



Postglacial environments in the southern coast of Lago Fagnano, central Tierra del Fuego, Argentina, based on pollen and fungal microfossils analyses



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ABSTRACT

We analyzed a peat-bog sequence from the central region of Tierra del Fuego, southernmost Patagonia, to reconstruct the environmental changes over the past 15,000 years. Postglacial vegetation was mainly composed by grasslands and shrubby communities with sparsely distributed *Nothofagus* trees under dry conditions. The predominance of *Glomus* sp. and *Gelasinospora* sp. may also indicate less humid conditions related to the steppe communities. The presence of herbivorous grazers is suggested by the record of ascospores of coprophilous *Sordaria*-type and *Sporormiella*-type throughout the profile. Between 11,200 and 6500 cal yr BP, the *Nothofagus* woodland established under warmer and wetter climate than before. However, precipitation must have remained below present-day levels. Most fungal remains (*Gaeumannomyces* sp., *Glomus* sp., *Gelasinospora* sp., Microthyriaceae, *Spegazzinia tessartha*, *Alternaria* sp.) are likely associated with the development of forest-steppe ecotone communities. Following 6500 cal yr BP, when climate conditions were more humid and colder than before, the closed-canopy forest dominated the landscape, and Microthyriaceae remains prevailed among fungi. During the last 1000 years, the record showed open forest communities accompanied by the presence of *Glomus* sp. These palaeoenvironmental changes observed along the sequence suggested variations in the amount of precipitation of westerly origin related to shifts in the position and/or strength of the southern margin of the westerlies. This study revealed that fungal remains complement pollen/spores analysis by providing important independent information on the palaeoenvironmental and palaeoclimate conditions that prevailed during the late Pleistocene-Holocene in the Lago Fagnano area.

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1. Introduction

Lago Fagnano (54° 34' S), also known as Lago Kami by the native inhabitants, lies in the central part of the Isla Grande de Tierra del Fuego. With a total area of ~560 km², Lago Fagnano is the largest ice-free water body close to Antarctica. The region is known to

have been a large glaciated area of southernmost South America during the Last Glacial Maximum (LGM; ca. 25,000 cal yr BP; Rabassa, 2008) because of the proximity to the main ice cap centered on the Cordillera Darwin (Fuegian Andes; 2000 m a.s.l., 55° S–69° W) from which the glacier network covered the region (Coronato et al., 2009). No reliable deglaciation ages are yet available for the studied area, but basal ages of peat bogs, located ~16 km east of the lake, yielded minimum-limiting ages for ice retreat between 15,400 and 13,800 cal yr BP (Coronato et al., 2002, 2009; Musotto et al., 2016).

Most previous late-Quaternary palaeoecological studies from Tierra del Fuego targeted sites in the southernmost part of the island, along the Canal Beagle lowlands (Heusser, 1989a, 1989b, 1990, 1995, 1998, 2003; Borromei and Quattrocchio, 2008; Pendall et al., 2001;

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Markgraf and Huber, 2010; Borromei et al., 2014), and on several inner valleys of the Fuegian Andes (Markgraf, 1993; Borromei, 1995; Mauquoy et al., 2004; Borromei et al., 2007, 2010). Several palynological studies, however, focused on northern and central areas of the archipelago (Markgraf, 1980; Heusser, 1993, 2003; Heusser and Rabassa, 1995; Burry et al., 2007; Musotto, 2013; Waldmann et al., 2014; Musotto et al., 2016). These studies reveal that the palaeovegetation development in Tierra del Fuego was influenced by past variations in the temperature and precipitation regimes. These climatic fluctuations have been related to changes in the latitudinal position and/or strength of the Southern Westerly winds (SWW), Antarctic sea-ice extension, position of the Antarctic Polar Front, solar irradiation, or a combination of these factors (Heusser, 2003; Markgraf and Huber, 2010; Waldmann et al., 2010).

Among non-pollen palynomorphs (NPPs), fungal microfossils provide important palaeoproxy records for environmental change

(van Geel, 2001). Fungal microfossils give useful information about soil moisture content and substrate (e.g. specific host plants, decaying organic matter) conditions (Cugny et al., 2010). A multiproxy approach, or one that combines fossil pollen and fungi, affords a richer understanding of past environmental conditions (Limaye et al., 2007; Montoya et al., 2010). Changes in late Pleistocene-Holocene fungal types and frequencies remain largely unknown in Tierra del Fuego despite the widespread use of fungal remains as supplementary tool in palynology (Mauquoy et al., 2004; Borromei et al., 2010; Musotto, 2013; Musotto et al., 2012, 2013).

In this paper we present the results of the pollen/spores and fungal remains analyses from the Terra Australis mire (54° 36' 59.1" S; 67° 46' 21.5" W; 120 m a.s.l.) (Fig. 1) to document the postglacial vegetation and environmental changes in the central portion of Tierra del Fuego island during the last 15,000 years. We hypothesize

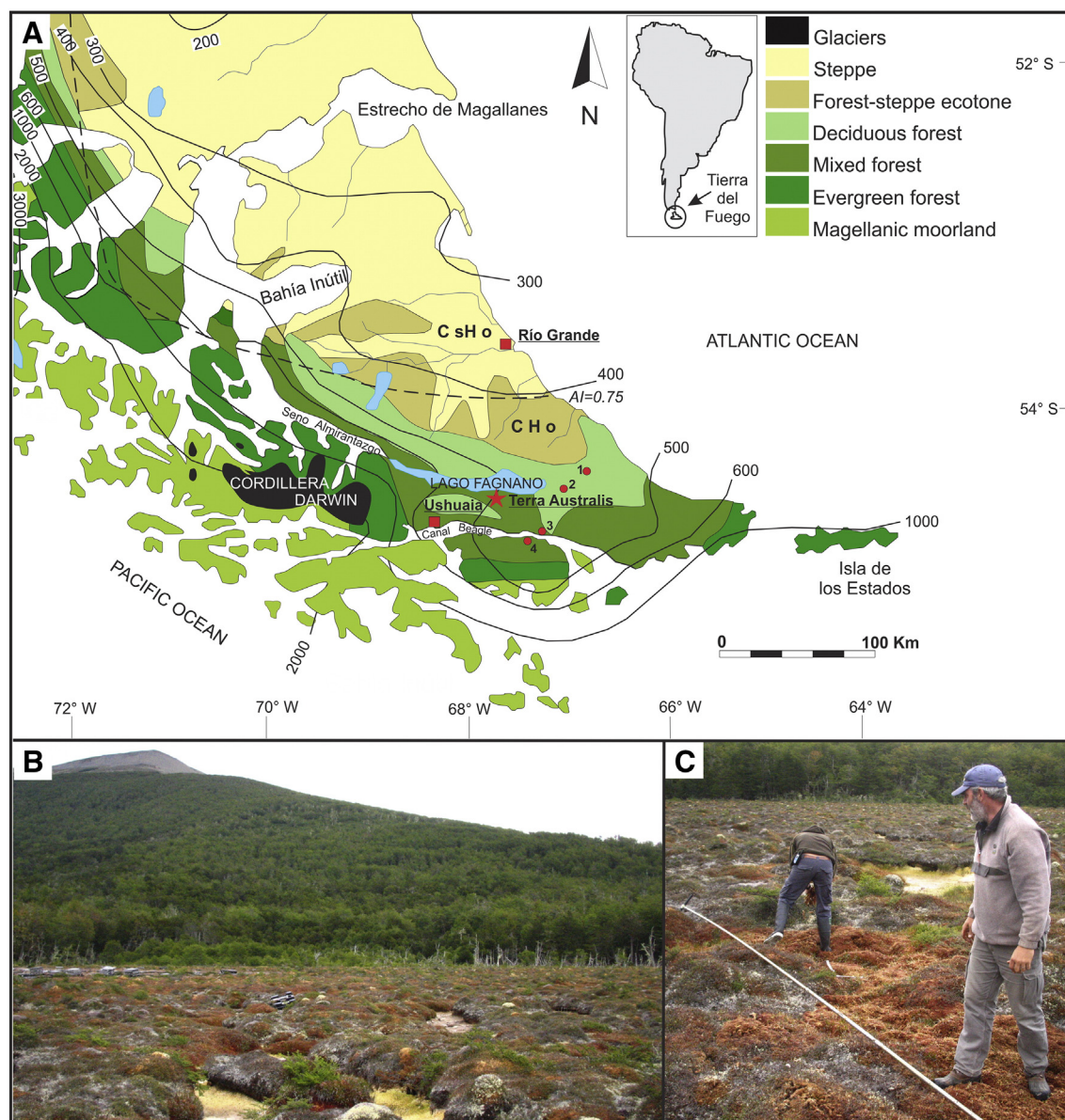


Fig. 1. Study area. A) Vegetation map of the Tierra del Fuego island with the mean annual precipitation isohyets (from Tuhkanen, 1992) and the location of the Terra Australis mire (red star) and sites mentioned in the text: 1. San Pablo 1, 2. La Correntina, 3. Puerto Harberton, 4. Caleta Róbal. C: cold, H: humid, sH: subhumid, o: oceanic, AI: aridity index. Climate data from Coronato et al. (2008). B) Photograph of the overall view of the mire. C) Detail photograph of the coring site.

that because of Tierra del Fuego's location in the path of the SWW, our palynological data could record changes in the intensity and position of the SWW during the late Pleistocene-Holocene. We also evaluate our proxy records with other palaeoecological evidence from Tierra del Fuego island to better understand broadscale changes in environmental and climatic conditions since the Lateglacial.

