Veget Hist Archaeobot (2009) 18:235–244
DOI 10.1007/s00334-008-0200-8

ORIGINAL ARTICLE

Vegetation changes and human occupation in the Patagonian steppe, Argentina, during the late Holocene

Maria Eugenia De Porras · Maria Virginia Mancini · Aldo Raul Prieto

Received: 20 February 2008 / Accepted: 26 September 2008 / Published online: 26 November 2008

Abstract Vegetation changes during the late Holocene are interpreted from four fossil pollen sequences from two caves at the Los Toldos archaeological locality, Santa Cruz province, Argentina. Taphonomic processes are particularly taken into account in order to analyze the effects on the fossil pollen records of biotic factors such as human occupation and animals, and abiotic ones such as volcanic ash fall. Fossil pollen assemblages are interpreted using local modern pollen data. The main vegetation change occurred at ca. 3750 uncal B.P., when a shrub steppe of Asteraceae subf. Asteroideae with *Schinus*, *Ephedra frustillata* and a high proportion of grasses was replaced by a shrub steppe of *Colliguaja integerrima* and Asteraceae subf. Asteroideae. This change is synchronous with an archaeological record change and could be related either to moderate climatic variations or the effects of ash fall on the environment. Plant communities similar to the present-day ones were established in the Los Toldos area from ca. 3750 uncal B.P.

Keywords Patagonia · Late Holocene · Pollen · Caves · Taphonomy · Human occupation

Communicated by L. Newsom.

M. E. De Porras (✉) · M. V. Mancini · A. R. Prieto
Laboratorio de Paleoecología y Palinología,
Facultad de Ciencias Exactas y Naturales,
Universidad Nacional de Mar del Plata, Funes 3250,
7600 Mar del Plata, Argentina
e-mail: deporras@mdp.edu.ar

M. E. De Porras · A. R. Prieto
CONICET, Consejo Nacional de Investigaciones Científicas
y Técnicas, Avda. Rivadavia 1917, (C1033AAJ),
Buenos Aires, Argentina

Introduction

Caves have played an important role as the main source of archaeological, palaeoecological and palaeoenvironmental information through the late Pleistocene and Holocene in Patagonia (Cardich and Paunero 1994; Mancini et al. 2002; Paez et al. 1999; Prieto et al. 1998). However, inferences based on fossil pollen information from this kind of depositional environment have been largely questioned because of the complex processes that affect them. In fact, fossil pollen records from caves are mostly the result of environmental, climatic and cultural interactions. The analysis of taphonomic processes is therefore essential when studying fossil records from these depositional environments (López Sáez et al. 2003; Hunt and Rushworth 2005; Navarro Camacho et al. 2001; Prieto and Carrión 1999).

The reconstruction of past vegetation through pollen analysis is exceptionally difficult in extra-Andean Patagonia because of the scarcity of sites such as lakes or peat bogs. However, the excellent preservation of pollen in sedimentary sequences in caves and rock-shelters has allowed the reconstruction of the late Pleistocene and Holocene vegetation changes in the Patagonian steppe, and particularly of the Santa Cruz central plateau (meseta) (Mancini 1998, 2002, 2003; Mancini et al. 2007; Paez et al. 1999; Prieto et al. 1998). Nevertheless, these previous pollen investigations of the extra-Andean Patagonian caves did not analyze the taphonomic processes when interpreting the changes in the pollen assemblages.

The present study aims to reconstruct the vegetation history of the late Holocene at Los Toldos cañadón (ravine) from pollen analysis of fossil cave sequences. In order to distinguish anthropogenic and biogenic disturbance related to human occupation, taphonomic processes were taken into account.

Environmental setting

Climate and vegetation

Los Toldos cañadón (47°29′57″S, 68°45′24″W) is located in northeastern Santa Cruz province, in a region of the central plateau (meseta) characterized by ignimbrites (pyroclastic flows) and basaltic plateaus (Fig. 1). The climate is semiarid and cold with a mean annual temperature of 8.5°C, and mean maximum and minimum temperatures between 14 and 3°C, respectively. The region experiences an annual precipitation of 180 mm in winter (Servicio Meteorológico Nacional 1969, 1986).

The main vegetation unit of the central plateau is a dwarf-scrub steppe associated with a shrub steppe. The former is mostly located in the upper parts of the plateau whereas the shrub steppe develops in cañadón, depressions and valley bottoms (León et al. 1998; Roig 1998; Soriano et al. 1983). The vegetation developing in the highest areas of Los Toldos cañadón, above 450 m a.s.l., is a steppe composed of dwarf shrubs such as *Nassauvia glomerulosa, N. ulicina*, *Acantholippia seriphioides, Satureja darwinii, Nardophyllum obtusifolium* and cushion plants such as *Ephedra frustillata*, *Azorella seriphioides*, *A. caespitosa, A. monanthos* and *Chuquiraga aurea*. This steppe vegetation has a low growth form, which is the product of the erosive and dehydrating wind affecting these high areas (Roig 1998). In the bottom of the cañadón, at 430 m a.s.l., tall shrubs such as *Colliguaja integerrima*, *Schinus polygamus*, *Berberis heterophylla*, *Junellia ligustrina* and *J. tridens* are present, associated with Asteraceae subf. Asteroideae (*Senecio* spp., *Nardophyllum obtusifolium*), *Ephedra frustillata*, *Stipa* spp., *Glycyrrhiza astragalina* and *Acaena* sp. Along the ephemeral stream, *Chenopodium hircium*, *Glycyrrhiza astragalina* and *Lepidium spicatum* var. *spicatum* are present. On the slopes of the cañadón at 430–450 m a.s.l., plants from the bottom and from the upper slopes of the plateau occur together. With increasing altitude, tall shrubs decrease in size and abundance and dwarf and cushion shrubs such as *Mulinum spinosum*, *Acantholippia seriphioides*, *Nassauvia glomerulosa*, Asteraceae subf. Asteroideae and *Chuquiraga aurea* are present.

