Forest Systems
25(3), e075, 12 pages (2016)
eISSN: 2171-9845
http://dx.doi.org/10.5424/fs/2016253-08971
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Micro-environmental changes induced by shape and size of forest openings: effects on *Austrocedrus chilensis* and *Nothofagus dombeyi* seedlings performance in a *Pinus contorta* plantation of Patagonia, Argentina

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Abstract

Aim of the study: to analyze, within a *Pinus contorta* plantation, the effects of artificially created small rectangular and small medium circular canopy gaps on: i) photosynthetic active radiation (PAR), and soil temperature and moisture, and ii) survival and growth of planted *Austrocedrus chilensis* and *Nothofagus dombeyi* seedlings, species which formerly composed the natural forest of the area.

Study area: A 2 ha stand of a *Pinus contorta* stand in Los Alerces National Park, Argentina (42°43'S, 71°43'W, 490 m.a.s.l.).

Material and methods: The *Pinus contorta* stand was 25 yr old, 22 m height and 26 cm DBH, presenting 1000 trees ha^{-1} of density and 53 $m^2\,ha^{-1}$ of basal area. In 2009, rectangular and circular gaps were created within the stand and then seedlings were planted. During two growing seasons (2010-2011 and 2011-2012), PAR, soil temperature and moisture were measured in gaps and understory (control), and seedling survival and growth in gaps.

Main results: During both seasons, soil temperature did not differ among gaps and control, whereas PAR and soil moisture were lower in control than in gaps. Seedling survival was high in all gaps regardless of species and season. Seedlings showed higher diameter growth in rectangular than in circular gaps.

Research highlights: *Austrocedrus chilensis* and *N. dombeyi* seedlings survival is high and their growth slightly affected, when planted in differently-sized canopy gaps within a *Pinus contorta* plantation in Patagonia. However, other gap sizes and stand densities should be tested before recommending which one shows better results for reconverting monocultures into former native forests.

Keywords: planted seedlings; gap structure; photosynthetic active radiation; soil temperature; soil moisture.

Abbreviations used: PAR (Photosynthetic Active Radiation); DBH (Diameter at Breast Height); INTA (Argentinean Institute of Agricultural Technology); IFONA (Argentinean Forest Institute).

Citation: Pafundi, L., Urretavizcaya, M.F., Defossé, G.E. (2016). Micro-environmental changes induced by shape and size of forest openings: effects on *Austrocedrus chilensis* and *Nothofagus dombeyi* seedlings performance in a *Pinus contorta* plantation of Patagonia, Argentina. Forest Systems, Volume 25, Issue 3, e075. http://dx.doi.org/10.5424/fs/2016253-08971.

Received: 11 Nov 2015. **Accepted:** 09 Sep 2016.

Funding: Funding was provided by ANPCyT, PICT-O Nº 20/36663 and a doctoral assistantship from CONICET to Leticia Pafundi.

Authors contributions: LP did the field and laboratory work; LP and MFU designed the experiment and run the analyses; MFU and GD supervised the work and coordinate the research project. All three authors wrote the paper.

Competing interests: The authors have declared that no competing interests exist.

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Introduction

In the Andean forests of northern Patagonia, Argentina, exotic conifers were introduced around the early 1940´s in experimental stations of the former Argentinean Forest Institute (IFONA) (Defossé, 2015). Up to the late 1980´s, part of these plantations replaced natural forests mainly composed of native mixed *Austrocedrus chilensis* (D. Don) Pic. Serm. & Bizarri (ciprés de la cordillera, hereafter ciprés) and *Nothofagus dombeyi* (Mirb.) Oerst. (coihue) (Sarasola *et al.,* 2006). Although these plantations showed high growth rates, they changed the structure and function, including loss of connectivity and biodiversity, and the microenvironment of the replaced forests (Sarasola *et al.,* 2006; Paritsis & Aizen, 2008). This land-use policy was gradually abandoned, and about 4,700 ha of planted conifers still remain within Patagonian forests (Ríos Campano, personal communication). One challenge of today´s global silviculture is to gradually reconvert monoculture plantations into compositional and structurally heterogeneous stands in which native plants prevail (Albanesi *et al*., 2008).

Canopy opening is one of the first steps for actively restoring natural mixed forests in dense and monospecific plantations of exotic conifers. This practice mimics natural gap dynamics and creates conditions for re-establishment of native plants. In some cases, they remain in the understory as either seeds or seedlings that develop under favorable micro-environmental conditions whereas in others, active restoration for tree establishment is needed (Spies & Franklin, 1989; McIver & Starr, 2001).

These openings produce abrupt changes in soil temperature, water content, light, and nutrient cycling in the forest understory. These changes vary from site to site, and are also affected by the shape and size of the gaps and by the overstory tree species involved (Veblen *et al.,* 1981; Carlson & Groot, 1997; Heinemann *et al.,* 2000). Differences in openings structure, in turn, could affect future successional paths, favoring the recruitment of some species while delaying others (Gray *et al.*, 2002; D'Antonio & Chambers, 2006). In conifer stands, small openings may frequently appear as circles, due to the death and fall of one or a few trees (Kuuluvainen, 1994). Rectangular gaps, by instance, are generally produced as a consequence of tree fall due to snow avalanches and/or wind disturbances (Nowacki & Kramer, 1998; Bava, 1999). Rectangular gaps allow light entrance parallel to the larger side, increasing the direct light reaching the gap (Álvarez Pacheco & Lara, 2008). Large disturbances (natural or artificial) favor the establishment of shade intolerant species, while small ones benefit the shade tolerant (Zhu *et al.,* 2003; Gobbi, 2007). Small gaps made in adult stands of exotic species, can facilitate the reintroduction of native species by improving surrounding micro-environmental conditions, as compared to non vegetated areas (Engel & Parrotta, 2001).

