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RESEARCH ARTICLE

Effect of Sowing Season, Plant Cover, and Climatic Variability on Seedling Emergence and Survival in Burned *Austrocedrus chilensis* Forests

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Abstract

Fire is the most important disturbance factor in Cypress (*Austrocedrus chilensis*) forests in Patagonia, Argentina. This ecosystem recovers poorly after fire, and direct sowing could be a potentially useful restoration practice. To evaluate the effect of season of sowing, post-fire plant cover (PC), and climatic variability on seedling emergence and survival, three direct sowing studies were established in two burned cypress stands: Trevelin (xeric conditions) and El Bolsón (mesic conditions). Two studies were conducted in winter (2000 and 2001) and one in spring (2001). Precipitation was higher than the mean during the 2000–2001 growing season and lower during 2001–2002. At both sites, emergence and survival were much higher for winter- than for spring-sown seedlings. In the xeric stand, emergence and survival of winter-sown seedlings increased with medium and high PC values, after the humid and dry summers, respectively. However, most spring-sown seedlings did not emerge, and those that did were short-lived. Because of the more favorable growing conditions in the mesic stand, PC had no effect on emergence and only favored first year survival of winter-sown seedlings after the dry summer. Spring-sown seedlings showed no association with PC in the mesic site, probably because the first summer was exceptionally humid. We speculate that shading plants exert a positive effect on cypress seedling establishment, likely by reducing the stress from high temperatures and low water availability. Sowing of small patches under the protection of understory vegetation could be useful in restoring burned cypress stands.

Key words: **ciprés de la cordillera, direct seeding, fire, restoration ecology, seedling emergence, seedling survival.**

Introduction

Andean cypress (*Austrocedrus chilensis* (D. Don) Pic. Serm. et Bizzarri), ciprés de la cordillera in Spanish, is a native conifer in the Andean temperate forests of southern South America. Although some trees of this species can reach 1,000 years of age on the western slope of the Andes in Chile (LaMarche et al. 1979), individuals older than 400 years are rare on the eastern slopes in Argentina (Villalba 1995). About 80% of all cypress forests (140,000 ha) are located on the eastern side of the Andes, in a narrow strip between 37° 08′ 09″ and 43° 43′ 57″ South latitude (Bran et al. 2002). In the rain shadow of the Andes in Argentina, western sites are much more humid than eastern ones. Because cypress reproduces almost exclusively by seed, regeneration is contingent upon the chance of seeds finding "safe sites" (*sensu* Harper 1977) to successfully germinate and become established. Regeneration depends on several factors such as availability of germinable seeds (constrained by distance from the mother tree, which has low dispersal capacity) (Veblen et al. 1995), a transient seed bank (Urretavizcaya & Defossé 2004), occurrence of favorable weather periods (Villalba & Veblen 1997a) and the presence of a propitious soil microsites. On unburned sites, the protection provided by understory vegetation seems to benefit cypress stand recruitment (Gobbi 1999; Rovere 2000).

Although different disturbances (earthquakes, wind, herbivory, fire) influence cypress forests dynamics, fire is considered the most important one (Veblen et al. 1996). The reduction in fire frequency caused by the suppression policy implemented in the 20th century, allowed for the accumulation and continuity of fine fuels in the stands, increasing the probability of larger and more intense fires (Kitzberger & Veblen 1999). During the past 25 years, fire affected 110,000 ha of native forests within the range of cypress forests in the Río Negro and Chubut provinces, about 18,000 ha of which were cypress stands. Forest fires usually are of anthropogenic origin (accidental and/or intentional), and rarely occur due to natural causes (DGByP 2009).

After a fire event, cypress establishment is mainly influenced by site conditions, occurring relatively more rapidly on humid

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and mesic sites than in xeric areas (Kitzberger et al. 2000; Veblen et al. 1995). In burned areas, the biomass consumption and vegetation cover reduction increase soil temperature, and this effect persists for several years. Also, burned areas show significantly fewer germinable seeds than unburned areas (Urretavizcaya & Defossé 2004). High soil temperatures and low seed availability reduce the possibility for seeds to find safe sites. This synergistic effect is more severe on xeric sites, reducing the chances of seeds germinating and becoming established (Urretavizcaya et al. 2006).

Between the 1950s and the 1980s, burned native forests began to be replaced by exotic species such as ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.), radiata pine (*Pinus radiata* D. Don), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) (López & Hranilovic 1966). Some of these exotic species, which have the capacity to out-compete native pioneer species in burned environments (Sarasola et al. 2005), began exhibiting invasive behavior. Recent studies demonstrated that biotic factors, such as species invasion, could result in the loss of connectivity to native seed sources, which are essential elements in the natural restoration of disturbed sites (Suding et al. 2004).

When disturbed areas are being degraded, ecological restoration becomes an important conservation strategy allowing for the recovery of natural processes in these ecosystems (Clewell 2000). Restoration of degraded areas could be optimized by applying techniques based on the natural ecosystem functioning (Whisenant 1999). It is well known that the structure and composition of vegetation communities are strongly influenced by positive interactions among plants or "facilitation" (Callaway & Walker 1997). This process is particularly relevant in areas exposed to strong environmental stress (Bertness & Callaway 1994). Generally, under favorable conditions (e.g. humid and mesic areas) spatial closeness among plants may produce negative effects (competition) (McAuliffe 1984; Holzapfel & Mahall 1999; Berkowitz et al. 1995), whereas under unfavorable conditions (e.g. arid, semiarid, or ecotonal areas) the proximity of shrubs could have positive effects (facilitation), favoring seedling establishment (Keeley 1992; Chambers et al. 1999).

