in February 2007, near the end of the growing season. In this case, treatment C2 presented the highest moisture values, followed by C3 and C1 (Fig. 2b). Soil moisture values (in volume) were above 10 % at the beginning of the growing season, steadily decreasing to about 5 % in C2 and <3 % in C3 and C1 (Fig. 2b).

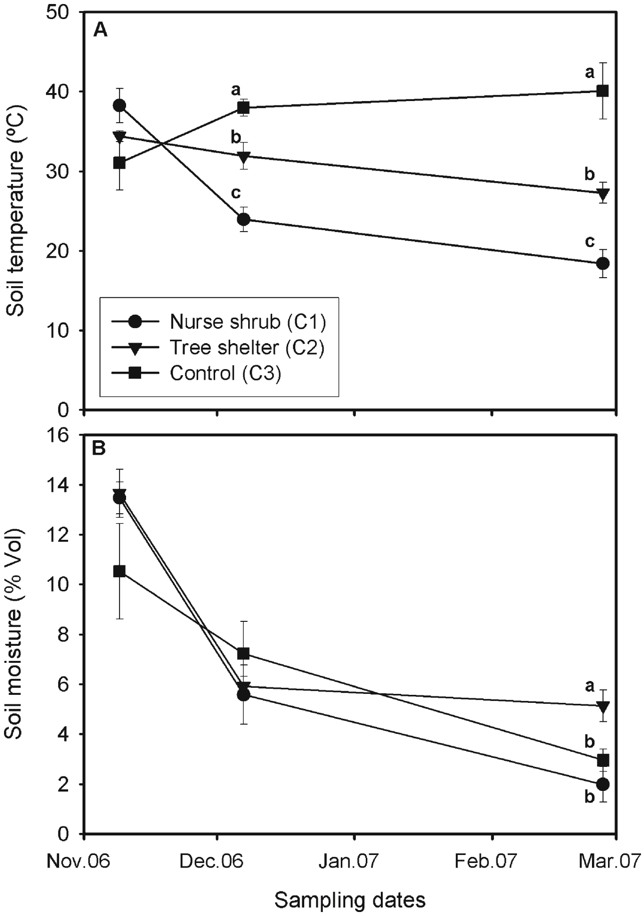

Fig. 2 **a** Soil temperature (average±1 standard error). **b** Soil moisture (average±1 standard error) by cover type during the first growing season. *Different letters* indicate statistically significant differences at each date ($p<0.05$)

3.3 Seedling survival and growth

Of the 180 seedlings planted, 71 % survived through the first year, 50 % the second, and 34 % the fifth year after planting. The type of cover, seedling type, and time showed significant effects on seedling survival; the interaction between cover and time was also significant. No significant effects on seedling survival were found considering all other interactions analyzed (Table 2). Taking into consideration the significant interaction found between cover and time (undoubtedly affected by the climatic conditions observed during the first two growing seasons), we focused our analysis on the single effects of cover and seedling type within each sampling date.

Survival percentage (Fig. 3) was highest in S1 seedlings (83–93 % across cover) and lower in S2 seedlings (42–71 % across cover) during the first year. For the sampling dates registered at the end of spring 2006 (December) and in mid-summer (February) and in winter (July) of 2007 (113, 194, and 345 days after plantation, respectively), survival was not affected by cover type ($p>0.05$), but it was significantly affected by seedling type ($p<0.05$). In the middle of the second growing season (January 2008, 503 days after plantation), seedling survival significantly decreased in relation to either cover or seedling type. Within both control treatments (C3-S1 and C3-S2), seedling survival for type S1 diminished from 82 to 56 %, while for S2 these values diminished from 42 to 22 % (Fig. 3). It is interesting to note that neither of the other two cover treatments (C1 and C2) presented this abrupt diminution in survival at that moment. In October 2008 (777 days after plantation), 4 months after the end of the extremely dry second growing season, survival was affected in all treatments ($p<0.05$). This effect was significant for both cover and seedling type, although survival remained higher in C1-S1 as compared to C3-S2.

