Late-glacial and Holocene climate dynamics at the steppe/forest ecotone in southernmost Patagonia, Argentina: the pollen record from a fen near Brazo Sur, Lago Argentino

Michael Wille · Frank Schäbitz

Abstract We present a pollen record from a fen at the eastern shore of Brazo Sur south of Lago Argentino, Argentina (core BRS 1/06, 50°34′54″S, 72°54′52″W, 198 m a.s.l.). The coring site is located in the transition zone from humid grass steppe to Andean *Nothofagus* forest. With the exception of a mid-Holocene sand layer, the record covers the interval between 13,350 and 1,700 cal B.P., indicating that there could have been no recurrence of Late-glacial conditions in Brazo Sur, as has been suggested in the literature as having been contemporary with the Younger Dryas interval in the northern hemisphere. The Late-glacial and early Holocene periods at Brazo Sur are characterized by fluctuations between humid grass-dominated steppe associations and drier ones dominated by Asteraceae and Ericaceae. At the start of the Holocene, the pollen influx increased. *Nothofagus* dominance began by 7,700 cal B.P. probably due to increasing moisture. Present-day closed *Nothofagus* forest developed around 2,500 cal B.P., related to a further increase in moisture.

Keywords Pollen · Climate · Andes · South Patagonia · Late-glacial · Holocene

Introduction

Well dated pollen records from the lowlands east of the Andes in southernmost Patagonia (48°–52°S) that cover the

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Late-glacial to Holocene transition and Holocene period are rare. The first pollen diagrams from this area, without dating, were presented by Auer (1958). Pollen records from archaeological excavations have provided some information on past vegetation change, although they are often poorly dated (Paez et al. 1999; Mancini 2002). The record from Meseta Latorre, a high plateau about 900 m a.s.l., cannot easily be extrapolated to the lowlands as it reflects the vegetation and climate setting of higher elevations (Schäbitz 1991). The pollen records from Rio Rubens bog (Huber and Markgraf 2003a) and Vega Ñandú (Villa-Martinez and Moreno 2007) are the only pollen records so far that are located inside the ecotone spanning Late-glacial and Holocene times. Unfortunately, the published pollen diagram from Rio Rubens contains only a few of the main taxa because the focus of the authors was the reconstruction of the fire history interpreting the amount of charcoal particles. Other pollen records from the study area that date back to glacial times originate from Lago Cardiel (Markgraf et al. 2003) and Laguna Potrok Aike (Wille et al. 2007) which are located in the dry steppe several kilometres east of the forest/steppe ecotone (Fig. 1). These records show a pollen signal from the Andes that was probably caused by the strong westerly winds transporting pollen from the Andes into the lakes of the steppe, but it is very likely that this pollen signal is reduced due to the great distance. Therefore, records from sites directly located in the transitional zone between humid steppe and forest are needed to add more important information about the vegetation history and climate dynamics of the most productive vegetation formations in southernmost South America outside the Andes.
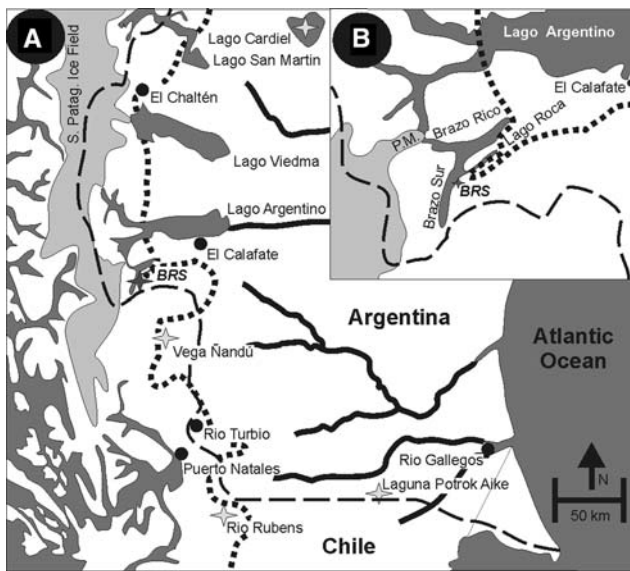
A database of surface pollen samples from all over Patagonia gives a relatively precise image of the recent pollen rain of different vegetation formations in this region

Fig. 1 a Map of the southernmost South American mainland. The *dark asterisk* indicates the Brazo Sur coring site. The *light asterisks* indicate published pollen records mentioned in the text. **b** Area map of the surroundings of the coring site. *PM* glacier Perito Moreno, *BRS* Brazo Sur coring site, *dashed line* border between Argentina and Chile, *dotted line* recent steppe/forest ecotone

(Mancini 1998, 2003; Quintana et al. 2003). This information is an important tool for reconstructing vegetation and climate history from pollen records (Paez et al. 2001; Mancini et al. 2005).

In this paper, we present the pollen record from a fen near the eastern shore of Brazo Sur of Lago Argentino (BRS 1/06) which today is located in the transition zone from humid grass steppe to Andean Forest and which dates back to 13,350 cal B.P. The pollen record from this site provides new insights into the dynamics of the forest/steppe ecotone in Late-glacial and Holocene times and offers a new possibility for identifying and separating the fossil pollen signals of dry and humid steppe formations in the study area.