Weather conditions also influence seedling establishment, this effect being more evident in arid or semiarid areas than in mesic environments (Veblen et al. 1995; Baumeister & Callaway 2006). The relationship between facilitation and weather conditions during the stages of germination and early seedling establishment seems to be essential to plant regeneration success (Greenlee & Callaway 1996; Kitzberger et al. 2000). In Patagonia, studies carried out on xeric sites, 15 years after burning, showed that cypress natural regeneration is favored by the presence of shrubs acting as nurse plants (Kitzberger et al. 2000) that improve the microenvironment for cypress seedling germination and establishment. Nonetheless, on recently burned sites (burned within the past 10 years) the association between post-fire plant cover and seedling establishment has not been studied.

Restoration practices could allow for the recovery of disturbed ecosystems (Hobbs & Harris 2001; Suding et al. 2004; King & Hobbs 2006). The use of facilitative interactions between a nurse plant and the species of interest has been proposed as a successful restoration technique for different environments (Maestre et al. 2001; Padilla & Pugnaire 2006). The most common approach to restore disturbed forests is to plant seedlings, but an alternative technique which is slowly being adopted in restoration ecology is direct sowing (Sun et al. 1995; Guariguata & Pinard 1998; Ammer et al. 2002; Camargo et al. 2002; Doust et al. 2006). Direct sowing is easier, simpler, and cheaper than planting seedlings (Engel & Parrotta 2001; Doust et al. 2006). However, sometimes direct sowing can present some disadvantages such as low germination, low survival owing to competing vegetation and slow growth, as compared with nursery seedlings (Engel & Parrotta 2001; Doust et al. 2006). There are a few studies on cypress direct sowing, and results are not consistent (Gobbi & Sancholuz 1992; Kitzberger et al. 2000).

Considering that post-fire vegetation can provide microenvironments with suitable conditions for regeneration, the objective of this study was to determine the effect of season of sowing, plant cover, and climatic variability on the emergence and survival of cypress seedlings established by direct seed sowing at two burned cypress forest stands in northern Patagonia, Argentina.

Methods

Study Sites

The trials were carried out in 2000 and 2001 at two burned cypress stands. One was located near the town of Trevelin, Chubut province (latitude 43° 12′ 57″ S and longitude 71° 31′ 15″ W); this site had burned in 1996. The other was close to the city of El Bolsón, Río Negro province (latitude 41° 59′ 02″ S and longitude 71° 33′ 20″ W) and had burned in 1999. Both fires were accidental, and vegetation and climatic characteristics of each site were different (Table 1). At the El Bolsón site, there were 1,540 dead trees per hectare (25 m^2/ha of basal area), whereas at the Trevelin site, there were fewer snags, 350 per hectare (10 m^2/ha of basal area), because the fire event had been more recent (Fig. 1). Salvage logging was not carried out at either site.

At the Trevelin site, the most conspicuous post-fire plant species were native shrubs such as laura (*Schinus patagonicus* (Phil.) I. M. Johnst.), retamo (*Diostea juncea* (Gillies ex Hook.) Miers), chacay (*Discaria trinervis* (ex Hook. and Arn.) Geim.), and calafate (*Berberis heterophylla* Juss.), as well as grasses of the genera *Holcus*, *Stipa*, and *Agrostis*. At the El Bolsón site, the most important post-fire species were the shrub maqui (*Aristotelia chilensis* (Molina) Stuntz); the herbs lengua de vaca (*Rumex acetosella* L), cardo (*Cardus nutans* L.), facelia (*Phacelia secunda* J.F. Gmel.), lechuga espinosa (*Lactuca serriola* L.), and *Galium* sp.; and the grasses pasto miel (*Holcus lanatus* L.), and pasto ovillo (*Dactylis glomerata* L.).

Table 1. Climate characteristics of both sites.

Climatic Characteristics	*Trevelin*	*El Bolsón*
Mean temperature of hottest month: January (°C)	14.4	16.2
Mean temperature of coldest month: July (°C)	1.6	3.6
Average annual precipitation (mm/yr)	683.7	920.8
Average precipitation of the dry period: Sep-Feb (mm)	200	250
Predominant winds	W	SW

Information source for Trevelin: Arbuinés (1998); for El Bolsón: Bustos and Rocchi (1993).