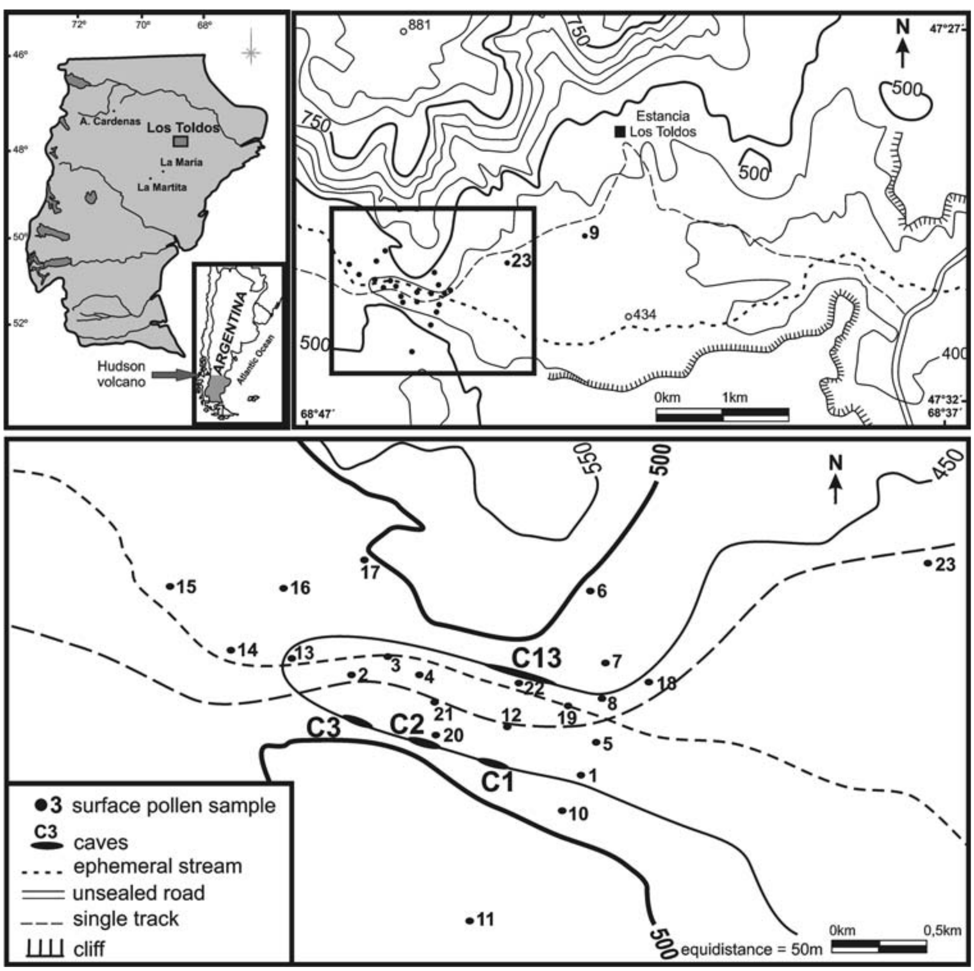

Fig. 1 Location of the Los Toldos cañadón (ravine) and sites discussed in the text. Topographic map showing the position of caves and surface pollen samples

Cave sedimentology and archaeology

There are several caves and rock-shelters in the steep walls of Los Toldos cañadón. Caves C13 and C1 were selected for the present study (Fig. 1).

Cave C13 is located on the southern facing slope of the cañadón (Fig. 1) with its 100 m wide entrance facing southward (Fig. 2a). The depth of the cave varies between 3 and 7 m, and its height reaches 2.20 m in the centre and decreases towards the east, the west and the rear. The

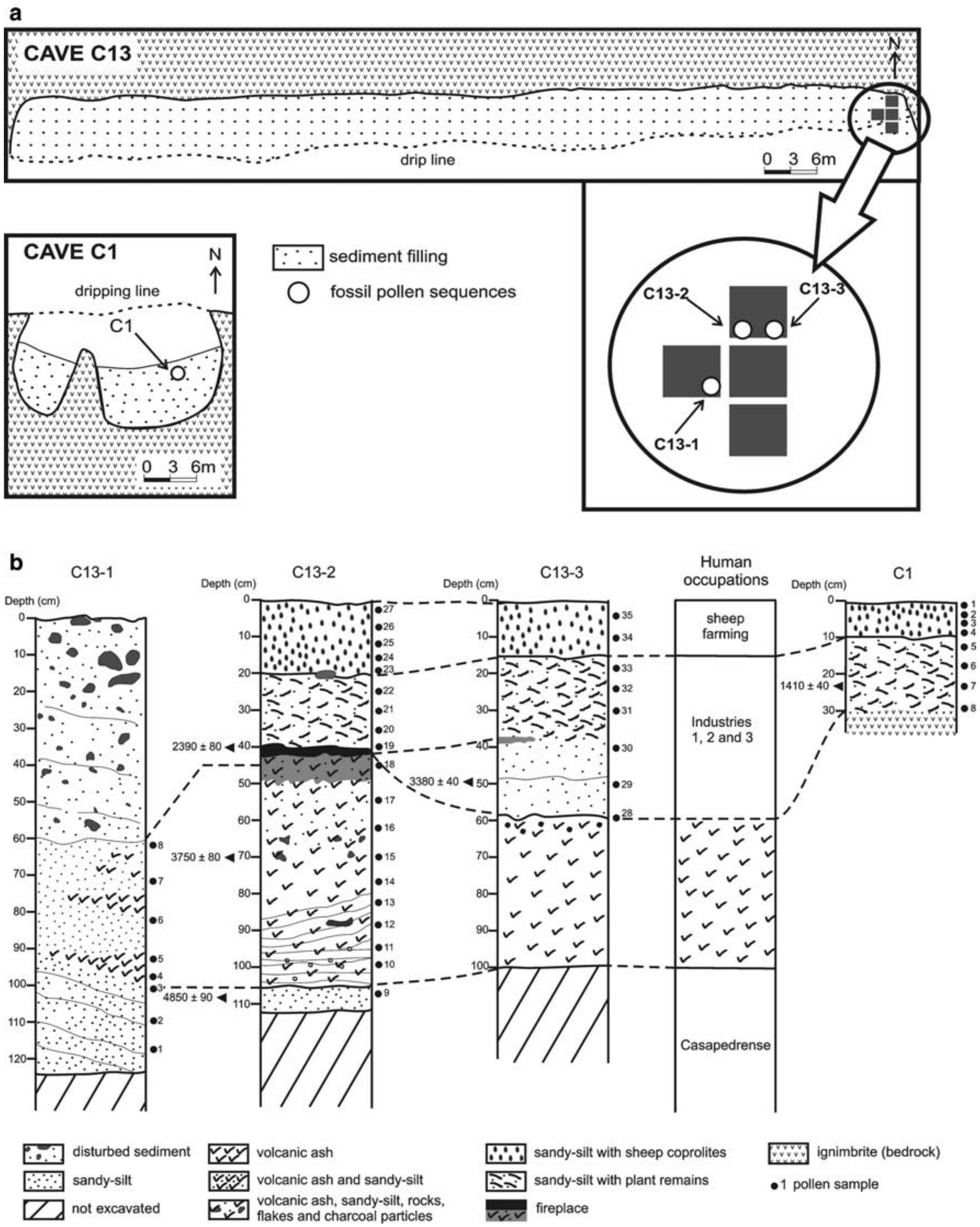

Fig. 2 **a** Plans of caves C13 and C1 showing the locations of fossil sequences. **b** Stratigraphic sequences from caves C13 and C1, fossil pollen samples and human occupation