Geographical setting

The coring site BRS 1/06 is located a few metres from the eastern shore of the southern arm of Lago Argentino (Brazo Sur, 50°34′54″S, 72°54′52″W, 198 m a.s.l.), about 60 km southwest of the city of El Calafate (Fig. 1). The coring point lies in a small wetland which is separated from the lake by a rocky ridge about 3 m high and 10 m wide. During the time of our visit in 2006 at the end of the southern spring, the fen was located about 10 m above the water level of Brazo Sur (Fig. 2). The lakes Brazo Sur, Lago Roca and Brazo Rico are fed by intermittently flowing rivers primarily during the snow melt season.

During times when the Perito Moreno glacier advances, it dams the drainage of the three lakes into Lago Argentino so that the water levels of the dammed lakes rise by about four m in the case of Brazo Sur until the outlet becomes free again, following a spectacular breakthrough at the ice front.

Modern vegetation types of the region

The five major vegetation zones in southern Patagonia are primarily related to the strong trans-Andean precipitation gradient under the prevailing westerly circulation system (Hueck and Seibert 1981; Movia et al. 1987; Roig 1998). West of the Andes in regions with up to 4,000 mm annual precipitation, wet Magellanic Moorland and evergreen Magellanic Rain Forest occurs, while deciduous *Nothofagus* forest grows near the upper tree line as well as on the eastern slopes and foothills of the Andes, where annual precipitation decreases to 400 mm. Above the tree line, Andean Tundra dominates. There is Patagonian Steppe and semidesert between the Andean foothills and the Atlantic coast where annual precipitations range between 400 and less than 200 mm. Today, the Patagonian Steppe/Andean Forest ecotone lies at the eastern foot of the Andean mountains (Fig. 1).

According to Movia et al. (1987) the lower elevations south of Lago Argentino and east of Brazo Sur are covered by humid grass steppe (precipitation 300–500 mm/year, vegetation cover 70–100%). South of the Rio Santa Cruz this formation reaches as far east as 71°W. The Rio Santa Cruz valley is covered by a semidesert (<200 mm/year, vegetation cover about 40%). East of 71°W dry shrub steppe stretches to the Atlantic coast where the annual precipitation reaches 200–300 mm. In this area the vegetation covers only about 40–60% of the ground surface and has a 20–30% contribution of shrubs. Only the southernmost regions in the vicinity of the Strait of Magellan (Estrecho de Magalanes) and the Atlantic Ocean are again covered with humid steppe. Human impact on the steppe vegetation by fire is suspected to have been started in the seventeenth century (Huber and Markgraf 2003b). Since around A.D. 1880, the introduction by Europeans of sheep farming in the dry steppe and cattle farming in the humid steppe has strongly altered the entire region by overgrazing (Liss 1979). The forest on the eastern slopes of the Andes was extensively logged and cleared by fire to increase pasture (Endlicher 1993). Therefore, there has been much soil erosion and desertification and the flora has been greatly modified during the last 130 years (Aagesen 2000).

The coring site is surrounded by Andean Forest composed of *Nothofagus antarctica* and *Embothrium coccineum* shrubs and trees. Only a few metres further upslope the forest disappears and gives way to steppe

Fig. 2 Photograph of the coring site on the eastern shore of Brazo Sur; view in western direction

vegetation (Fig. 2). However, stumps of what had been big *Nothofagus* trees at the outlet of Lago Roca into Brazo Sur demonstrate the settlers' logging activity.

Materials and methods

The sediment record presented here was cored to a depth of 300 cm with a Dachnowski corer in 30 cm increments in November 2006 at the eastern shore of Brazo Sur (Figs. 1, 2). Pollen samples were analysed at 5 cm intervals. For calculation of pollen concentration and influx, two tablets of *Lycopodium* spore markers were added to each sample (Stockmarr 1971). Samples were then sieved through a 112 μm mesh and treated with HCl and KOH. After acetolysis (Fægri and Iversen 1989), the samples were sieved on a 5 μm mesh using ultrasonic treatment, and stored in glycerol. The pollen preparations were mounted in glycerine and sealed with paraffin wax on microscope slides. In a total of 49 pollen samples, up to 300 grains were counted in each, excluding aquatic taxa and spores. Due to low pollen concentrations the samples 76, 81, 91 and 136 cm have lower pollen sums of 276, 52, 103 and 166 grains and should be interpreted with caution. In the relatively coarse sandy sediments between 100 and 123 cm, no pollen was preserved. Charcoal particles >20 μm were counted on the pollen slides. In total, 55 pollen, nine fern spore, four algal and 13 other non-pollen-palynomorph types were identified. For identification of pollen types, Markgraf and D'Antoni (1978), Heusser (1971) and the pollen reference collection of the authors were consulted. For algal identification, Komárek and Jankovská (2001) was used. Percentages were calculated in relation to the pollen sum of higher plants excluding aquatic taxa. Using CONISS cluster analysis five pollen assemblage zones (BRS 1 to BRS 5) were identified. The diagrams were calculated and drawn up using TILIA and TILIAGRAPH software (Grimm 1991) and show only the most important taxa (Figs. 3, 4). The complete data set of the pollen record

will be available through the authors or at the latin American pollen data base (NOAA Paleoclimatology Program). Values are plotted against calibrated ages before present.

