ECOTROPICA 8: 219–224, 2002

OPTIMIZING RESTORATION OF *POLYLEPIS AUSTRALIS* WOODLANDS: WHEN, WHERE AND HOW TO TRANSPLANT SEEDLINGS TO THE MOUNTAINS?

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Resumen. Con el objetivo de contribuir a la conservación de los bosquecillos de *P. australis* comenzamos un proyecto de reforestación en las Sierras Grandes de Córdoba, Argentina, y estamos desarrollando las mejores técnicas para optimizar el proceso. Los objetivos de este estudio fueron determinar en términos de supervivencia y crecimiento: (1) la mejor fecha para el transplante de los plantines a la montaña, (2) si la protección de los plantines con piedras y plástico es conveniente, y (3) si es conveniente plantar tanto en buenos suelos como en suelos degradados. Durante dos temporadas, produjimos los plantines en un invernáculo, y los transportamos y plantamos en las áreas de estudio cuando tenían menos de un año. Nuestros resultados indican que los mejores meses para plantar los plantines difieren con el año dependiendo de las precipitaciones, pero diciembre y enero fueron buenos meses en ambas temporadas de estudio. Los plantines protegidos con piedras y tubo plástico tuvieron el mayor crecimiento, los plantines protegidos únicamente con piedras tuvieron un crecimiento intermedio y los plantines sin protección tuvieron el menor crecimiento. Los mejores suelos para el crecimiento de los plantines fueron los que no estaban degradados, mientras que los plantines plantados en suelos erosionados y en roca expuesta tenían un crecimiento más lento. Los distintos tratamientos afectaron al crecimiento, pero encontramos pocas diferencias en la supervivencia.

Abstract. With the objective of contributing to the conservation of *P. australis* woodlands we began a reforestation project in the Sierras Grandes (Cordoba province, Argentina), and are developing the appropriate techniques to optimize the reforestation process. The objectives of this study were to determine, in terms of seedling survival and growth, (1) the best date for transplanting the seedlings to the mountains, (2) whether protection of the seedlings with stones and plastic tubing makes a difference, and (3) whether planting is convenient both in good soils and in degraded soils. During two seasons seedlings were produced in a greenhouse, transported and planted in the study areas when less than one year old. Our results indicate that the best months for transplanting the seedlings differed according to the year depending on precipitation, but December and January were good months for transplanting in the two seasons of our study. Seedlings protected with stones plus plastic tubing had the highest growth, seedlings protected with stones alone were intermediate in growth, and unprotected seedlings had the lowest growth. Non-degraded soils were the best for seedling growth, while seedlings in eroded soils and bare rock had similarly low growth. Though the different treatments appeared to affect growth, we found few differences in survival. *Accepted 24 May 2002.*

Key words: Polylepis australis, *reforestation methods, mountain conservation.*

INTRODUCTION

Polylepis woodlands are restricted to the mountains of South America and in most of their range their distribution is in decline due to anthropogenic causes (Cabido & Acosta 1985, Fjeldså & Kessler 1996). As a consequence, the "World Conservation Monitoring Center" has declared the protection and restoration of *Polylepis* woodlands a priority (Hjarsen 1997).

In Cordoba province (Argentina), the present distribution of "tabaquillo" or "queñoa" (*Polylepis australis*) is mostly restricted to the valleys and slopes of the Sierras Grandes, a grassland dominated ecosystem which has historically been used for domestic grazing (Luti *et al.* 1979, Cabido & Acosta 1985). There is ample evidence that the distribution of *Polylepis* woodlands was wider in the past, and its present area is reduced due to intentional burning to allow the regrowth of grasses, browsing of livestock, and use as timber and fuel (Cabido & Acosta 1985, Renison *et al.*, unpubl.).

The conservation of *Polylepis* woodlands in the Sierras Grandes is especially important because of

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their ecological benefits. They protect the upper portion of the watersheds of most rivers in the region. *Polylepis* woodlands increase water retention capacity by trapping fog, increase the infiltration of water into the soil, control the runoff by reducing soil erosion and the consequent soil deposition in dams downstream (Fjeldså & Kessler 1996). *Polylepis* woodlands also provide the only available firewood for many local people.