The creation of canopy openings within plantations is one of the first steps to promote adequate environmental conditions for the establishment of target native plants (Carlson & Groot, 1997; Muscolo *et al.,* 2014). The success of restoring previous native forests, however, depends on the knowledge of the former ecosystem functions (Whisenant, 1999; Baron *et al,*. 2002), the ecology, and particularly the safe site requirements (*sensu* Harper, 1977) of the target species, and the silvicultural treatment that allows meeting those requirements (Rhoades *et al.*, 2009). In Patagonia, active restoration by sowing or seedling plantation accelerates restoration after natural or man-caused disturbances (i.e. fire, grazing, etc.) (Urretavizcaya *et al.* 2012; Pafundi *et al.,* 2014).

In northwestern Patagonia-Argentina, mixed coihue-ciprés forests extend from the 36º 30' S along the eastern slope of the Andes. Ciprés is the dominant species in xeric and low altitude areas, coihue dominates mesic and mid-altitude areas, while both species intermix and co-dominate in transitional zones between mesic and xeric areas, where they naturally coexist (Dezzotti, 1996). Within xeric sites, ciprés establishment is linked to the nurse protection effect that exerts a nearby shrub over a young ciprés seedling (Kitzberger *et al.,* 2000; Urretavizcaya & Defossé, 2013). In mesic areas, instead, ciprés seedlings establish under high herbaceous and shrub cover, in small and mid-sized gaps (Gobbi, 2007). Coihue is a shade-intolerant, pioneer species which in mesic areas of northern Patagonia, regenerates at small-scale openings (from 400 to 600 m^2) mainly produced by tree-falls (Veblen, 1989). However in Patagonia, there is a lack of knowledge about the effects of artificial openings in conifer plantations and their impact on seedling of native species planted for restoring former natural forests.

The hypotheses upon which this study was based are: 1) Canopy gaps performed on a *Pinus contorta* Dougl. (lodgepole pine, ~25 yr) planted in a former mixed ciprés-coihue native forest, significantly change micro-environmental conditions (soil moisture and temperature, and PAR) as compared to untreated monoculture and, 2) Different gaps types affect the performance (survival and growth) of both ciprés and coihue planted seedlings.

In order to test these hypotheses, we analyzed during two growing seasons (2010-2011 and 2011-2012), how small rectangular and small and medium circular canopy openings in a *Pinus contorta* plantation affects the: i) photosynthetic active radiation (PAR) and soil temperature and moisture; and ii) survival and growth of planted ciprés and coihue seedlings. The results will provide basic information for early stages of restoration of former mixed ciprés-coihue forests now occupied by exotic conifer monocultures.

Material and methods

Study area

The study site is located in Los Alerces National Park at 42° 43' S and 71° 43' W, and at 490 m.a.s.l. Climate comprises cold and rainy winters and dry and warm summers (Peel *et al.,* 2007). Mean annual precipitation and temperature are 1032 mm and 10 °C, respectively, whereas during the growing season from October to March reach 300 mm and 13 °C, respectively (INTA weather station, 43º 07' S, 71º 33' W, 1970 - 2009). Soil is classified as Inceptisols Vitrandepts, it derives from volcanic ash, and contains allophane and other amorphous materials (SAGyP– INTA, 2013). Within the lodgepole pine stand, soil presents a sandy loam A-horizon covered by a 3 to 4 cm- deep mantle of pine needles, and its topography is mainly flat.

In 1985, 2 ha of a ciprés-coihue natural forest was replaced by a lodgepole pine stand that, when the cutting treatments were established, exhibited in average 26 cm DBH and 22 m height, and 1000 trees ha^{-1} of density and 53 m^2 ha^{-1} of basal area.

Determining opening types using gap shape and gap size

In 2009, the pine stand was subjected to two cutting treatments, which included rectangular and circular openings. We selected 3 rectangular gaps (located in East-West direction) and 6 circular gaps, that were chosen based on their homogeneity with regard to relief and canopy protection. As a previous site preparation, the soil was scarified (~4 cm depth) to eliminate the seed bank of exotic species to avoid future germination and possible competition with the planted seedling (Orellana & Raffaele, 2010).

Nine openings were classified according the mean height of trees and the mean diameter (for circular gaps) or width (for rectangular gaps). This ratio (R) was calculated as (eqn. 1).

$$R = \frac{D}{H} \quad (1)$$

where D was the mean distance between the South-North and East-West edges of the gap (m) and H was the average height (m) of dominant trees with DBH > 10 cm that surrounded the gap (measured by a Vertex Laser instrument) (López Bernal *et al.*, 2010). The resulting ratios allowed determining three categories, together with the gap shapes: small rectangular gaps, and small and medium circular gaps (Albanesi *et al.,* 2008) (Table 1).