Table 1 Radiocarbon dates for caves C13 and C1 from Los Toldos cañadón (ravine); all dates were calibrated using Calib 5.0 (Stuiver and Reimer 1993; Stuiver et al. 2005)

Cave	Depth (cm)	Profile	Lab. code	^{14}C age B.P.	Calibrated age (cal B.P.)	Material
13	50	C13-3	Beta 183025	3380 ± 40	3553	Charcoal
13	75	C13-2	LP 1524	3750 ± 80	4038	Charcoal
13	50	C13-2	LP 1516	2390 ± 80	2377	Charcoal
1	25	C1	Beta 183024	1410 ± 40	1283	Plant remains

The southern hemisphere calibration data set used is from Reimer et al. (2004) and McCormac et al. (2004). The 4850 ± 90 uncal B.P. (LP-136) radiocarbon date was taken from a fireplace lying immediately under the ash level in cave 3 (Cardich 1984–1985), and has been extrapolated to cave 13 ash level base in the present study

sedimentary sequence has been described in the eastern area of the cave where archaeological excavations have taken place (Miotti 1998). The sequence consists of geogenic, anthropogenic and biogenic sediments from the last 4,850 years, with a sandy-silt level that is overlain by volcanic ash, a sediment level with plant remains of *Colliguaja integerrima,* and a sediment level with sheep coprolites which seals the sequence (Fig. 2b; Table 1).

The ash level is found in the same stratigraphic position in the sedimentary sequences of the other caves within the cañadón (Cardich 1984–1985; Miotti 1998). In cave C13, volcanic ash is present as an isolated lens near the entrance and as a 60 cm thick level to the rear (Fig. 2b). The ash is laminated at the base without evidence of disturbance. However, disturbance is evident at the top, produced by human activities and abiotic agents after deposition, which caused a resuspension, deposition and mixing of the ash with sandy-silt sediments, charcoal particles, flakes and rocks inside the cave. This volcanic ash level is attributed to the H_2 eruption of the Hudson volcano (45°54′S; 72°58′W, Stern 1991), situated 360 km northwest of Los Toldos (Fig. 1). Hudson volcano erupted three times during the Holocene, at ca. 6700 B.P. (H_1), ca. 3600 B.P. (H_2) and during August of 1991. The H_2 eruption was not as large as H_1 but greater than the 1991 event (Naranjo and Stern 1998). The deposition of H_2 volcanic ash at the Los Toldos caves was a single and sudden event (Mazzoni and Spalletti 1974).

Cave C1 is located on the northern facing slope of the cañadón, 2 m above the ephemeral stream (Fig. 1). The cave is a simple chamber with a 13 m wide entrance facing northwards (Fig. 2a). The depth of the cave varies between 10 and 12 m, and its height decreases to the rear. The sedimentary sequence is 30 cm thick and consists mainly of anthropogenic and biogenic sediments with a sediment level containing remains of Poaceae dated to 1410 ± 40 B.P. that lies on the ignimbrites which form the cave bedrock, and a level with sheep coprolites (Fig. 2b; Table 1).

The sedimentary sequences together with the pollen and archaeological records are discontinuous in both caves (Fig. 2b).

During the time covered by this study, the cave fossil sequences indicate three levels of human occupation. These consist of two archaeological levels, the Casapedrense level between ca. 7200 and 4850 B.P., and the Industries 1, 2 and 3 level from ca. 4000 B.P. to the 16th century A.D. (Cardich and Paunero 1994) and the third level formed by sheep farming some time in the 20th century (Fig. 2b). According to the zooarchaeological and lithic records belonging to both archaeological levels, the caves were home bases or concentration areas of hunter-gatherer groups. The main differences between the archaeological levels are particularly the stone artefacts (Miotti 1998). In the Casapedrense level, there is a predominance of *láminas* (long and thin artefacts), various kinds of end-scrapers, side-scrapers and artefacts made by chipping and abrasion. The industries 1, 2 and 3 level shows the presence of bifacial and unifacial technology, with end-scrapers and stemmed triangular projectile points. There are also bone artefacts using ungulate bones, such as engraved plaques, punches and tools used for retouching. The Casapedrense occupation would have been denser and more abundant than the Industries 1, 2 and 3 one. In both cases, *Lama guanicoe* (guanaco) was the main food source. The removal of the hide as well as the butchering, processing and consumption of the animals would have taken place close to the cave, and then all the parts of the animal would have been brought into the cave (Miotti 1998).

The third level of occupation is related to recent sheep farming and is represented in the sedimentary sequence by the level with coprolites. In Santa Cruz central plateau, sheep farming development was restricted in the 20th century and was characterized by the low density of animals because of the poor quality of pastures (Barbería 1995; Oliva et al. 2001). The caves were used by shepherds for sheltering flocks during bad weather (R. Paunero 2005, personal communication).

Materials and methods

Twenty-three surface pollen samples from the cañadón area (Fig. 1) and four from the cave surfaces were collected to study the modern pollen-vegetation relationship and to interpret the fossil pollen record changes in vegetational terms.

Three sedimentary sequences were sampled in cave C13 and one in cave C1 (Fig. 2a). The sequences from cave C13 were sampled from two archaeological pits dug in the eastern part of the cave. The upper part of profile C13-1 (<0–60 cm) was not sampled because it was disturbed during the excavations. Coprolites and sediment samples from the level with sheep coprolites were sampled together and later separated in the laboratory to study pollen contents independently.

