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DENDROECOLOGICAL POTENTIAL OF COMMON TREE SPECIES ALONG A TRANSECT ACROSS THE SOUTHERNMOST ANDES, CHILE (53°S).

POTENCIAL DENDROECOLÓGICO DE ESPECIES DE ÁRBOLES TÍPICOS EN UNA TRANSECTA SOBRE LOS ANDES AUSTRALES DE CHILE (53°S).

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RESUMEN

Se han investigado, por su potencial dendrocronológico, las especies mayores de árboles a lo largo de un transecto este-oeste de 100 km en los Andes Australes de Chile. El objetivo de este estudio piloto ha sido encontrar las especies de árboles y los sitios más adecuados para reconstrucciones climáticas y dendroglaciológicas. Para esto, se han estudiado cuatro sitios a lo largo del transecto en los 53°S, cubriendo desde el clima Andino dividido desde más de 8.000 mm de precipitación anual, hasta las franjas occidentales de la Estepa Patagónica con menos de 500 mm de precipitación anual. A lo largo del transecto el Bosque Lluvioso Magallánico es reemplazado hacia el este por bosque deciduo y por la Estepa Patagónica. Desde oeste a este se obtuvieron tres cronologías de ancho de anillos de árboles: cronología *Pilgerodendron uviferum* (D. Don.) Florin, del bosque lluvioso siempre verde Magallánico, cronología *Nothofagus pumilio* (Poepp. & Endl.) Oerst. para el bosque deciduo y cronología *Cupressus macrocarpa* Hartw. cerca de la Estepa Magallánica. Estas cronologías fueron comparadas con series de tiempo meteorológico provenientes de las cuatro estaciones climáticas más cercanas al perfil. En la sección más húmeda, *Pilgerodendron* muestra respuesta positiva a la temperatura y negativa a las precipitaciones. En la sección semiárida, *Nothofagus* y *Cupressus* responden ambos positivamente a las precipitaciones y negativamente a la temperatura. Además, durante períodos registrados de avances glaciares desde los Andes Patagónicos, *Pilgerodendron uviferum* ha mantenido un crecimiento por debajo del promedio, posiblemente debido a las altas precipitaciones. También, se encontró que el fenómeno de El Niño (ENSO), erupciones volcánicas mayores y terremotos locales apenas afectan el crecimiento radial de los árboles.

Palabras clave: *Pilgerodendron uviferum, Nothofagus pumilio, Cupressus macrocarpa*, Dendroclimatología, Dendroglaciología.

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INTRODUCTION

Exclusively influenced by the southern hemisphere westerlies, the southernmost Andes represent a strong climate divide for which regional and local climate variations during the last centuries are mostly unknown. Tree-rings may document these climate fluctuations in the ecotones of this area. Tree-ring studies, while abundant in the northern hemisphere, are generally sparse in the southern hemisphere and specifically in South America (Boninsegna 1992, Boninsegna & Villalba 1996, Villalba 2000). The only region of South America with adequate research is along the Andes from 37° to 43° S (Villalba 1990, 1994, Villalba *et al.* 1990, Szeics 1997 among others). Except for studies on Tierra del Fuego (Boninsegna *et al.* 1989, Roig *et al.* 1996) south of 46° S only preliminary research was carried out (Sweda & Inoue 1987, Rivera *et al.* 1997). However, first results related to the Pole – Equator – Pole transect (PEP I; Markgraf *et al.* 2000) improve this situation (*e.g.* Aravena *et al.* 2002, Lara *et al.* 2000[1]; Roig *et al.* 2000[2]).

To establish the dendroecological potential of the common tree species in southernmost Patagonia, 23 trees were sampled along an Andean E–W transect at 53° S (Fig. 1). Along this transect climate ranges from super humid in the central section of the Andes to semiarid in the Patagonian Steppe. Therefore associated ecotones are dominated by different tree species, which may incorporate different ecological signals. The sampled native tree species include *Pilgerodendrum uviferum* (D. Don.) Florin, *Nothofagus betuloides* (Mirb.) Blume, *Nothofagus pumilio* (Poepp. & Endl.) Oerst., *Nothofagus antarctica* (Forst) Oerst., and *Drimys winteri* J.R. & G. Forst. At the easternmost sampling site *Cupressus macrocarpa* Hartw., an exotic tree species, was also sampled, because the local native species, *Nothofagus antarctica*, is often deformed by the strong predominant westerlies and shows flagged tops and non-circular stems.

