Growth of ponderosa pine in the northern Patagonian Andes, Argentina

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ABSTRACT

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is the most widely planted exotic tree species in the Patagonian Andes region in Argentina. Currently there are about 60,000 ha of ponderosa pine forests along a narrow north-south stretch in the rain shadow of the Andes, where the annual precipitation ranges between 500 and 800 mm. However, there are about 1,000,000 ha of rangelands, often overgrazed, suitable for commercial afforestation with this species. Most ponderosa pine plantations provide thin logs because they are relatively young. To properly manage the stands it is necessary to know how the species grows on different sites. Two thinning trials were established in this region 13 and 9 years ago on two, 20 year old overstocked plantations, to study the effect of density on tree growth. Site quality was defined in terms of a growth intercept index (GII). One of the trials, established in Abra Ancha in 1995 on a highly productive site (GII = 4.2 m), is a case study with three treatments and large 2 ha study plots. The other trial, established near Meliquina lake on a medium quality site (GII = 3.5 m), has two replicates with four treatments and 0.7 ha plots. For both studies treatments were relative density ranges expressed in terms of Reineke's stand density index (SDI). It was assumed that the lower density range allows trees to grow freely without competing, and the high density range provides for complete site occupation with the minimum stock possible. The medium density range was defined as the mid point between the low and high ranges. Plots have been repeatedly thinned whenever they reach the upper limit of the assigned density range. Results show that ponderosa pine grows well on both sites. For the medium density treatment mean current annual volume growth is over 20 m^3 ha^{-1}, and mean diameter growth is more than 1 cm a year in both trials. Volume growth per unit area at both trials is higher than the one registered in plots with the same relative density, site quality and number of trees per unit area in thinning trials established in ponderosa pine stands located in Oregon, Idaho and California, where the species grows naturally. The conditions are given for Patagonia to be known by its ponderosa pine timber as New Zealand and Chile are known by their radiata pine (*Pinus radiata* D. Don) plantations.

Key-words: Ponderosa pine, relative density, Patagonia, thinning.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is the most widely planted exotic tree species in the Patagonian Andes region in Argentina, where it grows vigorously without any serious pest problems. Lately, the attack of sirex woodwasp (*Sirex noctilio)* is becoming a concern, but the pest basically attacks unmanaged overly dense stands and thus, it seems possible to prevent economic losses just by applying simple silvicultural treatments. Currently there are about 60,000 ha of ponderosa pine forests along a narrow north-south stretch between 37º and 44º latitude in the rain shadow of the Andes, where the annual precipitation ranges between 500 and 800 mm. However, there are about 1,000,000 ha of rangelands, often overgrazed, suitable for commercial afforestation with this species. Despite it is desirable and efforts are being made to grow other kind of trees, ponderosa pine will remain to be the main species in the region for years to come because: 1) it can grow at reasonable rates throughout the whole area suitable for afforestation, 2) seedlings are so sturdy that high outplant survival is achieved even without any site preparation, and 3) there is a market for the timber that is internationally known. Environmental conditions in northern Patagonia are similar to those in the Pacific Northwest where ponderosa pine grows naturally.

Most ponderosa pine plantations are still young, below 30 years of age. The main objective of these stands is to produce timber to contribute with the economy of the region. However afforestation has also the potential to produce several environmental benefits such as: 1) amelioration of soil erosion due to overgrazing, 2) transformation of the steppe environment to allow for establishing native tree species in future rotations, 3) carbon sequestration, and 4) provision of habitat for wildlife species. The scarce population in Patagonia could only consume a small portion of the timber to be potentially produced from ponderosa pine plantations. Thus, lumber will have to be shipped either to Argentina's large cities (2,000 km away) or exported through the Atlantic Ocean ports (700 km away). These long distances call for the production of good quality timber with the highest possible value. Hence, intensive management practices are strongly encouraged by all Patagonia institutions. To properly manage the stands it is necessary to know how the species grows on different sites. Several trials have been established by the Patagonian Andes Forest Research and Extension Center (CIEFAP) since 1995 to study the effect of site quality and density on tree growth. The objective of this paper is to present the main results of these studies and compare them with the growth rates of ponderosa pine stands in their native environment in the Pacific Northwest in United States.