Table 2 Mixed ANOVA model for the effects of cover, type of seedling, and time on seedling survival

Factor	*F*	*df*	*p* values
Cover	7.73	2	0.0028
Type of seedling	20.64	1	< 0.0001
Time	30.01	5	< 0.0001
Cover×type of seedling	0.84	2	0.4723
Time×cover	2.06	10	0.0281
Time×type of seedling	1.13	5	0.3272
Time×cover×type of seedling	0.52	10	0.8888

At the end of the fifth growing season in April 2011 (1,689 days after plantation), survival was significantly affected by cover ($p=0.0086$) and marginally affected by seedling type ($p=0.0557$). Survival varied from near 40 % to around 60 % for cover types C1 and C2 for both seedling types and was not significantly different between them. Nevertheless, the survival recorded for both control treatments (C3-S1 and C3-S2) reached 30 and 18 % for seedling types S1 and S2, respectively, and were significantly different from C1-S1 treatment. While C3-S2 treatment was different to both C1 treatments, C3-S1 was only different from C1-S1 (Fig. 3).

As was indicated in the description of seedling morphology, at the beginning of the study (2006), both seedling types showed significant differences ($p<0.05$) in height. These differences were also verified later right after plantation (Fig. 4). At the end of the first growing season (2007), however, seedling height was rather homogenized, being similar for all treatments involving seedling cover or seedling type. Five years after plantation (2011), seedling height was significantly affected by the cover type ($p=0.0318$), but not by the seedling type ($p>0.05$), and the interaction between those factors was not significant ($p>0.05$). The highest mean heights (53 and 48 cm) were achieved by both types of seedlings grown under shrub cover (C1 treatment), while the other treatments did not show significant differences (Fig. 4).

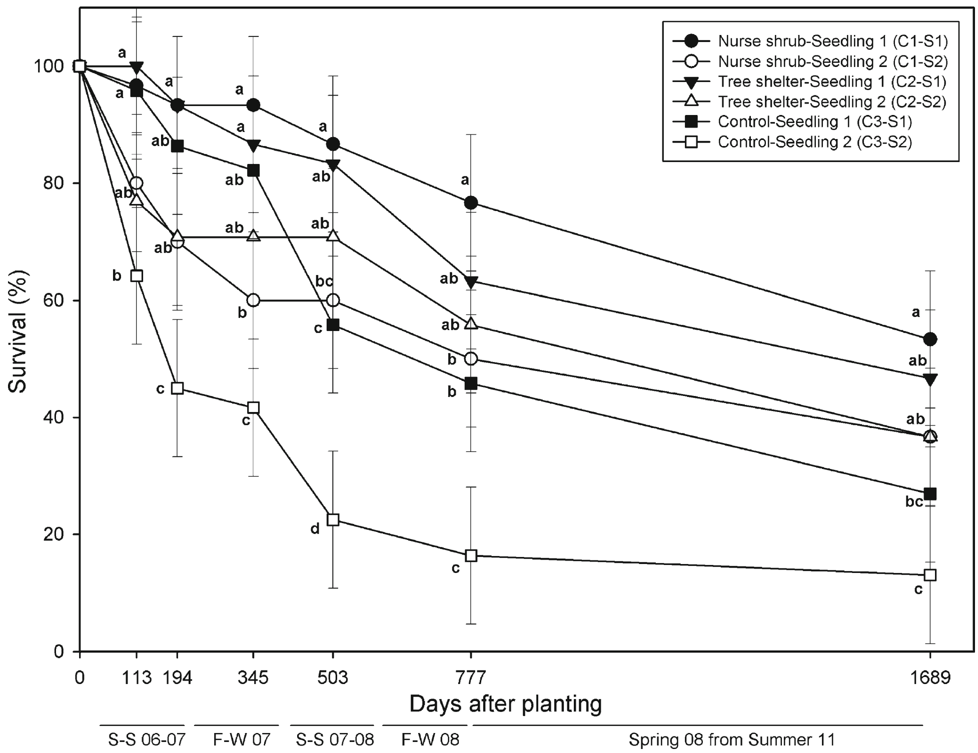

Fig. 3 Mean percentage (±1 standard error) of cypress seedling survival at different sampling periods for each cover and seedling type. For the cover treatment plots, C1 is represented by *circles*, C2 by *triangles*, and C3 by *squares*. For the subplots, S1 (*black symbols*) and S2 (*white symbols*) represent seedling types 1 and 2, respectively. The *x*-axis represents days from the start of the experiment (August 2006). The notations *S-S* corresponds to the spring–summer period and *F-W* to the fall–winter period. *Different letters* indicate statistically significant differences at each date ($p<0.05$)

