THE LAST GLACIAL TERMINATION ON THE EASTERN FLANK OF THE CENTRAL PATAGONIAN
ANDES (47°S)
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15 ABSTRACT

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Few studies have examined in detail the sequence of events during the last glacial termination 17 18 (T1) in the core sector of the Patagonian Ice Sheet (PIS), the largest ice mass in the Southern 19 Hemisphere outside Antarctica. Here we report results from Lago Edita (47°8'S, 72°25'W, 570 m.a.s.l.), a small closed-basin lake located in a valley overridden by eastward-flowing Andean 20 21 glaciers during the Last Glacial Maximum (LGM). The Lago Edita record shows glaciolacustrine 22 sedimentation until 19,400 yr BP, followed by a mosaic of cold-resistant, hygrophilous conifers and rainforest trees, along with alpine herbs between 19,400-11,000 yr BP. Our data suggest 23 24 that the PIS retreated at least ~90 km from its LGM limit between ~21,000-19,400 yr BP and that scattered, low-density populations of cold-resistant hygrophilous conifers, rainforest trees, 25 high Andean and steppe herbs thrived east of the Andes during the LGM and T1, implying high 26 precipitation and southern westerly wind (SWW) influence at 47°S. The conifer *Podocarpus* 27 nubigena increased between 14,500-13,000 yr BP suggesting stronger SWW influence at 47°S 28 29 during the Antarctic Cold Reversal, after which declined and persisted until 11,000 yr BP. Large increases in arboreal pollen at ~13,000 and ~11,000 yr BP led to the establishment of forests 30 31 near Lago Edita between 10,000-9000 yr BP, suggesting a rise in the regional treeline along the 32 eastern Andean slopes driven by warming pulses at ~13,000 and ~11,000 yr BP and a subsequent decline in SWW influence at ~11,000 yr BP. We propose that the PIS imposed a 33 regional cooling signal along its eastern, downwind margin through T1 that lasted until the 34 separation of the North and South Patagonian icefields along the Andes during the Younger 35 Dryas period. We posit that the withdrawal of glacial and associated glaciolacustrine 36 37 environments through T1 provided a route for the dispersal of hygrophilous trees and herbs from the eastern flank of the central Patagonian Andes, contributing to the afforestation of the 38 39 western Andean slopes and pacific coasts of central Patagonia during T1.

41 INTRODUCTION

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The Patagonian ice sheet (PIS) was the largest ice mass in the southern hemisphere 43 44 outside Antarctica during the last glacial maximum (LGM). Outlet lobes from the PIS flowed westward into the Pacific coast south of 43°S and eastward toward the extra-Andean 45 Patagonian plains, blanketing a broad range of environments and climatic zones across and 46 47 along the Andes. Land biota from formerly ice-free sectors underwent local extinction or migrated toward the periphery of the advancing PIS during the last glaciation until its 48 culmination during the LGM. The PIS then underwent rapid recession and thinning through the 49 50 last glacial termination (termination 1= T1: between ~18,000-11,000 yr BP) toward the Andes as 51 illustrated by stratigraphic, geomorphic and radiocarbon-based chronologies from northwestern Patagonia (39º-43ºS) (Denton et al., 1999; Moreno et al., 2015). These data, 52 along with the Canal de la Puntilla-Huelmo pollen record (~41°S) (Moreno et al., 2015) (Figure 53 1), indicate abandonment from the LGM margins in the lowlands at 17,800 yr BP, abrupt 54 arboreal expansion, and accelerated retreat that exposed Andean cirgues located above 800 55 m.a.s.l. within 1000 years or less in response to abrupt warming. Similarly, glaciers from 56 57 Cordillera Darwin (54º-55ºS), the southernmost icefield in South America, underwent rapid 58 recession from their LGM moraines located in central and northern Tierra del Fuego prior to 17,500 yr BP, and led to ice-free conditions by 16,800 yr BP near the modern ice fronts (Hall et 59 al., 2013). Sea surface temperature records from the SE Pacific (Caniupán et al., 2011) are 60 consistent with these terrestrial records, however, their timing, structure, magnitude and rate 61 of change may be overprinted by the vicinity of former ice margins and shifts in marine 62 reservoir ages (Caniupán et al., 2011; Siani et al., 2013). 63

In contrast, very few studies have been conducted in the Andean sector of central-west Patagonia (45º-48ºS) about the timing of glacial advances near the end of the LGM as well as the structure/ chronology of glacial retreat and climate changes during T1. Recent chronologies include cosmogenic radionuclides of terminal moraines of the Río Blanco and recessional moraines deposited by the Lago Cochrane ice lobe (LCIL) (Boex et al., 2013; Hein et al., 2010) (Figure 1), and optically stimulated luminescence dating of glaciolacustrine beds associated

70 with Glacial Lake Cochrane (GLC) (47°S) (Glasser et al., 2016). These studies reported ages 71 between 29,000-19,000 yr BP for the final LGM advance and drainage of GLC toward the Pacific 72 between 13,000-8000 yr BP caused by breakup of the North and South Patagonian Icefields 73 during the final stages of T1 (Turner et al., 2005). Palynological interpretations from the Lago 74 Shaman (44°26'S, 71°11'W, 919 m.a.s.l.) and Mallín Pollux (45°41'S, 71°50'W, 640 m.a.s.l.) sites 75 (de Porras et al., 2012; Markgraf et al., 2007), located east of the Andes (Figure 1), indicate 76 predominance of cold and dry conditions during T1 and reduced southern westerly wind (SWW) influence. The validity and regional applicability of these stratigraphic, chronologic and 77 palynologic interpretations, however, awaits replication with detailed stratigraphic/geomorphic 78 79 data from sensitive sites constrained by precise chronologies.