Modern surface and fossil sediment samples and sheep coprolites were treated following standard methods (Fægri and Iversen 1989; Gray 1965). Sheep coprolite samples were four or five coprolites (ca. 1.5–2.5 g). *Lycopodium* spore tablets (Batch No.938934, Department of Quaternary Geology, University of Lund) were added in order to calculate pollen concentration per gram of sample. Heavy liquid separation treatment with $ZnCl_2$ was omitted when sheep coprolite samples were treated. Furthermore, these samples were sieved through a 70 µm and on a 10 µm mesh. Then, a short centrifugation was used to eliminate light organic matter (Brown 1960).

The reference collection of the Laboratorio de Paleoecología y Palinología at the Universidad Nacional de Mar del Plata was used to identify pollen grains and spores. The pollen sums ranged from 211 to 1,949 grains. In cave C13, pollen samples 4, 9, 10, 11 and 12 were barren and sample 19 was sterile. Each taxon is expressed as the percentage of the total pollen sum. Long distance pollen such as *Nothofagus dombeyi* type, *Podocarpus* and *Misodendrum*, unidentified pollen grains and spores are excluded. Chenopodiaceae pollen is also excluded because it is overrepresented in samples 3 and 13, and represents halophytic plants such as *Chenopodium* sp., which grow in the ephemeral stream during the summer.

Macrofossil plant remains were identified using vegetation keys (Correa 1969–1999) and herbarium specimens.

Pollen diagrams showing percentages and concentrations were drawn up using TGView 2.0.2 (Grimm 2004). Surface and fossil pollen data were grouped using Cluster Analysis, applying square root transformation with Edwards and Cavalli-Sforza's chord distance. A correspondence analysis was applied to compare coprolites and the whole sediment fossil pollen samples from caves C1 and C13. Pollen variables for statistical analysis were selected considering that the mean value of each variable in percentage was higher than 2%, except for entomophilous pollen types representative of the vegetation of the area.

Results

Surface pollen data are shown in a percentage pollen diagram (Fig. 3). The surface pollen samples are divided into two groups by cluster analysis. Group 1 is dominated by *Nassauvia* (45–10%), associated with *Chuquiraga* (<20%), *Ephedra frustillata* (25–5%), *Azorella* and *Acantholippia* with values lower than 20% each. Group 2 is divided into two subgroups, of which subgroup 2A is dominated by *Colliguaja integerrima* (50–25%), associated with Poaceae (<20%), Asteraceae subf. Asteroideae (<25%), and *Schinus* (<10%). Subgroup 2B is dominated by Asteraceae subf. Asteroideae (80–20%), associated with Poaceae (40–5%), *Colliguaja integerrima* (25 to >5%), *Junellia tridens/ligustrina* (<20%), *Berberis* and *Acantholippia* with values lower than 15% each.

Fossil pollen data from the cave C13 and cave C1 profiles are shown in percentage and concentration pollen diagrams (Fig. 4).

The fossil pollen sequences of caves C13 and C1 are divided into three and two zones respectively. Pollen Zones 2 and 3 from cave C13 and cave C1 are partially comparable (Fig. 4). In the cave C13 sequences, Zone 1 is dominated by Asteraceae subf. Asteroideae (60–10%), associated with Poaceae (50–10%), *Ephedra frustillata* (20–5%), *Schinus* (25–5%) and *Lycium* (<5%). Zone 2 is dominated by *Colliguaja integerrima* (60–30%), associated with Asteraceae subf. Asteroideae (30–10%) and Poaceae (25–5%). Zone 3 is dominated by Asteraceae subf. Asteroideae (50–25%), associated with *C. integerrima* (40–20%) and Poaceae (15–10%). In the cave C1 sequence, the zones are dominated by *C. integerrima* (40–15%), associated with Asteraceae subf. Asteroideae (25–15%) and Poaceae (30–15%). Slight differences in the percentages of the major pollen types have allowed the zonation of this pollen sequence.

Zone 1 total pollen concentration is low (<4,000 grains/g) compared to those of Zones 2 and 3 (mean value ~15,000 grains/g and ~40,000 grains/g, respectively). Pollen concentration values are lower than 22,400 grains/g and there are barren samples from the rear of the cave. In cave C13, Zone 2 pollen concentration values vary according to location, being the lowest (<2,000 grains/g) towards the entrance and the highest towards the rear of the cave for all the sequences (98,000 and 73,500 grains/g in C13-2 and C13-3, respectively). In cave C13, Zone 3 total pollen concentration is lower than in Zone 2, but in cave C1, it is similar for the whole sequence.

Correspondence analysis shows that the coprolite pollen assemblages are different from those of the sediments (Fig. 5). Axis 1 separates the coprolite samples from the sediment samples for both caves. The coprolite pollen assemblages are defined by *Nassauvia*, Apiaceae and