Reforestation with *Polylepis* is thus important to restore the ecological benefits of the Sierras Grandes and to provide firewood, which in turn would diminish the impact of logging on natural woodlands. With the objective of contributing to the reforestation of *Polylepis* our working group is developing the appropriate techniques to optimize the reforestation process. In a previous publication we determined that trees growing in woodlands provide better seeds than those growing in isolation, that the treatment of seeds with cold is not effective and that vegetative propagation through cuttings is feasible though seedling growth was higher than cutting growth (Renison & Cingolani 1998). Now our aim is to improve reforestation techniques, analyzing when, where, and how to transplant seedlings to the mountains. We are especially interested in their survival and growth rate. Survival is important to restore woodlands for their ecological benefits, and growth rate is important when considering their potential for firewood use.

When to transplant? Conventional forestry protocols for the Cordoba hills, which surround the Sierras Grandes mountain range and are on average 1000 meters lower, indicate that the best season for the transplant of perennial trees is during spring or autumn when water deficit is lowest. However, the climate of the Sierras Grandes, with frosts almost all year round, low average temperatures, and dry winters that can extend until October or November in some years (Cabido 1985), suggests that early summer, rather than spring, could be the best season for transplanting.

How to transplant? Due to the climate, and other factors such as the presence of skunks that dig up the seedlings (pers. observ.), and the competition with grasses (Bazzaz 1979), protection with stones and plastic tubing following transplantation would be recommendable. However, this implies more work, and is only justified if it actually represents a significant benefit compared to the absence of protection.

Where to transplant? Another factor that could determine differences in growth and survival of the transplanted seedlings is the microhabitat in which they are placed. The Cordoba mountains are heterogeneous at various levels, especially notorious being the heterogeneity of microhabitats, which can change drastically within a distance of a few meters (Acosta *et al.* 1989), from very well developed soils with a complete plant cover to bare rock almost without soil, which can be natural outcrops or the result of human-triggered erosion processes. Therefore, the objectives of this work were to determine in terms of seedling survival and growth: (1) the best date for planting seedlings in the mountains, (2) whether protection with stones and plastic tubing makes a difference, (3) whether planting is as effective in good soils as in degraded soils.

METHODS

Study areas. We selected our study areas in a valley in "Los Gigantes", which is at the northern extreme of the Sierras Grandes mountain range (31° 24' 46"S, 64° 48' 22"W), situated at 2270 m a.s.l., with a general western aspect. Vegetation is dominated by short grasslands, intermingled with patches of tussock grassland, rock outcrops, and eroded areas with bare soil or rock with sparse plant cover (Cabido 1985, Pucheta *et. al* 1998). The presence of old *Polylepis* roots and stumps suggest that in the past this valley was covered by *Polylepis* woodland. The experiments were done during the seasons of 1998–1999 and 1999–2000 in two exclosures built in the winters of 1997 (0.5 ha) and 1998 (6 ha). We used precipitation records from Cuesta Blanca, situated 20 km from the study areas. Monthly and annual precipitation in both seasons under study were compared with mean values for a 6-year period.

Production of seedlings. Seeds were sown in May 1998 and 1999 and were transplanted to individual tubes 5 cm in diameter and 15 cm high two months later, as detailed in Renison & Cingolani (1998). Seedlings were transported to the study area when 4 to 11 months old depending on the experimental protocol, where they were planted and watered with around two liters of water within 12 hours of having left the greenhouse. Once planted, seedlings were never watered or taken care of again.

Month of transplant. To determine the best date to transplant the seedlings to the mountains, from September to April we planted 15 (in 1998–1999) and 12 (in 1999–2000) seedlings at the middle of each month (totals of 120 and 96 seedlings respectively). We choose homogeneous slopes with deep non-eroded soils. Numbered metal pins were placed at a distance of around 1.5 meters from each other and seedlings were planted at pins selected randomly, and protected with stones and a plastic tube. During the winter following each season (July 1999 and 2000) we recorded if the seedlings were dead (disappeared or completely dry) or alive. If alive, we measured their height from the base to the most distant growth bud.

Protection. To determine if the protection of the seedlings with stones and plastic made a difference in their growth and survival, during November and December 1998 we planted 78 seedlings without protection, 305 seedlings protected only by stones (approximately 10 to 30 cm in diameter) which were placed around the seedling at a distance of 1 to 10 cm, and 58 seedlings protected with stones and a transparent plastic tubing 10 cm in diameter and 20 cm high (made from discarded soda bottles) which were buried around 4 cm deep and held in place with stones. Treatments were assigned randomly and seedlings were only planted at sites with less than 20% rock in an area of 30 cm around the seedling. Height and survival of the seedlings was measured on the date they were transplanted and in July 2000.