80 Paleoclimate simulations (Bromwich et al., 2005; Bromwich et al., 2004) and stratigraphic studies (Kaufman et al., 2004) in the periphery of the Laurentide Ice Sheet in North America, 81 have detected that large ice sheets exerted important impacts on the thermal structure and 82 atmospheric circulation at regional, continental and zonal scale from the LGM to the early 83 Holocene. This aspect has remained largely unexplored in the PIS region, and might be a factor 84 of importance for understanding the dynamics of the SWW and climatic/biogeographic 85 86 heterogeneities through T1 at regional scale. Progress in this field requires understanding the 87 deglacial chronology of the PIS and a suite of sensitive paleoclimate sites across and along the residual ice masses through the last transition from extreme glacial to extreme interglacial 88 conditions. 89

In this study we report high-resolution pollen and macroscopic charcoal records from 90 sediment cores we collected from Lago Edita (47°8'S, 72°25'W, ~570 m.a.s.l.), a medium-sized 91 closed-basin lake (radius ~250 m) located in Valle Chacabuco ~16 km northeast of the Cochrane 92 93 township, east of the central Patagonian Andes (Figure 1). The relevant source area for pollen 94 from lakes of this size is about 600-800 m from the lake's edge, according to numerical 95 simulations using patchy vegetation landscapes (Sugita, 1994). Stratigraphic and chronologic results from Valle Chacabuco are important for elucidating the timing and rates of deglaciation 96 in this core region of the PIS because this valley is located approximately two thirds (90 km) 97 upstream from the LGM moraines deposited by LCIL east of Lago Cochrane relative to the 98

99 modern ice fronts, and its elevation spans the highest levels of GLC during T1. The Lago Edita data allow assessment of vegetation, fire-regime and climate changes during the last global 100 101 transition from extreme glacial to extreme interglacial conditions in central-west Patagonia. The 102 aim of this paper is to contribute toward: (1) the development of a recessional chronology of 103 the LCIL and (2) regressive phases of GLC, (3) documenting the composition and geographic 104 shifts of the glacial and deglacial vegetation, (4) understanding the tempo and mode of 105 vegetation and climate changes during T1 and the early Holocene, (5) constraining the regional climatic influence of the PIS during T1 in terrestrial environments, and (6) improving our 106 understanding of the biogeography of the region, including the identification of possible 107 108 dispersal routes of tree taxa characteristic of modern evergreen forests in central-west 109 Patagonia during T1.

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111 Study Area

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113 Central Chilean Patagonia, i.e. the Aysén region (43°45'S-47°45'S), includes numerous channels, fjords, islands, and archipelagos along the Pacific side, attesting for tectonic 114 115 subsidence of Cordillera de la Costa and intense glacial erosion during the Quaternary. The central sector features an intricate relief associated to the Patagonian Andes with summits 116 117 surpassing 3000 m.a.s.l., deep valleys, lakes of glacial origin, and active volcanoes such as Hudson, Macá, Cay, Mentolat and Melimoyu (Stern, 2004). The Andes harbors numerous 118 119 glaciers and the North Patagonian Icefield (Figure 1), which acted as the source for multiple 120 outlet glacier lobes that coalesced with glaciers from the South Patagonian Icefield and formed 121 the PIS during Quaternary glaciations, blocked the drainage toward the Pacific funneling large 122 volumes of glacial meltwater toward the Atlantic (Turner et al., 2005). Farther to the east the 123 landscape transitions into the back-arc extra-Andean plains and plateaus.

Patagonia is ideal for studying the paleoclimate evolution of the southern mid-latitudes including past changes in the SWW because it is the sole continental landmass that intersects the low and mid-elevation zonal atmospheric flow south of 47°S. Orographic rains associated with storms embedded in the SWW enhance local precipitation caused by the ascent of

128 moisture-laden air masses along the western Andean slopes, giving way to subsidence and 129 acceleration of moisture-deprived winds along the eastern Andean slopes (Garreaud et al., 130 2013). This process accounts for a steep precipitation gradient across the Andes, illustrated by 131 the annual precipitation measured in the coastal township of Puerto Aysén (2414 mm/year) and the inland Balmaceda (555 mm/year) (http://explorador.cr2.cl/), localities separated by 132 ~80 km across the west to east axis of the Andes. The town of Cochrane, located ~15 km south 133 134 of our study site features annual precipitation of 680 mm/year and mean annual temperature of 7.8 °C (Figure 1). 135

Weather station and reanalysis data along western Patagonia show positive correlations 136 137 between zonal wind speed and local precipitation, a relationship that extends to sectors adjacent to the eastern slopes of the Andes (Garreaud et al., 2013; Moreno et al., 2014). 138 Therefore, changes in local precipitation in the Aysén region are good diagnostics for 139 atmospheric circulation changes associated with the frequency/intensity of storms embedded 140 in the SWW over a large portion of the southeast Pacific. This relationship can be applied to 141 paleoclimate records from central Chilean Patagonia for inferring the behavior of the SWW on 142 the basis of past changes in precipitation or hydrologic balance. 143

The steep precipitation gradient, in conjunction with adiabatic cooling and enhanced continentality toward the east, influences the distribution and composition of the vegetation, inducing altitudinal, latitudinal and longitudinal zonation of plant communities throughout the Patagonian Andes. Physiognomic and floristic studies (Gajardo, 1994; Luebert and Pliscoff, 2006; Pisano, 1997; Schmithüsen, 1956) have recognized five units or communities which we characterize succinctly in the following sentences:

Magellanic Moorland: this unit occurs in maritime sectors with high precipitation (3000 4000 mm/year and low seasonality) along the islands, fjords and channels, it is
 dominated by cushion-forming plants such as *Donatia fascicularis*, *Astelia pumila* and

153 *Tetroncium magallanicum*. Also present are the hygrophilous cold-resistant trees

154 Nothofagus betuloides and the conifers Pilgerodendron uviferum, Lepidothamnus fonkii

and *Podocarpus nubigena*.