From this data set three preliminary tree-ring width chronologies were developed. Each chronology incorporates only 2-3 trees and thus all results reported here are tentative and need to be proofed by an enhanced data set. The data of the *Pilgerodendron uviferum*, the *Nothofagus pumilio* and the *Cupressus macrocarpa* chronologies record the natural variability of environmental factors back to A.D. 1628, 1808 and 1932 respectively (Fig. 2). Even though our data set is restricted, the chronologies were compared statistically with regional temperature and precipitation records of the last 112 yeas (Fritts 1976, Schweingruber 1996). The tree-ring series were also compared with reported major glacier advances in the southernmost Andes since A.D. 1638 (*e.g.* Villalba *et al.* 1990, Villalba 1994). In addition, we have considered the potential influence on tree-ring width by 3 major southern hemisphere plinian volcanic eruptions since A.D. 1815 (*e.g.* Villalba & Boninsegna 1992, Jones *et al.* 1995), local earthquakes of magnitude >5 registered during the last 50 years (Kitzberger *et al.* 1995, National Earthquake Information Center 1999) as well as major ENSO events since 1707 (Enfield 1992, Quinn & Neal 1992, Lough & Fritts 1985).

The study

The investigated Andean area at 53° S is characterized by deeply incised fiords and islands due to various glaciations during the Quaternary (Clapperton *et al.* 1995). The highest elevations are ≤ 2000 m. Due to active subduction along the continental margin, small earthquakes occur occasionally (National Earthquake Information Center 1999). East of the Cordillera the landscape is dominated by proglacial lakes (Fig. 1).

The north-south trending Andes build an orographic barrier to the very strong and highly predominant westerlies, causing an extremely pronounced precipitation divide with up to 10.000 mm annual precipitation in the Andes and very little precipitation (< 500 mm) typical for the area east of the Andes (Fig. 1; Miller 1976, Prohaska 1976, Weischet 1996). Precipitation in the Andes is evenly distributed throughout the year, resulting in 300 to 320 days of the year with precipitation. The Andean area is characterized by cool summers and mild

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[1] Lara, A., J.C. Aravena, A. Wolodarsky, R. Villalba & B.H. Luckman 2000. Dendroclimatology of *Nothofagus pumilio* treelines in Chile along a latitudinal gradient from 35° 40' to 55° S. *Abstracts of the International Conference on Dendrochronology for the Third Millennium*, Laboratorio de Dendrocronología, Mendoza, Argentina: 232.

[2] Roig, F.A., J.C. Aravena & A. Lara 2000. Tree-ring studies from upper treeline environments of Tierra del Fuego and Navarino Island. *Abstracts of the International Conference on Dendrochronology for the Third Millennium*, Laboratorio de Dendrocronología, Mendoza, Argentina: 239.

winters with an annual mean of around 6.5°C and a small mean daily and yearly temperature amplitude (± 5° C; Miller 1976, Weischet 1996).

Along our west – east transect, concurrent with the decreasing precipitation, four main forest communities can be distinguished (Moore 1983). At the Gran Campo Nevado sampling site the evergreen Magellanic Rainforest consists predominantly of *Nothofagus betuloides*, complemented by *Pilgerodendron uviferum* and *Drimys winteri* (Fig. 1; Young 1972, Moore 1983; Veblen *et al.* 1995, 1996). To the east at the Peninsula Diadema a mixed evergreen – deciduous forest is characterized by the evergreen *Nothofagus betuloides* and *Drimys winteri* as well as the deciduous *Nothofagus pumilio.* At Seno Skyring pure stands of *Nothofagus pumilio* make up the forests, while on the fringes of the Patagonian Steppe at Seno Otway *Nothofagus antarctica* forms pure stands (Fig. 1).