Microhabitat. To determine if seedlings prospered equally in degraded and undegraded sites, in November and December 1998 we planted 29 seedlings in cracks and crevices in bare rock with almost no soil (soil less than 20% of the area 30 cm around the seedling), 34 seedlings in eroded soil with less than 50% plant cover (inside gullies or on erosion edges), and 39 seedlings in good soil with 100% plant cover. All seedlings were protected by stones only. Height and survival of the seedlings was measured on the date they were transplanted and in July 2000.

Data analysis. For all experiments, survival of seedlings between treatments was compared using the Chi-square test. When comparing month of transplant, to avoid expected values less than 5 we grouped months into spring (September, October and November), summer (December, January and February) and fall (March, April). Final height of live seedlings, or growth on the mountain (final height – height when planted), depending on the experiment, was compared with ANOVA and Tukey paired contrasts. In all tests, alpha was 0.05 and mean values were reported with their standard error (SE).

RESULTS

Precipitation. Average total annual precipitation over a period of six years (winter 1994 to winter 2000) was 838 mm, with a peak of 158 mm in December and almost 0 mm in the winter months (Fig. 1). The pattern of precipitation in both seasons under study showed some contrast. The first season (1998–1999) was drier than the average, with an annual total of 782 mm, with lower values than the mean in the summer months (December, January and February) and a high peak late in the season (March), while the second season under study (1999–2000) was wetter than the average (1121 mm) with a high peak of 243 mm early in the season (October) (Fig. 1).

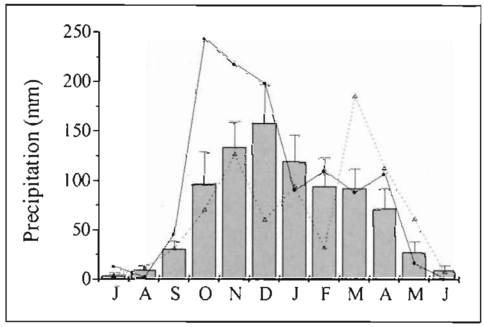

FIG. 1. Average monthly precipitation (mean ± SE) over a six-year period (gray bars), and of the two seasons under study (1998–1999 dotted line, 1999–2000 continuous line), in a locality situated 20 km from the study area.

Month of transplant. No significant differences were found in survival of seedlings transplanted in the three different periods in the dry year (1998–1999), while in the wet year seedlings transplanted earlier had a better survival rate than those transplanted later (Table 1). Results of the comparisons of the final height show that in the dry year (1998–1999) the total growth was better for seedlings transplanted later (especially from November to February), while in the wet year seedlings transplanted early (especially from October to January) reached their greatest height the following winter (Fig. 2). December and January were good months to transplant the seedlings in both seasons.

TABLE 1. Percentage survival of seedlings transplanted in different periods of the two seasons under study. In brackets the total number of transplants each season is indicated, and in the last row, the results of the Chi-squared test of goodness of fit.

Season	1998 –1999	1999–2000
Sep.–Nov.	75% (n=45)	81% (n=36)
Dec.–Feb.	73% (n = 45)	72% (n=36)
Mar.–Apr.	73% (n = 30)	50% (n=24)
	$c^2 = 0.07$ ($P = 0.96$)	$c^2 = 6.54$ ($P = 0.04$)

Protection. No significant differences were found in the survival of seedlings planted without protection, protected with rocks, or with rocks and plastic tubes (92, 82, and 81% survival respectively from November–December 1998 to July 2000, $c^2 = 5.36$, d.f. = 2, $P = 0.07$). On the other hand growth in the same period was least for seedlings without protection, intermediate for seedlings protected with rocks and greatest for seedlings protected with rocks and plastic tubes (Fig. 3, ANOVA: F = 30.73, d.f. = 2, $P < 0.0001$, all differences significant).

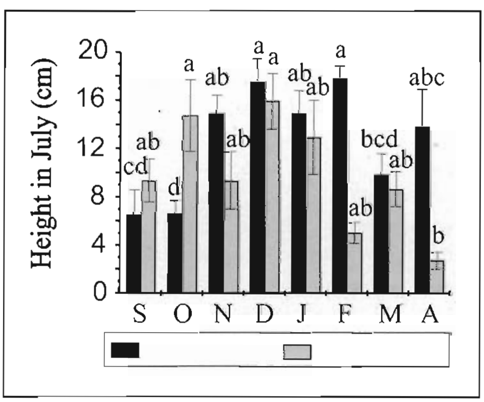

FIG. 2. Height (mean SE) in July for seedlings set to germinate in May of the previous year and transplanted to the study area from September to April of the 1998–1999 (black) and 1999–2000 (gray) season. Bars which do not share the same letters differ significantly; comparisons valid only within the same season.