Evergreen rainforest: present in humid, temperate (1500 -3000 mm/year; <600 m.a.s.l.)
 sectors of Aysén, this unit is characterized by the trees *Nothofagus nitida*, *N. betuloides*,
 Drimys winteri, *P. nubigena* along with *P. uviferum* in waterlogged environments.

Winter deciduous forests: located in cooler and/or drier sectors with higher seasonality 159 (400-1000 mm/year; 500-1180 m.a.s.l.). The dominant tree is Nothofagus pumilio, which 160 161 intermingles with *N. betuloides* in western sites and the Patagonian steppe eastward. In the latter *N. pumilio* forms monospecific stands and presents a species-poor understory. 162 A study of the spatial and temporal variation in *N. pumilio* growth at treeline along its 163 latitudinal range (35°40'S-55°S) in the Chilean Andes (Lara et al., 2005) showed that 164 temperature has a spatially larger control on tree growth than precipitation, and that 165 this influence is particularly significant in the temperate Andes (> 40°S). These results 166 suggest that low temperatures are the main limiting factor for the occurrence of 167 168 woodlands and forests at high elevations in the Andes, considering that precipitation 169 increases with elevation at any given latitude (Lara et al., 2005). The modern treeline near Cochrane is dominated by N. pumilio and lies between 800-1180 m.a.s.l. 170

171 Patagonian steppe: occurs in substantially drier (<500 mm/year) lowland areas with heightened continentality. This unit is dominated by herbs of the families Poaceae 172 173 (Festuca, Deschampsia, Stipa, Hordeum, Rytidosperma, Bromus, Elymus), Rubiaceae 174 (Galium), and shrubs of families Apiaceae (Mulinum), Rosaceae (Acaena), Fabaceae 175 (Adesmia) and Rhamnaceae (Discaria). 5) High Andean Desert: occurs in the wind-swept 176 montane environments above the treeline (>1000 m.a.s.l.) under cold conditions, high 177 precipitation regime and prolonged snow cover throughout the year. This vegetation unit is represented by herbs of the families Poaceae (*Poa, Festuca*), Asteraceae 178 (Nassauvia, Senecio, Perezia), Berberidaceae (Berberis), Brassicaceae (Cardamine), 179 180 Santalaceae (Nanodea), Rubiaceae (Oreopulus) Apiaceae (Bolax), Ericaceae (Gaultheria, Empetrum), along with Gunnera magellanica and Valeriana, with occasional patches of 181

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184 MATERIALS AND METHODS

Nothofagus antarctica.

We collected overlapping sediment cores over the deepest sector of Lago Edita (8 m water depth) from an anchored coring rig equipped with 10-cm diameter aluminum casing tube, using a 5-cm diameter Wright piston corer and a 7.5-cm diameter sediment-water interface piston corer with a transparent plastic chamber. We characterized the stratigraphy through visual descriptions, digital X radiographs to identify stratigraphic structures and losson-ignition to quantify the amount of organic, carbonate and siliciclastic components in the sediments (Heiri et al., 2001).

The chronology of the record is constrained by AMS radiocarbon dates on bulk sediment and chronostratigraphic correlation of the H1 tephra from Volcán Hudson (Stern et al., 2016). The radiocarbon dates were calibrated to calendar years before present (yr BP) using the CALIB 7.0 program. We developed a Bayesian age model using the Bacon package for R (Blaauw and Christen, 2011) to assign interpolated ages and confidence intervals for each level analyzed.

We processed and analyzed continuous/contiguous sediment samples (2 cm³) for pollen 198 199 and fossil charcoal. The samples were processed using a standard procedure that includes 10% 200 KOH, sieving with a 120 μm mesh, 46% HF and acetolysis (Faegri and Iversen, 1989). We 201 counted between 200-300 pollen grains produced by trees, shrubs and herbs (terrestrial pollen) 202 for each palynological sample and calculated the percent abundance of each terrestrial taxon relative to this sum. The percentage of aquatic plants was calculated in reference to the total 203 pollen sum (terrestrial + aquatic pollen) and the percentage of ferns from the total pollen and 204 205 spores sum. Zonation of the pollen record was aided by a stratigraphically constrained cluster analysis on all terrestrial pollen taxa having $\geq 2\%$, after recalculating sums and percentages. 206

We identified the palynomorphs based on a modern reference collection housed at the
laboratory of Quaternary Paleoecology of Universidad de Chile, along with published
descriptions and keys (Heusser, 1971). In most cases the identification was done at family or
genus level, in some cases to the species level (*Podocarpus nubigena, Drimys winteri, Gunnera magellanica, Lycopodium magellanicum*). The palynomorph *Nothofagus dombeyi* type includes
the species *N. antarctica, N. pumilio, N. betuloides* and *N. dombeyi*, the morphotype *Fitzroya/Pilgerodendron* includes the cupressaceous conifers *Fitzroya cupressoides* and

Pilgerodendron uviferum. We calculated running means of selected pollen taxa using a
triangular weighing function of values along 7 adjacent levels.

216 We tallied microscopic (<120 μ m) and macroscopic (>106 μ m) charcoal particles to document regional and local fire events, respectively. Microscopic particles were counted from 217 each pollen slide, while macroscopic charcoal was counted from 2-cm³ sediment samples 218 obtained from 1-cm thick and continuous-contiguous sections. The samples were prepared 219 220 using a standard procedure which involves deffloculation in 10% KOH, careful sieving through 106 and 212 µm-diameter meshes to avoid rupture of individual particles, followed by visual 221 inspection on a ZEISS KL 1500 LCD stereoscope at 10x magnification. These results were 222 223 analyzed by a time-series analysis to detect local fire events using the CharAnalysis software 224 (Higuera et al., 2009), interpolating samples at regular time interval based in the median time 225 resolution of the record. We deconvoluted the CHAR signal into a peaks and background 226 component using a lowess robust to outliers smoothing with a 100-yr window width. We calculated locally defined thresholds to identify statistically significant charcoal peaks or local 227 fires events (99th percentile of a Gaussian distribution). 228