2. Environmental setting

The Terra Australis mire lies 3 km south of Lago Fagnano coast and 1 km north of Lago Escondido, in central Tierra del Fuego (Fig. 1A). This 0.913 km² mire has formed over late Quaternary drift. This drift is composed of till, glacialustrine and glaciofluvial sediments emplaced during deglaciation (Coronato et al., 2009). Most of the outwash bottom valleys in the region have been covered by peat-bogs and mires, but stratified-drift is present as kames terraces or isolated hills.

A mixed evergreen-deciduous *Nothofagus* forest surrounds the bog, and the ombrogenous (raised) bog surface is formed mainly by *Sphagnum magellanicum* and covered by *Empetrum rubrum*, *Nothofagus antarctica*, *Sphagnum fimbriatum*, Cyperaceae, Juncaginaceae, Juncaceae and lichens (Fig. 1B and C).

3. Present climate and vegetation of Tierra del Fuego

The climate of Tierra del Fuego is influenced by the strength and location of the prevailing westerlies, in the path of eastward moving cyclones, not far from the Antarctic ice (Tuhkanen, 1992). The latitudinal position and overall strength of the SWW are determined by the intensity and latitudinal location of the subtropical high pressure cells in the Pacific and the circum-Antarctic low pressure belt. The Fuegian Andes, the only Andean mountain system that extends in a W–E direction with peaks reaching up to 2500 m a.s.l. in the west, form a pronounced topographic barrier to atmospheric circulation in the SWW, causing a progressive rain shadow to the north and east of the Andes. The climate is cold oceanic humid in the centre and south of Tierra del Fuego and cold oceanic subhumid towards the north. Both regions differ in their aridity indices; the northern limit of the 0.75 isoline is located approximately 30 km south of the Río Grande (Coronato et al., 2008) (Fig. 1A). Prevailing winds are from the W–SW and they are active throughout the year. In the centre of Tierra del Fuego, average temperatures are between 10 °C in summer (January) and 0 °C in winter (July) (Tuhkanen, 1992). Mean annual precipitation ranges from 400 to 500 mm and snowfall generally occurs between May and October. The location of the Terra Australis mire, at the foot of the northern slope of Sierras de Alvear, in the Fuegian Andes, imposes the climatic conditions of mountain areas, namely a decrease in daylight hours, precipitation originated by topographic effect and influence of the katabatic winds. Its position close to the Lago Fagnano coast favours the passage of humid air-masses from the Pacific Ocean as the lake acts as a corridor for the arrival of the SWW into the region.

Modern vegetation in northern Tierra del Fuego corresponds to the Fuegian–Patagonian steppe, followed southward successively, by the Subantarctic Deciduous Forest and Subantarctic Evergreen Forest (Fig. 1A). Steppe of grassland, scrub and heath develops where mean annual precipitations are <400 mm. The tussock grassland of *Festuca gracillima* covers the area, grading into scrub or shrubby composites or into dwarf shrub heaths of *Empetrum rubrum* (Moore, 1983; Collantes et al., 1999). Contact of steppe with deciduous forest occurs through an ecotone with precipitation values between 350 and 500 mm yr⁻¹ (Tuhkanen, 1992). Subantarctic Deciduous Forest (Pisano, 1977; Moore, 1983) is represented by two species of southern beech, *Nothofagus pumilio* and *N. antarctica*, which grow to an average altitudinal limit of 550–600 m a.s.l. and become dominant where precipitation exceeds 450 mm yr⁻¹. Towards

the south and west of Tierra del Fuego, the annual precipitation rises to over 700 mm and the Subantarctic Evergreen Forest develops, which is dominated by *Nothofagus betuloides*, accompanied by *Drimys winteri*, *Maytenus magellanica* and abundant ferns and mosses (Moore, 1983). Initially, *Nothofagus betuloides* forests intermingle with *N. pumilio* establishing a mosaic that has been termed Mixed Evergreen-Deciduous Forest (Moore, 1983). Magellanic Moorland occurs beyond the forest along the exposed outermost coast under conditions of increased precipitation (>1500 mm yr⁻¹), winds and poor drainage. The moorland is typically treeless, dominated by cushion bogs of *Astelia pumila* and *Donatia fascicularis*. Above the treeline, Andean Tundra is characterized by cushion plants (*Azorella lycopodioides* and *Bolax gummifera*), dwarf shrub heaths (*Empetrum rubrum*), and herb communities (Pisano, 1977; Heusser, 2003).

4. Materials and methods

4.1. Lithology and chronology. Age-depth model

We collected a sediment core from the mire with a Russian-type peat corer (chamber length 0.5 m and 5 cm diameter). We logged the lithostratigraphy of the sediments in the field. Six AMS radiocarbon dates provided chronologic control for the core. The NSF-Arizona AMS Laboratory, USA, undertook radiocarbon analysis on peat and bulk organic matter contained in the basal clays. The radiocarbon ages were converted to calendar years BP using the Calib 7.1 software (Stuiver et al., 2015) and the South Hemisphere curve (SHcal13) (Hogg et al., 2013) (Table 1). We constructed an age model for the core using the Bacon programme (Blaauw and Christen, 2011) (Fig. 2). The Bayesian method determined 95% confidence limits of the age-depth model with the uncertainties of the calibrated radiocarbon ages, expected sedimentation rates at the core location (i.e. priors), and Markov Chain Monte Carlo (MCMC) simulation.

4.2. Tephrochronology

During the coring we identified a tephra layer based on the coloration, degree of weathering, lithic content, and shard vesicularity. We confirmed tephra identification by determining the geochemistry of individual glass shards and the relative abundance of microphenocrysts at the University of Calgary Laboratory for Electron Microbeam Analysis (UCLEMA). Prior to analysis, organic matter was removed with hydrogen peroxide, the samples were washed and wet-sieved through a 230 mesh screen, and the coarse fraction was mounted in epoxy, polished, and carbon-coated. Inclusion-free glass shards from each sample were analyzed for K₂O, CaO, FeO, SiO₂, Na₂O, TiO₂, MnO, MgO, and Al₂O₃ with a wavelength-dispersive spectrometer (WDS) JEOL JXA-8200 electron microprobe. The accelerating voltage was 15.0 kV, the beam current was 10 nA, and the beam width was 5 µm. We adjusted data using the ZAF matrix correction scheme to account for differences between the standards and the samples (Armstrong, 1984) and then compared our measurements to microprobe glass geochemistry data reported by Stern (2008).

4.3. Palynological analysis

We collected 1-cm-thick samples from the core at 4 cm intervals and prepared them using standard techniques (Faegri and Iversen, 1989). To estimate microfossil concentrations per gram of sediment, *Lycopodium clavatum* tablets were added to each sample (Stockmarr, 1971). We counted a minimum of 300 terrestrial pollen grains with the exception of some Late-glacial samples at 710, 700 and 685 cm depth, with lower pollen sums. The reported frequencies (%) of

Table 1
Radiocarbon dates and calibrated ages of selected samples from the Terra Australis mire.