Microhabitat. No significant differences were found in the survival of seedlings planted on rock, degraded or good soils (81, 83, and 75% survival respectively from November–December 1998 to July 2000, $c^2 = 0.94$, d.f. = 2, $P = 0.63$). Growth for the same period was higher for seedlings planted in good soils than for those planted on rock or degraded soils (Fig. 4, ANOVA: F = 7.60, d.f. = 2, $P = 0.001$).

DISCUSSION

Our results indicate that timing of the season, protection of the seedlings, and micro-habitat influence growth, while seedling survival did not appear to be much affected by these factors. The only case in which survival was affected was during the second and wettest season under study (1999–2000), in which seedlings transplanted later had higher mortality (Table 1). This result could be due to contamination of the seedlings by fungus in the greenhouse during February. On three other occasions with very wet spells of weather many of the seedlings in our greenhouse died from a fungus which produced brownish areas in the leaves and subsequent drying of the plant (pers. obs.). We cannot determine if this will happen in all wet years, but the risk of being contaminated by fungus suggested that an early transplant of seedlings would be recommendable for a greater survival rate.

Results of the comparisons of the final height were in line with climatic data. In the dry year, with relatively low precipitation in the spring months, seedlings transplanted in September and October had lower growth than seedlings transplanted after November. During the first month of the dry year, the scarcity of water damaged the tissues of recently planted seedlings (Harper 1990) and they probably did not completely recover from the stress, resulting in low growth.

The wet year, when the rainy season began early, seedlings transplanted early had a high growth rate, while seedlings transplanted later grew less. It seems that during the wet year seedlings had sufficient water to establish themselves, and their subsequent growth was not negatively affected. By contrast, and probably due to the fungus, seedlings which were maintained until later in the greenhouse were affected, resulting in a lower growth.

In both years December and January were good months to transplant the seedlings and judging from

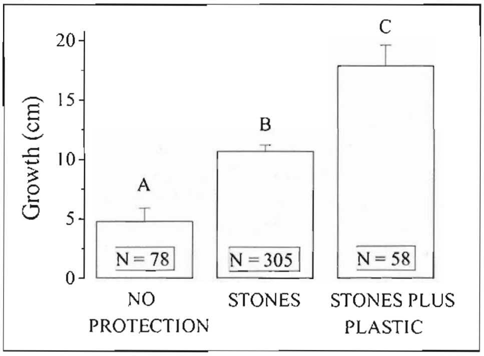

FIG. 3. Seedling growth (mean SE) when they were not protected, protected with stones, or with stones and plastic. Bars which do not share the same letters differ significantly.

the precipitation data of the last 6 years those months are a good choice. This recommendation coincides with the suggestions of Fjeldså & Kessler (1996) for *Polylepis* species of the Andes of Bolivia and Peru, but is contrary to what is recommendable in the lower Cordoba hills, where the best periods for transplanting the seedlings of evergreen species are spring and autumn. This is probably due to the lower evapotranspiration in the mountains compared to the lower hills where temperatures are higher (Cabido 1985).

Although no significant differences were found in the survival of seedlings planted with or without protection, growth was hastened by the surrounding rocks and plastic tubes, indicating that it is advisable to protect the transplanted seedlings when possible. To maximize growth, stones should be used when it is unsure if seedlings will be revisited, and stones and plastic tubing can be used when the area will be revisited to take the tubes off and permit the trees to grow. Protection with stones is recommended by Fjeldså & Kessler (1996) for other *Polylepis* species. Stones probably protect the seedlings from competing grasses and herbs, and the plastic tube could protect the seedling from the wind.

Growth was higher for seedlings planted in good soils than for those planted on rock or degraded soils, suggesting that to optimize growth rate it is desirable to plant seedlings in good soils which have not been degraded. Soils which are eroded have often lost the top layer where most nutrients are, appears to dry faster after rains (pers. obs.), and both a nutrient and a water deficit could be the cause of the diminished growth compared to soils which are not degraded. These restrictions seem to be more important at this stage than possible limitation of light, water, and nutrients caused by competition with the grasses and forbs which cover the non-degraded soils, at least when seedlings were protected by stones.