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230 RESULTS

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The sediment stratigraphy (Figure 2) reveals a basal unit of blue-grey mud between 1726-232 819 cm, horizontally laminated for the most part, in some sectors massive and sandier with 233 234 small amounts of granule and gravel immersed in a clayey matrix (segment PC0902AT9). These inorganic clays are overlain by organic silt between 819-678 cm and organic-rich lake mud 235 (gytjja) in the topmost 678 cm. We found laminated authigenic carbonates between 794-759 236 237 and 394-389 cm (range: 5-20%), for the remainder of the record carbonate values are negligible 238 or null (<5%). The record includes 2 tephras between 630-628 and 661-643 cm, which exhibit 239 sharp horizontal contacts with the over and underlying mud and, consequently, we interpret them as aerial fallout deposits from explosive events originated from Volcán Hudson (H1 240 241 tephra) and from Volcán Mentolat (M1 tephra) based on geochemical data, respectively (Stern 242 et al., 2016).

The radiocarbon results show an approximately linear increase of age with depth between 19,000-9000 yr BP (Figure 3) which, in conjunction with the sediment stratigraphy, suggests undisturbed in-situ pelagic deposition of lake mud and tephras in the Lago Edita basin. This study focuses on the interval between 19,000-9000 yr BP (Figure 2, Table 1), and consists of 155 contiguous palynological and macroscopic charcoal levels with a median time step of 65 years between analyzed samples.

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250 Pollen stratigraphy

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We divided the record in 6 zones to facilitate its description and discussion, based on conspicuous changes in the pollen stratigraphy and a stratigraphically constrained cluster analysis (Figure 4). The following section describes each pollen zone indicating the stratigraphic and chronologic range, and the mean abundance of major taxa in parenthesis.

Zone Edita-1 (795-780 cm; 19,000-18,100 yr BP) is co-dominated by Poaceae (33%) and 256 257 *Empetrum* (32%). This zone starts with a gradual increase in *Empetrum*, attaining its maximum abundance (~53%) at the end of this zone. Asteraceae subfamily Asteroideae (7%), Acaena 258 259 (4%), Caryophyllaceae (3%) and Cyperaceae (9%) decrease, while Poaceae shows fluctuations in 260 its abundance between 2-16 % over the entire interval. Other herbs and shrubs such as Ericaceae (3%), Phacelia (~2%), Valeriana (1%), Gunnera magellanica (~2%), Apiaceae (<1%), 261 and Asteraceae subfamily Cichorioideae (<1%) remain relatively steady. The arboreal taxa N. 262 dombeyi type (10%), Fitzroya/Pilgerodendron (2%), P. nubigena (<1%) and D. winteri (<1%) are 263 present in low abundance, as well as the ferns L. magellanicum (1) and Blechnum type (5%) 264 265 and the green-microalgae Pediastrum (2%).

266Zone Edita-2 (780-758 cm; 18,100-16,800 yr BP) begins with a decline in *Empetrum* (30%)267and an increase in Poaceae (34%) followed by its decrease until the end of this zone. N.

268 *dombeyi* type (15%), Caryophyllaceae (5%) and Asteraceae subfamily Asteroideae (5%) show a

rising trend during this zone, while other arboreal taxa (*Fitzroya/Pilgerodendron* (3%), *P.*

270 nubigena (<1%) and D. winteri (<1%) and most of the herbs maintain similar abundance to the

previous zone. *L. magellanicum* (2%) and *Pediastrum* (4%) rise slightly, along with high
variability in Cyperaceae (7%).

273 Zone Edita-3 (758-701 cm; 16,800-13,200 yr BP) is characterized by a sharp rise in 274 Poaceae (45%) and declining trend in *Empetrum* (15%). The conifer *P. nubigena* (2%) starts a 275 sustained increase, while N. dombeyi type (13%) and Fitzroya/Pilgerodendron (3%) remain relatively invariant. D. winteri (<1%) and Misodendrum (<1%), a mistletoe that grows on 276 277 Nothofagus species, appear in low abundance in an intermittent manner. Pediastrum (30%) shows a rapid increase until 15,600 yr BP, followed by considerable variations in its abundance 278 279 until the end of this zone (between 19% and 55%). L. magellanicum (3%) shows a steady 280 increase, while *Blechnum* type (6%) remains invariant and Cyperaceae (7%) exhibits large 281 fluctuations superimposed upon a declining trend.

282 Zone Edita-4 (701-681 cm; 13,200-11,600 yr BP) starts with an increase in N. dombeyi type (29%) and a minor rise in *Misodendrum* (1%). *P. nubigena* (5%) starts this zone with 283 variability and stabilizes toward the end of this zone, concurrent with Fitzroya/Pilgerodendron 284 (3%) and traces of D. winteri (<1%). Poaceae (38%) shows a steady decrease, while Empetrum 285 (6%) continues with a declining trend that started during the previous zone. Asteraceae 286 287 subfamily Asteroideae (5%) and Caryophyllaceae (2%) decrease, L. magellanicum (3%), Cyperaceae (4%) and Pediastrum (24%) decline gradually with considerable fluctuations, while 288 Blechnum- type (11%) shows modest increases. 289

Zone Edita-5 (681-674 cm; 11,600-11,100 yr BP) shows marked declines in *N. dombeyi*type (27%) and Poaceae (33%) in concert with a conspicuous increase in the conifers *Fitzroya/Pilgerodendron* (12%) and *P. nubigena* (9%) that reach their peak abundance in the
record. The abundance of herbs and shrubs decreases or remains steady, with the exception of
an ephemeral increase in *Phacelia* (3%). *Blechnum* type (39%) shows a remarkable increase to
its peak abundance in the entire record, while *L. magellanicum* (3%), Cyperaceae (8%) and *Pediastrum* (17%) rise slightly.