Sample depth (cm)	Lab. code	Uncalibrated age (^{14}C yr BP)	$\delta^{13}\text{C}$ (‰)	Calibrated years BP (median probability)	1 σ range	2 σ range
29–30	AA86262	602 \pm 35	–24.3	555	532–560	514–569
90–91	AA86256	1154 \pm 36	–24.3	1012	1014–1056	934–1068
501–502	AA86261	5362 \pm 43	–26.5	6099	6007–6083	5988–6214
553–554	AA86260	6881 \pm 48	–26.5	7671	7612–7710	7586–7786
558–559	AA86259	7018 \pm 46	–26.9	7808	7740–7858	7691–7879
735–737	AA83314	12,397 \pm 62	–26.1	14,387	14,163–14,541	14,092–14,771

terrestrial plant taxa were based on a sum of pollen from trees, shrubs and herbs. Percentages of pollen of wetland herbs and aquatics, and spores of cryptogams were calculated separately and related to the sum of terrestrial pollen. “Other shrubs and herbs” included taxa with low values (<1%), such as *Astelia pumila*, *Ephedra*, *Papilionaceae*, *Santalaceae*, *Valeriana* and *Verbenaceae*. Also, *Iridaceae*, *Liliaceae*, *Juncaceae* and *Polypodiaceae* were grouped as “Other aquatics and cryptogams”. Given the difficulty in species separation, *Nothofagus betuloides*, *N. pumilio* and *N. antarctica* are collectively shown as “*Nothofagus dombeyi*-type”.

The pollen spectra was subdivided into zones through visual inspection considering the major transitions in the pollen stratigraphy, and supported with a stratigraphically constrained cluster analysis using Edwards & Cavalli-Sforza's chord distance (TGView 2.0.2, Grimm, 2004). For the analysis all taxa with percentages of >2% of the sum of terrestrial pollen were included. Fossil pollen spectra were compared with modern pollen datasets from surface soil samples (Heusser, 1989a; Trivi de Mandri et al., 2006; Musotto et al., 2012) and with present-day vegetation from Tierra del Fuego (Pisano, 1977; Moore, 1983).

Palynological richness, as estimated by rarefaction analysis, has been interpreted to represent changes in floristic diversity on the landscape (Birks and Line, 1992). Therefore, this index allowed us to evaluate vegetation structure and dynamics since deglaciation. The analysis was carried out using Psimpoll 4.27 (Bennett, 2009), based on 210 grain minimum pollen sum ($E(T_{210})$).

We tried to assign the fungal microfossils (fm) to modern taxa. Otherwise we used the informal ‘type’ denomination to label those fungal remains which have only a superficial morphological resemblance with modern taxa (following van Geel, 1978 or Gelorini et al., 2011, among others). The fungal types were indicated as ‘HdV-xxx’ (HdV = Hugo de Vries- Laboratory, University of Amsterdam, The Netherlands) when already described previously by van Geel and others. A systematic list of the fungal taxa is shown (Appendix

A). Morphological descriptions and ecological/environmental preferences for the newly distinguished taxa are also provided (Appendix B). The reader is referred to earlier reports (Musotto et al., 2012, 2013) for descriptions of all the other fungal remains. “Microthyriaceae” included both the ascomata identified (mostly as cf. *Microthyrium fagi*) as those fragments in poor condition that could not be assigned to any genus.

5. Results

5.1. Lithology and chronology

The core consisted of bluish gray clays [737–729 cm], light gray clay lenses interspersed with peat layers [729–720 cm], that were overlain by 220 cm of dark brown peat consisting mainly of fibrous remains of vascular plants (*Carex* and grasses). In this unit [720–500 cm] we observed woody material [700–696 cm], peat containing clayey lenses [681–676 cm], and a unit of light brown tephra [558–554 cm]. From 500 to 92 cm the core consisted of humified dark brown peat with fibrous material. The upper 92 cm of the core was composed of light brown unhumified fibrous peat.

Geochemical and petrologic analyses on the tephra sample collected at 557 cm depth indicated a Hudson origin (Table 2). Radiocarbon dates performed on the under and overlying peat from the studied core yielded a 2 σ age range of 7808–7671 cal yr BP. This age range fall within the proposed age range for the mid-Holocene tephra (H_1) layer erupted from Volcán Hudson, regionally dated 7960–7423 cal yr BP (Stern, 2008).

5.2. Palynological analysis

We subdivided the pollen record into three palynological zones, TA-1 to TA-3. The first zone (TA-1) contains two distinct subzones (Fig. 3). Selected pollen types were graphed over the entire sequence and Lateglacial–early Holocene portion of the pollen spectra in order to adjust the broad range of concentrations (Fig. 4A and B, respectively). To avoid biased representation of the fungal assemblage attributable to over-dominance of some pollen taxa (e.g. *Nothofagus dombeyi*-type), we calculated the main fungal microfossil concentrations (Fig. 5).

5.2.1. Zone TA-1 (735–655 cm; 14,300–11,300 cal yr BP)

5.2.1.1. Pollen frequencies

5.2.1.1.1. Subzone TA-1a (735–690 cm; 14,300–12,400 cal yr BP). This subzone is dominated by Asteraceae subf. Asteroideae (up to 48%), *Empetrum rubrum* (<27%) and Poaceae (16–25%). *Acaena* (19%), Asteraceae subf. Mutisieae (15%), Caryophyllaceae (10%) and Apiaceae (7%) are also present. *Nothofagus dombeyi*-type reaches 54% at the beginning of the subzone, declines and then increases to 60% near the end of the subzone. Among the aquatic taxa, Cyperaceae

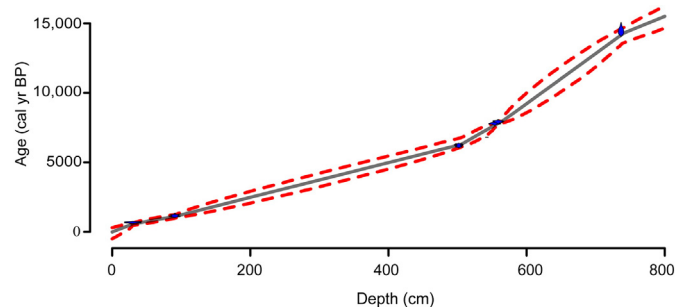


Fig. 2. Age–depth model based on methods described in Blaauw and Christen (2011). The probability distributions of the ^{14}C age are shown in blue. The dashed red lines denote 95% confidence limits of the age–depth model.

Table 2

Chemical composition of the tephra sample collected at 557 cm depth from the Terra Australis mire.

Shard	Al ₂ O ₃	K ₂ O	FeO	Na ₂ O	MgO	CaO	MnO	SiO ₂	TiO ₂	Total
1	16.201	2.762	5.240	5.230	1.506	3.033	0.207	64.751	1.192	100.122
2	15.971	3.037	4.940	4.667	1.199	2.616	0.181	66.395	1.032	100.038
3	16.058	2.964	4.912	4.744	1.291	2.876	0.118	66.305	1.151	100.419
4	16.235	2.850	4.907	4.807	1.461	2.916	0.139	65.666	1.259	100.240
5	16.065	2.830	4.915	5.101	1.506	2.976	0.120	65.816	1.174	100.503
6	16.027	3.019	4.810	4.674	1.208	2.565	0.146	66.381	1.082	99.912
7	16.008	2.999	4.586	4.542	1.183	2.430	0.163	66.599	0.987	99.497
8	16.003	2.752	5.084	4.956	1.375	3.019	0.164	64.607	1.202	99.162
9	15.901	2.960	4.708	4.780	1.149	2.547	0.208	66.299	1.085	99.637
10	16.084	2.893	5.060	5.163	1.312	2.740	0.136	65.755	1.165	100.308
11	16.166	2.885	5.083	5.262	1.330	2.763	0.208	66.052	1.060	100.809
12	16.532	2.761	5.191	5.000	1.570	3.215	0.140	64.805	1.206	100.420
13	16.227	2.950	4.402	4.839	1.155	2.341	0.149	66.737	1.143	99.943
14	15.931	2.928	5.079	4.740	1.326	2.725	0.197	64.549	1.105	98.580
15	16.338	2.730	5.554	4.690	1.576	3.111	0.199	64.966	1.291	100.455
Min	15.901	2.730	4.402	4.542	1.149	2.341	0.118	64.549	0.987	98.580
Max	16.532	3.037	5.554	5.262	1.576	3.215	0.208	66.737	1.291	100.809
Mean	16.116	2.888	4.965	4.880	1.343	2.792	0.165	65.712	1.142	100.003

fluctuates between 12 and 74%, and *Myriophyllum* is below 4% but reaches 18% in the middle of the subzone. Palynological richness records the highest values (17).

5.2.1.1.2. Subzone TA-1b (685–655 cm; 12,400–11,300 cal yr BP). Poaceae (88%) increases abruptly and attains maximum frequencies throughout the record accompanied by increases in *E. rubrum* (35%). Asteraceae subf. Asteroideae rises to 45% at the beginning of the subzone and then declines to <9%. *Nothofagus dombeyi*-type drops to <22%. Cyperaceae decreases (<37%), and *Lycopodium magellanicum* reaches up to 9%. In this subzone, the palynological richness declines.