Seedlings used for restoration

Seeds came from local sources. Ciprés seeds were sown in a seed bed composed of mixed common topsoil of the area and volcanic sand in 1:1 proportion. The emerging seedlings remained in that seedbed for one year. At the beginning of the second year, ciprés seedlings were manually transplanted into individual 900 cm^3 (18 cm deep) polyethylene pots until they were planted in the field. Coihue seedlings were cultivated for a year in 250 cm^3 (13 cm deep) containers with a substrate composed of *Sphagnum* peat (Sphagnaceae) and volcanic sand in 2:1 proportion, until planted into the field. When transplanted to the field, ciprés seedlings (n=20) initial mean stem height and their standard error was 9.7 ± 0.4 cm, mean root length was 19.1 ± 0.2 cm and mean collar diameter was 2.4 ± 0.1 mm. Coihue seedlings (n=20) had a mean initial stem height of 52.6 ± 2.1 cm, mean root length was 20.1 ± 0.7 cm and mean collar diameter was 5.2 ± 0.2 mm. Stem height (cm) and collar diameter (mm) were respectively measured with a graduated ruler and a digital caliper (Digimess brand). Seedlings were then planted in 15 cm-wide by 22 cm-deep shovel-made holes, and covered with the same soil.

Plantation design

Three plots were set up within each category or gap type (see table 1) as repetition. In July 2010, six subplots (20 m^2) were established inside each rectangular plot, in which 6 ciprés and 6 coihue seedlings were planted randomly, resulting in 72 seedlings per rectangular gap. Similar to what was done in rectangular gaps, five subplots (12 m^2) were established and planted with 6 ciprés and 6 coihue seedlings inside each circular plot. This resulted in 60 seedlings per circular plot (Fig. 1).

Environmental variables and seedling measurements

We measured PAR at bimonthly intervals and soil temperature and soil moisture at monthly intervals dur-

Table 1. Shapes and sizes of the gaps

Gap shape	Mean gap diameter or width (m) (a)	Surrounding tree height (m) (b)	Ratio (a/b)	Gap size
Rectangular gap	9.00	18.40	0.49	Small
	10.00	17.90	0.56	Small
	11.00	18.00	0.61	Small
Circular gaps	10.17	17.63	0.58	Small
	12.90	26.98	0.48	Small
	15.04	24.17	0.62	Small
	14.56	17.45	0.83	Medium
	17.29	19.02	0.91	Medium
	18.69	26.45	0.71	Medium

ing both growing seasons (from November 2010 to April 2011; and from November 2011 to April 2012). This was done for each plot and in the other three areas (4 m^2) delimited inside the pine plantation and without any intervention (control).

PAR was registered with a ceptometer (Cavadevices brand), 1 m above the ground at noon. Soil temperature was registered by a Digi-Sense (Cole-Parmer Instrument Co.) thermocouple thermometer at 10 cm soil depth, while soil moisture was recorded with a TDR Imko Trime FM3 that measured from 0 cm to 16 cm of soil depth. These two soil depths were chosen because they coincided with the location of the bulk of seedling´s root system of both species at the time of plantation. Measurements were taken in the center of each small and medium circular gaps, and in middle subplots of each rectangular gaps and controls (Fig. 1).

One month after plantation, we determined seedling stem height and collar diameter for all plants located in the north, center and south plots. These measurements were repeated again at the end of the first and second growing seasons to determine seasonal growth increments. The relative growth (RG) was calculated (eqn. 2):

$$RG = \frac{x_1 - x_0}{x_0} \times 100 \quad (2)$$

where x_0 y x_1 are the measured variables (stem height and collar diameter) at time 0 (beginning) and 1 (end) of the growing season. The result is then multiplied by 100 to relate it to the percentage increase as compared to initial values.

Seedling survival (S) was also determined at the end of both growing seasons at 2011 and 2012. It was calculated as percentage (eqn. 3):

$$S = \left(\frac{F}{I}\right) \times 100 \quad (3)$$

where F is the number of alive seedlings at the end of the season and I is at the beginning of each season.

Statistical analyses

PAR, soil temperature and soil moisture were analyzed using multivariate analysis of variance for repeated measures, among two factors: treatments (gap type + control) and time (Park *et al.,* 2009). The levels of the treatment factor correspond to small rectangular gaps, small and medium circular gaps and control, and the levels of the time were the seasons from spring to fall for PAR variable, and the months from October to March for soil temperature and soil moisture. If the analyses gave significant differences among levels of treatments, they were compared using the HSD Tukey test (SPSS, 2007).

Survival for each species was analyzed with the Chi-Square test of homogeneity in both growing seasons. Stem height and collar diameter growth at the end of both growing seasons, were evaluated with one-way analysis of variance with the initial height or diameter as a co-variable. As there were no planted seedlings in the control plots, the levels of the factor “gap type” for survival and growth analyses were: small rectangular gaps, small, and medium circular gaps. Since collar diameter growth data for ciprés seedlings after the second growing season did not meet the assumptions of homogeneity of variance, they were transformed by $\log_{10}$. The Tukey – Kramer´s