Lithology and dating

The stratigraphy of the sediment record can be summarized as follows:

0–54 cm	Not recovered as water content was too high for successful coring
54–90 cm	Dark brown organic rich silt with peaty and sandy components
90–120 cm	Light grey sand with few organic remains
120–290 cm	Dark brown organic rich silt with peaty and sandy components
290–300 cm	Transition to grey sand with few organic remains

Although different authors found tephra from various volcanic eruptions in sediments from the study area (Villa-Martinez and Moreno 2007; Stern 2008), no tephra layers were visible in the sediment record of BRS 1/06.

The age-depth model is based on seven AMS radiocarbon dates (Fig. 5, Table 1) performed on bulk material. Calib 5.0.2 was used for calibration of the radiocarbon dates (Stuiver et al. 2005). As the ages reach beyond 11,000 years B.P. the northern hemisphere data set was used for calibration (Stuiver et al. 1998). All diagrams are plotted against calibrated ages. The sandy layer probably represents an event during which the original sediments were eroded and sand was deposited, but it has to be considered that it was possible to count three pollen samples (91, 96 and 100 cm) from within it. As the pollen spectra of these samples are no outliers we included them in the calculation of the time axis and excluded the depth interval between 101 and 120 cm. The sediment record covers the last 13,350 cal B.P. The interval between pollen samples is between 50 and 500 years (average 240 years).