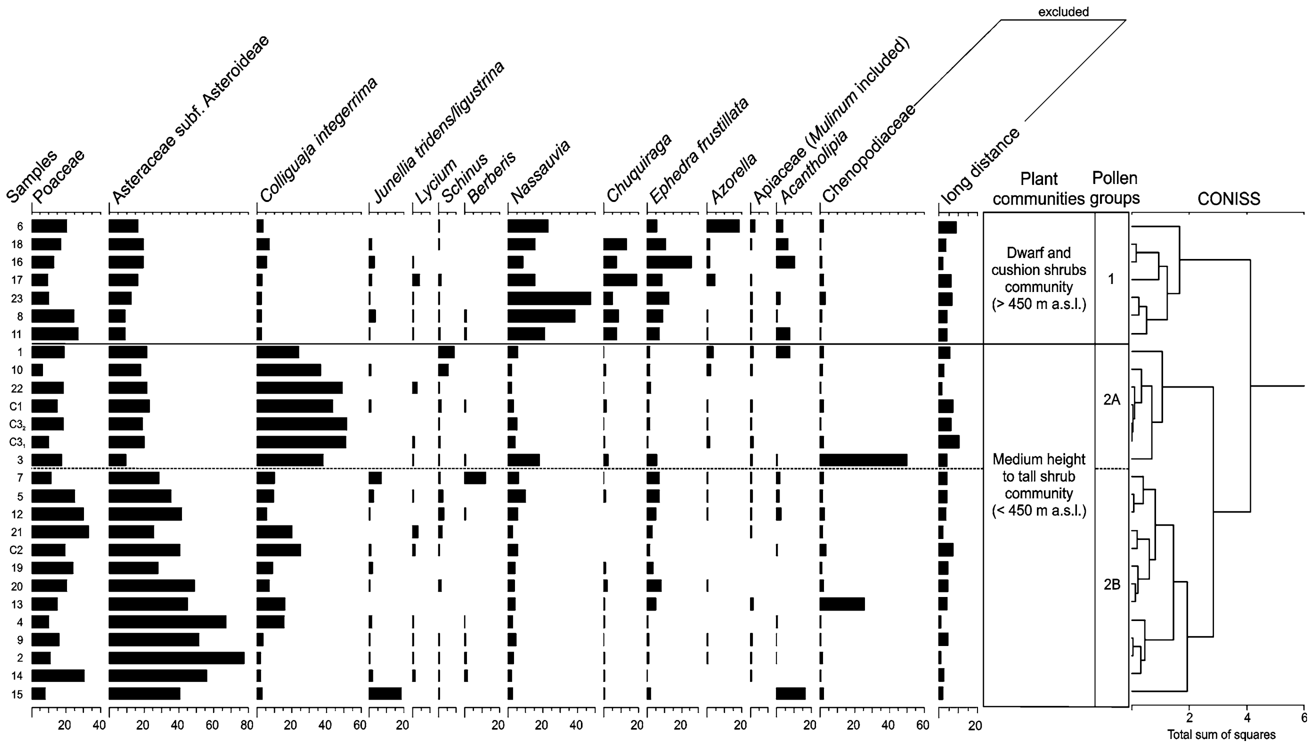

Fig. 3 Surface pollen diagram showing modern pollen assemblages of Los Toldos cañadón (C1, C2, C31 and C32 are cave surface pollen samples)

Junellia tridens/ligustrina while sediment ones are defined by *Ephedra frustillata*, *Lycium*, *Schinus*, Asteraceae subf. Asteroideae and C*olliguaja integerrima*. Axis 2 separates sediment pollen samples of Zone 1 from those of Zones 2 and 3. *Lycium*, *Schinus* and *E. frustillata* define samples in Zone 1, and Asteraceae subf. Asteroideae and *C. integerrima* samples in Zones 2 and 3.

Discussion

Modern pollen-vegetation relationship

The modern pollen spectra reflect the vegetation that grows locally in and around Los Toldos cañadón. Pollen spectra from the highest areas of the cañadón represent a dwarf and cushion shrub community dominated by *Nassauvia* and accompanied by *Ephedra frustillata*, *Chuquiraga*, *Acantholippia* and *Azorella* (group 1, Fig. 3) that match the regional dwarf-scrub steppe. *Nassauvia*, *E. frustillata* and *Chuquiraga* percentages are higher in the highest areas of the plateau, above 450 m a.s.l., than in the bottom of the cañadón, reflecting the distribution of these plants in the surroundings.

Pollen spectra from the bottom of the cañadón represent a medium to tall shrub community dominated by *Colliguaja integerrima* (subgroup 2A, Fig. 3) and Asteraceae subf. Asteroideae (subgroup 2B, Fig. 3). Although Asteraceae subf. Asteroideae pollen is widespread all over the bottom of the cañadón, the highest percentages are near the entrance of cave C3. *C. integerrima* pollen dispersal is limited to the bottom of the cañadón, particularly next to caves C1 and C13. This is related to the plant distribution near these caves and to the fact that *C. integerrima* is an entomophilous plant so its pollen is shed almost directly on to the ground and shows little lateral travel. *Junellia tridens/ligustrina* and *Berberis* are also entomophilous taxa, so their values of 20% and 15, respectively indicate the growth of these shrubs in situ (Fig. 3).

The distribution of these plant communities is mainly related to topography which determines edaphic characteristics and differential conditions of water availability, temperature and wind. In the bottom of the cañadón, shrubs are protected from the wind leading to warmer temperatures, and during the wet season water flows to the cañadón bottom as a consequence of the snow melting.

The cave surface pollen assemblages reflect the cañadón bottom vegetation, even though there are some differences among them. These differences may be related to variations in the screening and filtering effects caused by the presence of *Colliguaja integerrima* at the entrances of caves C1 and C3 (Fig. 1). Furthermore, *C. integerrima* is over-represented because it is growing at and near the cave entrances. Studies of surface pollen samples in other caves