4 Discussion

The highest survival rates presented by seedlings S1 as compared to S2 during the first growing season, which presented climatic conditions (mean precipitation and temperatures) similar to the long-term mean, could be directly related to the morphologic characteristics of each seedling type. Seedlings S1 presented a lower dry weight shoot-to-root ratio (1.5) than S2 seedlings (2.4) and also a significantly higher root weight at the moment of plantation. During a certain period after planting, the initial root system size determines the ability of seedlings to take up water so they can initiate the establishment process (Carlson and Miller 1990). In general, seedlings with larger root volumes have a better ability to take up water than those having small root volumes, and then, after planting, they become established earlier (Grossnickle 2005). The differences in the initial sizes of roots as compared to shoots can have a direct effect on seedling water balance after planting (Burdett 1990; Grossnickle 2005). These differences may explain why survival was higher for seedlings S1 than for S2. Similar results were reported in a study involving *Pinus taeda* seedlings (Larsen et al. 1986). These authors also stated that when seedlings are planted in cold soils or in windy areas, the dry weight shoot-to-root ratio may be more important than the other parameters of characterization for seedling survival and establishment. The different morphologies in *Austrocedrus* seedling types could be associated with the kind of container/bag they are confined in after germination and the time they are stored there. Seedlings S2 remained 2 years in cavities of 120 cc before they were transplanted to a larger container for another growing season. This later period appeared not long enough to allow these seedlings to develop their root systems as did seedlings S1, which had 2 years to develop theirs in containers of 900 cc. However, seedlings with higher sturdiness quotients were more susceptible to damage from wind, drought, and frost exposure (Hasse 2007). These characteristics could also help explain the

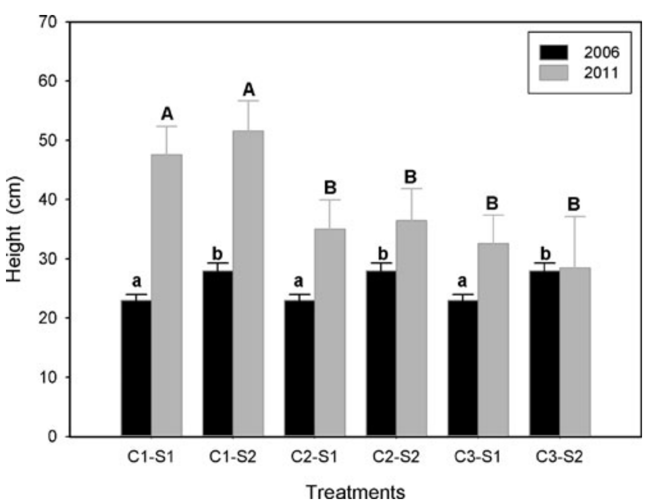

Fig. 4 Initial seedling height (2006, average±1 standard error) and after 5 years (2011, average±1 standard error) by cover type (*C1*, *C2*, and *C3* correspond to nurse shrub, tree shelter, and control, respectively) and seedling type (*S1* and *S2* correspond to seedling types 1 and 2, respectively), respectively. *Different lowercase letters* indicate statistically significant differences ($p<0.05$) in 2006; *different capital letters* indicate statistically significant differences ($p<0.05$) in 2011

lower survival rate of seedlings S2 (42 %) as compared to seedlings S1 (82 %), grown under the same treatment (C3), during the first year after plantation.

During the first summer after plantation, and because of the above-normal precipitation and favorable temperatures for growth, the different cover types (C) did not show any influence on seedling survival. However, the cover types produced a significant effect in changing their microenvironmental conditions around the seedlings, especially at the end of this season. Soil temperature around seedlings grown in the control treatment (C3) was, on average, from 10 to 20 °C higher than that registered either in tree shelters (C2) or under shrub canopies (C1). These data coincide with what Bergez and Dupraz (2009) reported about soil temperature changes inside and outside tree shelters. These authors found that when the sun reaches the zenith, the soil temperatures inside the shelters are significantly lower than those registered outside them. It is interesting to note the lower temperatures found under shrub canopy protection (C1) as compared to those found in the control (C3) during the growing season. This effect could be explained by considering that, during mid-spring, the solar elevation angle above the horizon at this latitude (42°55′ SL) is about 47°, while as the season advances toward the summer, this angle reaches nearly 70° (Rosemberg et al. 1983). The high soil temperature experienced by treatment C1 during the month of November (mid-spring in the Southern Hemisphere) could have been due to the effects of direct solar radiation, while this effect changed as the growing season advanced. Later in the growing season, it seems that because of the changes in the solar elevation angle, oncoming radiation reached the soil below shrub canopies as a diffuse radiation. As a consequence, the soil temperature was lower than that during mid-spring. In the case of the control, C3, direct radiation reached the soil during the whole growing season; this effect explains the upward trend of increasing temperatures during the whole growing season. In the case of the tree shelters, direct radiation reached the protecting wall of the shelters, which in turn absorbed and reflected part of this radiation. The quantities of radiation absorbed and reflected are a function of the wall transmissivity and the angle of incidence of the beam. In general and during noon hours, the soil temperature inside the shelters is lower than that found outside them (Bergez and Dupraz 2009).