MATERIALS AND METHODS

Abra Ancha Thinning Trial

Location and treatments

A thinning trial was established by CIEFAP in 1995 in a 20 year-old ponderosa pine stand (Gonda et al. 2007). The study was located at a place called Abra Ancha, 8 km south of Aluminé, Neuquén province, in a forest plantation owned by Neuquén Forest Corporation (CORFONE S.A.), a mix enterprise shared by Neuquén Government and private investors. Treatments were defined in terms of relative density. This concept has the advantage of being independent of site quality and age (Cochran et al. 1994, Curtis 1970, Daniel et al. 1979, Reineke 1933) simplifying stand-density regimes. Among the different relative density expressions we chose Reineke's stand-density index (SDI) because it is simple and the most widely used in Patagonia (Andenmatten and Letourneau 1995, Gonda and Rechene 1993) and Western United States (Ducey and Larson 1997, Long 1985, Long and Daniel 1990, Oliver 1997). We utilized the simplified version of the formula (Daniel and Sterba 1980) in metric units, with a reference quadratic mean diameter (QMD) of 25 cm, and a slope of -1.7653 for the curve that represents the maximum density expected for any particular stand diameter. This slope was computed for ponderosa pine stands in western United States (Cochran 1992, Cochran and Barret 1993, Demars and Barrett 1987, Oliver and Powers 1978).

$$SDI = TREES/HA\ (QMD/25)^{1.7653}$$

Where: SDI = Reineke's stand density index
QMD = Quadratic mean diameter measured at 1.3 m
TREES/HA = number of trees per hectare

The significance of a particular SDI for tree growth is defined in relation to the species maximum. We assumed that competition, full site occupancy and self thinning occur with SDI values over 25%, 35% and 60% of the species maximum respectively (Langsaeter 1941, Long 1985). Thus, it is necessary to know the maximum density a species can reach in the region where SDI will be used as a stand density measure. It should be pointed out that this study, and other similar trials, will allow for revision of whether the different percents of the species maximum SDI produce the expected effect on tree growth. The study included the following treatments (Figure 1):

- Control (SDI=2,300): No thinning. This treatment will allow to validate the maximum SDI value for ponderosa pine in the region. Preliminary studies suggest that it would be about 2,300 (Gonda et al. 1998b).

- Medium density: SDI=500-700. At the lower limit of this treatment, trees start to compete because they have almost 25% of the maximum SDI. At the upper limit the competition is higher but the site is not fully occupied because the SDI is less than 35% of the maximum.

- Low density: SDI=300-500. Trees grow freely because onset of competition does not take place with a SDI below 25% of the maximum.