5.2.1.2. Pollen concentrations. In the subzone TA-1a total pollen concentration is low (90,000 grains g⁻¹), contributed mainly by Cyperaceae (69,300 grains g⁻¹) and Asteraceae (22,400 grains g⁻¹). Total pollen concentration increases up to 592,000 grains g⁻¹ during the subzone TA-1b with the highest values corresponding to Poaceae (244,100 grains g⁻¹) and Asteraceae (215,000 grains g⁻¹) accompanied by *E. rubrum* (54,700 grains g⁻¹) and Cyperaceae (36,400 grains g⁻¹). *Nothofagus dombeyi*-type concentration reaches low values throughout the zone (7500 grains g⁻¹).

5.2.1.3. Fungal microfossil concentrations. In the zone TA-1 ascospores of *Sordaria*-type (5600–6800 fm g⁻¹), *Sporormiella*-type (1900 fm g⁻¹) and *Gelasinospora* sp. (660 fm g⁻¹) are registered. Concentrations of *Glomus* sp. (720 fm g⁻¹), *Gaeumannomyces* sp. (190 fm g⁻¹), *Arthrinium puccinioides* (140 fm g⁻¹), and *Microthyriaceae* (110 fm g⁻¹) are the lowest of the entire record.

5.2.2. Zone TA-2 (650–520 cm; 11,300–6600 cal yr BP)

5.2.2.1. Pollen frequencies. This zone displays an abrupt rise in *Nothofagus dombeyi*-type from 45 to 78%. Poaceae declines and fluctuates between 9 and 44%. *Empetrum rubrum* (24%) maintains similar values relative to the previous subzone (TA-1b). Asteraceae subf. Asteroideae (<11%) declines while *Acaena* (<5%) and *Gentiana* (<2%) exhibit low abundances. *Misodendrum* (a hemiparasite on *Nothofagus* species) approaches 7.5% and becomes continuous thereafter. Cyperaceae increases up to 48% with a peak of 67%. *Lycopodium magellanicum* records up to 14%, then declines (<4%) towards the end of the zone. Palynological richness remains with similar values to those recorded in the previous subzone (TA-1b).

5.2.2.2. Pollen concentrations. Total pollen values increase up to 209,000 grains g⁻¹ with a peak of 332,000 grains g⁻¹. A decline in

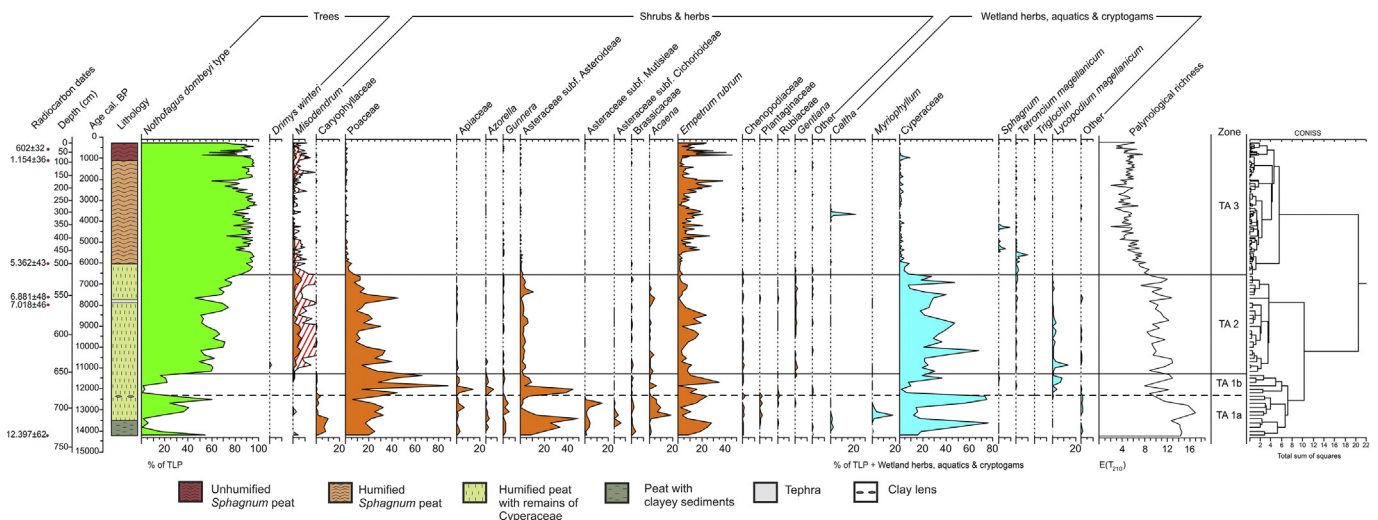


Fig. 3. Fossil pollen/spore frequency diagram (%) from Terra Australis, including stratigraphy and palynological richness (base sum of 210). Exaggeration percentage curve (10×) is shown in red shading lines for *Misodendrum* pollen. TLP: total land pollen.

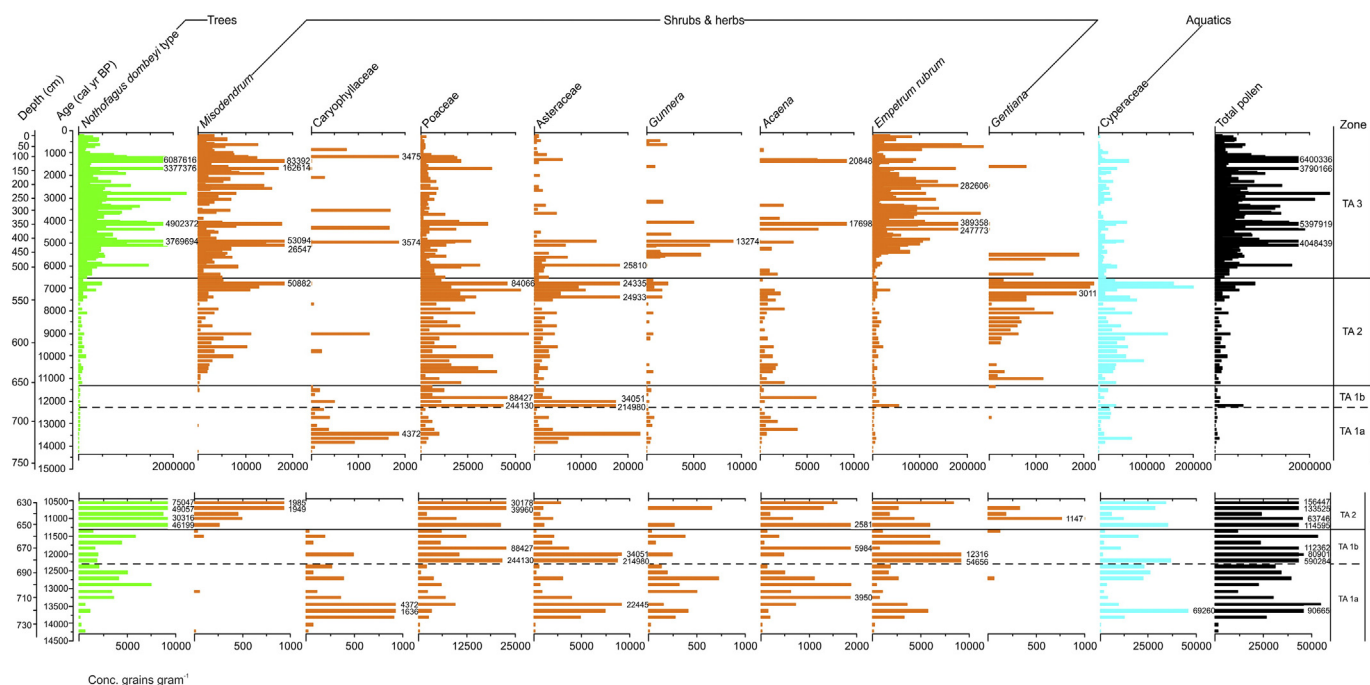


Fig. 4. A) Fossil pollen concentration (grains g^{-1}) diagram of selected taxa from Terra Australis. B) Concentration diagram of selected taxa for the Lateglacial–early Holocene portion from Terra Australis.

total concentration at 555 cm depth ($26,000 \text{ grains g}^{-1}$) coincides with the unit of tephra. Above the tephra, total pollen values increase up to $850,000 \text{ grains g}^{-1}$, driven primarily by *N. dombeyi*-type ($482,000 \text{ grains g}^{-1}$) and Cyperaceae ($200,000 \text{ grains g}^{-1}$), and secondarily by Poaceae ($84,000 \text{ grains g}^{-1}$) and *Misodendrum* ($51,000 \text{ grains g}^{-1}$).