Fig. 3 Pollen percentage
diagram of taxa mentioned in
the text from core Brazo Sur
(BRS 1/06), southern Argentina,
showing percentage changes of
taxa, lithology, pollen zones,
cluster analysis and the position
of radiocarbon dates on a linear
time scale. The profile of pollen
sum shows the positions of
samples in the record
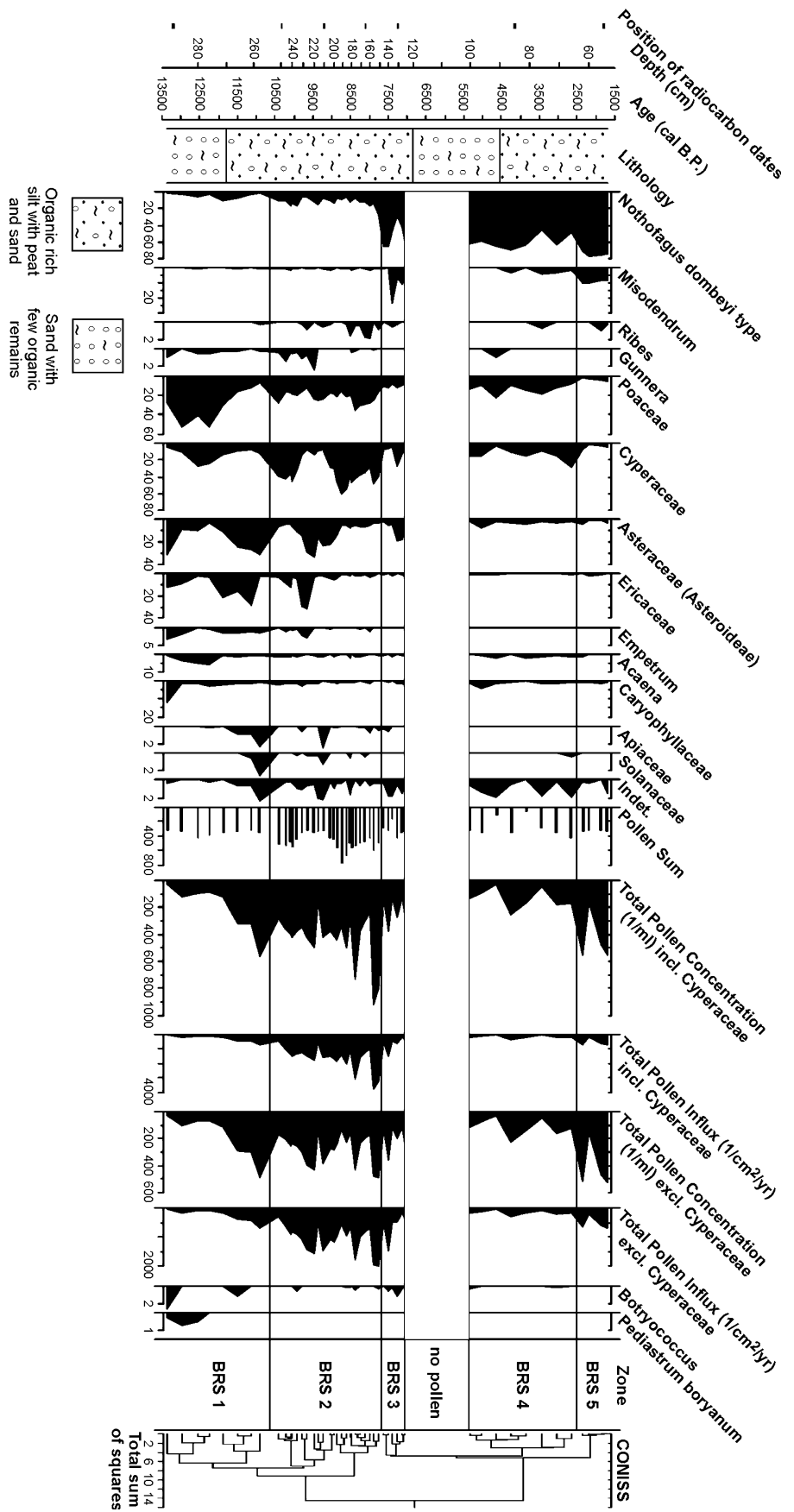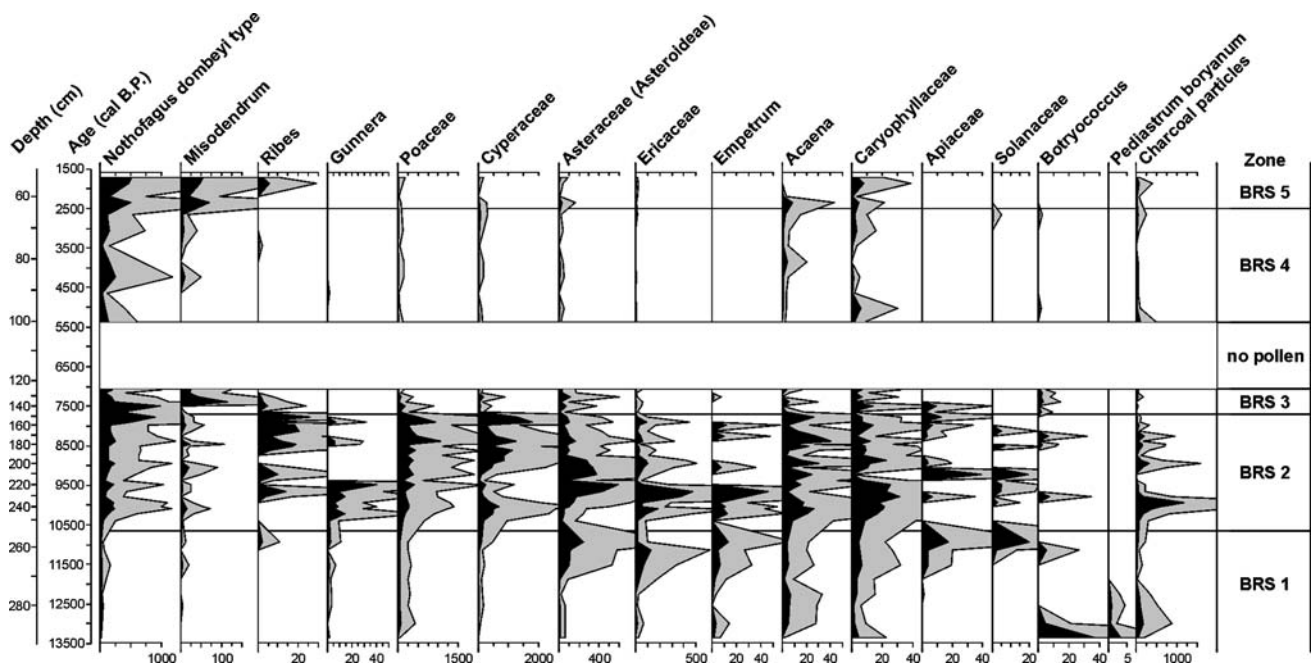
Fig. 4 Pollen influx diagram of taxa mentioned in the text from core Brazo Sur (BRS 1/06), southern Argentina showing influx changes of taxa and pollen zones on a linear time scale. Shaded profiles have an exaggeration by five
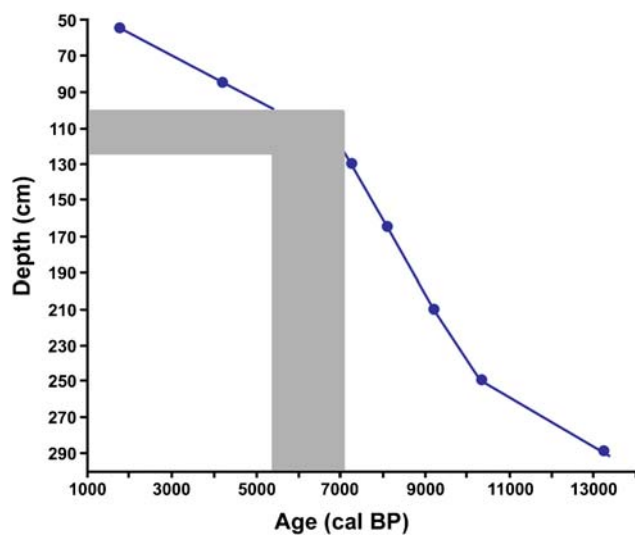
Fig. 5 Depth versus age graph of sediment core Brazo Sur (BRS 1/06). *Dots* indicate positions of ^{14}C AMS radiocarbon dates. The *shaded area* marks the part of the record without pollen

Table 1 List of ^{14}C AMS radiocarbon dates from the sediment record from Brazo Sur (BRS 1/06)