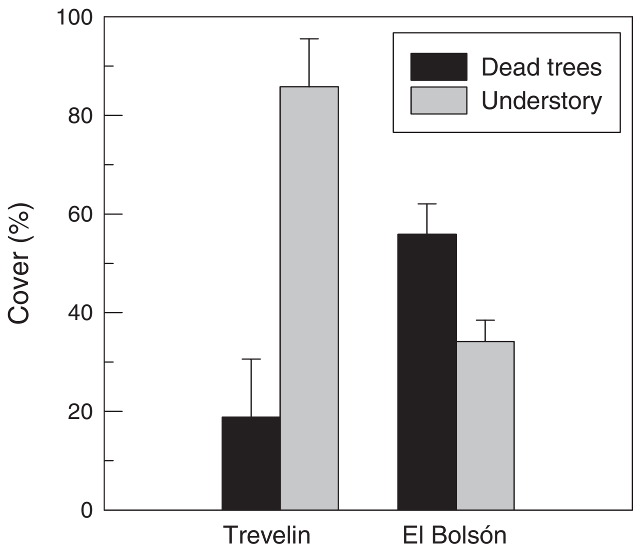

Figure 1. Dead trees and understory (shrubs, grasses, and forbs) cover at each site at the start of the trials.

Seed Collection and Pre-germination Treatments

Seeds used in the trials were collected at the end of summer 2000 at both study sites. Branch tips were cut off when fruits turned brownish and started opening, both signs of cypress seed maturity. Fruits were then naturally dried by leaving them outdoors on trays for about 2 weeks, after which seeds were cleaned by hand. There were 253,165 and 270,270 seeds per kilo, with a germination rate of 91 and 95%, at the Trevelin and El Bolsón sites, respectively (Urretavizcaya et al. 2001). Only 6 and 2% of the seeds showed some kind of damage at the Trevelin and El Bolsón sites, respectively, and only 3% of them were empty at each site. Damage was mainly produced by microlepidoptera insects. Only seeds considered filled, healthy, and without signs of damage were used for the studies. Prior to sowing, the seeds were subjected to a 30-day cold-moist stratification treatment in a laboratory to assure homogeneous germination. Since laboratory stratification is completed in about 45 days (Contardi 1995) the process was completed in the field.

Experimental Design

At each study site, three sowing trials were conducted; two in 2000 and one in 2001. At each site, the year 2000 2-year trials were initiated at the end of winter (4 and 5 September) and spring (25 and 26 October). The objective of having winter and spring sowing trials in 2000 was to evaluate a possible sowing time effect on seedling emergence and survival. The dates were chosen to mimic natural cypress germination events occurring on undisturbed sites (Gobbi 1999). The 2001 trial was established at the end of the winter (3 and 5 September) at both sites. The objective of installing winter sowing trials in two consecutive years was to detect any association between summer conditions, mainly precipitation, and seedling emergence and survival.

Both year 2000 trials were established within a rectangular 80 by 4 m area at each study site. Sampling units were 16 furrows per trial. Furrows were 30 cm long, and 31 or 61 seeds were sown in each for the winter and spring trials, respectively (Fig. 2). A total of 496 seeds were sown in winter and 976 seeds in spring at each site. The year 2001 trial was also established within a rectangular 80 by 4 m area at each study site; however, in this case sampling units were two furrows. They also were 30 cm long but contained 50 seeds each, with 100 seeds per sampling unit and a total of 1600 seeds at each site. For the six studies, furrows were established to include a wide range of plant cover (0–100%), mainly provided by shrubs and grasses in Trevelin and standing dead trees and grasses in El Bolsón (Fig. 1). Although the treatment (plant cover) was not randomly assigned to each sampling unit, they were assumed to be independent replicates owing to the small size of the furrow and seed, as compared with size of the study area and the distance between sampling units. Before sowing, the upper 10 cm of the soil was turned over with a small rake to facilitate root development and water infiltration. Immediately after sowing, each furrow was covered with a thin layer of soil and irrigated with 0.25 L of water.

Data Collection and Analyses

We compared precipitation and temperature measurements recorded during the two growing seasons of the trials (2000–2001 and 2001–2002) with the long-term means (Table 1). Information was obtained from two weather stations located close to the study sites: the Chubut Province Fire Department Station, located 13 km from the Trevelin study site, and the Río Negro Province Water Department Station, located 2 km from the El Bolsón study site.

Similar measurements were taken during the three studies at each site. Each year at the end of the spring (December), we determined plant cover at each sampling unit with a spherical densiometer. During the first growing season, we monitored the number of seedlings that emerged, as well as their survival every 15–20 days. Seedling survival was also determined in the fall (April) and spring (September) of 2001, and in the fall (April) of 2002. For both year 2000 trials, we registered the number of whorl branches on a sample of five seedlings from each sampling unit. Seedling emergence was calculated as the