Zone Edita-6 (674-640 cm; 11,100-8940 yr BP) is characterized by an abrupt increase in *N. dombeyi* type (62%) and *Misodendrum* (2%), along with conspicuous decline in
 Fitzroya/Pilgerodendron (2%) and *P. nubigena* (2%) at the beginning of this zone. Poaceae (26%)

300 shows a downward trend over this period, while others herbs and shrubs (Empetrum,

301 Ericaceae, Caryophyllaceae, Asteraceae subfamily Asteroideae, Acaena, Phacelia, Valeriana,

302 Gunnera magellanica, Apiaceae and Asteraceae subf. Cichorioideae) show their lowest

abundance in the record. *Blechnum* type (7%) drops sharply, followed by a gradual decline in

304 concert with *L. magellanicum* (1%). Cyperaceae (7%) and *Pediastrum* (6%) show initial declines

followed by increases toward the end of this zone.

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307 Charcoal stratigraphy

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309 The record from Lago Edita shows absence of macroscopic charcoal particles between 19,000-14,300 yr BP followed by an increase in charcoal accumulation rate (CHAR) that led to a 310 variable plateau between 13,200-12,000 yr BP, a 1000-year long decline, and a sustained 311 increase led to peak abundance at 9700 yr BP. Charcoal values then declined rapidly to 312 intermediate levels by 9000 yr BP. We note a close correspondence between the arboreal 313 pollen abundance (%) and the CHAR suggesting that charcoal production was highly dependent 314 upon quantity and spatial continuity of coarse woody fuels in the landscape (Figure 5). 315 316 Time-series analysis of the macroscopic charcoal record revealed 11 statistically 317 significant peaks we interpret as local fires events within the Lago Edita watershed (Figure 5). The temporal structure of these events indicates a sequence of millennial-scale peaks in fire 318 frequency with maxima at 14,100, 13,100, 12,000, 10,900 and 9600 yr BP. We observe a steady 319 increase in the fire frequency maxima from 14,100 to 10,900 yr BP (Figure 5). 320 321

322 DISCUSSION

323 Paleovegetation and paleoclimate

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Given the size of Lago Edita (radius ~250 m) its pollen record is adequate to reflect local vegetation within 600-800 m from the lake's edge. An extra-local component is also present considering that species of the genus *Nothofagus* also produce large quantities of pollen grains susceptible to long-distance transport (Heusser, 1989). These attributes suggest that the Lago

329 Edita fossil pollen record might be a good sensor of the vegetation located on the western end of Valle Chacabuco and the Lago Cochrane basin. The record (Figures 4, 6) documents 330 331 dominance of herbs and shrubs (chiefly Poaceae, *Empetrum*, Asteraceae, accompanied by 332 Caryophyllaceae, Acaena, Ericaceae, Phacelia, Valeriana, and Apiaceae in lower abundance) found above the modern treeline and the Patagonian steppe between 19,000 and 11,000 yr BP, 333 334 followed by increasing Nothofagus we interpret as the establishment of scrubland (~13,000-11,000 yr BP), woodland (~11,000-10,500 yr BP) and forest (~10,500-9000 yr BP). Within the 335 interval dominated by non-arboreal taxa we distinguish an initial phase with abundant 336 *Empetrum* between 19,000-16,800 yr BP, followed by diversification of the herbaceous 337 338 assemblage and predominance of Poaceae during the interval ~16,800-11,000 yr BP (Figures 4, 6). This change is contemporaneous with a sustained rise of *P. nubigena* and the mistletoe 339 Misodendrum coeval with conspicuous increases in Lycopodium magellanicum and the green 340 microalga Pediastrum. We emphasize the continuous presence of the arboreal Nothofagus and 341 *Fitzroya/Pilgerodendron* in low but constant abundance (~15% and ~3%, respectively) between 342 19,000-13,000 yr BP, along with traces (<2%) of hygrophilous trees (*Podocarpus nubigena*, 343 Drimys winteri) and herbs (Gunnera magellanica, Lycopodium magellanicum) accounting, in 344 345 sum, for a persistent ~25% of the pre-13,200 yr BP pollen record (Figures 4, 6). We note that 346 the Nothofagus parkland on the western end of Valle Chacabuco and the Lago Cochrane basin must have approached the vicinity of Lago Edita at 16,800 yr BP, judging from the appearance 347 of Misodendrum during that time (Figures 4, 6) under relatively constant mean Nothofagus 348 abundances. 349

350 The conifer *Podocarpus nubigena* remained in low abundance (<2%) prior to ~14,500 yr 351 BP in the Lago Edita record, increased between 14,500-13,000 yr BP, experienced a variable 352 decline between 13,000-11,800 yr BP, reached a maximum between 11,800-11,200 yr BP and 353 declined between 11,200-10,200 yr BP (Figures 4, 6). This cold-resistant hygrophilous tree is 354 commonly found in temperate evergreen rainforests along the Pacific coast of central Patagonia and is currently absent from the eastern Andean foothills at the same latitude. Its 355 356 presence and variations in the Lago Edita record suggest an increase in precipitation relative to 357 the pre-14,500 yr BP conditions, with millennial-scale variations starting at ~13,000 yr BP. The

variable decline in *P. nubigena* at 13,000 yr BP coincided with an increase in *Nothofagus* that
led to a variable plateau of ~30% between 13,000-11,200 yr BP we will discuss in the following
paragraphs.