Depth (cm)	Lab No	Uncal B.P.	Cal B.P.
54–55	Poz-21654	$1,850 \pm 30$	1,790
84–85	Poz-21653	$3,780 \pm 30$	4,160
129–130	Poz-21662	$6,330 \pm 40$	7,250
164–165	Poz-21661	$7,320 \pm 40$	8,110
209–210	Poz-21651	$8,240 \pm 40$	9,200
249–250	Poz-21652	$9,140 \pm 50$	10,330
288–289	Poz-19548	$11,340 \pm 50$	13,210

distributed in the grass steppe (Mancini 2002). The pollen concentration and pollen influx profiles, inclusive and exclusive of Cyperaceae (Fig. 3), show that Cyperaceae were never strongly overrepresented in our pollen record as in the case of the "*Carex* meadows" as described by Auer (1958). Thus we do consider Cyperaceae as an element of the humid steppe and we have included them in the pollen sum. The following description covers the pollen record BRS 1/06 from Brazo Sur, southern Argentina (Figs. 3, 4) according to the pollen assemblage zones identified by CONISS cluster analysis.

Pollen zone BRS 1 (eight samples, 291–254.5 cm, 13,350–10,660 cal B.P.) has increasing total pollen concentration from 2,750 grains per ml (gr/ml) at 291 cm to 55,900 gr/ml at 258 cm. Correspondingly the total pollen influx increases from 37 to 760 grains per cm^2 per year (gr/cm^2/year). The influx of charcoal particles reaches an

Results

As Cyperaceae are very often overrepresented in pollen spectra due to their local occurrence on the wet sites where cores are collected, they are often excluded from the pollen sum (Mancini 2002). However, Cyperaceae must also be considered as an important element of steppe vegetation (Oliva et al. 1998) and pollen studies of recent surface samples have showed that Cyperaceae are mainly

average of 4,344 particles/cm^2/year with a maximum at 286 cm (12,941 particles/cm^2/year). The lowermost pollen spectrum (291 cm) is dominated by Asteraceae (Asteroideae) and Poaceae with percentages of 31.4 and 27.6%. Other important pollen contributors are Ericaceae (12.7%), Caryophyllaceae (12.1%), Cyperaceae (4.8%), *Empetrum* (3.5%) and *Nothofagus dombeyi* type (2.2%). Here *Pediastrum boryanum* and *Botryococcus* reach their maximum values of 0.7 and 2.6%. At 286 cm Poaceae increase strongly to values of 52.6%. Cyperaceae increase to 27.7% at 280 cm. *Acaena* reaches 5.6% at 276 cm. *Nothofagus dombeyi* type increases to 10.4% at 271 cm. Asteraceae (Asteroideae) decrease to values of 3.3% at 276 cm. Ericaceae decrease to 2.4% at 280 cm. In the upper third of BRS 1, Poaceae drop to 6.9% in the uppermost sample at 258 cm. Cyperaceae values decrease to 7.1% at 261 cm and increase again to 12.4% at the top of the zone. *N. dombeyi* type decreases constantly to 1.2% towards 258 cm. Asteraceae (Asteroideae) increase to 31.8%. Ericaceae increase to 28.3% at 261 cm and drop to 2.6% at the top of BRS 1. Caryophyllaceae and *Empetrum* drop to values around 1%. In the uppermost sample, Solanaceae and Apiaceae reach maximum values of 2.6 and 2.3%.

Pollen zone BRS 2 (23 samples, 254.5–148.5 cm, 10,660–7,700 cal B.P.) has a rather high total pollen concentration with an average of 42,300 gr/ml. The total pollen influx reaches a maximum of 3,740 gr/cm^2/year at 156 cm. The influx of charcoal particles reaches an average of 4,813 particles/cm^2/year with a maximum at 236 cm (33,500 particles/cm^2/year). Poaceae show a relatively stable pattern with an average of 21.8%. The influx values of Poaceae increase constantly to maximum values of 1,075 and 940 gr/cm^2/year at 176 and 156 cm. Cyperaceae reach peaks of 44.7 and 60.7% at 240 and 191 cm. Between these peaks the percentages decrease to 7% at 226 cm. The pollen influx of Cyperaceae reaches its highest values at 186, 176 and 156 cm (100, 1,250 and 1,800 gr/cm^2/year). In contrast to Cyperaceae, the profile of Asteraceae (Asteroideae) is opposite and reaches one maximum peak with 33.4% at 220 cm. Before and after this peak values are around 5.5%. Ericaceae also reach a maximum of 31.5% at 226 cm. Above 226 cm, values drop to an average of 2.5%. *Gunnera* is present until 220 cm after which it almost disappears. The same is true for *Empetrum* which is present only until 226 cm. The regular occurrence of *Ribes* starts at 231 cm and continues at 186 cm towards the top of the pollen zone. Values of *N. dombeyi* type increase constantly toward the top of BRS 2 to values of 27.7%.