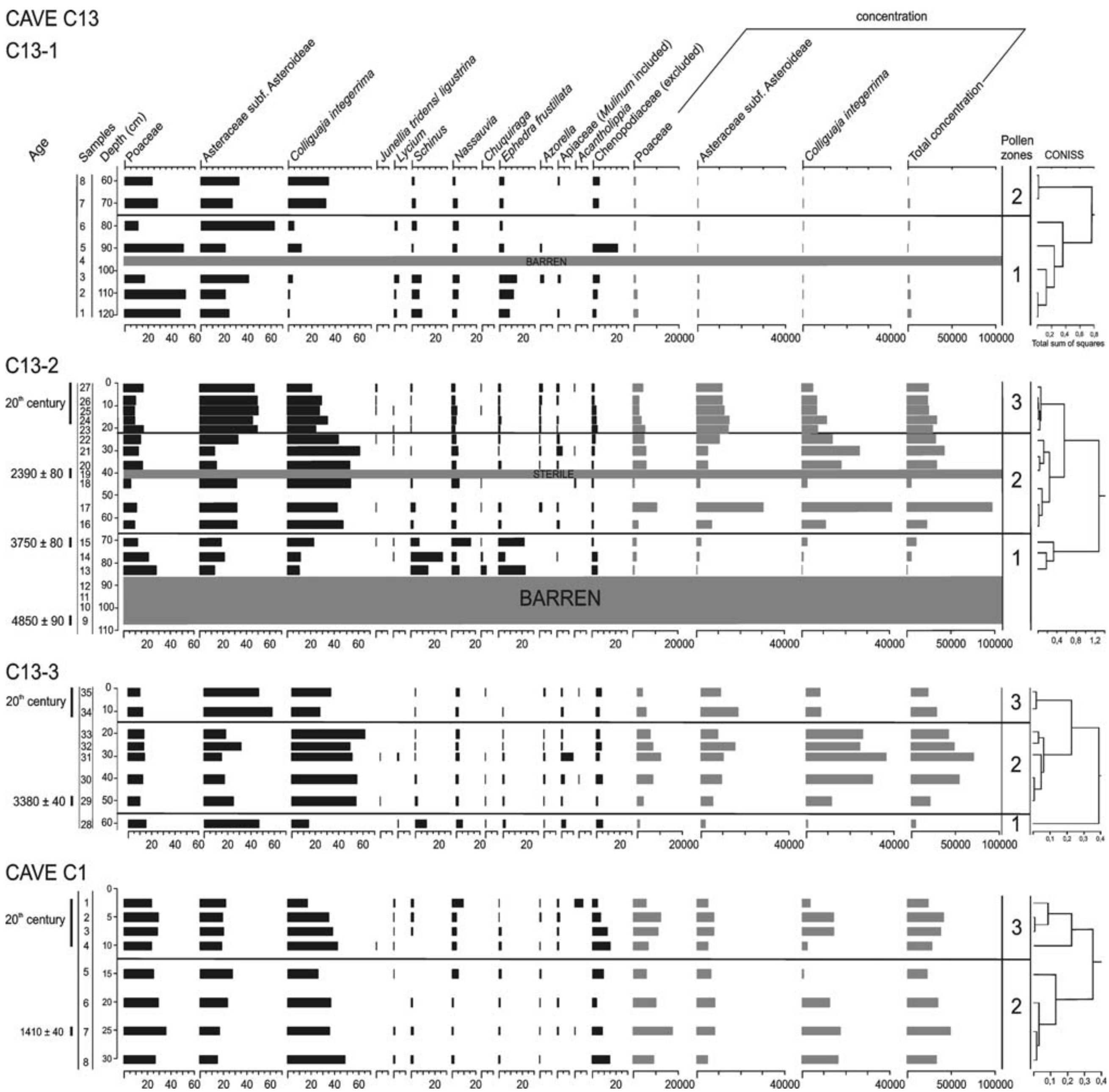

Fig. 4 Pollen percentage and concentration diagram of cave C13 and cave C1 fossil sequences. The dates are uncal B.P.

in the Santa Cruz central plateau, (La María locality, Fig. 1) and surrounded by similar vegetation communities, support the hypothesis that pollen from plants which grow near the entrances of these caves is over-represented (de Porras et al., unpublished data). As some previous studies of caves in Spain and the United Kingdom have recognized, other differences among cave surface assemblages may be due to the pollen brought in by animals and the orientation, morphology and size of the caves (Coles and Gilbertson 1994; Navarro Camacho et al. 2000, 2001; Prieto and Carrión 1999).

Vegetation history and human occupation

Reconstruction of vegetation changes was carried out by integrating the pollen data from the three profiles from cave C13 and the one from cave C1 (Figs. 4, 6), and using modern pollen assemblages as analogues of modern cañadón vegetation (Fig. 3). Fossil pollen percentages and concentration values were jointly analyzed and used to interpret the taphonomic processes.

Prior to 3750 B.P. (Zone 1, Figs. 4, 6), a shrub community of Asteraceae subf. Asteroideae with *Schinus*,

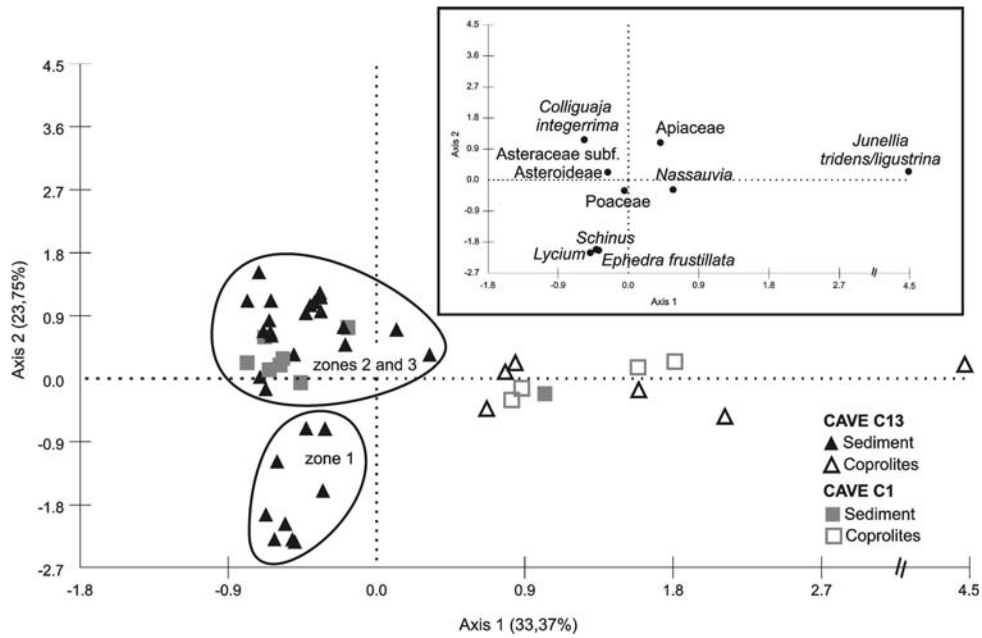

Fig. 5 Correspondence analysis plot for fossil sediment and sheep coprolite samples

Ephedra frustillata and a high proportion of grasses was present. Although total concentration values are low, the percentages of *Schinus* and *E. frustillata* suggest that this shrub community was different to the present day one in the cañadón (Fig. 3). Although this past community does not correspond with local modern pollen analogues, the fossil pollen spectra are similar to those of the shrub steppe with *Ephedra* (Mancini 1998) which is present in higher parts of the central plateau, highly exposed to the action of the wind under colder and drier conditions than those in the cañadón today. Therefore, the presence of this community in the cañadón where the present environmental conditions are more favourable for medium and tall shrubs than in the high areas of the plateau, suggests that there were drier conditions than at present before 3750 B.P.

Age	Pollen zones	Reconstructed plant communities	Human occupation
20th century	3	shrub community dominated by Asteraceae subf. Asteroideae	sheep farming
1410			
	2	shrub community dominated by *Colliguaja integerrima*	Industries 1,2 and 3
2390			
3360			
3750			
4850	1	shrub community of Asteraceae subf. Asteroideae with *Schinus*, *Ephedra frustillata* and high proportion of grasses	Casapedrense

Fig. 6 Summary plot showing plant communities and human occupation at Los Toldos cañadón during the late Holocene. Time scale ages are uncal B.P.