361 The mixed palynological assemblage between ~19,400-11,000 yr BP has no modern analogues in the regional vegetation (Luebert and Pliscoff, 2006; Mancini, 2002). Possible 362 363 explanations for its development involve: (a) downslope migration of High Andean vegetation 364 driven by snowline and treeline lowering associated with intense glaciation in the region, coupled with (b) the occurrence of scattered, low-density populations of hygrophilous trees and 365 herbs along the eastern margin of the PIS during the LGM and T1. We rule out the alternative 366 367 explanation that pollen grains and spores of hygrophilous trees and herbs in Lago Edita represent an advected signal through the Andes from ice-free humid Pacific sectors harboring 368 these species because: (i) no empirical basis is currently available for ice-free conditions and 369 occurrence of cold-resistant hygrophilous taxa along the western Andean slopes or the Pacific 370 coast of central Patagonia during the LGM; in fact, the oldest minimum limiting dates for ice-371 372 free conditions in records from Taitao Peninsula and the Chonos archipelago yielded ages of 14,335±140 and 13,560±125 ¹⁴C yr BP (median age probability [MAP]: 17,458 and 16,345 yr BP), 373 374 respectively (Haberle and Bennett, 2004; Lumley and Switsur, 1993); (ii) the appearance of 375 Fitzroya/Pilgerodendron and Podocarpus nubigena at ~15,000 and ~14,000 yr BP, respectively, occurred 4000-5000 years later in coastal Pacific sites relative to the Lago Edita record (Figure 376 7); (iii) background levels of *Nothofagus* between 15-20% in Lago Edita predate the appearance 377 and expansion of this taxon in coastal Pacific sites and, once realized, its abundance in Lago 378 Edita cannot be attributed to long-distance transport from the western Pacific coast (Figure 7). 379 380 Previous palynological studies from bogs located east of the central Patagonian Andes (de Porras et al., 2012; Markgraf et al., 2007) (Mallín Lago Shaman and Mallín Pollux, Figure 1) 381 382 interpreted dry conditions prior to ~12,000 yr BP, based on the premise that low abundance of 383 arboreal taxa and predominance of herbs and shrubs were indicative of Patagonian Steppe communities. The glacial-to-interglacial vegetation change in those studies was interpreted as a 384 385 westward shift of the forest-steppe boundary brought by lower-than-present SWW influence at 386 44°-46°S, followed by a rise in temperature and precipitation at the end of the last glaciation. In

387 contrast, the Lago Augusta site (located in Valle Chacabuco ~7 km northeast of Lago Edita) (Figure 1) shows a pollen assemblage prior to 15,600 yr BP dominated by high Andean herbs 388 389 and shrubs, along with taxa characteristic of hyperhumid environments along the Pacific coasts 390 of central Patagonia (Nothofagus, Fitzroya/Pilgerodendron, Podocarpus nubigena, Saxegothaea conspicua, Drimys winteri, Dysopsis glechomoides and the ferns Blechnum, Hymenophyllaceae, 391 392 *Cystopteris*) (Villa-Martinez et al., 2012). It appears then that floristic elements of modern 393 Patagonian forests were present in low abundance and in a discontinuous manner along the eastern flank of the PIS between 44°-47°S. The data from Lago Edita shown in this paper, along 394 with the results from Lago Augusta, suggest that Valle Chacabuco harbored cryptic refugia 395 396 (Bennett and Provan, 2008) of rainforest trees and herbs during the interval 19,000-11,000 yr 397 BP, therefore the interpretation of lower-than-present precipitation of SWW origin in previous studies (de Porras et al., 2012; Markgraf et al., 2007), is not applicable to the Valle Chacabuco 398 area over this time interval. Plant colonization of Valle Chacabuco must have started from the 399 LGM limits located east of Lago Cochrane and followed the shrinking ice masses to the west, 400 once the newly deglaciated sectors were devoid of glaciolacustrine influence through T1. 401

Declines and virtual disappearance of the cold-resistant hygrophilous trees 402 403 Fitzroya/Pilgerodendron, Podocarpus nubigena along with the herbs Gunnera magellanica and 404 Lycopodium magellanicum took place at ~11,000 yr BP in the Lago Edita record (Figures 4, 6), in response to a sudden decline in precipitation relative to the ~14,500-11,000 yr BP interval. 405 406 These changes were contemporaneous with a sustained rise in *Nothofagus*, decreases in all 407 other shrubs and herbs, and a major increase in macroscopic charcoal (Figure 5), signaling an increment in arboreal cover, higher spatial continuity of coarse fuels and forest fires. We 408 409 interpret this arboreal increase and fire-regime shift as driven by warming which might have 410 triggered a treeline rise and favored the spread/densification of woody species and coarse fuels 411 (Figures 4, 5, 6). Possible ignition agents for the beginning of fire activity at 14,300 yr BP in the 412 Lago Edita record include the incendiary effects of explosive volcanic activity, lightning strikes and human activity. We rule out volcanic disturbance as a driving factor, considering the lack of 413 414 contemporary tephras in the stratigraphy of the Lago Edita sediment cores, and cannot support nor reject other ignition agents considering the current lack of stratigraphic proxies to constrain 415

their likely influence in the Valle Chacabuco area. Finally, *Nothofagus* forests (~70% abundance)
established near Lago Edita between 10,000-9000 yr BP.

418

419 Glacial recession in Valle Chacabuco and the Lago Cochrane basin

420

421 Stratigraphic and chronologic results from Lago Edita are key for deciphering the evolution of 422 Valle Chacabuco and for constraining the timing and rates of deglaciation in this core region of the PIS. Previous studies (Hein et al., 2010) indicate that Valle Chacabuco was overridden by the 423 Lago Cochrane ice lobe (LCIL) during the LGM and deposited the Río Blanco moraines ~90 km 424 425 downstream from Lago Edita, distal to the eastern end of Lago Cochrane in Argentina (Argentinian name: Lago Pueyrredón). Cosmogenic radionuclide dating of three main moraine 426 limits by Hein et al. (2010) yielded cosmogenic ¹⁰Be exposure ages, recently recalculated by 427 Kaplan et al. (2011) at ~21,100, ~25,100, and ~28,700 yr BP. This was followed by glacial 428 recession starting at 19,600±800 yr BP, formation of Glacial Lake Cochrane (GLC), stabilization 429 and deposition of the Lago Columna and Lago Posada moraines before 17,600±900 yr BP, ~55 430 km upstream from the Río Blanco moraines (Hein et al., 2010; Kaplan et al., 2011) (Figure 1). 431 432 Further glacial recession led to the westward expansion and lowering of GLC until the LCIL 433 stabilized and deposited moraines in Lago Esmeralda between 13,600-12,800 yr BP ~60 km upstream from the Lago Columna and Lago Posada moraines (Turner et al., 2005). Recession 434 from this position led to sudden drainage of GLC toward the Pacific Ocean via Río Baker, once 435 436 the continuity between the North and South Patagonian icefields was breached by glacial recession and thinning. These data suggest that Valle Chacabuco may have been ice-free and 437 devoid of glaciolacustrine influence after ~17,600 yr BP. More recently Boex et al. (2013) 438 439 reported a cosmogenic radionuclide-based reconstruction of vertical profile changes of the LCIL 440 through the LGM and T1 that reveals deposition of (i) the Sierra Colorado lower limit by 28,980±1206 yr BP which can be traced to the Río Blanco moraines, (ii) the highest summits of 441 Cerro Oportus and Lago Columna moraines by 18,966±1917 yr BP, and (iii) the María Elena 442 moraine by 17,088±1542 yr BP. According to these data Valle Chacabuco may have been ice-443 444 free after ~17,000 yr BP.