5.2.2.3. Fungal microfossil concentrations. *Arthrinium puccinioides* ($53,700 \text{ fm g}^{-1}$), Type 810 cf. *Byssothecium alpestre* (7900 fm g^{-1}), *Gaeumannomyces* sp. (6400 fm g^{-1}), and *Glomus* sp. (2100 fm g^{-1}) increase their abundances. Ascospores of *Sporormiella*-type ($<2600 \text{ fm g}^{-1}$) and *Sordaria*-type ($<1300 \text{ fm g}^{-1}$) are also recorded. *Gelasinospora* sp. (620 fm g^{-1}), *Spegazzinia tessartha* (660 fm g^{-1}), and *Alternaria* sp. (260 fm g^{-1}) display low concentration values.

Microthyriaceae reaches 2200 fm g^{-1} towards the uppermost part of this zone.

5.2.3. Zone TA-3 (515–0 cm; 6600–0 cal yr BP)

5.2.3.1. Pollen frequencies. *Nothofagus dombeyi*-type dominates this zone (53–99%), Poaceae declines to 7%, and *Empetrum rubrum* is variable, reaching frequencies up to 46%. *Misodendrum* ($<5\%$) persists in low abundances. Cyperaceae decreases (9%), and *Caltha* peaks (22%) in the middle of the zone. *Tetroncium magellanicum* and *Sphagnum* are also present ($<10\%$). Palynological richness is lower than in Zone TA-2.

5.2.3.2. Pollen concentrations. Total concentration records high values (up to $1,420,000 \text{ grains g}^{-1}$) and achieves a maximum

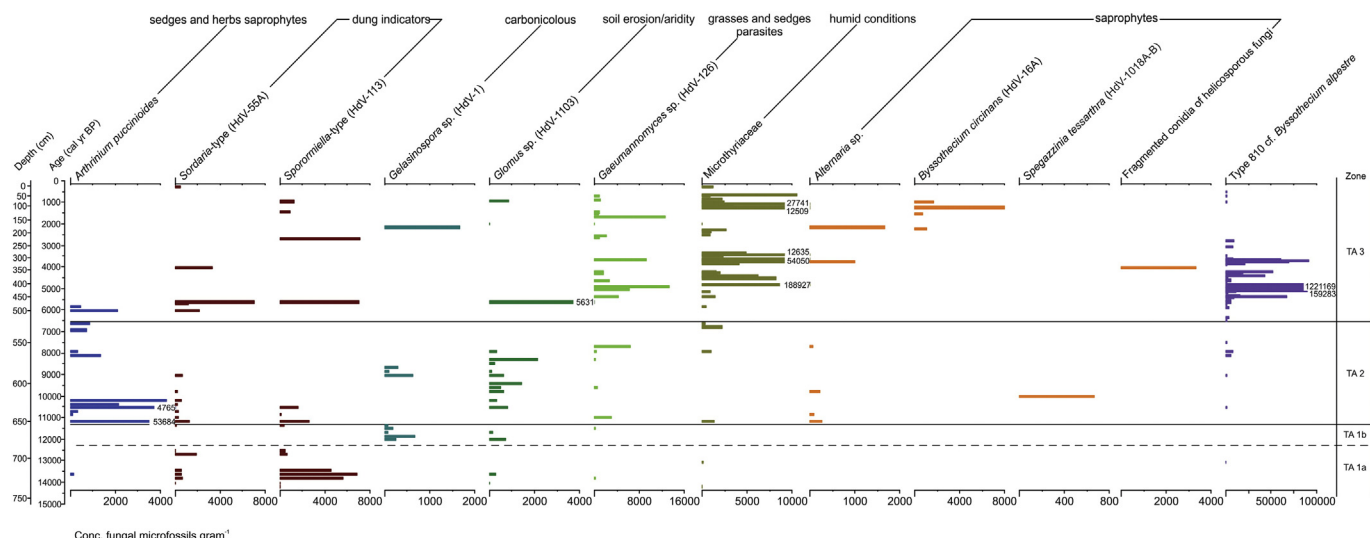


Fig. 5. Main fungal microfossil concentration (fm g^{-1}) diagram from Terra Australis. HdV: Hugo de Vries-Laboratory.

(6,400,000 grains g^{-1}) at 1300 cal yr BP. The main contributor, *N. dombeyi*-type, reaches its highest abundance (6,000,000 grains g^{-1}) throughout the sequence. *Empetrum rubrum* peaks at 390,000 grains g^{-1} and *Misodendrum* records a maximum of 163,000 grains g^{-1} . Over the last 1000 yr, total concentration decreases (150,000 grains g^{-1}).

5.2.3.3. Fungal microfossil concentrations. The concentration of fungal remains for this uppermost zone is high. The highest abundances of Type 810 cf. *Byssosporium alpestre* (1,220,000 fm g^{-1}) and Microthyriaceae (189,000 fm g^{-1}) are recorded in this zone. *Byssosporium circinans* (18,800 fm g^{-1}) and *Gaeumannomyces* sp. (13,300 fm g^{-1}) exhibit high abundances. *Sordaria*-type (7000 fm g^{-1}) and *Sporormiella*-type (7100 fm g^{-1}) are registered. Spores of *Glomus* sp. display a maximum of 5600 fm g^{-1} . Fragmented conidia of helicosporous fungi (3300 fm g^{-1}), *Gelasinospora* sp. (1600 fm g^{-1}) and *Alternaria* sp. (1600 fm g^{-1}) are also present.

6. Discussion

6.1. Palaeoenvironmental evolution at Terra Australis mire

6.1.1. Lateglacial (ca. 14,300–11,500 cal yr BP)–early Holocene (11,500–8000 cal yr BP)

The pollen assemblage between ~14,300 and 13,100 cal yr BP (lower subzone TA-1a) is characterized by the highest palynological richness associated to the development of grasses (Poaceae), shrubs (Asteraceae subf. Asteroideae, *Empetrum rubrum*, Asteraceae subfs. Mutisieae and Cichorioideae), herbs (*Acaena*, *Gunnera*, Apiaceae, Caryophyllaceae, Brassicaceae), and cushion plants (*Azorella*). These plant palaeocommunities resemble the present Fuegian steppe of the northern part of Tierra del Fuego, where precipitation is <400 mm annually (Moore, 1983; Pisano, 1977). The lowest total pollen concentration recorded throughout this zone (TA-1) reflects a sparse vegetation cover, and also the initial low concentration values (560 grains g^{-1}) of *Nothofagus dombeyi*-type pollen imply the existence of limited numbers of trees in the landscape. The determination of local and regional *Nothofagus* presence based on pollen proportions is controversial because *Nothofagus* species are anemophilous and its pollen can be carried far from its emission sources. The low pollen production of the local vegetation along with the openness of the landscape could explain in most cases the record of high proportions of *Nothofagus* pollen (Fontana and Bennett, 2012). However, the finding of fungal rests of cf. *Microthyrium fagi* ascomata together with increases in *Nothofagus* frequencies seems to indicate that some trees grew close to the site. Nowadays, *Microthyrium fagi* is one of the most abundant species found on dead autumn leaves of *N. pumilio* (Arambarri and Gamundi, 1984). Other Microthyriaceae, besides cf. *M. fagi*, have been documented in surface samples from *Nothofagus* deciduous forest (Musotto et al., 2012). The environmental conditions at the mire reflect a telmatic stage, as shown by the abundance of sedges (Cyperaceae) that indicate minerotrophic conditions. The record of *Caltha* and *Myriophyllum* may be associated with the development of shallow ponds during the initial stages of the peat bog. Among the fungal remains, the mycorrhizal *Glomus* sp. is related to open ground vegetation such as grasses and shrubs. In this sense, the distribution of *Glomus* spp. is often associated with arid conditions and soil erosion processes (Chmura et al., 2006; Kramer et al., 2009; Gelorini et al., 2011). The finding of ascospores of coprophilous genera like *Sordaria*-type and *Sporormiella*-type throughout the profile suggests the presence of herbivorous grazers (López-Sáez and López-Merino, 2007). Evidence of Lateglacial herbivores in Tierra del Fuego was reported by Massone (2004) from an archaeological site, located about 160 km to the northwest. The remains found in this site belong to *Lama guanicoe* (“guanaco”) and representatives

of large, later extinct, South American mammals, such as *Hippidion saldiasi* (American horse), *Vicugna vicugna* (“vicuña”), and *Mylodon darwini* (“milodón”). Although there are no palaeontological records in the studied area, these herbivores might have occurred around Terra Australis, since the climate and the natural environment were similar to those reported from the archaeological site.