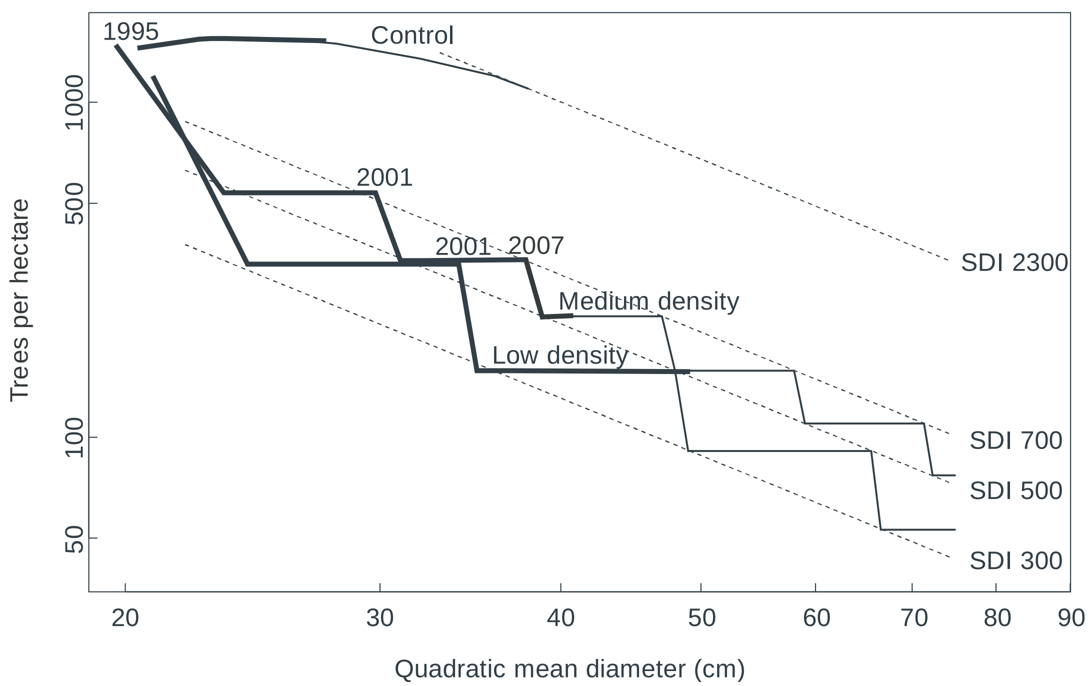

Figure 1. Quadratic mean diameter and number of trees per hectare measured between 1995 and 2009 (thick lines) and expected for the rest of the experiment (thin lines) at Abra Ancha. Years when thinnings were carried out, and density lower and upper limits of each treatment in terms of Reineke's stand density index are also shown (dotted lines). Both axes were built in logarithmic scale.

Except for the control, to maintain the density range of the treatments, plots are thinned whenever they reach the upper density limit. Low thinning is applied since moisture is the main limiting factor for growth. However, badly formed dominant trees are also removed.

Study layout and measurements

Abra Ancha is a case study because there is one replicate per treatment. However, the large size of the three plots (control: 1.4 ha., high and medium density: 2.2 ha) made the study especially suitable for extension purposes (Figura 2).

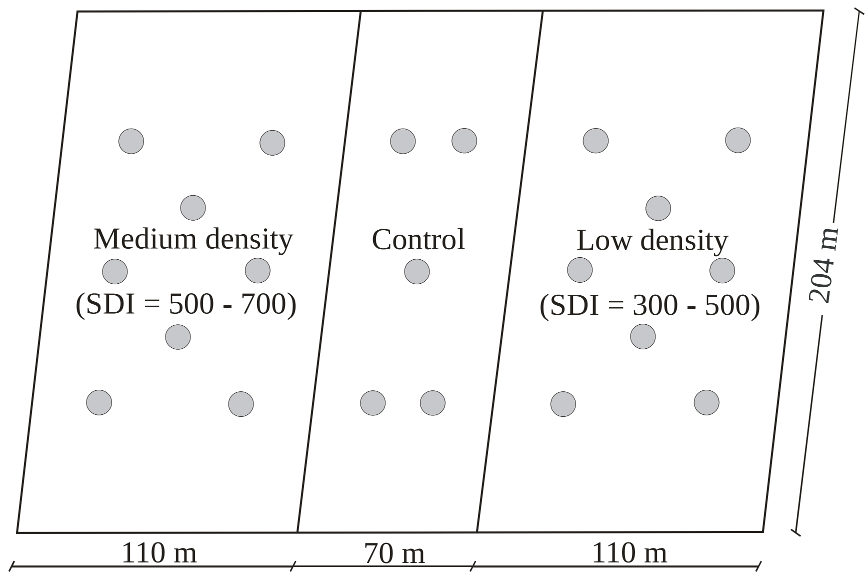

Figure 2. Layout of Abra Ancha thinning trial. Grey circles are the 300 m^2 subplots where measurements were taken.