445 Lago Edita is a closed-basin lake located ~11 km east of the Cerro Tamango summit along the ridge that defines the southern edge of the Valle Chacabuco watershed (Figure 1). 446 447 Lacustrine sedimentation in Lago Edita started when ice-free conditions developed in Valle 448 Chacabuco, as the LCIL snout retreated eastward to a yet unknown position. The Lago Edita 449 cores show 9 meters of blue-gray clays with millimeter-scale laminations, interrupted by 450 sporadic intervals of massive pebbly mud appreciable in x radiographs and the LOI₅₅₀ record as 451 increases in the inorganic density data (Figure 2). We also found exposed glaciolacustrine beds 452 and discontinuous fragments of lake terraces in the vicinity of Lago Edita, attesting for a large lake that flooded Valle Chacabuco in its entirety. Differential GPS measurements of 570 m.a.s.l. 453 454 for the Lago Edita surface and 591 m.a.s.l. for a well-preserved terrace fragment located ~150 455 m directly south of Lago Edita, provide minimum-elevation constraints for GLC during this stage. The Lago Augusta site (Villa-Martinez et al., 2012), located ~7 km northeast of Lago Edita 456 457 on the Valle Chacabuco floor at 444 m.a.s.l. (Figure 1), shows 8 meters of basal glaciolacustrine mud (Figure 2) lending support to our interpretation. 458

459 Glaciolacustrine sedimentation persisted in Lago Edita and Lago Augusta until the surface elevation of GLC dropped below 570 and 444 m.a.s.l., respectively, and the closed-basin lakes 460 461 developed. The chronology for this event is constrained by statistically identical AMS dates of 16,250±90 and 16,020±50 ¹⁴C yr BP (UCIAMS-133418 and CAMS-144454, respectively) (Table 1) 462 from the same level in the basal portion of the organic sediments in the Lago Edita record; this 463 estimate approaches the timing for the cessation of glaciolacustrine influence in Lago Augusta, 464 radiocarbon-dated at 16,445±45 ¹⁴C yr BP (CAMS-144600) (Table 1). Because we observe 465 approximately the same age for the transition from glaciolacustrine to organic-rich mud in both 466 stratigraphies, we interpret the weighted mean age of those three dates (16,254±63 ¹⁴C yr BP, 467 468 MAP: 19,426 yr BP, two different laboratories) as a minimum-limiting age for ice-free 469 conditions and nearly synchronous glaciolacustrine regression from elevations 591 and 444 470 m.a.s.l. in Valle Chacabuco. We acknowledge that Villa-Martínez et al. (2012) excluded the age of date CAMS-144600 from the age model of the Lago Augusta palynological record because it 471 472 was anomalously old in the context of other radiocarbon dates higher up in the core.

473 Comparison of the radiocarbon-dated stratigraphy from Lago Edita record with the
474 exposure-age-dated glacial geomorphology from Lago Cochrane/Pueyrredón, Valle Chacabuco
475 and surrounding mountains reveals the following:

The geochronology for the innermost (third) belt of Río Blanco moraines (~21,100 yr BP)
(Hein et al., 2010; Kaplan et al., 2011), glacial deposits on the highest summits of Cerro
Oportus and the Lago Columna moraines (18,966±1917 yr BP) (Boex et al., 2013) are
compatible (within error) with the onset of organic sedimentation in Lago Edita and
Lago Augusta at 19,426 yr BP in Valle Chacabuco. If correct, this implies ~90 km
recession of the LCIL from its LGM limit within ~1500 years.

Hein et al. (2010)'s dates for the "final LGM limit", Lago Columna and Lago Posada
 moraines should be considered as minimum-limiting ages, as well as Boex et al. (2013)'s
 chronology for the María Elena moraine. This is because cosmogenic radio nuclide ages
 for these landforms postdate the onset of organic sedimentation in Lago Edita and Lago
 Augusta, despite being morphostratigraphically distal (older) than Valle Chacabuco.

487 As shown in Figure 1, Lago Edita is located along a saddle that establishes the southern limit of the Río Chacabuco catchment and the northern limit of the Lago Cochrane basin. 488 According to Hein et al. (2010) the drainage divide on the eastern end of Lago 489 490 Cochrane/Pueyrredón basin is located at 475 m.a.s.l., therefore the presence of this 491 perched glacial lake with a surface elevation of 591 m.a.s.l. requires ice dams located in 492 the Valle Chacabuco and the Lago Cochrane basin. This suggests that both valleys 493 remained partially ice covered and that enough glacier thinning and recession early during T1 enabled the development of a topographicaly constrained glacial lake that 494 495 covered Valle Chacabuco up to the aforementioned saddle.