Due to the high correlation existing between rock outcrops and inaccessibility to livestock, fire, and man, there is controversy on whether *Polylepis* trees prefer this habitat or if they are restricted to the rocky outcrops due to anthropogenic causes (Fjeldså & Kessler 1996). Though most *P. australis* in our study area grow in rock cracks and crevices, this does not appear to be the best habitat for their growth during the seedling stage, supporting Ellenberg's (1979) hypothesis that *Polylepis* distribution is a consequence of human use of its habitat.

Because survival does not seem to be affected by soil conditions, the planting of *P. australis* to recuperate degraded lands, improving the ecological benefits of the system, is highly recommended (Beeby 1993). It would be interesting to study if their growth in degraded areas can be accelerated by providing water (for example planting them in a hollow where water can accumulate after rain), nutrients, or both.

We conclude that when restoring woodlands for their ecological benefits and their survival is more important than growth rates our results suggest that planting is most effective early in the season, with no

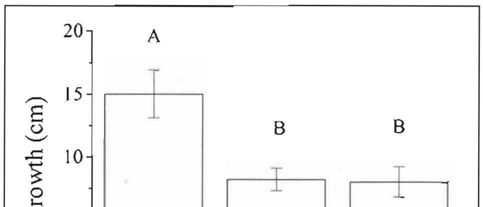

FIG. 4. Seedling growth (mean SE) when they were planted in non-degraded soil, degraded soil, or on exposed rock. All treatments differed significantly.

plastic tube or rock protection so as to minimize planting time and avoid having to take the plastic protection off when seedlings grow, and that seedlings may be planted in degraded or non-degraded habitats. When restoring woodlands for use as firewood, and growth rate is more important, our results suggest December and January are the best months for transplanting to the mountains, that it is advisable to protect the transplanted seedlings with rocks and plastic tubes when possible, and desirable to plant the seedlings in good soils.

ACKNOWLEDGMENTS

We thank Ricardo Suarez, Silvia Zingoni, the students of the Umberto Ilia school, and volunteers who helped with the field work, Ronaldo Renison for providing weather data and taking care of the project's greenhouse, and the Nores family for allowing us to do the experiments on their property. We thank "Los Algarrobos" association which through Lloyds Bank provided part of the funds for this project and the Club Andino Villa Carlos Paz for providing lodging during field work.

REFERENCES

Acosta, A., Cabido, M., Díaz, S., & M. Menghi. 1989. Local and regional variability in granitic grasslands in the mountains of central Argentina. Geobotanisches Institut ETH, Stiftung Rübel. Zürich.

Bazzaz, F.A. 1979. The physiological ecology of plant succession. Ann. Rev. Ecol. Syst. 10: 351-371.

Beeby, A. 1993. Applying ecology. London.

Cabido, M. 1985. Las comunidades vegetales de la Pampa de Achala, Sierras de Córdoba, Argentina. Documents Phytosociologiques 9:431-443.

Cabido, M., & A. Acosta. 1985. Estudio fitosociológico en bosques de *Polylepis australis* BITT. ("Tabaquillo") en las Sierras de Córdoba. Argentina. Documents Phytosociologiques. N.S. 9: 385-400.

Ellenberg, H. 1979. Man's influence on the tropical mountain ecosystems in South America. Ecology 67: 401–416.

Fjeldså, J., & M. Kessler. 1996. Conserving the biological diversity of *Polylepis* woodlands of the highland of Peru and Bolivia. A Contribution to sustainable natural resource management in the Andes. NORDECO, Copenhagen.

Harper, J.L. 1990. Population biology of plants. London.

Hjarsen, T. 1997. The effects of plantations in the Andes. Tropical Forest Update, 7: 15.

Luti, R., Solis, M., Galera, F., Ferreira, N., Berzal, M., Nores, M., Herrera, M., & J. Barrera. 1979. Vegetación. Pp. 297–368 *in:* Vázquez, J.B., Miatello, R.A., & M.E. Roqué (eds.). Geografía Física de la Provincia de Córdoba. Buenos Aires.

Pucheta, E., Vendramini, F., Cabido, M., & S. Díaz. 1998. Estructura y funcionamiento de un pastizal de montaña bajo pastoreo y su respuesta luego de su exclusión. Revista de la Facultad de Agronomía, La Plata 103: 77–93.

Renison, D., & A.M. Cingolani. 1998. Experiencias en germinación y reproducción vegetativa aplicados a la reforestación con *Polylepis australis* (Rosaceae) en las Sierras Grandes de Córdoba, Argentina. AgriScientia 15: 47–53.