In pollen zone BRS 3 (six samples, 148.5–123 cm, 7,700–7,070 cal B.P.) the total pollen concentration decreases again to an average value of 21,100 gr/ml. The total pollen influx decreases from 1,530 gr/cm^2/year at 140 cm to 198 gr/cm^2/year at 126 cm. The influx of charcoal particles reaches an average of 367 particles/cm^2/year, with a maximum at 131 cm (1,369 particles/cm^2/year). *N. dombeyi* type reaches percentages of 65.3% at 146 cm. After a decrease to 28.2% at 131 cm, the values increase again to 56.8% in the top sample. Correspondingly *Misodendrum* has a peak with 23.5% at 136 cm. Above this sample it has an average contribution of 7.9%. Values of Poaceae are relatively constant with an average of 10.1%. Cyperaceae reach a maximum of 27.8% at 131 cm. Below and above they have an average value of 7.8%. Asteraceae (Asteroideae) show the same pattern with a peak of 18.4% at 131 cm and an average of 7.7% for the whole pollen zone.

In pollen zone BRS 4 (eight samples, 100–64 cm, 5,350–2,500 cal B.P.) the total pollen concentration is slightly lower than before (av. 13,400 gr/ml). The total pollen influx decreases to an average of 180 gr/cm^2/year. The influx of charcoal particles reaches an average of 1,798 particles/cm^2/year with a maximum at 100 cm (6,588 particles/cm^2/year). *N. dombeyi* type has relatively stable values around 63% only with two drops at 76 and 66 cm (44.6 and 48.8%). *Misodendrum* is absent from the lower part of BRS 4. The pollen record starts again at 100 cm. Towards the top *Misodendrum* reaches about 3%. Poaceae show two peaks of 22.3 and 18.8% at 91 and 76 cm and two depressions with about 9% at 86 and 66 cm. Cyperaceae show one peak of 28.5% at 66 cm and two depressions of 3.9 and 9.8% at 91 and 76 cm. The percentages of Asteraceae (Asteroideae) are rather low with an average of 3.2%.

In pollen zone BRS 5 (four samples, 64–54 cm, 2,500–1,700 cal B.P.) the total pollen concentration increases to an average of 43,660 gr/ml and the average pollen influx increases to 550 gr/cm^2/year. The influx of charcoal particles reaches an average of 3,081 particles/cm^2/year with a maximum in the uppermost sample (6,237 particles/cm^2/year). *N. dombeyi* type reaches its highest values (average 73.9%). *Misodendrum* also has its highest contribution with an average value of 8.8%. All other taxa have relatively low average percentages. Main contributors are Cyperaceae (average 4.3%), Poaceae (3.8%) and Asteraceae (Asteroideae) (2.4%).

Palaeoenvironmental reconstruction from record BRS 1/06

The pollen record obtained from Brazo Sur (BRS 1/06) starts around 13,350 cal B.P. indicating that the coring site must have been ice free by this time. The presence of the algae *Botryococcus* and *Pediastrum boryanum* in the

lowermost samples shows that the site was covered with open water until around 13,000 cal B.P. As the recovered sediments have a peaty component (with exception of the sandy layer) it is likely that the coring site was not connected to the lake system 13,350 years ago. Major contributors to the pollen spectrum at 13,350 cal B.P. were Asteraceae (Asteroideae), Ericaceae, *Empetrum* and Caryophyllaceae and the total pollen influx was low. Thus at that time the cold climate supported the growth of shrubby steppe taxa at a generally low vegetation density. A closed Andean Forest with tall trees had probably not developed and *Nothofagus* might be mostly represented by shrubs in scattered stands comparable to *N. antarctica* today at the forest/steppe ecotone.

Between 13,000 and 12,000 cal B.P. algae disappeared, showing that the site changed from open water into a fen. A major fire event was detected by increased influx of charcoal particles at 13,000 cal B.P. The vegetation changed so Poaceae and Cyperaceae became dominant which suggests that the area was covered with grass steppe. *Nothofagus* slightly increased. All this suggests that the temperature was higher than before.

Between 12,000 and 10,900 cal B.P. the vegetation changed again to a situation comparable to that of around 13,350 cal B.P. Major fire events were not detected. Asteraceae (Asteroideae), Ericaceae became dominant again with a certain contribution of *Empetrum*. Poaceae, Cyperaceae and *Nothofagus* became less important. The pollen spectra indicate that conditions became drier and vegetation changed to more drought tolerant taxa. The occurrence of Solanaceae, an element of the shrub steppe, especially indicates that the climate became significantly drier and warmer than around 13,350 cal B.P.

Between 10,400 and 9,900 cal B.P. the influx of charcoal particles increased, suggesting frequent fires. Cyperaceae were important again with corresponding decreases of Asteraceae (Asteroideae), Ericaceae, *Empetrum* and Solanaceae. Poaceae percentages show no significant changes. The major vegetation community in the area was probably a grass steppe but with less contribution of Poaceae. The total pollen influx reached highest values suggestive of a dense vegetation probably due to more available moisture than before. The *Nothofagus* values were relatively stable but a slightly higher average contribution than before. This also indicates more moisture and better growing conditions for Andean Forest than before.

Between 9,900 and 9,000 cal B.P. the influx of charcoal particles was low suggesting a low fire frequency. Asteraceae (Asteroideae) again reached high values in combination with Ericaceae (between 9,900 and 9,500 cal B.P.). Around 9,500 cal B.P. the closed records of *Gunnera* and *Empetrum* became discontinuous, while Apiaceae and Solanaceae were present with somewhat higher values at

around 9,200 cal B.P. All this shows that shrubby vegetation became more abundant probably enhanced by drier conditions. This is also indicated by the appearance of the shrubby Andean Forest taxon *Ribes*.