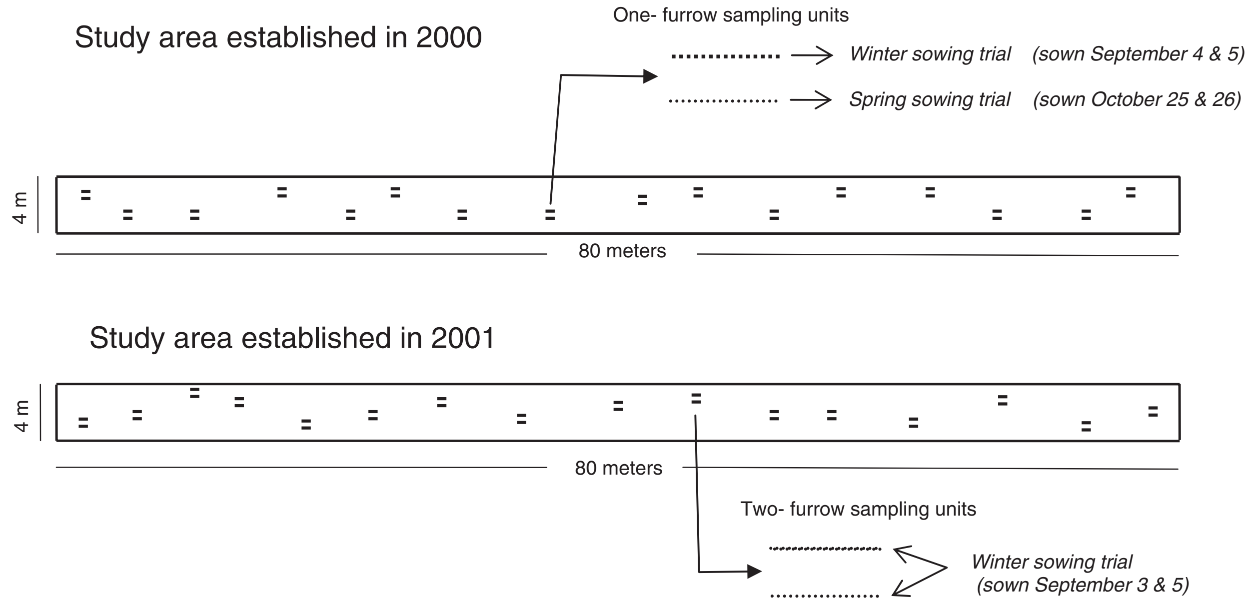

Figure 2. Layout of the sampling units established for the 2000 and 2001 studies at each site.

percentage of seedlings that emerged 90 days after sowing in relation to the total seeds sown. First-summer survival was defined as the percentage of live seedlings at the end of the first summer in relation to the number of plants that emerged. Winter survival was defined as the percentage of live plants at the end of the winter in relation to the number of plants alive at the end of the first summer. Finally, second-summer survival was determined as the percentage of live seedlings at the end of the second summer in relation to those alive at the end of the previous winter. For the 2001 trials, only emergence and 1SS were evaluated.

To compare emergence, survival, and sowing success between the two sowing seasons studies (winter vs. spring) we grouped the information by site and growing season regardless of plant cover. Linear regression was performed to determine if cover conditions were associated with seedling emergence, first summer survival, winter survival, and second summer survival for the year 2000 studies and with seedling emergence and first summer survival for the year 2001 studies. We transformed the equations to account for heteroscedasticity. For the 2001 winter sowing experiment at Trevelin, the response variable first summer survival was transformed (1/(first summer survival + 1)) to reduce heterogeneity of the variance owing to the presence of values equal to zero.

Results

Environmental Conditions

In Trevelin, during the first growing season (2000–2001) precipitation was 87% higher and mean temperature was slightly above the respective historical means. In El Bolsón, precipitation was 56% higher and temperature was slightly lower than the respective long-term means. During the second growing season, both study sites had considerably lower precipitation values (49% at Trevelin and 60% at El Bolsón) and higher mean temperatures than the respective long-term means (Fig. 3). Coincidentally, in accordance with other studies (Kitzberger et al. 2000; Letourneau et al. 2004), the first growing season was considered humid and the second one dry. Thus, year 2000 studies had a humid first growing season and a dry second one, whereas year 2001 studies had a dry first growing season.

Sowing Season

With plant cover data pooled, sowing emergence from both winter trials were at least double the spring sowing emergence at one site and triple at the other (Table 2). Survival varied between seasons. However, at the end of the studies, the proportion of seeds that survived to seedlings was at least four times higher for those sown in the winter at one site, and six times higher at the other (Table 2).

Plant Cover

Trevelin Results: Year 2000 Winter Sowing Trial. Seedlings started to emerge 40 days after sowing and reached maximum germination a month later (15 November). Seedling emergence was associated ($p = 0.0254$) with plant cover and peaked with 35% coverage (Fig. 4a). Seedling survival at the end of the first summer (Fig. 4b) was marginally associated with plant cover ($p = 0.0952$). The majority of the seedlings that survived the first summer remained alive the following winter and the second summer (Fig. 4c & 4d). Seedlings showed some damage from soil arthropods, mainly coleopterans of the Tenebrionidae family. At the end of the first growing season, seedlings had five to seven whorl branches. At the end of the study, only 2.7% of the sown seeds survived to seedlings.