Measurements were taken in 300 m^2 sub-plots (Figura 2). Stand site quality was determined in terms of a growth intercept index (GII) developed for northern Patagonia ponderosa pine plantations (Gonda et al. 1998c). This index is calculated as the length of the five internodes located above breast height measured on the dominant trees, that is the 100 trees/ha with the largest diameter at breast height (DBH). The study was measured in 1995, 2000, 2001, 2002, 2005, 2006, 2008 and 2009. Diameter, height, basal area and volume in the other years were calculated by interpolation. Total height (H) of each tree was computed with a non-linear H-DBH equation fit for each plot (Gonda et al. 2004); the H-DBH samples included trees form all diameter classes. Inside bark volume was estimated using a two parameter model fit for Neuquén ponderosa pine plantations (Gonda et al. 1998a).

$$H = 1.3 + \exp(a + (b / (DBH + 1)))$$

where:

H = total height (m)
DBH = diameter at breast height (cm)
a and b = coefficients computed for each plot.

$$V = 0.000214 + 0.000030 * DBH^2 * H + 0.000538 * DBH$$

where:

V = total inside bark volume (m^3)
DBH = diameter at breast height (cm)
H = total height (m)

<u>Meliquina Study</u>

Location and treatments

A second thinning trial was established by CIEFAP in 1999, on a 20 year-old ponderosa-Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) stand (Gonda and Cortés 2005). This stand was chosen because it presented the desired age and density, besides being the most homogeneous in the area in terms of spacing. The fact that it was a mixed stand was not considered a drawback for the results to be valid for pure ponderosa pine plantations because these two species can be combined for growth and yield modeling purposes as they grow at about the same rate and have similar form (Hallin 1957). The study was located at Meliquina ranch, 45 km southwest of San Martín de los Andes. Treatments were also defined in terms of SDI, but they were four instead of three; a high density treatment was added between the control and the medium density (Figure 3). A low thinning with the removal of a few poorly formed dominant trees was also applied to maintain the density range of each treatment.

- Control (SDI=2,300): No thinning. This treatment will allow for validating the maximum SDI value for ponderosa pine in the region. Preliminary studies suggest that it would be about 2,300 (Gonda et al. 1998b).

- High density: SDI= 900-1,100. The site is fully occupied because at the lower limit of this treatment the SDI is slightly over 35% of the maximum density.

- Medium density: SDI=600-800. At the lower limit of this treatment trees start to compete because they have almost 25% of the maximum SDI. At the upper limit the competition is higher but the site is not yet fully occupied because the SDI is less than 35% of the maximum.

- Low density: SDI=300-500. Trees grow freely because onset of competition does not take place with a SDI below 25% of the maximum.