Between 9,000 and 7,700 cal B.P. the increased influx of charcoal particles, the abundance of Cyperaceae, the increased contribution of Poaceae (between 8,400 and 7,900 cal B.P.) and also the increasing *Nothofagus* values suggest an increase of available moisture.

Around 7,700 cal B.P. the influx of charcoal particles became very low. *Nothofagus* forest spread strongly and became the dominant vegetation type at Brazo Sur. Only between 7,400 and 7,100 cal B.P. a drop in *Nothofagus* and corresponding peaks of *Misodendrum*, Cyperaceae and Asteraceae (subf. Asteroideae) lead to a time interval with less forest and a spread of steppe vegetation. The strong abundance of *Misodendrum* suggests that the forest density at that time became less and the trees were vulnerable to this parasite as they usually are under poor growing conditions. This points to a drier climate between 7,400 and 7,100 cal B.P.

The core interval without pollen preservation is characterized by relatively coarse sandy sediments. An extrapolation of the radiocarbon ages above this interval show that the pollen record starts again at 5,350 cal B.P. (100 cm). Therefore it is likely that the sand layer was deposited shortly before then. A possible explanation would be an event of exceptionally strong rainfall which mobilized soil and sandy material upslope of the site and washed it into the swamp.

Between 5,350 and 2,500 cal B.P., the influx of charcoal particles is still low and the pollen record again shows a strong dominance of *Nothofagus* forest at Brazo Sur. After 2,500 cal B.P. the influx of charcoal particles becomes somewhat higher but the dominance of *Nothofagus* forest increased as suggested by increasing values. Andean Forest probably spread to additional areas that had previously been covered by steppe. This indicates higher moisture availability than ever before. However, it might be possible that on these new stands the growing conditions were not optimal for forest. This might explain the slight increase in fire frequency and why *Misodendrum* values increased in combination with reduced steppe elements.

Discussion and conclusions

According to Wenzens (1999), deglaciation in the Lago Argentino area began around 13,500 B.P. (ca. 14,100 cal B.P.) which is confirmed by our pollen record starting at 13,350 cal B.P. During Late-glacial and early Holocene times the record from Brazo Sur is continuous. This contradicts results from Caldenius (1932) and Wenzens (1999)

who suggested glacier advances covering Brazo Sur, Lago Roca and Brazo Rico during the Younger Dryas chronozone. Our record shows that at least the eastern shore of Brazo Sur never became glaciated again after 13,350 cal B.P.

Our record indicates that from 13,350 to 7,700 cal B.P. the vegetation underwent six fluctuations of about 1,000 years duration each, between humid grass steppe and a drier association with significantly more shrubs. The timing of none of these phases corresponds with the Younger Dryas chronozone (12,700-11,500 cal B.P.) well known from the northern hemisphere. Vega Ñandú (Villa-Martinez and Moreno 2007) and Rio Rubens (Huber and Markgraf 2003a) are pollen records in the vicinity and both show fluctuations in vegetation linked to fire activity between the Late-glacial and the early Holocene. At Rio Rubens only the profiles of Nothofagus and Poaceae are available for comparison. Although the Poaceae curve shows fluctuations that are negatively correlated with the Nothofagus values, the Rio Rubens record has fluctuations of higher frequency than the record from Brazo Sur. Whereas Rio Rubens shows a Poaceae peak every 1,000 years (12,500, 11,500, 10,500, 9,500 and 8,500 cal B.P.), Brazo Sur only has peaks of Poaceae/Cyperaceae at 12,500, 10,400 and 8,700 cal B.P. This lower frequency seems to correlate with the Poaceae peaks found in Vega Ñandú dated to about 12,000, 10,200, 8,500 and 7,000 cal B.P. However, we need to consider that the record from Vega Ñandú shows fluctuations throughout the record and that the fluctuations in the record from Brazo Sur do not show a strong correlation to fire activity. We suggest that the fluctuating vegetation changes recorded in the Brazo Sur profile are the result of periodic climate oscillations. Whether the timing of Poaceae and Nothofagus fluctuations in Rio Rubens and Vega Ñandú and the Poaceae/Cyperaceae and Asteraceae/Ericaceae alternations in Brazo Sur are due to seasonal fluctuations in the strength of the westerly winds, resulting in changes of precipitation over the entire region, needs further research. At Lago Cardiel, lake levels were at their highest during the interval between 10,000 and 8,500 B.P. (ca. 9500–7,500 cal B.P.), indicating precipitation substantially above present-day levels, most likely from the Atlantic Ocean (Markgraf et al. 2003). Fluctuations were not found. The record from Laguna Potrok Aike shows decreasing moisture availability without fluctuations during the Late-glacial and early Holocene (Wille et al. 2007). We conclude that at the Late-glacial/Holocene transition, the climate setting at the eastern foot of the Andes differed from that of the steppe as there were no distinct climate fluctuations recorded in the steppe records.