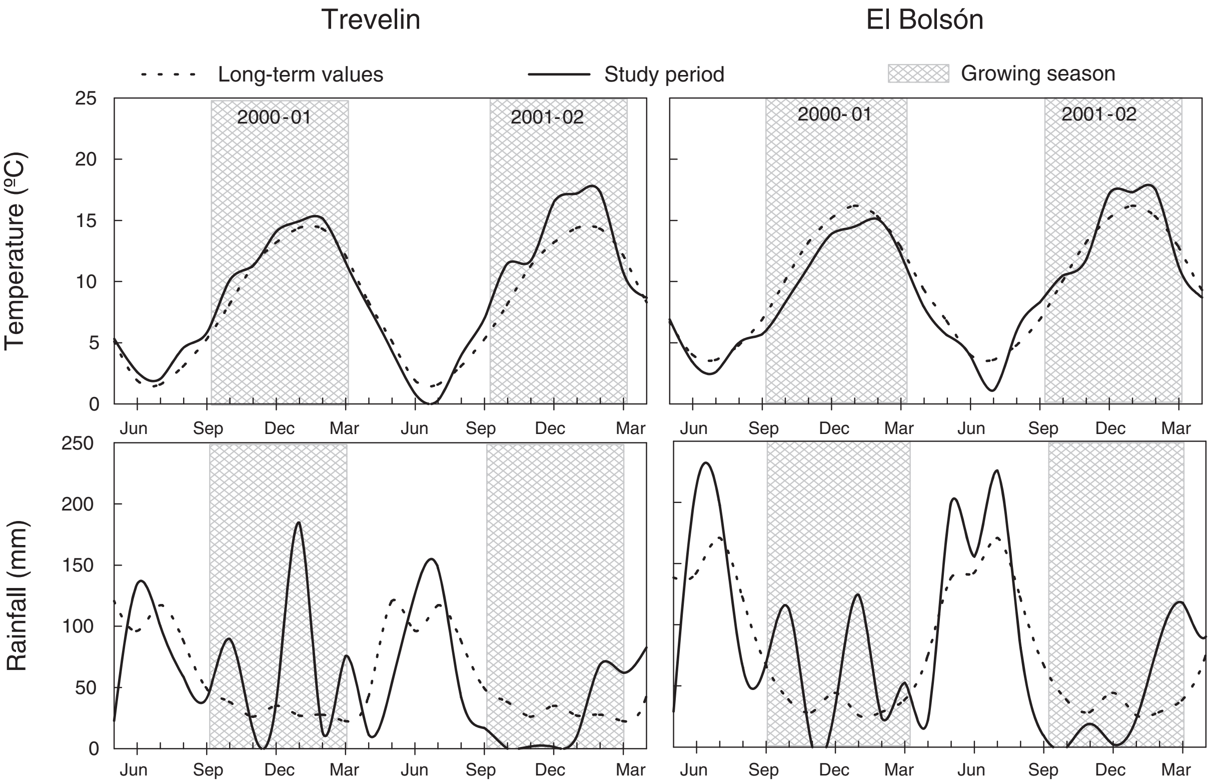

Figure 3. Temperature and precipitation recorded at both sites during the study (2000–2001 and 2001–2002) growing seasons (September to February) compared to historical values.

Trevelin Results: Year 2000 Spring Sowing Trial. Emergence occurred in only six plots (Fig. 4e), started in 6 December and was low (4.6%). Neither emergence nor survival was associated with plant cover (Fig. 4f–h). Seedlings showed damage from the same soil arthropods as in the winter trial. At the end of the first growing season, seedlings had four to five whorl branches. At the end of this study only 0.2% of the seeds became seedlings.

Trevelin Results: Year 2001 Winter Sowing Trial. Average emergence (16.8%) was lower than that documented for the year 2000 winter sowing trial (22.2%). Emergence ($p = 0.0001$) and first summer survival ($p = 0.011$) were higher with higher plant cover (Figs. 3i & 4j). Most non-emerged seedlings had germinated, but their primary roots were dead underneath the soil surface. Seedlings also showed some herbivore damage mostly due to soil coleopterans. After the first summer, only 3.3% of the seeds became seedlings.

El Bolsón Results: Year 2000 Winter Sowing Trial. Emergence started 45 days after sowing, and maximum values were reached by mid-November. Neither emergence (54.2%) nor survival (29.0%) was associated with plant cover at the end of first and second summer (Fig. 5a, 5b, & 5d). However, after the winter, survival was higher ($p = 0.0542$) with intermediate cover (Fig. 5c). There was some loss of seedlings due to soil arthropods (not of the Tenebrionidae family). At the end of the first growing season, seedlings had five to seven whorl branches. Two years after sowing, 14.2% of the seeds became seedlings.

El Bolsón Results: Year 2000 Spring Sowing Trial. Neither emergence nor survival was related to plant cover. A loss of seedlings due to soil arthropods was also noted. At the end of the first growing season, seedlings had four or five whorl branches. By the end of the study only 1.4% of the sown seed became seedlings.

Table 2. Seedling emergence and survival at the end of the studies for the winter- and spring-sown seed at each site.

	Study Site	*2000 Winter Sowing*	*2000 Spring Sowing*	*2001 Winter Sowing*
Emergence (%)	Trevelin	22.2	4.6	16.8
	El Bolsón	54.2	24.0	52.2
Seeds that survived to seedlings at the end of the study (%)	Trevelin	5.2	0.8	3.7
	El Bolsón	6.0	1.0	16.9