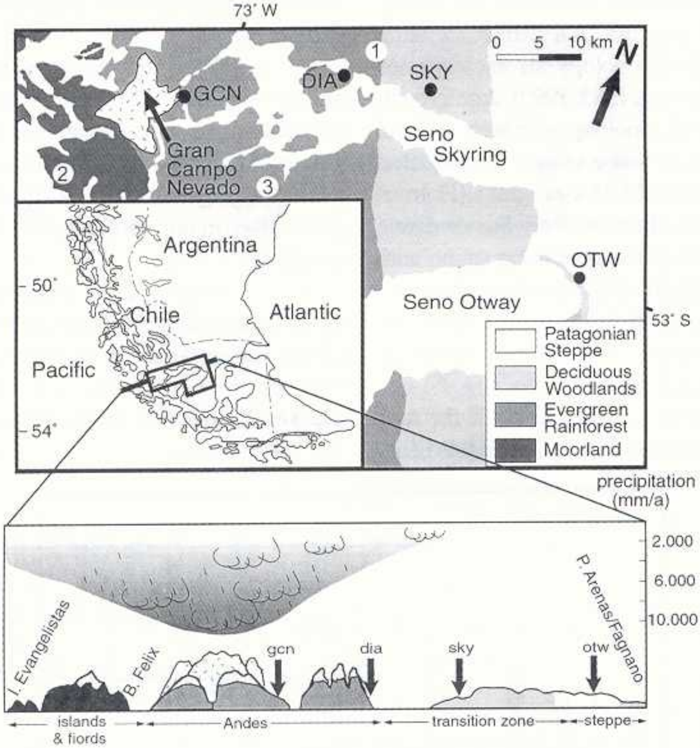

Fig. 1. The location of the different sampling sites in the southernmost Andes of South America (map inset), related vegetation zones (Markgraf 1993) and locations of three earthquakes epicentres considered in the study (National Earthquake Information Center 1999). They are numbered 1-3, with 1 occurring in April 1973, 2 in October 1988, and 3 in August 1996. Variations in the annual precipitation along this transect are shown in the cross section below.

TABLE 1. The four meteorological stations from which data are used in the study. The location, the time span of each used parameter and the mean annual temperature and precipitation are given (Miller 1976, Rosenblüth et al. 1995, 1997). Height is given in metres above mean sea-level (a.s.l.). Not available records are indicated by n/a.

Climate station	Lat. (S)	Long. (W)	Height (a.s.l.)	Temp. record	Prec. record	Mean annual Temp.	Mean annual prec.
Punta Arenas	53°02'	70°51'	33 m	1905-1987	1888-1986	6.5° C	433 mm
Fagnano	53°10'	70°55'	32 m	1900-1987	n/a	6.3° C	286 mm
Bahía Félix	52°58'	74°04'	42 m	n/a	1915-1969	6.7° C	4025 mm
I. Evangelistas	52°25'	75°06'	52 m	1900-1987	1899-1952	6.8° C	2261 mm

Sampling at breast height was conducted in October of 1999. Preparation and analysis was done at the Institute for Forest Growth (IWW) in Freiburg, Germany. Samples were sanded with 40, 80 and 120 DIN paper and some selected samples have been prepared with a shaper developed by the IWW (Spiecker *et al.* 2000). Rings along 2-4 representative radii for each tree were measured on a sliding stage, developed by the IWW, with a precision of ±0.01 mm (Spiecker *et al.* 2000). The series were checked and verified by the International Tree-Ring Data Bank (ITRDB) software program COFECHA, creating a master ring width chronology for each species and for each site (Holmes 1983, 1999). Age-growth trends in the master chronology were removed and standardised ring width indices were constructed using the ITRDB COFECHA program (Holmes 1983, 1999, Cook & Kairiukstis 1990). Standardising was done by fitting a cubic smoothing spline with a 50% frequency cut-off of 32 years to each series. After the standardising process, each series was tested against the adjusted master series and correlation coefficients were calculated.

Three time series for each of the four climate stations (Punta Arenas, Fagnano, Bahía Félix, and Islote Evangelistas; Table 1 and Fig. 1) were calculated and correlated with the tree-ring width chronologies. The first includes a 17-month interval, including the previous growing season until the end of the current growing season from November of the previous year until the current March, the second the southern hemisphere year from July to June and the third the growing season from November until March. As some of the meteorological time-series were incomplete with more than three monthly means missing a year, these years were omitted from the correlation.

Years and periods with either negative and/or positive anomalies in the tree-ring chronologies were compared with periods of glacier advances, years with local earthquakes, years with significant ENSO events as well as 1-3 years after major southern hemisphere volcanic eruptions.