The low total pollen concentration in C13-1 is not related to post-deposition deterioration since pollen preservation is excellent. These concentration values may be related to a high deposition rate of sediments at the entrance of the cave as a result of the debris flow falling from the high part of the plateau. Towards the rear of the cave, the low pollen concentration at the base of the ash level (C13-2) may be explained by the rapid deposition and the absence of post-depositional disturbance. The pollen spectra are similar to the previous ones.

According to Cardich (1984–1985), the Casapedrense cultural level which had been present in the area since ca. 7200 uncal B.P., was replaced by Industries 1, 2 and 3 after the fall of the volcanic ash. The main activities in cave C13 included secondary processing and consumption of hunted animals as well as the making of stone and bone tools. These cultural activities of Industries 1, 2 and 3 disturbed the upper part of the ash level and produced a great mixture with rocks, charcoal and flakes. However, this is not shown by the pollen spectra since the assemblages are similar to those of the upper part of the sequence (Fig. 6).

Between 3750 B.P. and the 16th century A.D. (Zone 2, Figs. 4, 6) the pollen spectra represent a shrub community dominated by *Colliguaja integerrima* accompanied by Asteraceae subf. Asteroideae and Poaceae. Pollen assemblages from both caves are similar to the modern samples from the bottom of the cañadón and to the cave surface samples (group 2A, Fig. 3), indicating that *C. integerrima* is over-represented in fossil pollen assemblages.

In cave C13, the over-representation of *Colliguaja integerrima* points to either a larger growth of these plants at the entrance of the cave, or a high pollen input caused by flowers of *C. integerrima* being brought into the cave together with its branches. Although the use of the branches was not explained by the archaeologists, people might have used them as firewood. Pollen concentration is relatively constant in C13-3, but disturbed ash samples in C13-2 have fluctuating values related to the densest human occupation of the cave during this time. For example, low pollen concentration and bad preservation in sample 18, located under the hearth, is due to the effects of fire and high temperatures on pollen. In addition, zooarchaeological analysis pointed out that a great part (80%) of the bones was very well preserved although they had been broken by trampling after deposition (Miotti 1998).

In cave C1, Zone 2 ranges from 1410 ± 40 B.P. to the 16th century A.D. The pollen spectra do not show changes related to the presence of macrofossil Poaceae remains in the sedimentary sequence, which were brought in by humans, and as recorded in other pollen sequences from Patagonia (Mancini et al. 2002; Prieto and Stutz 1996). The purpose of this level in C1 is unknown, because it is not associated with hearths or other structures (R. Paunero personal communication 2008).

The complementary information of the pollen records from these two caves indicates that the over-representation of *Colliguaja integerrima* may not be due to the presence of plant levels brought in by humans, but rather to a large growth of these shrubs by the entrances of the caves.

The levels with sheep coprolites are from some time in the 20th century (Zone 3, Figs. 4, 6). Fossil pollen records indicate the development of a shrub community similar to that of the modern cañadón dominated by Asteraceae subf. Asteroideae and *C. integerrima*. Some differences between the pollen spectra from caves C1 and C13 could be related to the orientations of the caves and the filtering effects caused by the shrubs which grew by the entrances. Even though the differences between Zones 2 and 3 are minor, the pollen assemblages reflect the increase in percentage and concentration of Asteraceae subf. Asteroideae, and the decrease of *C. integerrima*. These differences, which coincide with sheep farming in Los Toldos cañadón, could be either an actual change in the dominant shrubs, or a biogenic bias of the record related to the breakdown of the coprolites due to sheep trampling. It is possible that the shrubs of *C. integerrima* which grew next to or at the entrances of the caves were cut down to be used by shepherds for sheltering flocks during bad weather. Therefore, the change may not be related to the sheep grazing itself because of the low density of sheep and the short period of sheep farming in this area at some time in the 20th century (Barbería 1995; R. Paunero personal communication 2005). On the other hand, coprolites have not been broken down and mixed with the sediment of the level since the sediment and the coprolite pollen assemblages are very different (Fig. 5). These differences may be caused by selectivity in the animals' diet and the time and space scales represented by each sample (Bjune et al. 2005; King 1977; Moe 1983).

Conclusions

The present study supports the potential of fossil pollen records from caves to reconstruct past vegetation changes in the semi-arid environments of extra-Andean Patagonia. Moreover, taphonomic analysis is a fundamental tool to prove that changes in pollen assemblages are not the results of pollen record bias and do reflect actual vegetation changes. Fossil pollen records from caves C13 and C1 verify that sequences from caves are the products of environmental, climatic and cultural interactions. Environmental factors affecting these caves are related to the ash fall, while cultural factors are represented by both anthropogenic evidence in the plant level, hearth and trampling and biogenic evidence from coprolites.

Pollen analyses from caves C13 and C1 have allowed discussion of the changes to the fossil pollen record in time and space. The sequences together indicate a main vegetation change in Los Toldos cañadón at ca. 3750 uncal B.P., shown by the replacement of a shrub community dominated by Asteraceae subf. Asteroideae with *Schinus* and *Ephedra frustillata* to another community with *Colliguaja integerrima*. This change between shrub communities is synchronous with the change in archaeological assemblages, and could be related either to moderate climatic variations or to the effects of the volcanic ash on the environment and particularly on the plants. Plant communities similar to the modern ones have occupied the Los Toldos area since 3750 uncal B.P., suggesting similar environmental conditions to the present. Zooarchaeological studies from cave C13 (Miotti 1998) and pollen records from other caves of the Santa Cruz plateau (La Martita and Alero Cárdenas, Mancini 1998, Fig. 1) also indicate the establishment of environmental conditions similar to those of the present during the late Holocene.

Acknowledgments This work was financial supported by PICT ′05 32345, EXA 349/06, EXA 434/08, CONICET PIP 5667. We are grateful to Rafael Paunero and Nora Franco for their invaluable help regarding to the archaeological subject of this study. We thank José S. Carrión for his comments on the first version of the manuscript and Lic. F. Sangermano for the English revision. We also would like to thank Alfred Traverse and two anonymous reviewers whose comments led to considerable improvements.