Between ~13,100 and 12,400 cal yr BP (upper subzone TA-1a), the increase in frequency and concentration values of *Nothofagus* along with fungal remains that are well-known epiphyllous suggest greater proximity of *Nothofagus* under moderating climatic conditions at the site.

Following 12,400 cal yr BP (subzone TA-1b), the decrease in *Nothofagus* pollen occurred in conjunction with the expansion of grasses, shrubs (Asteraceae subf. Asteroideae, *Empetrum rubrum*), cushion plants (*Azorella*), and herbs (Apiaceae, *Acaena*) accompanied by a decline of sedges and an increase of *Glomus* spores. Taken together, these data suggest low-humidity environments. *Glomus* species occur in rhizospheric soils around the most frequent grasses of Tierra del Fuego (Mendoza et al., 2002). Surface samples of the Fuegian steppe, located ~80 km north the studied site, also contain *Glomus* spores (Musotto et al., 2012). The record of *Gelasinospora* sp. for subzone TA-1b may indicate less humid conditions related to the steppe communities. *Gelasinospora* species are ubiquitous, being terricolous, carbonicolous and lignicolous, with only a few coprophilous species (Cai et al., 2006; van Geel and Aptroot, 2006). Its finding could be related to the occurrence of fires, highly probable when the above mentioned conditions are met. Maxima in the frequency curves of *Gelasinospora* sp. have been reported from several Holocene peat deposits formed under relatively dry and oligotrophic conditions; these same peats often contain charred plant remains (van Geel and Aptroot, 2006).

An increase of *Nothofagus* commenced by about 11,200 cal yr BP (zone TA-2), combined with open ground vegetation of grasses, herbs (*Acaena*, *Gunnera*, *Gentiana*), dwarf shrub heaths (*E. rubrum*), scrubs (Asteraceae subf. Asteroideae), and ferns (*Lycopodium magellanicum*), suggesting conditions characteristic of a forest-steppe ecotone. A general decrease in palynological richness is associated to the reduction of the open tracts in the landscape. Nowadays, analogous vegetation communities develop in the northern Lago Fagnano area, where annual precipitation varies between 350 and 500 mm and summer temperatures average 10 °C (Tuhkanen, 1992). The increase in frequency (up to 6%) and concentration (up to 11,100 grains g^{-1}) values of the beech hemiparasite *Misodendrum*, in addition to the presence of *Spegazzinia tessarthra* conidia, argues for the local presence of *Nothofagus*. *Spegazzinia tessarthra* has been found on many kinds of plants as well as in soil and wood of *N. pumilio* from Tierra del Fuego (Codeas and Arambarri, 2007). The fungal assemblage was also characterized by the records of *Arthrinium puccinioides*, *Gaeumannomyces* sp., *Glomus* sp., *Gelasinospora* sp., and *Alternaria* sp. The increase of dematiaceous spores of *A. puccinioides* was probably associated with the development of sedges surrounding the peatland. This fungus usually grows on dead leaves of various species of Cyperaceae (Saccardo, 1886; Ellis, 1971). The fungus occurs in Tierra del Fuego (Ellis, 1971; Musotto et al., 2012). Moreover, the record of hyphopodia of *Gaeumannomyces* sp. was related to the prevalence of grasses and sedges in the mire. According to Walker (1980), this fungus is a parasite on roots, crowns and lower stems and leaf sheaths of Poaceae and Cyperaceae. The presence of *Alternaria* sp. might be linked to the development of forest communities and locally more humid conditions. *Alternaria* species are common saprophytes and often occur on decaying plant tissues (Ellis, 1971). In Tierra del Fuego, these fungi develop in soils of *Nothofagus* forests (Martínez et al., 2001; Musotto et al., 2012) as well as in a *Donatia*–*Astelia* cushion bogs located in eastern Tierra del Fuego (Paredes et al., 2014).

6.1.2. Mid-Holocene (8000–4000 cal yr BP)–late Holocene (4000–0 cal yr BP)

Following 7700 cal yr BP (zone TA-2), total pollen concentration values ($26,000 \text{ grains g}^{-1}$) abruptly declined in coincidence with the deposition of the tephra layer originating from the Hudson H₁ eruption. Large concentration of grasses, scrubs (Asteraceae subf. Asteroideae), herbs (*Gunnera*, *Gentiana*), and sedges occur after the tephra fall perhaps as a consequence of the large input of nutrients leached from the surroundings into the mire. *Gaeumannomyces* sp. may be associated with the development of local grasses and sedges.

The development of a closed-canopy *Nothofagus* forest after ~6500 cal yr BP is inferred by the increase in arboreal pollen frequencies and concentrations (zone TA-3). The understory and/or forest edges are represented by the light-demanding grasses, scrubs (Asteraceae subf. Asteroideae), and other herbs (*Caltha*, *Acaena*, *Gunnera*). Values of palynological richness show a decreasing tendency related to the spread of forest communities. According to Birks and Line (1992), in forested environments pollen dispersal below the canopy is restricted, and the vegetation richness is not well represented palynologically. In addition, the high pollen production of anemophilous trees (e.g. *Nothofagus*) results in the dominance of their pollen types, reducing the probability of finding rare taxa. Variations in the *Nothofagus* densities are indicative of discontinuities in the forest canopy, and the persistence of *Misodendrum* pollen ($163,000 \text{ grains g}^{-1}$) suggests that more parts of the forest had been affected by this parasite. The intensity of *Misodendrum* infestation is dependent upon light and host availability, being maximal under high luminosity conditions and intermediate *Nothofagus* densities (Moreno et al., 2014). Studies of damage caused by mistletoe *Misodendrum punctulatum* on *N. pumilio* forests located in a region with 500 mm of rain per year, show that the excessive infection reduces growth rates by water stress and produces a clear effect on canopy shape (Henríquez-Velásquez et al., 2012). Probably, the closest analogue for these plant communities would be the Sub-antarctic Deciduous Forest that occurs in the south of Tierra del Fuego where precipitation is between 450 and 650 mm yr⁻¹ and mean summer temperature averages 10 °C (Tuhkanen, 1992). At this time, the bog communities also changed towards ombrotrophic conditions when species like *Sphagnum magellanicum* colonized the bog surface. *Sphagnum* has a pattern of irregular sporulation, a potential reason why its spores were virtually absent in samples with high macroremain content (Heusser and Rabassa, 1995). *Sphagnum* bogs occur today on the lee side of the Andes as well as throughout the cool-temperate deciduous and evergreen forest ecoregions of Tierra del Fuego when precipitation exceeds 400 mm yr⁻¹ (Loisel and Yu, 2013). The occurrence of *Empetrum rubrum* reflects hydrologic conditions within the bog, since this species grows on dry hummocks, whereas sedges develop in submerged bog settings (Birks and Birks, 1980; Markgraf and Huber, 2010). The presence of grasses and sedges may also be related to a marginal position with nearby minerogenic soils (Birks and Birks, 1980; Musotto et al., 2012). Variations in the water-table level at the site were inferred by *Caltha* taxon including species that grow in damp areas where groundwater table is near the surface (Moore, 1983). Among the fungal microfossils, Microthyriaceae remains (mainly cf. *M. fagi*) are dominant probably associated to the development of forest communities. Besides, microthyriaceous reproductive bodies correlate well with humid climates and heavy rainfall that is considered essential for their abundance and rapid spread (Limaye et al., 2007). The fungal association is also characterized by the records of Type 810 cf. *Byssothecium alpestre*, *Byssothecium circinans*, *Gaeumannomyces* sp., helicosporous fungi, and *Alternaria* sp., suggesting wet environmental conditions linked to the development of forest communities. *Byssothecium circinans* is a saprobe or weak parasite on woody substrates; their fossil ascospores have been reported in Holocene peat deposits formed under oligo-mesotrophic conditions (van Geel and

Aptroot, 2006). Helicosporous hyphomycetes include a group of microfungi growing on plant litter, rotten wood, decaying twigs in moist places or around water (Zhao et al., 2007). During the last 1000 years, the decline in arboreal pollen concentration along with increase in *Empetrum rubrum* pollen are indicative of a reduction of *Nothofagus* forest and a drier bog surface. The decrease in Microthyriaceae and the record of *Glomus* sp. also suggest less humid local conditions during that time.