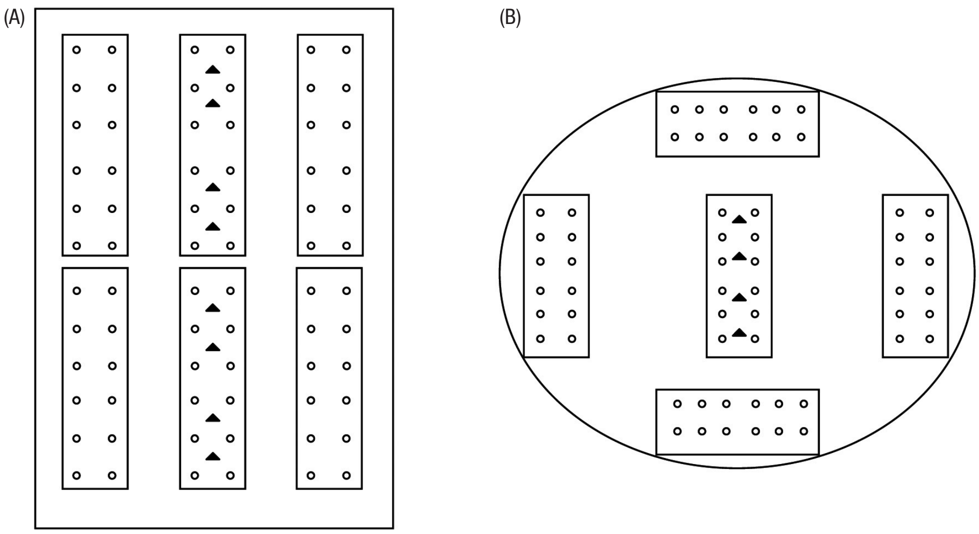

Figure 1. Experimental design for rectangular (A) and circular (B) gaps with six and five subplots, respectively. In each subplot, the circles represent seedlings. Triangles are the PAR, soil temperature and moisture measurement points.

test was used to determine differences among gap types (Balzarini *et al.,* 2008).

Results

Photosynthetic active radiation

In general, PAR decreased from late spring to fall, except for the control, which remained constant during the two seasons analyzed (Fig. 2). During the first growing season, PAR showed significant differences among treatments and time, while the interaction between them was not significant (Table 2). Medium circular gaps presented significantly higher PAR values (462.2 ± 119.0 µmol m^{-2} s^{-1}) than the control (49.4 ± 13.4 µmol m^{-2} s^{-1}). During the second growing season, PAR showed significant differences among treatments, time, and their interaction (Table 2). Taking into account that the interaction was significant, we analyzed the treatments for each date. In spring of 2011, PAR in medium circular gaps was significantly higher than in small circular gaps and, together with rectangular gaps, it was higher than the control. In fall, rectangular gaps showed significantly higher PAR values (56.4 ± 1.4 µmol m^{-2} s^{-1}) than all other treatments.

Soil temperature

At the beginning of the first growing season after setting the experiment (2010-2011), soil temperatures showed a high dispersion in mean values among treatments, although they were not significant (Fig. 3). These temperatures converged, and showed the same trend for all treatments for the rest of the first and during the whole second season. Soil temperatures were significant through time and the interaction between treatments and time ($F_{3;8}$=3.5; $F_{4;5}$=187.5; p<0.01). Soil temperature reached a maximum of 18 °C in mid- summer of both growing seasons, and decreased to their lowest values at the beginning of the fall (Fig. 3).

Soil moisture

During both growing seasons, soil moisture showed, in general, a declining trend as the growing season