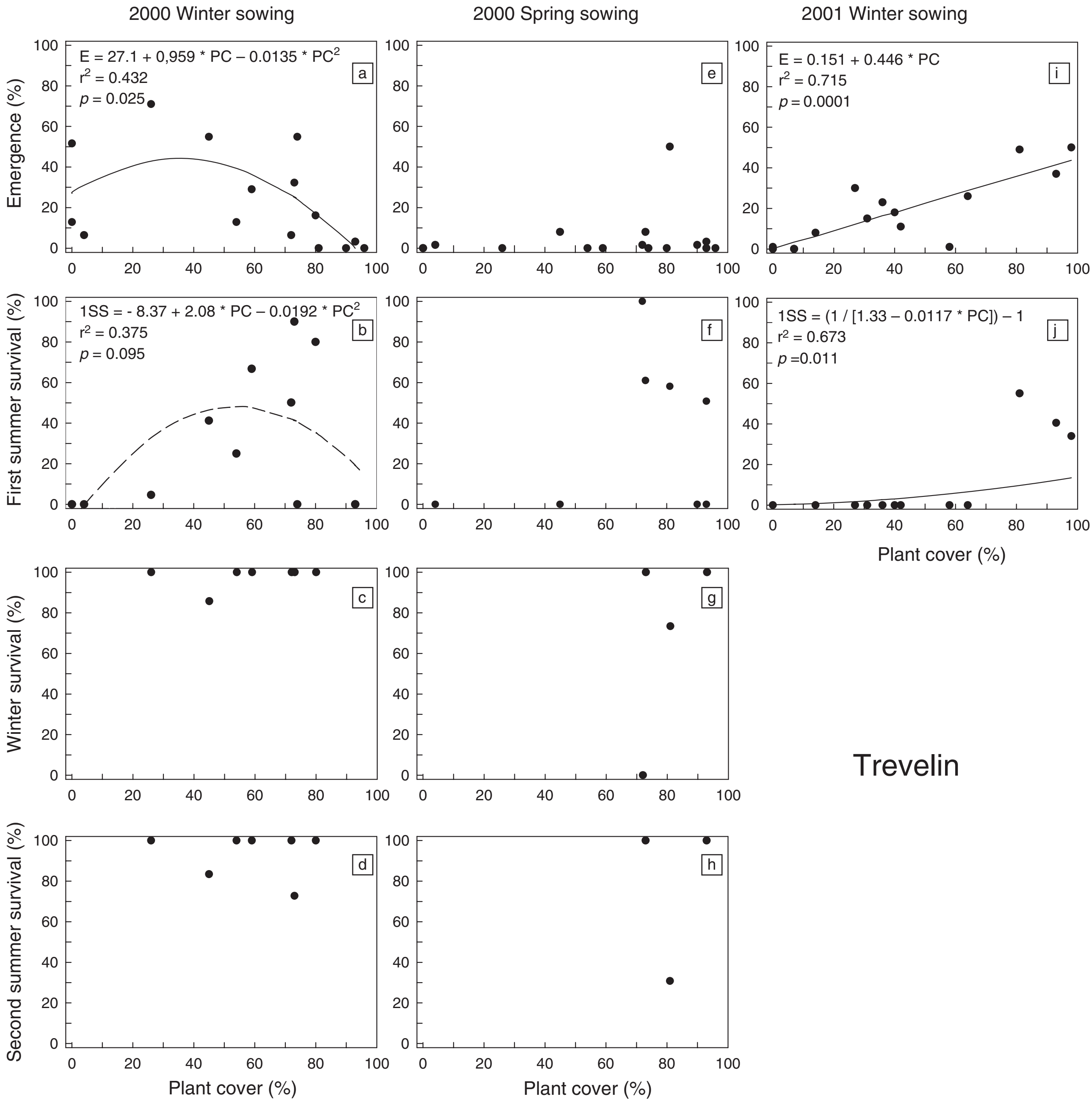

Figure 4. Trevelin plant cover (PC) results. Seedling emergence (E), first summer survival (1SS), winter survival and second summer survival by PC of trials sown in winter 2000 (a–d) and spring 2000 (e–h). Seedling emergence and 1SS by PC of trials sown in winter 2001 (i & j). Equations and respective regression lines are shown for the significant relationships (a & b and i & j).

El Bolsón Results: Year 2001 Winter Sowing Trial. Emergence (52.2%) was not associated with plant cover (Fig. 5i), but survival at the end of the first summer increased with high cover values ($p = 0.0041$) (Fig. 5j). Some seedlings were lost owing to the presence of soil arthropods. At the end of the first growing season, seedlings sown in the winter had six to seven, and in some cases up to eight whorl branches. After the first dry growing season, only 12.7% of the seeds sown become seedlings.

Discussion

Winter-sown seedlings achieved much higher emergence and survival than spring-sown seedlings at both sites. Winter-sown seedlings look sturdier than those sown in the spring. This is not surprising, considering that they emerged earlier in the growing season and were able to develop deeper roots and a thicker stem cuticle, making them more resistant to the dry summer.