6.2. Comparison with other palaeoclimate records

The basal age of peat-bogs located into the terminal position of the Fagnano palaeoglacier during the LGM, with a distance approximately 16 km east from the eastern head of the lake, yield 15,400–14,400 cal yr BP (Coronato et al., 2002, 2009; Musotto, 2013; Musotto et al., 2016), indicating a westward retreat of the ice and the existence of ice-free lands in this part of the valley during the Lateglacial times. Also, by 14,770 cal yr BP, the ice front recedes from the southern-central coast of Lago Fagnano, at the Terra Australis site. In southern Tierra del Fuego, the minimum radiocarbon age for the Beagle glacier recession is 17,710 cal yr BP at Puerto Harborton, approximately 25 km inside the glacier maximum centered on Isla Picton, at the eastern mouth of the Canal Beagle (Heusser, 1998).

During the Lateglacial period, an impoverished vegetation dominated by grasses, herbs, scrubs and heaths with scarce *Nothofagus* trees developed throughout both sides of the Andes in Tierra del Fuego island (Markgraf, 1993; Heusser, 2003; Musotto et al., 2016). The Terra Australis and La Correntina sites documented low *Nothofagus* abundances implying that scattered trees may have been present in the Lago Fagnano area after glacial retreat (Musotto et al., 2016; this paper). The arboreal vegetation was also poorly represented in the eastern end of Canal Beagle, as indicated by low influx values of *Nothofagus* pollen (<350 grains cm⁻² per year) from the Puerto Harborton pollen sequence (Heusser, 1989b), and almost nil pollen influx of *Nothofagus* trees at the Caleta Róbaló site (on Isla Navarino) (Heusser, 1989a). These findings allude to the survival of trees in multiple glacial refugia during the LGM. This hypothesis is supported by genetic polymorphisms and ecological niche modeling (ENM) from Tierra del Fuego forest populations (Premoli et al., 2010).

According to palaeoclimate data, the Lateglacial interval was characterized by several abrupt climate change events such as the Antarctic Cold Reversal (ACR, 14,500–12,900 cal yr BP; Blunier et al., 1997), and the Younger Dryas chronozone (YD, 12,800–11,700 cal yr BP; Rasmussen et al., 2006). The geological evidences from Fuegian Andes show that cirque glaciers first advanced at about 14,830–12,850 cal yr BP near Ushuaia, during the ACR, and may have later advanced or stabilized in the YD chronozone (Menounos et al., 2013). These latter data indicate that, by 12,500 and 11,230 cal yr BP, glaciers north and west of Ushuaia were no larger than those at the maximum of the Little Ice Age (LIA, <1000 cal yr BP) and never extended significantly past LIA limits through the Holocene (Menounos et al., 2013).

The *Nothofagus* pollen recorded in the Lago Fagnano area (Musotto et al., 2016; this paper) as well as along the Canal Beagle (Heusser, 1998; Markgraf and Huber, 2010) show variable behavior during the Lateglacial interval as a consequence of fluctuations in the temperature and effective moisture. Weber et al. (2014) identified five phases of enhanced iceberg flux from various parts of the Antarctic Ice Sheet (AIS) during the ACR as well as the YD chron. The increased iceberg flux from the AIS during these events led to the enhanced sea-ice extent around Antarctica, and the northward displacement of the southern margin of the SWW belt (Zimmermann et al., 2015). Thus, fluctuations in the *Nothofagus* pollen records during the Lateglacial period and by inference the regional climate may

have been controlled in some degree by the coupled atmospheric-ice sheet Antarctic climate system. Low *Nothofagus* abundances implying intervals of cold/dry climate conditions may reflect a LGM-northward position of the southern margin of the SWW. Conversely, increases in *Nothofagus* may signal intervals of cool/wet climatic conditions due to a poleward migration of the southern margin of the SWW from its LGM-northward position. Similar shifts in the position of SWW's southern limit during the Lateglacial have been reported from the Última Esperanza area in the SW Chilean Patagonia (51°–52° S, 72° W) (Moreno et al., 2012) and from Laguna Potrok Aike (52° S, 70° W) in southern Argentinean Patagonia (Zimmermann et al., 2015).

During the early Holocene, pollen data from central and southern parts of Tierra del Fuego on the Pacific slope (Heusser, 2003; Markgraf and Huber, 2010; this paper) reveal that *Nothofagus* forests expanded in concert with steppe communities after 11,500 cal yr BP, due to higher-than-present temperatures and dry climatic conditions; these conditions are inferred to result from the weakening and southward shift of the SWW (Whitlock et al., 2007; Moreno et al., 2012). High fire activity during this time may have likewise favoured open forests (Markgraf and Huber, 2010). Fire occurrences in Tierra del Fuego have been attributed to greater climate variability, an overall decrease in precipitation of westerly origin (Whitlock et al., 2007), and deliberate burning by Paleoindian hunters (Heusser, 1994). Later, by 9500 cal yr BP, the forest-steppe ecotone developed on the Atlantic slope (Heusser, 2003; Musotto et al., 2016) under lower moisture levels. The prevalence of *Glomus* sp. and *Gelasinospora* sp. seen in Terra Australis and La Correntina (Musotto et al., 2013) palynological profiles stem from dry conditions. The latter fungal microfossil is also indirectly associated with fire events in the area during this time.

The *Nothofagus* woodland vegetation and fires lasted up to 7000 cal yr BP after which a closed-canopy *Nothofagus* forest expanded at the Terra Australis site and along Canal Beagle lowlands (Heusser, 2003; Markgraf and Huber, 2010). After about 5500 cal yr BP, the closed-canopy *Nothofagus* forest approached the Lago Fagnano area located on the Atlantic side of the Fuegian Andes (Markgraf, 1983; Heusser, 2003; Musotto et al., 2016), and by 1400 cal yr BP, the northwest of the island (Heusser, 1993). The climate change towards colder and wetter conditions during the late Holocene implied strengthened SWW that promoted high levels of effective moisture in the region. In this sense, the high abundance of Microthyriaceae fungal remains in the studied profile supports the presence of humid environments.

7. Conclusions

The palynological record from the Terra Australis mire provides evidence for past environmental and climate changes since deglaciation in the central part of the Tierra del Fuego island. The following conclusions can be drawn from our analysis:

- Postglacial vegetation pattern recorded in the Terra Australis mire is in good agreement with palaeoenvironmental data from southern Tierra del Fuego, probably due to its location between hills at the foot of the Fuegian Andes valleys, on the Pacific (windward side) slope.
- By 14,300 cal yr BP the southern-central coast of Lago Fagnano was free of ice and glaciolacustrine and glaciofluvial environments developed. Postglacial vegetation included grasses, herbs and shrubs with scarce *Nothofagus* trees. The record of remains of cf. *Microthyrium fagi* points to the presence of some trees close to the peatland.
- Between 11,200 and 6500 cal yr BP, *Nothofagus*-dominated woodland expanded in response to warm, dry conditions. Most fungal remains (*Gaeumannomyces* sp., *Glomus* sp., Microthyriaceae,

Spegazzinia tessarthra, *Alternaria* sp.) are likely associated with the development of forest-steppe ecotone communities. Ascospores of *Gelasinospora* sp. may also be indirectly related to fire occurrences.

- Following 6500 cal yr BP, closed-canopy forest dominated the landscape when climate conditions cooled and became wetter. These changes in vegetation coincide with an increase in microthyriaceous reproductive bodies remains (mainly cf. *M. fagi*).
- After 1000 cal yr BP, a shift towards locally less humid environmental conditions was inferred by the opening of the forest along with the occurrence of spores of *Glomus* sp.
- Vegetation and environmental changes are related to variations in the amount of precipitation of westerly origin attributed to changes in the wind intensity and/or position of the southern margin of the SWW belt.

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Appendix A. Fungal taxa list.