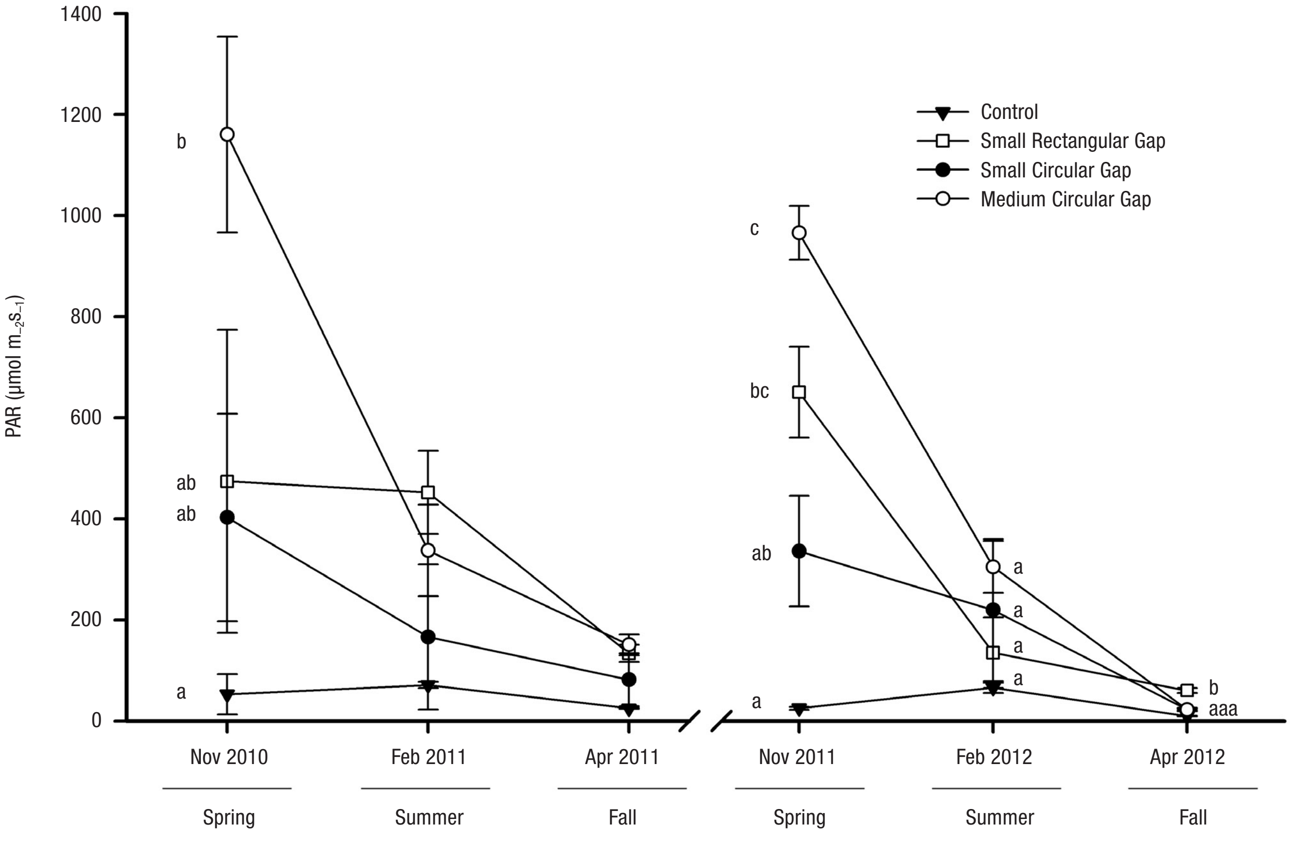

Figure 2. Photosynthetic active radiation (PAR) for each treatment during the first (left) and second (right) growing seasons. Vertical bars indicate the standard error of the mean and different letters indicate significant differences among treatments (Tukey test, p<0.05). In the first season, the letters compare the whole season.

Table 2. Results for the Wilks (MANOVA) test for photosynthetic active radiation during the first (2010-2011) and second (2011-2012) growing seasons

Growing Season	Source of Variation	Statistical	F	Numerator df	Denominator df	p
First	Gap	0.30	6.20	3	8	0.01
	Time	0.30	8.20	2	7	0.01
	Interaction	0.25	2.30	6	14	0.09
Second	Gap	0.08	28.70	3	8	<0.01
	Time	0.04	94.80	2	7	<0.01
	Interaction	0.06	7.60	6	14	<0.01

advanced, reversing it in early fall when the rainy season begun (Fig. 4). Soil moisture presented significant differences among treatments and time ($F_{3;8}$=551.7; $F_{4;5}$=30.2; p<0.01); all opening types presented significantly higher soil moisture values than the control. During the first growing season, medium circular gaps showed consistently higher values (although not significantly different) as compared to rectangular openings and/or small circular gaps. In summer 2011, we registered the lowest value of soil moisture, when the difference was near 15% in volume with respect to the control. In summer 2012, soil moisture presented a peak that reached 30% in volume, due to an unusual precipitation event, that accounted for 15% of the average annual precipitation (Fig. 4).

Seedling survival and growth

Both species showed high survival during the two seasons analyzed. During the first growing season, ciprés seedlings showed 97, 100, and 96% survival for small rectangular openings, small and medium circular gaps, respectively. For the second growing season, survival values were 95, 96, and 94% for the same gap types, respectively. These values showed no significant differences among gap types (χ^2=1.7 and χ^2 =0.9; p>0.05). For coihue seedlings and during the first growing season, survival rates were similar than those of ciprés for small rectangular gaps (99%) and small circular gaps (98%), while it was significantly lower (χ^2=11.5; p<0.01) in medium circular gaps (88%). For the second growing season, coihue seedling survival was 99, 96, and 86% for rectangular gaps, small and medium circular gaps, respectively. These values did not significantly differ among gap types (χ^2=18.0; p>0.05).

Related to stem height growth, ciprés seedlings did not show significant differences among gap types at the end of both seasons. Collar diameter growth in the first season, however, was significantly higher ($F_{2;6}$=9.3; p<0.05) for seedlings grown in rectangular openings than for those grown in circular gaps (Table 3).

Coihue stem height growth showed no differences among gap types, but collar diameter growth during the first season was higher ($F_{2;6}$=8.5; p<0.05) in seedlings grown in the rectangular gaps as compared to the other two gap types (medium and small circular gaps) (Table 3).

Considering the relative stem height growth during the first season, ciprés showed an increase of 60% with respect to the original height in circular gaps, while in rectangular openings this increase exceeded the 100%. In the second season, this percentage was high (90%) in all opening types. The relative collar diameter growth of ciprés seedlings presented a 30 to 40% increase as compared to the initial diameter for all opening types in the two seasons. For coihue seedlings and during the first growing season, this increase only represented 15% of the original height for all gap types, but it increased to 70% in the second season. Similar response was obtained with the relative collar diameter growth.

Discussion

In our study, the measured micro-environmental conditions inside the *Pinus* plantation varied with respect to those in the different gap types. Photosynthetic active radiation and soil moisture were lower below *Pinus* canopy as compared to rectangular or circular gaps, although soil temperature at 10 cm depth was similar in all treatments. Within gap types, medium circular gaps presented significantly higher values of PAR as compared to small circular gaps, while rectangular gap presented intermediate values. In general within pine plantations, PAR reaching the soil surface depends on tree density and height, diminishing as canopy closes and approaches the lower stratum (Donoso Zegers, 1997; Holst & Mayer, 2005). Our study showed that higher amounts of PAR occurring in medium circular as compared to small circular gaps,