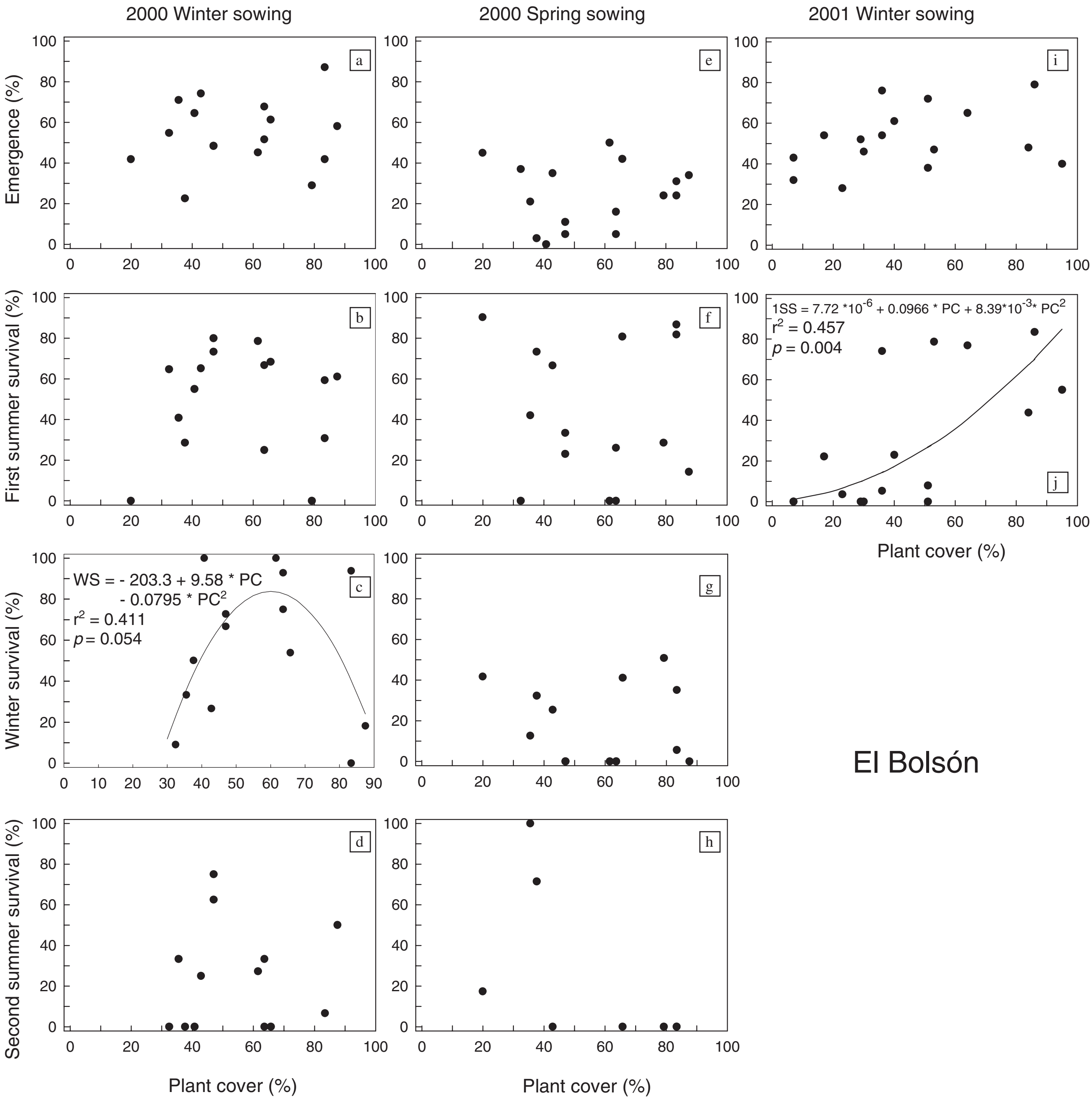

Figure 5. El Bolsón plant cover (PC) results. Seedling emergence, first summer survival (1SS), winter survival (WS) and second summer survival by PC of trials sown in winter 2000 (a–d) and spring 2000 (e–h). Seedling emergence and 1SS by PC of trials sown in winter 2001 (i & j). Equations and respective regression lines are shown for the significant relationships (c & j).

Seedling emergence was associated with plant cover only at the xeric site (Trevelin) and for the winter studies. For the Trevelin spring studies, a possible beneficial effect of plant cover on emergence could not be detected because emergence was nil for most plots (Fig. 4e). We speculate that at the mesic site (El Bolsón), the higher availability of water during the summer masked the potential association of plant cover with seedling emergence. Previous studies showed that a high number of cypress seedlings die during the first growing season, and mortality is higher on xeric areas (Veblen et al. 1995; Villalba & Veblen 1997a,b). It has also been demonstrated that in xeric sites, there are some facilitation mechanisms between shrubs and cypress seedlings, because the former protect cypress from direct radiation, and the shadow effect may improve soil water availability (Kitzberger et al. 2000). Our results support those previous findings. Seedling emergence was also affected by the precipitation that occurred during the growing seasons. In Trevelin during a low water stress growing

season (2000 winter trial), maximum emergence was achieved with medium cover, whereas during a high stress growing season (2001 winter trial) emergence increased with higher cover values. These results consistent with previous studies demonstrated that on xeric sites cypress establishment is strongly influenced by climatic variability (Veblen et al. 1995; Villalba & Veblen 1997a,b; Kitzberger et al. 2000). They proposed that precipitation is an adequate estimator of the abiotic stress that can affect seedling establishment.