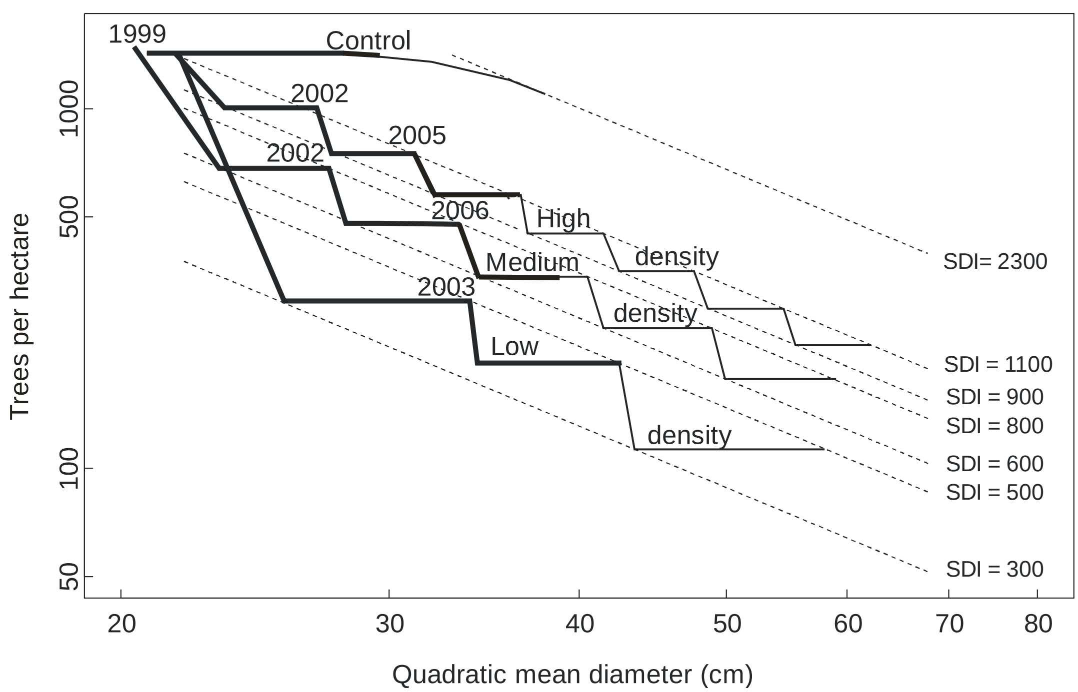

Figure 3. Quadratic mean diameter and number of trees per hectare measured between 1999 and 2009 (thick lines) and expected for the rest of the experiment (thin lines) at Meliquina. Years when thinnings were carried out, and density lower and upper limits of each treatment in terms of

Reineke's stand density index are also shown (dotted lines). Both axes were built in a logarithmic scale.

Study layout and measurements

The study has two replicates because the four treatments were randomly assigned to eight, ¼ ha, square plots surrounded by a 10 m wide buffer strip (Figure 4). Stand site quality was determined using the local growth intercept index (Gonda et al. 1998c). The study was measured every year since it was established (1999-2009) and all trees were measured in each plot for DBH. Total height was predicted fitting to each plot the same equation form used in Abra Ancha study. Total inside bark volume was also computed with the same equation as in Abra Ancha study. Results were analyzed as a repeated measures experiment that can be viewed as equivalent to a completely random split plot experiment in which each measurement is treated as a subplot (Curtis and Marshall 1986, Von Ende 1993).

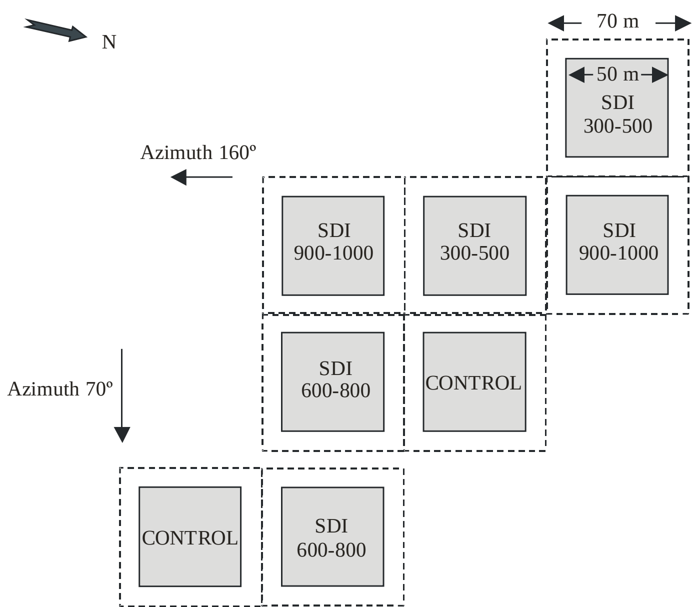

Figure 4. Layout of Meliquina thinning trial.