References

Barbería EM (1995) Los dueños de la tierra en la Patagonia Austral, 1880–1920. Universidad Federal de la Patagonia Austral, Río Gallegos

Bjune AE, Mangerud D, Moe D (2005) Past grazing habitats for Svalbard reindeer indicated by the pollen content of 3300-year-old faeces from Edgeøya, Svalbard. Grana 44:45–50

Brown CA (1960) Palynological techniques. Louisana State University, Baton Rouge, L.A

Cardich A (1984–1985) Una fecha radiocarbónica más de la Cueva 3 de Los Toldos (Santa Cruz, Argentina). Relaciones Nueva Serie T 16:269–273

Cardich A, Paunero R (1994) Mid-Holocene herding in Central Patagonia. Res Explor 10:368–369

Coles GM, Gilbertson DD (1994) The airfall-pollen budget of archaeologically important caves: Creswell Crags, England. J Archaeol Sci 21:735–755

Correa MN (ed) (1969–1999) Flora Patagónica, vol III (1978); vol V (1988). Colección Científica INTA, Buenos Aires

Fægri K, Iversen J (1989) Textbook of pollen analysis, 4th edn. Wiley, Chichester

Gray J (1965) Palynological techniques. In: Kummel B, Raup D (eds) Handbook of palaeontological techniques. Freeman, San Francisco, pp 471–587

Grimm E (2004) Tilia software 2.0.2, Illinois State Museum. Research and Collection Center. Springfield

Hunt CO, Rushworth G (2005) Pollen taphonomy and airfall sedimentation in a tropical cave: the west mouth of the great cave of Niah in Sarawak, Malaysian Borneo. J Archaeol Sci 32:465–473

King FB (1977) An evaluation of the pollen contents of coprolites as environmental indicators. J Acad Sci 12:47–52

León RJC, Bran D, Collantes M, Paruelo JM, Soriano A (1998) Grandes unidades de vegetación de la Patagonia extra andina. Ecol Aust 8:125–144

López Sáez JA, López García P, Burjachs F (2003) Arqueopalinología: síntesis crítica. Polen 12:5–35

Mancini MV (1998) Vegetational changes during the Holocene in Extra-Andean Patagonia, Santa Cruz Province, Argentina. Palaeogeogr Palaeoclimatol Palaeoecol 138:207–219

Mancini MV (2002) Vegetation and climate during the Holocene in southwest Patagonia, Argentina. Rev Palaeobot Palynol 122:101–115

Mancini MV (2003) Paleoecología del cuaternario tardío en el Sur de la Patagonia. Revista del Museo Argentino de Ciencias Naturales n.s. 5:273–283

Mancini MV, Paez MM, Prieto AR (2002) Cambios paleoambientales durante los últimos 7000 14C años en el ecotono bosque-estepa, 47°–48°S, Santa Cruz, Argentina. Ameghiniana 39:151–162

Mancini MV, Prieto AR, Paez MM, Schäbitz F (2007) Late Quaternary vegetation and climate of Patagonia. In: Rabassa J (ed) The Late Cenozoic of Patagonia and Tierra del Fuego, developments in Quaternary Sciences. Elsevier, Amsterdam, pp 351–368

Mazzoni MM, Spalletti LA (1974) Sedimentología de la cueva de Los Toldos, Provincia de Santa Cruz. Revista de la Asociación Argentina de Mineralogía, Petrología y Sedimentología 5:15–34

McCormac FG, Hogg AG, Blackwell PG, Buck CE, Higham TFG, Reimer PJ (2004) SHCal04 Southern hemisphere calibration 0–1000 cal BP. Radiocarbon 46:1087–1092

Miotti L (1998) Zooarqueología de la meseta central y costa de Santa Cruz: un enfoque de las estrategias adaptativas aborígenes y los paleoambientes. Museo Municipal de Historia Natural, San Rafael, Mendoza

Moe D (1983) Palynology of sheep's faeces: relationship between pollen content, diet and local pollen rain. Grana 22:105–113

Servicio Meteorológico Nacional (1969). Estadísticas climatológicas 1951–1960. Publicación B1 (6), Buenos Aires

Servicio Meteorológico Nacional (1986). Estadísticas climatológicas 1971–1980. Publicación 36, Buenos Aires

Naranjo JA, Stern CR (1998) Holocene explosive activity of Hudson volcano, southern Andes. Bull Volcanol 59:291–306

Navarro Camacho C, Carrión JS, Navarro J, Munuera M, Prieto AR (2000) An experimental approach to the palynology of cave deposits. J Quat Sci 15:603–619

Navarro Camacho C, Carrión JS, Munuera M, Prieto AR (2001) Sedimentación y distribución superficial de palinomorfos en cuevas del SE Ibérico. Implicaciones en Paleoecología. Anales de Biología 23:103–132

Oliva G, González L, Rial P, Livraghi E (2001) El ambiente de la Patagonia Austral. In: Borrelli P, Oliva G (eds) Ganadería ovina sustentable en la Patagonia Austral. INTA, Río Gallegos, pp 17–80

Paez MM, Prieto AR, Mancini MV (1999) Fossil pollen from Los Toldos locality: a record of the Lateglacial transition in the Extra-Andean Patagonia. Quat Internat 53–54:69–75

Prieto AR, Carrión JS (1999) Tafonomía polínica: sesgos abióticos y bióticos del registro polínico en cuevas. Ameghiniana Publicación Especial 6:54–59

Prieto AR, Stutz S (1996) Vegetación del Holoceno de la estepa Patagónica: palinología de la cueva Epullán Grande (Neuquén). Praehistoria 2:267–277

Prieto AR, Stutz S, Pastorino S (1998) Vegetación del Holoceno en la cueva Las Buitreras, Santa Cruz, Argentina. Revista Chilena de Historia Natural 71:277–290

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac FG, Manning SW, Ramsey CB, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, Van der Plicht J, Weyhenmeyer CE (2004) IntCal04 terrestrial radiocarbon age calibration, 26-0 cal kyr BP. Radiocarbon 46:1029–1058

Roig FA (1998) La vegetación de la Patagonia. Colección Científica INTA. Tomo VIII, vol I, INTA, Río Gallegos

Soriano A, Movia CP, León RJC (1983) Deserts and semideserts of Patagonia: vegetation. In: West NE (ed) Temperate deserts and semi-deserts. Elsevier, Amsterdam, pp 423–460

Stern CR (1991) Mid-Holocene tephra on Tierra del Fuego (54°S) derived from the Hudson volcano (46°S): evidence for a large explosive eruption. Revista Geológica de Chile 18:139–146

Stuiver M, Reimer PJ (1993) Extended ^{14}C database and revised CALIB radiocarbon calibration program. Radiocarbon 35:215–230

Stuiver M, Reimer PJ, Reimer RW, 2005 CALIB 5.0. [WWW program and documentation]