Among the six different tree species investigated along the transect only three yielded chronologies. There is no significant correlation between the chronologies of the different sites. The results are presented separately for each site. Fig.2. / Table 2.

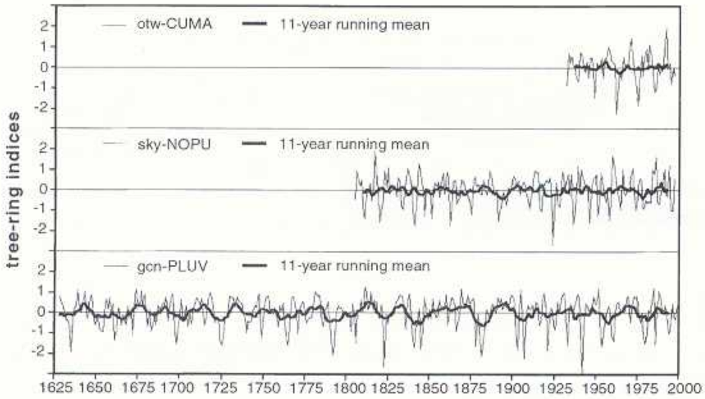

Fig. 2. The three chronologies, otw-CUMA, sky-NOPU and gcn-PLUV, spanning the periods of 1932-1997, 1808-1997 and 1628-1999 respectively. The determined tree-ring width indices and their smoothed values (11-year running mean; bold lines) are shown.

TABLE 2. Statistics of the COFECHA chronologies.

Chronology name	**No. of trees**	**No. of radii**	**period**	**Interseries correlation**	**Mean measurement**	**Mean sensitivity**	**Standard deviation**
gcn-PLUV	2	4	1628-1999	.424	.37 (mm)	.214	.269
sky-NOPU	3	6	1845-1997	.456	1.31 (mm)	.206	.302
otw-CUMA	3	15	1943-1996	.522	2.49 (mm)	.260	.391

In the superhumid area of the Andes at the Gran Campo Nevado site (Fig. 1) only *Pilgerodendron uviferum* shows a significant correlation (r = 0.424) at the 99% level. This chronology (gcn-PLUV) is illustrated in Figure 2 and its statistics are given in table 2. We were unable to cross-date *Nothofagus betuloides* and *Drimys winteri* at this site. The gcn-PLUV chronology correlates weakly with the temperature record of Islote Evangelistas west of the Andes (+0.182 for the 17-month period; Table 3). Also, a weak negative correlation with precipitation of the climate record at Islote Evangelistas and Bahía Félix are observed (-0.235 for the 12-month period and -0.193 for the 17-month period respectively; Table 3).

The gcn-PLUV chronology shows below average growth rates during periods when Glaciar Frías (41°10'S, 71°50'W; Villalba *et al.* 1990) and several glaciers of the Southern Patagonian Icefield (48°20'S-51°30'S; Warren & Sugden 1993) had calendar-dated advances (Fig. 3).

At the humid sample site of Seno Skyring on the eastern slopes of the Andes (Fig. 1), a chronology of *Nothofagus pumilio* (sky-NOPU) shows a significant interseries correlation (r = 0.456; Fig. 2, Table 2). The sky-NOPU chronology correlates only with meteorological data east of the Andes. The chronology correlates negatively with temperature (-0.264 for the 17-month period) and positively with precipitation (+0.260 for the growing season) of Punta Arenas (Table 3). However, these correlations are not significant at the 99% level.

At the semiarid sampling site of Seno Otway a significant correlation (r = 0.522) was obtained for the *Cupressus macrocarpa*. This chronology (otw-CUMA) is illustrated in Figure 2 and its statistics are given in table 2. We were unable to cross-date *Nothofagus antarctica* from the same sampling site. The otw-CUMA chronology correlates negatively with the temperature record of Punta Arenas (-0.249 during the 17-month period), and also negatively with the temperature record of Fagnano (-0.418 for the 17-month period and -0.388 for the 12-month period) (Table 3). The otw-CUMA chronology is correlated positively with precipitation of Punta Arenas (+0.396 for the growing season; Table 3), but negatively with