Phylum GLOMEROMYCOTA C. Walker & A. Schüßler, 2001

Glomus sp. (Type HdV-1103) (Plate I, 1)

Phylum ASCOMYCOTA Cavalier-Smith, 1998

Bysothecium circinans Fuckel, 1861 (Type HdV-16A) (Plate I, 2)

Gaeumannomyces sp. (Type HdV-126) (Plate I, 3)

Gelasinospora sp. (Type HdV-1) (Plate I, 4)

cf. *Microthyrium fagi* Ellis, 1977 (Plate I, 13–17)

Sordaria-type (fide van Geel et al., 2003) (Type HdV-55A) (Plate I, 5)

Sporormiella-type (fide van Geel et al., 2003) (Type HdV-113) (Plate I, 6)

Type 810 cf. *Bysothecium alpestre* (Tóth) Boise, 1989 (fide Mauquoy et al., 2004) (Plate I, 7)

Mitosporic fungi

Alternaria sp. (Plate I, 8)

Arthrimum puccinioides Kunze & Schmidt, 1823 (Plate I, 11)

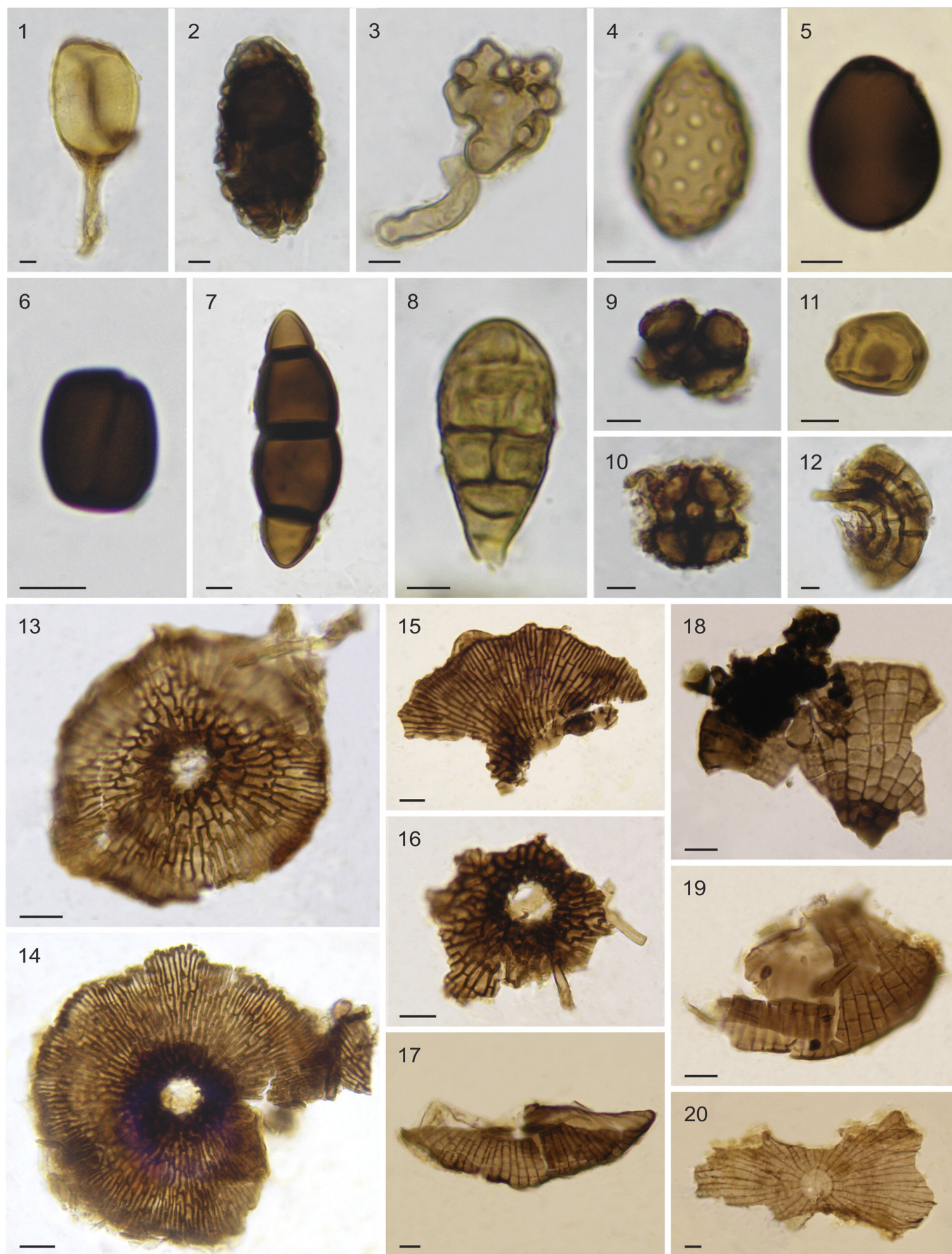
Spegazzinia tessarthra Berkeley & M.A. Curtis, 1886 (Type HdV-1018A-B) (Plate I, 9–10)

Helicosporous conidium indet. 1 (Plate I, 12)

Appendix B. Descriptions of newly distinguished fungal microfossils from Terra Australis mire

Bysothecium circinans Fuckel 1861 (Type HdV-16A) (Plate I, 2)

Ascospores ellipsoidal, 3-septate, constricted at septa, brown, 46–49 × 19–25 µm; surface covered with large and undulating, wart-like projections. Central cells dark brown, large (15–24 × 13–17 µm); end cells subhyaline and small (3–6 µm long, 8–12 µm wide). Wall



formed by two layers, outer layer (2–4 µm) thicker than the inner one (ca. 1 µm). Studied material: UNSP TTA 4063: X44/2, 4074: N36/4, 4079: Y37.

Comments. *Byssothecium* species are commonly found on plant substrates, both on terrestrial as aquatic habitats. Boise (1983) found it associated with *Medicago sativa*, a plant species which is common in the studied area. *Byssothecium circinans* ascospores are frequently registered in Quaternary peat deposits in several parts of the world such as the Netherlands (van Geel, 1978; van Geel et al., 1981), North Western Iberian Peninsula (Mighall et al., 2006), Southern Brazil (Medeanic and Silva, 2010) and Venezuelan Andes (Montoya et al., 2010).

Spegazzinia tessartha Berkeley & M.A. Curtis 1886 (Type HdV-1018A-B) (Plate I, 9–10)

Conidia of Type A cruciately (cross-shaped) septate, equally and symmetrically 4-celled, dark brown, 14–15 × 16–18 µm; wall about 1 µm thick, echinate (spines up to 3 µm long). Studied material: UNSP TTA 3698: H29/2, B44/4.

Comments. Only Type A conidia were observed. This is a cosmopolitan species frequently recorded on dead leaves and stems of many plants (Ellis, 1971). It has been reported in lake sediments from south-eastern Kenya by Gelorini et al. (2011). *Spegazzinia tessartha* has also been isolated as an endophyte from the lichen *Heterodermia flabellata* (Tripathi et al., 2014).

Helicosporous conidium indet. 1 (Plate I, 12)

Fragment of helicoid conidium, multiseptate, not constricted at septa, pale brown, 41 × 28 µm; conidial filament 5–6 µm diam., tightly coiled 5 times. Wall slightly punctate, ca. 1 µm thick. Studied material: UNSP TTA 3826: U45.

Comments. This material resembles conidia of *Inesiosporium* R.F.Castañeda & W.Gams 1997, but it was not assigned to any genus because only a small part of a conidium was found. Helicosporous hyphomycetes occur frequently in aquatic environments (Zhao et al., 2007). Several helicosporic fungi have been described from plant debris in rivers of Tierra del Fuego (Godeas and Arambarri, 1993).

Appendix C. Supplementary data

Supplementary data associated with this article can be found in the online version, at <http://dx.doi.org/10.1016/j.revpalbo.2016.11.016>. These data include the Google map of the most important areas described in this article.

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Plate I. Fungal microfossils found at the Terra Australis mire. Each photograph indicates the sample number, and England Finder coordinates. 1. *Glomus* sp. (HdV-1103), UNSP TA 3652: S48; 2. *Byssothecium circinans* (HdV-16A), UNSP TA 4079: Y37. 3. *Gaeumannomyces* sp. (HdV-126) hyphopodium, UNSP TA 3738: Y41; 4. *Gelasinospora* sp. (HdV-1), UNSP TA 3672: D33/1; 5. *Sordaria*-type (HdV-55A), UNSP TA 3774: J44/4; 6. Separate ascospore-cell of *Sporormiella*-type (HdV-113), UNSP TA 4083: Z36/3; 7. Type 810 cf. *Byssothecium alpestre* (fide Mauquoy et al., 2004) UNSP TA 3795: Y27/1; 8. *Alternaria* sp., UNSP TA 3675: X40; 9–10. *Spegazzinia tessartha* (HdV-1018A-B) (9: UNSP TA 3698: H29/2, 10: UNSP TA 3698: B44/4); 11. *Arthrinium puccinioides*, UNSP TA 4000: U38/4; 12. Fragment of helicosporous conidium indet. 1, UNSP TA 3826: U45; 13. Entire reproductive body of cf. *Microthyrium fagi*, UNSP TA 3804: S38/1; 14–16. Remains of cf. *Microthyrium fagi* (14: UNSP TA 3958: X46, 15: UNSP TA 4081: W46, 16: UNSP TA 3823: Z42); 17–19. Fragments of unidentified ascomata with scutellum composed of isodiametrical to cylindrical cells (17: UNSP TA 3809: R33/1, 18: UNSP TA 4062b: X33, 19: UNSP TA 4061: K47); 20. Unidentified body remain, UNSP TA 3977: Z48/4. Scale bars: 1–12 = 5 µm, 13–20 = 10 µm.

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