Soil moisture at the end of the first spring after plantation was above 10 % (in volume) for all treatments and steadily diminished toward the summer. This diminution, however, was not so pronounced in the tree shelter treatment (C2), which showed moisture values above those registered in the other two treatments. These higher moisture values in C2 could be explained by the radiative condenser effect that tree shelters may produce (del Campo et al. 2006). On the other hand, the soil moisture values recorded under shrub understories (C1) were significantly lower than those found in C2 and similar to those found in the control (C3). This situation could be explained by considering that in semiarid areas, such as that found in our study site, rains may occur as small precipitation events. Shrub canopies intercept this rainwater, limiting its availability in their understories, making the soil under shrub canopies drier than the adjacent open areas (Tielbörger and Kadmon 2000). In other cases in the same areas, if a moderate to heavy rainfall event occurs, some shrubs increase water availability by directing water intercepted by the canopy to their understory through stem flow (García Ortiz 2006). Besides these two examples, other mechanisms for water uptake under shrub canopies may occur, such as hydraulic lift (Flores and Jurado 2003).

The above-average rainy conditions and moderate temperatures during the first growing season after planting may have somehow overcome, or masked, the protective effects given by either shrub cover or tree shelters. This effect is similar to what was reported in another study involving *Austrocedrus* seedlings, when above-average rainfall events prevailed during a specific growing season (Urretavizcaya et al. 2012). However, these beneficial growth conditions found during the first season after plantation in this study drastically changed during the second growing season, when rains were 42 % lower and the mean temperatures 1.2 °C higher than the long-term means. In this dry season, the type of cover exerted a pronnounced effect on the survival of both seedling types. Seedling survival significantly diminished in the control treatment of both seedling types (25 in average), while survival for those grown under the protection of shrub cover or tree shelters, was not significantly affected.

Ecophysiological studies carried out in *Austrocedrus* seedlings showed that this species avoids water deficit in its tissues by stomatic control. Similar to what occurs in other species with the same growing strategies, the risk of photo inhibition or cellular damage by overheating is increased. These characteristics may explain the high mortality of *Austrocedrus* when it is exposed to high solar radiation, even though the soil underneath may have a higher moisture content than that of shadow areas. These results suggest that microenvironments with intermediate protection to radiation could be more adequate for *Austrocedrus* establishment (Gyenge et al. 2007). In our study, these adequate conditions were present under shrub cover or within tree shelters.

Several studies recommend the use of nurse plants for restoration in arid ecosystems (Padilla and Pugnaire 2006; Brooker et al. 2008). Gómez-Aparicio et al. (2004) investigated the use of naturally occurring shrubs as nurse plants for reforestation in a Mediterranean environment. They found that shrubs had a consistent beneficial effect on tree seedling survival and growth during four consecutive years. The mechanisms underlying facilitation in Mediterranean types of ecosystems are atribbuted primarily to a reduction of radiation during summer, which improves the water status of the seedlings through lowering the soil temperature and conserving soil moisture (Castro et al. 2006; Pugnaire et al. 2011). On the other hand, while the influence of shelters on seedlings in Mediterranean areas is still debated (Jiménez et al. 2005; Padilla et al. 2011), several studies show the positive effects of tree shelters on seedling survival and growth, although these positive effects can be detected after one or more years after installation (Oliet and Jacobs 2007). For example, in *Acacia salicina*, tree shelters did not affect survival until the fifth to the sixth year, when an intense drought affected the survival of non-protected seedlings as compared to shelter-protected seedlings (Oliet et al. 2005). The height of the shelters and their relationships with the type and quantity of holes they have for ventilation are variables that merit consideration in further analyses. In *Quercus coccifera*, the use of short tree shelters (30 cm tall) in semiarid dry–hot environments showed that the development of above- and belowground seedling parts was greater than those of the control or covered by other tree shelter types (Bellot et al. 2002). In our study, the effect of tree shelters and nurse shrubs on *Austrocedrus* seedling survival became apparent 2 years after plantation, while the differences in height were established after 5 years (additional figures are given in Electronic supplementary material Online Resource 1, 2, and 3). The highest growth found under shrub cover (C1) confirms that the facilitation effect also occurs in the restoration of this ecotonal environment.