In Brazo Sur, the strong increase of Nothofagus expansion is dated to 7,700 cal B.P. Mercer and Ager (1983) report one radiocarbon date of 9,150 ± 210 ¹⁴C years B.P. (ca. 9,000 cal B.P.) from a site close to the Perito Moreno glacier. Although they found comparatively high values of Nothofagus at that time, they extrapolate the start of the final Nothofagus increase to about 7,200 ¹⁴C years B.P. (ca. 6,000 cal B.P.). At Vega Ñandú, the spread of Nothofagus is dated to 6,800 cal B.P. (Villa-Martinez and Moreno 2007) and at Rio Rubens the dominance of Nothofagus started about 7,000 cal B.P. (Huber and Markgraf 2003). At Lago Cardiel, the climate between 8,500 and 6,000 B.P. (about 7,500–4,900 cal B.P.) is supposed to have become drier and warmer (Markgraf et al. 2003) and the Nothofagus signal in this record is relatively constant. At Laguna Potrok Aike, the forest contribution was highest between 8,600 and 7,600 cal B.P. (Wille et al. 2007). One suggested interpretation is that during this time interval there was a Holocene maximum in wind speed which transported more pollen from the Andes into the steppe. We conclude that on the basis of the dates from the Brazo Sur, Vega Ñandú and Rio Rubens pollen records, Nothofagus became dominant in the Andes between 7,700 and 6,800 cal B.P. We consider the extrapolation of one single radiocarbon date at the Perito Moreno glacier (Mercer and Ager 1983) as probably not accurate enough. The detected early increase of forest contribution in Laguna Potrok Aike was probably caused by enhanced pollen transport due to stronger westerly winds. This evidence of wind increase was not found in Lago Cardiel.

Between 7,070 and 5,350 cal B.P., no pollen is preserved in site Brazo Sur. This suggests that shortly before 5,350 cal B.P. an event of high sedimentary dynamics occurred probably due to geomorphological activity on corresponding slopes resulting in the deposition of sand. A change from dry to wetter climate might have caused a mobilization of soil as the vegetation cover in dry periods is thin and the soil can be eroded more easily during a strong precipitation event. Mancini (2003) claimed that the mid Holocene was humid. Glasser et al. (2004) inferred for the mid Holocene based on glacier fluctuations of the South Patagonian Ice Field, there was a shift from relatively warm conditions to a wetter and colder climate than at present. At Vega Ñandú, Villa-Martinez and Moreno (2007) suggest that there was increasing moisture after 6,800 cal B.P. At 5,700 and 5,200 cal B.P. they recorded two strong and short peaks of charcoal associated with strong vegetation changes around the site. At Rio Rubens, Huber et al. (2004) found an abrupt decrease in fire frequency and a change from fen to bog vegetation after 5,500 cal B.P. which were explained as the results of an increase in precipitation. At Lago Cardiel, the climate was still warm and dry but with fluctuations that were ascribed to seasonal shifts of the Westerlies from 8,500 B.P. (ca. 7,500 cal B.P.). In Laguna Potrok Aike, the pollen spectra suggest a weak

trend to more aridity such as between 7,600 and 5,900 cal B.P. We conclude that the detected sand layer in the sediments of Brazo Sur (7,070–5,350 cal B.P.) was probably deposited due to climate change with increasing precipitation or due to a catastrophic event as was recorded in Vega Ñandú at 5,200 cal B.P.

Between 5,350 and 2,500 cal B.P., the record of Brazo Sur suggests that climate conditions prevailed which were established around 7,070 cal B.P. For Lago Cardiel there are contradicting results. Whereas a high lake level around 6,000 B.P. (ca. 4,900 cal B.P.) is interpreted as the result of increased moisture at that time (Gilli et al. 2005), the pollen spectra indicate aridity culminating between 6,000 and 5,000 B.P. (ca. 4,900–3,750 cal B.P.) (Markgraf et al. 2003). At Laguna Potrok Aike, Patagonian Steppe and Andean Forest proportions underwent short time fluctuations between 5,900 and 2,300 cal B.P.. These fluctuations were explained by seasonal shifts of the Westerlies (Wille et al. 2007). We conclude that after fen sedimentation started again in Brazo Sur, climate conditions were comparable to those of 7,070 cal B.P. Climate fluctuations like those recorded in Potrok Aike were not found in the Andes or Lago Cardiel.

The spread of Andean Forest in the Brazo Sur record suggests an increase in moisture availability after 2,500 cal B.P. The same was found in Vega Ñandú (Villa-Martinez and Moreno 2007) where this spread was dated to 2,400 cal B.P. At Rio Rubens, Huber et al. (2004) also found a more humid period indicated by wetter conditions inside the bog starting at 2,500 cal B.P. Mancini (2002) found greater available moisture about 700 years later starting at 3,500 B.P. (ca. 1,800 cal B.P.) south of Lago Argentino. At Lago Cardiel after 5,000 B.P. (ca. 3,750 cal B.P.), variable climate conditions were found (Markgraf et al. 2003). At Laguna Potrok Aike, higher available moisture and an increase in *Misodendrum* was found since 2,300 cal B.P., which corresponds with the findings from Brazo Sur. We conclude that around 2,500 cal B.P., moisture availability increased probably not only in the Andes but also in the Patagonian Steppe near Laguna Potrok Aike. In Lago Cardiel, fluctuating climate conditions were recorded.

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