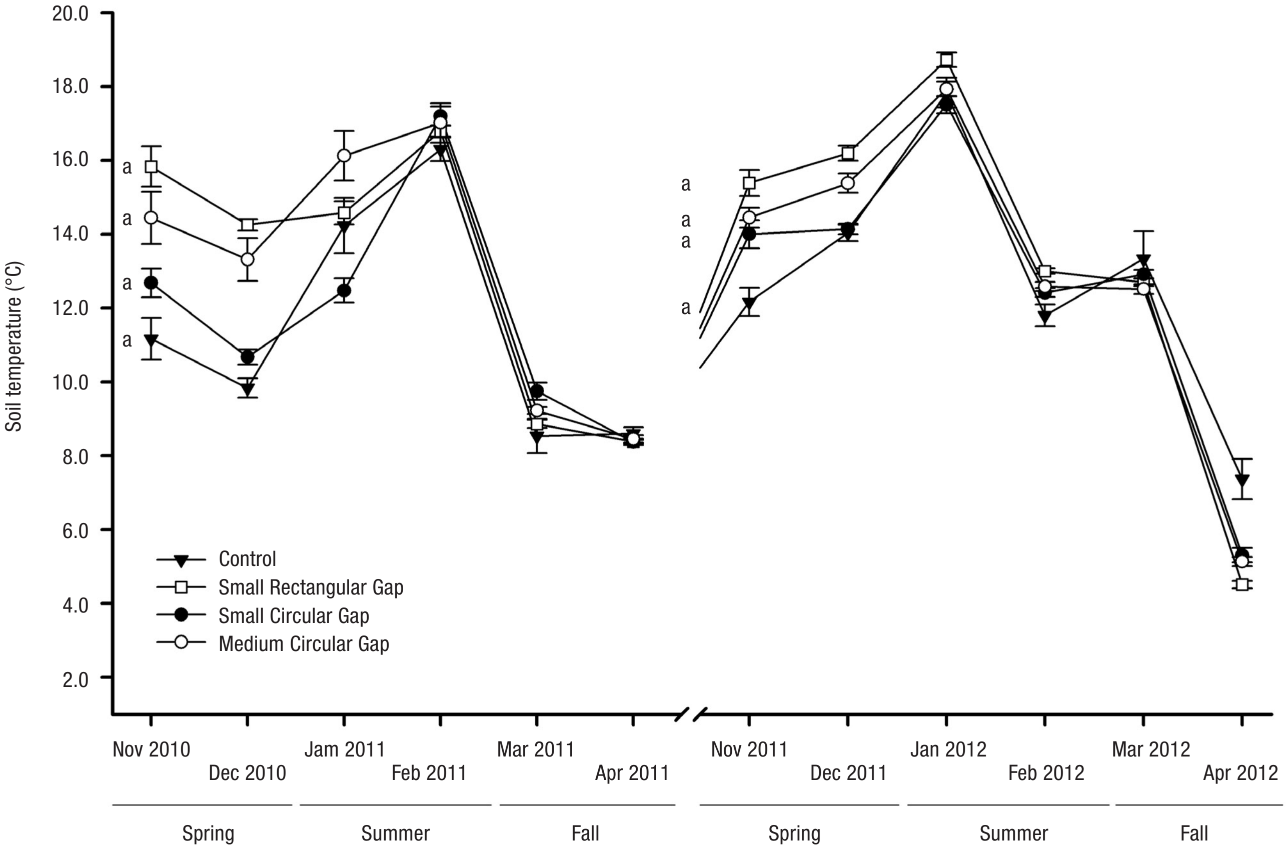

Figure 3. Soil temperature for each treatment during the first (left) and second (right) growing seasons. Vertical bars indicate the standard error and different letters indicate significant differences among treatments (Tukey test, $p<0.05$). In both season, the letters compare the whole season.

may have been directly influenced by size opening and sun position. Similar results have been reported by Gálhidy *et al.* (2005) in *Fagus* spp. forests. These authors found that the border of big gaps received similar values of incoming light as the center of smaller gaps. In general, incoming light passing through tree canopies in radiation angles lower than 90° reached the soil surface as diffuse light in small circular gaps, and as direct light in medium circular gaps (Donoso Zegers, 1997).

In our study, the particular shape and orientation of rectangular gaps (the longest side from east to west direction) may have favored the occurrence of subtle changes in other macro- and micro-environmental conditions. In Patagonia, the winds blow most of the time from the west, increasing their speed during the growing season (Defossé, 1995). The long and narrow shape of rectangular gaps and their orientation may have facilitated wind movement (Gómez Sanz, 2004), thus producing that shorter and more frequent sunflecks reached the ground, producing a more dynamic light distribution (Pearcy, 1990). Also the combination of rectangular gap width, tree height, and vegetation density, could have interfered with the wind flow and created little swirls than could have affected the temperature of the area (Oke, 1988). Related studies in the region are needed to explore the real effects of wind in gaps on the environmental variables.

Besides the possible wind effects, the east to west location of rectangular openings made them receiving similar or even higher PAR values than circular gaps at the end of the growing seasons. In fact, these values were similar at the end of the first growing season, but were significantly higher in rectangular openings as compared to circular gaps at the end of the second season (see Fig. 2). These significantly higher PAR values may have been related to the rapid decrease of daylight occurring at this latitude (42° 43’ S) at the beginning of the fall (Donoso Zegers, 1997). Because of their east to west location, rectangular openings continued receiving sunlight after it has vanished in either medium or small circular gaps. Also, the light received may have also been affected by the tree density of the stand. To cast light on this issue, it is important therefore, to conduct further studies with different tree densities.