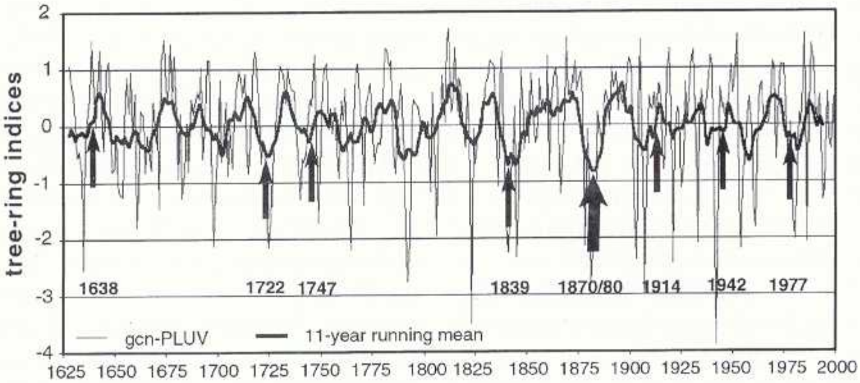

Fig. 3. The gcn-PLUV chronology, the smoothed values (11-year running mean; bold line) and the calendar dated moraines in Patagonia from Table 9 are shown.

TABLE 3. Best correlation of otw-CUMA, sky-NOPU, and gcn-PLUV with meteorological data. (1) is the 17 month interval, (2) the July-June interval and (3) the growing season period. * indicate significant correlation at the 99% level.

	Punta Arenas		**Fagnano**		**Islotes Evangelistas**			**Bahía Félix**	
	Temp	**Prec**	**Temp**		**Temp**	**Prec**		**Prec**	
	(1)	**(3)**	**(1)**	**(2)**	**(1)**	**(1)**	**(2)**	**(1)**	**(2)**
otw-CUMA	-0.249	0.396*	-0.418*	-0.388*	---	-0.497*	-0.343*	-0.590*	-0.477*
sky-NOPU	-0.264	0.260	---	---	---	---	---	---	---
gcn-PLUV	---	---	---	---	0.182	---	-0.235	-0.193	---

precipitation of Islote Evangelistas (-0.497 for the 17-month period and -0.343 for the 12-month period) and Bahía Félix (-0.590 for the 17-month period and -0.477 for the 12-month period) (Table 3), both of which are west of the Andes (Fig. 1).

Ring widths of all three chronologies are hardly affected by ENSO events. However, the sky-NOPU chronology could have been affected slightly by the highest ranked ENSO events of 1828, 1877/78 and 1925/26 (Quinn & Neal 1992). As no study known to the authors has found a significant influence on precipitation or temperature in this region and it is generally accepted that the influence of ENSO is decreasing towards southernmost South America (Rosenblüth *et al.* 1997), this was to be anticipated.

Also, no clear relation was found between large southern hemisphere volcanic events and the tree-ring chronologies, which corresponds to the fact, that all instrumental records do not show any signal related to the eruptions. The considered volcanic eruptions include that of Tambora (Indonesia) in 1815, Armagura (Nicaragua) in 1846, Krakatau (Indonesia) in 1883, Tarawera (New Zealand) in 1886, and Nilahue (Patagonia) in 1955 (Villalba & Boninsegna 1992). The main effect of volcanic eruptions on air temperature is caused by less direct sunshine (Bradley & Jones 1992). Cloud cover over Patagonia is extraordinary high throughout the year (Miller 1976, Prohaska 1976, Weischet 1996), thus, no strong influence of any volcanic eruption on temperature and tree-ring growth can be expected as direct sunshine is already limited.

We have considered the possible effect of three earthquakes closest to the transect and with a magnitude > 5 (National Earthquake Information Center 1999). The epicenters and years are shown in figure 1. Negative tree-ring anomalies were not observed for these years.

As described above possible effects by major volcanic eruptions, local earthquakes and/or ENSO events on tree-ring width can be widely precluded. Due to the distinct climate conditions and ecosystems along the transect, no chronologies could be developed for a common tree species of the different sites and the developed chronologies do not cross-date with each other. Therefore, we discuss our preliminary results separately for the three climatically distinct sites along the transect.