5 Conclusions

Seedling quality attributes—mainly those acquired from seed sown, nursery culture, and until the seedling is planted—and the type of protective cover affected the outplanting performance of *A. chilensis* throughout several years. In particular, the effects of the type of seedlings on establishment may last for 2–3 years after plantation, while the differences due to the type of cover appear to be maintained, lasting at least during the 5-year duration of this study. Similar to what happens to *A. salicina* in arid and windy areas (Oliet et al. 2005), *Austrocedrus* establishment is enhanced by nursery cultural treatments and the cover protection of seedlings after planting. However, and under certain planting conditions in semiarid environments, the dry weight of shoot-to-root dry ratio may also play an important role for further seedling survival. Facilitation has been recognized as an important structural and functional force in natural plant communities. It is being increasingly discussed as an ecological mechanism that could be used for developing vegetation restoration plans, particularly in severe and highly disturbed environments (Brooker et al. 2008). Particularly in *A. chilensis* forests, the use of nurse shrub cover is a restoration tool that has been demonstrated to be effective to assure its establishment, manly in the most disturbed xeric areas of its distribution. However, and when nurse plants are lost or not present in those harsh environments, the use of tree shelters is a good alternative to help restore this type of forests.

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References

Bellot J, de Urbina JM O, Bonet A, Sánchez JR (2002) The effects of treeshelters on the growth of *Quercus coccifera* L. seedlings in a semiarid environment. Forestry 75:89–106

Bergez JE, Dupraz C (2009) Radiation and thermal microclimate in tree shelter. Agric For Meteorol 149:179–186

Bertness MD, Callaway R (1994) Positive interactions in communities. Tree 9:191–193

Brooker RW, Maestre FT, Callaway RM, Lortie CL, Cavieres LA, Kunstler G, Liancourt P, Tielbörger K, Travis JMJ, Anthelme F, Armas C, Coll L, Corcket E, Delzon S, Forey E, Kikvidze Z, Olofsson J, Pugnaire F, Quiroz CL, Saccone P, Schiffers K, Seifan M, Touzard B, Michalet R (2008) Facilitation in plant communities: the past, the present, and the future. J Ecol 96:18–34

Bruno JF, Stachowicz JJ, Bertness MD (2003) Inclusion of facilitation into ecological theory. Trends Ecol Evol 18:119–125

Burdett AN (1990) Physiological processes in plantation establishment and the development of specifications for forest planting stock. Can J For Res 20:415–427

Carlson WC, Miller DE (1990) Target seedling root system size, hydraulic conductivity, and water use during seedling establishment. In: Rose R, Campbell SJ, Landis TD (eds) Target Seedling Symposium: Proceedings, Combined Meeting of the Western Forest Nursery Associations. USDA, Forest Service, Fort Collins, pp 53–66

Castro J, Zamora R, Hódar JA (2006) Restoring *Quercus pyrenaica* forests using pioneer shrubs as nurse plants. Appl Veg Sci 9:137–142

Chaar H, Mechergui T, Khouaja A, Abid H (2008) Effects of treeshelters and polyethylene mulch sheets on survival and growth of cork oak (*Quercus suber* L.) seedlings planted in northwestern Tunisia. Forest Ecol Manag 256:722–731

Damascos MA (2011) Arbustos Silvestres con frutos carnosos de Patagonia. Ciencias Naturales, 1ra edn. Fondo Editorial Río Negrino, Viedma

De Fina AL (1972) El clima de la región de los bosques andino-patagónicos argentinos In: Dimitri MJ (ed) La Región de los bosques andinospatagónicos. Colección científica INTA, Buenos Aires, pp 35–58

Defossé GE, Robberecht R, Bertiller MB (1997) Seedling dynamics of *Festuca* spp. in a grassland of Patagonia, Argentina, as affected by competition, microsites, and grazing. J Range Manage 50:73–79 del Campo AD, Navarro RM, Aguilella A, González E (2006) Effect of tree shelter design on water condensation and run-off and its potential benefit for reforestation establishment in semiarid climates. Forest Ecol Manag 235:107–115