The association between soil temperature and light, as a response to canopy openings, has been described

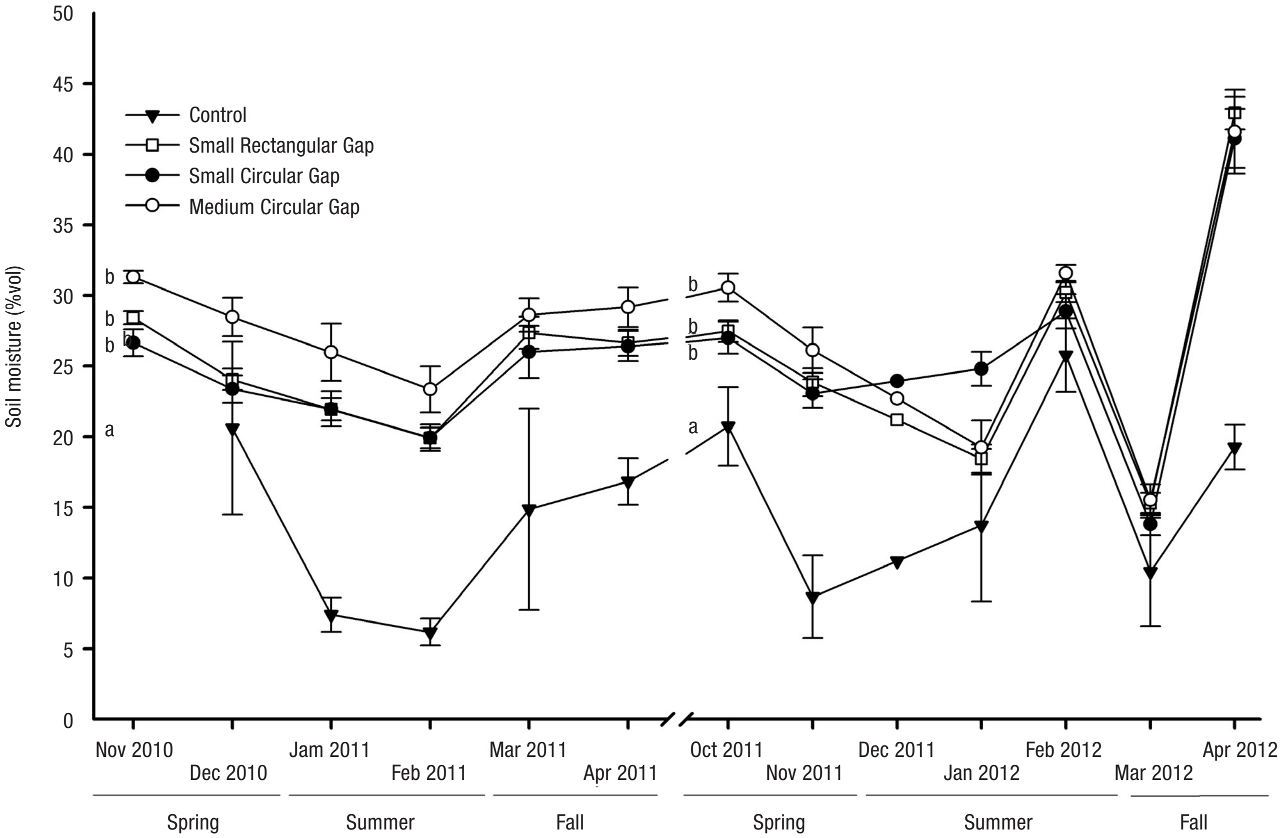

Figure 4. Soil moisture for each treatment during the first (left) and second (right) growing seasons. Vertical bars indicate the standard error and different letters indicate significant differences among treatments (Tukey test, p<0.05). In both season, the letters compare the whole season.

by several authors (Donoso Zegers 1997; Gray *et al.,* 2002; Brang *et al.,* 2005; Muscolo *et al.,* 2010). In general, large openings present higher increases in soil temperature and incoming light as compared to small openings and/or in the unmodified control. Also, and because of canopy shadow effects and organic matter accumulation on the soil surface, soil temperatures are in general lower in closed areas as compared to canopy openings (Breshears *et al.,* 1998; Muscolo *et al.,* 2007). Along the two seasons analyzed, our data showed that all gap types presented similar soil temperatures (at 10 cm depth) than those inside the *Pinus* plantation (control). It should be remembered, however, that when the experiment was set after the cutting treatment, the soil was scarified. This uneven pine needle removal product of this scarification, could have produced dissimilar soil temperature values among gap types at the beginning and up to mid-summer of the first growing season. As the season advanced and succession progressed, the soil started to be covered by herbs and grasses; as a consequence, these differences disappeared (see Fig. 3).

Related to ambient temperatures, during the two growing seasons analyzed, mean temperatures were slightly above the long-term average (2.2 °C higher). The 10-cm depth soil temperatures registered during the summer of both seasons, suggest that top soil temperatures never reached elevated temperatures as to compromise survival of either ciprés or coihue seedlings. The lower seedling survival found during the first growing season for coihue in medium circular (88%) as compared to rectangular openings (99%) or small circular gaps (96%), may have been caused by the unusual frost period occurred one month after plantation. In effect, mean minimum ambient temperatures remained below 0 °C during the whole month of August (average of –2 °C), as compared to the long-term mean of 0.1 °C. We assumed that this unusual frost may have increased coihue seedling mortality in the less "environmentally protected" medium circular gaps (more exposed to frost effects) than in the other two gap types.