At the superhumid sampling site in the Andes, the gcn-PLUV chronology shows a weak positive correlation with the temperature record as well as a weak negative correlation with the precipitation record of the meteorological stations Islote Evangelistas and Bahía Félix west of the Andes. However, the low correlation of gcn-PLUV with temperature is high enough to suggest that coring trees at or near treeline at Gran Campo Nevado would lead to a more significant correlation. The observed negative correlation between growth rates and precipitation suggests that precipitation is a limiting factor for tree growth. At the Gran Campo Nevado *Pilgerodendron uviferum* is only growing on rather waterlogged soils, which are often oversaturated with moisture. Excessive rainfall may lead to a shortage of oxygen supply and thereby damage the roots, which hampers tree growth.

In accordance with the climatological relationships, the gcn-PLUV chronology shows below average growth rates in periods of calendar-dated glacier advances (Fig. 3). Generally, high precipitation rates and low temperatures lead presumably to glacier advances. Glaciers often react slowly to changes to their budget, and it takes several years for a glacier to advance under favourable conditions. In the gcn-PLUV chronology precipitation of the western meteorological stations is the strongest observed climate signal and it is negatively correlated with tree growth. Therefore, high precipitation leads to below average growth and presumably to glacier advances. This suggests that the glacier fluctuations of the area are mainly driven by changes in precipitation. Furthermore, a significant gradual decrease in precipitation of up to 1.400 mm in the last 70 years was found west of the southernmost Andes (Rosenblüth *et al.* 1995) and may have caused an observed continuous retreat of most glaciers in this area (Warren & Sugden 1993).

At the humid sample site of Seno Skyring on the eastern slopes of the Andes (Fig. 1), the sky-NOPU chronology correlates only with the meteorological records of Punta Arenas. A weak negative correlation with temperature and a weak positive correlation with summer precipitation indicate that tree growth may already be affected by drought stress during summer. The generally low or missing correlations between the regarded climate records and this chronology may be due to the transitional position of this sampling site along the transect.

At the semiarid sampling site of Seno Otway in the Pampean area the otw-CUMA chronology correlates negatively with temperature and positively with summer precipitation. While higher precipitation during the growing season leads to increased cambial activity, higher temperatures put the trees under drought stress. Surprisingly, a high negative correlation with precipitation west of the Andes was found. High precipitation west of the Andes is negatively correlated with low growth rates at the Seno Otway site. This can be explained by the less frequent general weather situation of easterly winds, which lead to an increase in precipitation east of the Andes and a concurrent decrease in precipitation west of the Andes (Miller 1976, Weischet 1996). Frequent occurrence of this weather situation in one year, may produce relatively high precipitation east of the Andes, leading to increased cambial activity. Therefore, it could be possible to reconstruct the general weather situations of southernmost Patagonia with *Cupressus macrocarpa* at the Seno Otway sampling site. Also, reconstruction of temperature and precipitation of the eastern Patagonian environment could be possible. Unfortunately, as the species is not indigenous to the area, not many of them would be found for sampling. We were unable to cross-date *Nothofagus antarctica* from this sampling site, possibly due to its irregular and strongly wind influenced growing forms.

In conclusion, the comparison of the chronologies with climatic data of the area shows various correlations. These are often restricted to local climate fluctuations which are still not well constrained, especially due to the strong precipitation gradient along the transect. Especially precipitation may be an important factor on tree growth. In the Andean area with more than 8000 mm annual precipitation and year-round water saturated soils, extreme high precipitation seems to hamper tree growth, whereas in the semiarid area summer precipitation foster tree growth. Comparison of the tree-ring series to reported glacier fluctuations of the Patagonian Andes show that during times of glacier advances *Pilgerodendron uviferum* has prolonged below average growth.

The results of this study encourage further research. Especially given the few and the short length of instrumental climatic records available and the extremely diverse landscape along this transect, dendroclimatological reconstruction for the last 500 years would be welcome. Even though correlation was low, on-going and future research will focus on *Pilgerodendron uviferum* at Gran Campo Nevado. Especially encouraging are the dendroglaciological results. Future research with *Pilgerodendron uviferum* at the Gran Campo Nevado Icecap could lead to a reconstruction of glacier fluctuations during the Neoglacial, especially the Little Ice Age. Due to its longevity and its decay-resistant nature (Roig *et al.* 1992, Szeics *et al.* 2000) *Pilgerodendron uviferum* is the most suitable tree species at the Gran Campo Nevado for long dendroecological records.

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