Like emergence, seedling survival was also mainly associated with plant cover at the xeric site (Trevelin) and for the winter studies because first summer survival for the spring trial was almost nil for most plots. However, at the mesic site (El Bolsón) survival was associated with plant cover after the first exceptionally dry summer. This positive effect of plant cover on survival during dry growing seasons was also indicated for other species (Greenlee & Callaway 1996; Tielbörger & Kadmon 2000). Cover may counterbalance the negative effects of dry growing seasons on seedling establishment, by lowering the stress that high temperatures could produce (DeSteven 1991; Gill & Marks 1991; Berkowitz et al. 1995), reducing mortality rates of shaded plants during the summer (Hastwell & Facelli 2003; Pueyo et al. 2009). This effect has been pointed out for saguaro (*Carnegiea gigantea* (Engelm.) Britt. and Rose), indicating that seedling survival is related to temperature attenuation rather than to an improvement in hydric conditions (Turner et al. 1966). In the case of seedling recruitment of red pine (*Pinus resinosa* Ait.) and eastern white pine (*Pinus strobus* L.) the beneficial protection effect on seed germination and early seedling survival is associated with an improvement in temperature and moisture regimes (Kellman & Kading 1992).

The loss of cypress seedlings owing to herbivory by soil arthropods has been pointed out by other authors (Gobbi & Schlichter 1998; Kitzberger et al. 2000). As an example, in the forest-steppe ecotone of Patagonia, the loss of 100% of cypress seedlings during the first two weeks after emergence was attributed to the presence of beetles of the genera *Nyctelia* (Kitzberger et al. 2000). These beetles belong to the same family (Tenebrionidae) as the ones observed in our Trevelin study. At both study sites, the damage was observed within the first month after emergence.

It is well known that cold winter temperatures can affect cypress growth (Villalba & Veblen 1997b) and that the presence of some cover could improve winter survival, by protecting seedlings from radiation or freezing temperatures (Gobbi & Schlichter 1998; Gobbi 1999). The association between plant cover and winter seedling survival found at El Bolsón, where the winter of 2001 was colder and more humid than usual, allow us to infer that at this mesic site, surrounding vegetation could have provided cypress seedlings with a protective effect, as reported for other species in other ecosystems (Gill & Marks 1991).

In cypress forests unaffected by fire, seedling emergence has been reported to occur between November and January, with the peak occurring during the first month. Usually late emerging seedlings have higher survival rates (Gobbi 1999). Contrary to that, our studies showed that emergence started in October, and early emerging seedling had higher survival rates. As with other species, the emergence of cypress seedlings in the field is determined by environmental conditions, and the main factor promoting germination would be an adequate combination of moisture and temperature (Mayer & Poljakoff-Mayber 1989). Because climatic and sowing conditions of our studies were different from those reported by Gobbi (1999), results may not be fully comparable. Also, unlike Gobbi (1999), we stratified seeds, and this process may have accelerated seedling emergence. Another reason for the difference between studies could be that in our study, seedlings emerged earlier in the spring and thus they had more time to elongate their root system to explore deeper soil horizons and in turn developed a higher number of whorl branches. This could confer higher resistance to summer drought, as is the case with some bunchgrass seedlings occurring in the nearby Patagonian steppe (Defossé et al. 1997).

Conclusions

In our study sites, post-fire environment varied, and these landscape differences resulted in various plant cover conditions. Season of sowing and plant cover seemed to be associated with the emergence and survival of the sown seedlings. Emergence and survival were much higher for seedlings sown in winter than for those sown in the spring. At the xeric site, under conditions of low water stress provided by an exceptionally humid growing season, emergence of cypress seedlings was higher with intermediate plant cover. Under higher water stress conditions provided by a dry growing season, emergence and survival increased with higher cover values. At the mesic site, by contrast, only survival was associated with plant cover and this occurred when the summer was exceptionally dry. All these associations were observed only for winter-sown seedlings. At the dry site most spring-sown seedlings did not emerge, and those that did were short-lived. Spring-sown seedlings showed no association with plant cover in the mesic site, likely because the first summer was exceptionally humid.

We can conclude that hot and dry summers affect cypress establishment, diminishing its survival not only on xeric sites (Veblen et al. 1995; Villalba & Veblen 1997a,b; Kitzberger et al. 2000) but also on mesic ones. In both study sites, during the early successional stages following the fire events, pioneer herbs, and shrubs that colonize burned areas seem to develop a facilitating mechanism to promote cypress establishment, avoiding extreme temperatures and consequent desiccation that could affect germination and subsequent seedling survival.

Natural cypress regeneration could only be expected to occur in patches that have been unaffected by fire, such as rocky outcrops, naturally protected areas, discontinuous vegetation mosaics, or in areas affected by low severity fires. Different actions could be taken to prevent future cypress stand reduction and forest degradation. Recovery of cypress

forests could be promoted by human intervention in the form of restoration activities. One strategy could be restoration by sowing. In inaccessible areas, where cypress has disappeared because of repeated disturbances, the creation of small cypress patches by seeding with the protection of low vegetation is a low-cost practice that could have positive results.

Implications for Practice

- The use of local seed is recommended. Seeds should be healthy and undamaged to optimize germination rate.
- Seeds should be stratified in a cold and moist environment for about 30 days to achieve uniform germination.
- Sowing should be carried out at the end of the winter to allow time for seedlings to elongate their root system before the summer drought.
- Sites with medium to high (50–70%) plant cover should be selected to take advantage of the protection provided by natural vegetation.

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