Flores J, Jurado E (2003) Are nurse–protégé interactions more common among plants from arid environments? J Veg Sci 14:911–916

García Ortiz EM (2006) Efecto de la estructura de la copa en la partición de lluvia de tres especies arbustivas en clima semiárido. Tesis de Doctorado, Universidad de Almería, Almería

Gómez-Aparicio L, Zamora R, Gómez JM, Hódar JA, Castro J, Baraza E (2004) Applying plant facilitation to forest restoration: a meta-analysis of the use of shrubs as nurse plants. Ecol Appl 14:1128–1138

Grossnickle S (2005) Importance of root growth in overcoming planting stress. New Forest 30:273–294

Gyenge JE, Fernández ME, Schlichter T (2007) Influence of radiation and drought on gas exchange of *Austrocedrus chilensis* seedlings. Bosque 28:220–225

Hasse DL (2007) Morphological and physiological evaluations of seedling quality. In: Riley LE, Dumroese RK, Landis TD (eds) National Proceedings: Forest and Conservation Nursery Associations 2006, Fort Collins, CO, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station

Jiménez MN, Navarro FB, Ripoll MÁ, Bocio I, De Simón E (2005) Effect of shelter tubes on establishment and growth of *Juniperus thurifera* L. (Cupressaceae) seedlings in Mediterranean semi-arid environment. Ann For Sci 62:717–725

Kitzberger T, Steinaker DF, Veblen TT (2000) Effects of climatic variability on facilitation of tree establishment in Northern Patagonia. Ecology 81:1914–1924

Landrum LR (1999) Revision of *Berberis* (Berberidaceae) in Chile and adjacent southern Argentina. Ann Missouri Bot Gard 86:793–834

Larsen HS, South DB, Boyer JM (1986) Root growth potential, seedling morphology and bud dormancy correlate with survival of loblolly pine seedlings planted in December in Alabama. Tree Physiol 1:253–263

Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O (2006) SAS for mixed models. SAS Institute, Inc., Cary, NC

Oliet JA, Jacobs DF (2007) Microclimatic conditions and plant morpho-physiological development within a tree shelter environment during establishment of *Quercus ilex* seedlings. Agric For Meteorol 144:58–72

Oliet JA, Planelles R, Artero F, Jacobs DF (2005) Nursery fertilization and tree shelters affect long-term field response of *Acacia salicina* Lindl. planted in Mediterranean semiarid conditions. Forest Ecol Manag 215:339–351

Padilla FM, Pugnaire FI (2006) The role of nurse plants in the restoration of degraded environments. Front Ecol Environ 4:196–202

Padilla FM, JD M, Ortega R, Hervás M, Sánchez J, Pugnaire FI (2011) Does shelter enhance early seedling survival in dry environments? A test with eight Mediterranean species. Appl Veg Sci 14:31–39

Pugnaire FI, Armas C, Maestre FT (2011) Positive plant interactions in the Iberian Southeast: mechanisms, environmental gradients, and ecosystem function. J Arid Environ 75:1310–1320

Rosemberg NJ, Blad BL, Verma SB (1983) Microclimate: the biological environment. Wiley, New York

SMN (2000) Estadísticas Meteorológicas de Esquel (1900–1999). Servicio Meteorológico Nacional, Argentina

Tielbörger K, Kadmon R (2000) Temporal environmental variation tips the balance between facilitation and interference in desert plants. Ecology 81:1544–1553

Urretavizcaya MF, Defossé G, Gonda HE (2006) Short-term effects of fire on plant cover and soil conditions in two *Austrocedrus chilensis* (cypress) forests in Patagonia, Argentina. Ann For Sci 63:63–71

Urretavizcaya MF, Defossé GE, Gonda HE (2012) Effect of sowing season, plant cover, and climatic variability on seedling emergence and survival in burned *Austrocedrus chilensis* forests. Restor Ecol 20:131–140

Villar Salvador P (2003) Importancia de la calidad de planta en los proyectos de revegetación. In: Rey-Benayas JM, Espigares Pinilla T, Niclolau Ibarra JM (eds) Restauración de Ecosistemas Mediterráneos. Universidad de Alacalá—Asociación de Ecología Terrestre, Madrid, pp 65–86