RESULTS AND DISCUSSION

<u>Thinning studies</u>

Abra Ancha and Meliquina studies were established on a high (GII = 4.2 m) and a medium (GII=3.5 m) quality site respectively. At each study site, site quality, number of tress per ha, QMD, and mean H of the plots were so similar that calibration thinning was not considered necessary.

Diameter growth

At Abra Ancha, periodic annual diameter growth was 0.5, 1.1 and 1.6 cm a year for control, medium and low density treatments. Diameter growth of the largest 100 trees/ha was slightly higher: 0.7, 1.3 and 1.7 cm. At Meliquina, diameter growth was 0.9, 1.4, 1.6 and 2.1 cm a year, being higher for the treatments with lower density. Differences were significant except between the medium and height density treatments. Results show that diameter growth is strongly affected by density even when full site occupancy has not been achieved (SDI < 800). At similar stocking levels diameter growth seems to be higher at Meliquina. Ponderosa pine plantations established on highly productive sites with no competing vegetation in northern California (Oliver 1997, Oliver and Powers 1978), Oregon (Cochran and Barret 1993) and Washington (Cochran and Barret 1998) do not grow more than 1.4 cm a year in diameter.

Height growth

At Abra Ancha, periodic annual height growth was 0.62, 0.67 and 0.72 m a year for control, medium and low density treatments. Differences were more noticeable for the largest 100 trees/ha: 0.62, 0.70 and 0.74 m. Several long-term thinning studies established in ponderosa pine stands in Western United States also reported that annual height growth tends to be greater for wider spacings (Barrett 1963, Barrett 1982, Cochran and Barrett 1993, Cochran and Barrett 1998, Lilieholm et al. 1989, Oliver 1997). At Meliquina, however, height growth was 0.63 m for all treatments. Height growth at Abra Ancha matches height growth on the best sites in northern California. This is even more significant considering that in Patagonia there are sites where trees grow more rapidly in height than at Abra Ancha (Gonda et. al 1998b).

Basal Area Growth

At age 29, Abra Ancha periodic annual basal area growth was 2.1, 2.2, and 2.7 m^2 ha^{-1} $year^{-1}$ for the low, medium density, and control treatments. At the same age, Meliquina basal area growth was 2.7, 3.6, 4.7, and 4.7 m^2 ha^{-1} $year^{-1}$; the denser the treatment the higher the basal area. Differences were not significant only between the control and the high density treatments. Same as with diameter, at similar number of trees per hectare basal area growth is higher at Meliquina. Studies established on highly productive ponderosa pine plantations in western United States reported maximum periodic annual basal area increments of 1.8 m^2 ha^{-1} $year^{-1}$ (Oliver 1997, Oliver y Powers 1978).

Volume growth

At age 29, Abra Ancha periodic annual growth in volume was 18, 20, and 30 m^3 ha^{-1} $year^{-1}$ for low, medium density, and control treatments. At the same age, Meliquina volume growth was 18, 26, 35 and 36 m^3 ha^{-1} $year^{-1}$; the denser the treatment the higher the volume. Same as the case with basal area, volume differences were significant except between control and high density treatments. At a similar density, volume growth at Meliquina is equal or higher than it is at Abra Ancha. That is basically indicating that diameter growth at Meliquina is so high that compensates for the higher H growth registered at Abra Ancha. The latter is supposed to be a better site because GII at Abra Ancha is 4.2 m, while at Meliquina GII is 3.5 m. Further work is needed to determine what other variable/s should be considered along with height to explain the difference in productivity between both sites. Periodic annual volume growth of highly productive ponderosa pine plantations in Western United States seldom reaches 25 m^3 ha^{-1} $year^{-1}$ (Oliver 1979, Oliver and Powers 1978).