Soil moisture was similar in the three different gap types, being significantly higher than the one registered within the *Pinus* plantation. These results are in accordance with those reported by Albanesi *et al.* (2008) when comparing soil moisture in the center of circular gaps with those found within the surrounding *Abies* stand plantation. In both cases, soil water diminution within plantations as compared to open gaps could be clearly

Table 3. Height and diameter growth of seedlings on each gap type at the end of first and second growing seasons. Different letters show significant differences for collar diameter growth among gap types and within species (ANOVA, p<0.05)

Specie	Gap type	First season		Second season	
		Height growth (cm/yr)	Diameter growth (mm/yr)	Height growth (cm/yr)	Diameter growth (mm/yr)
Ciprés	Small Rectangular	9.2±0.9	0.9±0.0a	13.3±2.7	0.9±0.0
	Small Circular	5.7±1.0	0.7±0.0b	17.3±2.9	0.9±0.0
	Medium Circular	5.6±1.4	0.7±0.1b	14.2±3.0	0.9±0.2
Coihue	Small Rectangular	9.4±3.1	1.4±0.1a	41.6±3.3	3.0±0.1
	Small Circular	5.8±2.9	0.7±0.0b	23.2±2.2	1.8±0.2
	Medium Circular	6.1±2.7	0.8±0.2b	29.1±8.9	2.1±0.9

explained by the tree canopy effects. In fact, precipitation is intercepted by the canopy, following then different paths (stem flow, evaporation, etc.), and reducing water amounts that reaches the open ground (Kimmins, 1997).

Considering the combined effects of PAR, soil temperature and soil moisture on seedling survival and growth, results showed that maximum soil temperatures were achieved when soil water was at a minimum, and PAR declined to medium values. In forest ecosystems with high luminosity, direct sunlight during many hours reach different points of the understory, and may generate photo-inhibition in plants adapted to low radiation such as ciprés (Pearcy, 1990). Ciprés is a shade–tolerant specie (Gyenge *et al.,* 2007), whose transpiration rate is restricted through stomatal closure, so the capacity of cooling is limited and therefore susceptible to heat stress (Gyenge *et al.,* 2007). For this reason, in their first years as seedlings, ciprés grows better under the protection of a nurse plant (Gobbi, 2007).

Related to collar diameter growth, significantly higher values were shown during the first season by both ciprés and coihue seedlings grown in rectangular as compared to circular gaps. This higher relative growth was later compensated, showing all gap types similar values at the end of the second growing season. A larger seedling collar diameter may help improve root system function, by increasing the absorption capacity of water and/or nutrients (Mexal & Landis, 1990; Letourneau, 2006). Related to water availability, mean precipitation in the first growing season was 42% higher than the mean for the second growing season. This higher water availability may have produced favorable conditions for growth of root collar and hence for root biomass (Ericsson, 1995). In the second season, coihues' height in rectangular openings reached 40 cm, while in the circular gaps it only reached from 20 to 30 cm. These differences, however, were not significant, because of the high variance in growth recorded in the medium circular gaps. This tendency to grow higher in height and diameter in rectangular and medium circular openings as compared to small circular gaps, may be explained by the fact that small circular gaps received lower amounts of PAR during the early growing season. This coincides with the study by Donoso *et al.* (2013), who found that coihue seedlings grew more in diameter and height in medium circular gaps as compared to small ones. Confirming these findings, Lusk & del Pozo (2002) found that survival and growth of seedlings of coihue and other 11 Chilean rainforest trees increase as light in the gaps increase. Coihue presents a great efficiency in photochemical and CO_2 assimilation in sunny days with highly radiation values. Besides coihue present higher accumulation of photoprotective pigments, which contribute to the mechanism for thermal dissipation in case of excess of energy under high light (Zuñiga *et al.,* 2006). However and for the species grown in our region, it seems that more studies involving the addition of more frequent measurements of light quality (direct and diffuse light) during the growing season, may be needed to help elucidate these uncertainties.

With regard to which one of the three opening types may be recommended for future silvicultural treatments, results showed that two growing seasons after planting, both ciprés and coihue seedlings presented similar survival and growth rates regardless of the shape and size considered. Other studies in Patagonia involving seedling plantations in natural gaps of native forests indicate that their size varied, related to dominant height, from ratios of 0.5 to 1.5, or more (Dezzotti *et al.,* 2003; Donoso *et al.,* 2013). In our study, and irrespective of the shapes, these artificially created gaps varied in their height:width ratio from 0.47 to 0.90 (min-max) in the *Pinus contorta* stand analyzed. Through meta-data analyses, Zhu *et al.* (2014) showed that for plant establishment (as compared to nearby controls), the effect of gap size is more important in artificially created gaps than on natural gaps.

Although this study was conducted in only one plantation (with 1000 tree ha^{-1} in a plain area) and on a small range of opening sizes (small and medium), it represents a valid approach to recover the natural forest based on a silvicultural technique applied to an exotic pine plantation. It seems then that other openings sizes, emphasizing on rectangular shapes, should be experimented in the future in other Patagonian plantations. Also other tree densities should be evaluated for better understanding its effects on the micro-environmental conditions such as radiation and soil moisture. This aspect may help define silvicultural treatments in restoration plans in Patagonia or elsewhere, involving the re-conversion of plantations into former native forests.

Acknowledgements

Authors greatly appreciate field assistance provided by María-Florencia Oyharçabal, Guillermo Omad, Carolina Toledo, Daniela Morales, Tania Figueroa, Etelvina Violi, and Sergio Pérez-Gorjón. Authors also thank Los Alerces National Park and UNPSJB for accommodation near the field site, and their park rangers for plantation assistance.

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