<u>Growing stock</u>

Previous studies demonstrated that Patagonia plantations have more cubit-foot volume than highly productive California stands. A comparison was made among stands of the same age, dominant height, and number of trees per hectare at both regions, and thus Patagonia ponderosa pine trees should have a higher diameter growth (Gonda et. 1998b). The yield of California plantations reach a plateau around age 30. Conversely, the yield of Neuquén plantations increase proportionally to the number of trees per unit area at least up to age 40; the study did not include older plantations because in Patagonia most stands are relatively young, below 40 years of age. In short, stands with the same number of trees per hectare and dominant height, in Patagonia have more basal area that they do in western United States. This is reinforced by the fact that California plantations growing on the best sites (site index 100 and 120 feet at age 50) reach a maximum BA of approximately 64 $m^2 ha^{-1}$ around age 30 (Oliver and Powers 1978). In Neuquén some stands have BAs of about 100 $m^2 ha^{-1}$, and they may still not be the maximum possible values. Oliver and Powers (1978) determined a maximum SDI of 1,235 for dense, natural, even-aged stands in northern California. In Patagonia, self-thinning does not occur with SDIs below 1,700 (Gonda et al. 1998b) and in the few unmanaged older stands that show high suppression-related mortality, SDI is over 2,300. Why ponderosa pine tends to grow faster in Patagonia than in its natural environment in the northern hemisphere is beyond the scope of this paper. However, there are several analogous cases, such as radiata pine (*Pinus radiata* D. Don), a species that in New Zealand, Chile and Australia can achieve higher densities that it does in its natural environment.

CONCLUSIONS

Results of the thinning trials and other previous studies showed that in Patagonia it would be possible to grow ponderosa pine in relatively short rotations. If the objective were to maximize individual tree growth and size, without regard to volume production on an area basis (SDI=300-500), on medium to high quality sites it would be possible to achieve a final QMD of 50 cm in about 30 years. On the other hand, if the management objective were to reach a compromise between maximization of volume production on an area basis, and maximization of individual tree growth (SDI=500-700), a final QMD of 50 cm could be achieved in approximately 45 years. We also demonstrated that the average yield of ponderosa pine stands in Patagonia tends to be similar or higher than those growing in the more productive regions in the western Unites States. Hence, it would be biologically possible to establish a large plantation area with this forest species in our region. As pointed out in the introduction, creating a new forest will bring not only socio-economical, but also environmental benefits for local people. However, there are some factors that have the potential to hamper this project. Preliminary studies demonstrated that wood from the young ponderosa pine plantations presents some problems due to its low density associated with the high proportion of juvenile wood. Radical environmental groups raise their voice against any kind of monoculture, mainly in the case of exotic tree species. Long rotations (30-45 years) discourage potential investors to start the cycle, that is planting trees from scratch without having mature plantations from which to obtain some revenue. Growing trees is not part of the local culture traditionally based on extensive cattle and sheep raising. Dry summers and the presence of tourists make fire a real threat for forest plantations. Even though some forested areas have efficient fire control systems, that is not the case with many others. Climate change is being monitored since the impact can be strong on ecotone areas such as those where ponderosa pine is planted. So far, insects and diseases have not produced significant damage to crop trees when stands are managed. However, the future may bring more harmful organisms that could take advantage of weakened trees as a result of possible extreme climatic events. These and other problems we are facing to develop the high forest potential in Patagonia probably are not much different from those faced by people in other regions of the world that intended to convert their economies. There are two positive facts that can help to overcome the list of troubles. First, the National as well as the Provincial Governments have been committed to promote afforestation by providing funds as subsidies, not only to plant trees, but also to carry out precommercial thinning and pruning. Second, during the last 15 years numerous studies have produced an important amount of information on growth and yield of ponderosa pine. Professionals form institutions like CIEFAP, Patagonia and Comahue Universities, National Institute of Agricultural Technology, and others, continue doing research on the main problems that arise with the cultivation of this exotic tree. If we can take advantage of the favorable factors and be creative at solving the problems, a new forest could bring prosperity to the region.

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