The high stand of GLC at 591 m.a.s.l. lasted for less than 1500 years during the LGM and
 was followed by a nearly instantaneous lake-level lowering of at least ~150 m at ~19,400
 yr BP in Valle Chacabuco. The abrupt large-magnitude drainage event of this
 "predecessor lake" was recently recognized by Bourgois et al. (2016), but its chronology,
 hydrographic and climatic implications have not been addressed in the Quaternary
 literature.

503 Biogeographic and paleoclimatic implications

504 The persistence of scattered, low-density populations of rainforest trees and herbs east of 505 the Andes during the LGM and T1 (Figures 4, 6) implies that precipitation delivered by the SWW 506 must have been substantially higher than at present (680 mm/year measured in the Cochrane 507 meteorological station). Because local precipitation in western Patagonian is positively and 508 significantly correlated with low-level zonal winds (Garreaud et al., 2013; Moreno et al., 2010; Moreno et al., 2014), we propose that the SWW influence at 47°S was stronger than present 509 between 19,000-11,000 yr BP, in particular between 16,800-11,000 yr BP. Subsequent increases 510 in arboreal vegetation, chiefly Nothofagus, at ~13,000 and ~11,000 yr BP led to the 511 establishment of forests near Lago Edita between 10,000-9000 yr BP (Figures 4, 6). We 512 513 interpret these increases as treeline-rise episodes driven by warming pulses coupled with a 514 decline in SWW strength at 47°S (relative to the ~14,500-11,000 yr BP interval), as suggested by 515 the disappearance of cold-resistant hygrophilous trees and herbs at \sim 11,000 yr BP. We speculate that the warm pulse and decline in SWW influence at ~11,000 yr BP might account 516 517 for the abandonment of early Holocene glacier margins in multiple valleys in central Patagonia 518 (Glasser et al., 2012).

519 Five salient aspects of the Lago Edita record are relevant for deciphering the pattern and 520 rates of climate change and dispersal routes of the vegetation in Central Patagonia (47°S) 521 during the last glacial termination (T1):

522 1- Absence of stratigraphically discernable indications of deglacial warming between 19,400-13,000 yr BP, in contrast to northwestern Patagonian records (the Canal de la 523 Puntilla and Huelmo sites, Figure 1) (Moreno et al., 2015) which show that 75-80% of 524 525 the glacial-interglacial temperature recovery was accomplished between 17,800-526 16,800 yr BP (Figure 8). The record from Lago Stibnite (46°26'S, 74°25'W), located in 527 central-west Patagonia upwind from the PIS and Lago Edita (Figure 1), shows a rapid 528 increase in arboreal pollen from ~2% to >80% in less than 1000 years starting at 529 16,200 yr BP (Figure 8). We posit that cold glacial conditions lingered along the

530 periphery of the shrinking PIS during T1, affecting adjacent downwind sectors such as Valle Chacabuco. According to Turner et al. (2005) the LCIL stabilized and deposited 531 moraines in Lago Esmeralda, located ~10 km upstream along the glacier flowline and 532 533 ~240 m lower in elevation than Lago Edita, between 13,600-12,800 yr BP. We propose that the climatic barrier for arboreal expansion vanished in downwind sectors such as 534 Valle Chacabuco once glacial recession from the Lago Esmeralda (Figure 1) margin 535 breached the continuity of the North and South Patagonian icefields along the Andes. 536 Thus, we propose that regional cooling induced by the PIS along its eastern margin 537 through T1 accounts for the delayed warming in Valle Chacabuco relative to records 538 539 located in western and northwestern sectors (Figure 8).

Cold and wet conditions prevailed between 19,400-16,800 yr BP, followed by an
increase in precipitation at 16,800 yr BP. The latter event is contemporaneous with
the onset of a lake-level rise in Lago Lepué (43°S, central-east Isla Grande de Chiloé)
(Figure 8), which Pesce & Moreno (2014) interpreted as a northward shift of the SWW
as they recovered from a prominent southward shift from latitudes ~41°-43°S (Figure
following the onset of T1 (Moreno et al., 2015).

546 3- Significant ice recession (~90 km) from the eastern LGM margin of the Lago Cochrane 547 Ice lobe (LCIL) was accomplished between ~21,000-19,400 yr BP, at times when northwestern Patagonian piedmont glacier lobes experienced moderate recession 548 during the Varas interstade (Denton et al., 1999; Moreno et al., 2015) (Figure 8). In 549 contrast to the LCIL, northwestern Patagonian piedmont glacier lobes readvanced to 550 their youngest glacial maximum position during a cold episode between 19,300-551 552 17,800 yr BP that featured stronger SWW influence at 41°-43°S (Moreno et al., 2015) (Figure 8). One explanation for this latitudinal difference might be that northward-553 554 shifted SWW between 19,300-17,800 yr BP fueled glacier growth in northwestern Patagonia while reducing the delivery of moisture to central Patagonia, causing the 555 LCIL to continue the recession it had started during the Varas interstade. 556 4- A mosaic of cold-resistant and hygrophilous trees and herbs, currently found along 557

558 the humid western slopes of the Andes of central Chilean Patagonia, and cold-

resistant shrubs and herbs common to high-Andean and Patagonian steppe
communities developed along the eastern margin of the PIS during the LGM and T1
(Figures 4, 6). We posit that glacial withdrawal and drainage of GLC through T1
provided a route for the westward dispersal of hygrophilous trees and herbs,
contributing to the forestation of the newly deglaciated sectors of central-west
Patagonia.

5- The cold-resistant hygrophilous conifer *Podocarpus nubigena* increased between 14,500-13,000 yr BP, suggesting an increase in precipitation brought by the SWW to the eastern Andean slopes of central Patagonia. This was followed by a decline which was contemporaneous with a rise in the regional *Nothofagus*-dominated treeline between between 13,000-11,200 yr BP. These interpretations imply stronger SWW influence of the SWW at 47°S during the Antarctic Cold Reversal and warming during Younger Dryas time.

572 We conclude that warm pulses at ~13,000 and ~11,000 yr BP and a decline in SWW 573 influence at 47°S starting at ~11,000 yr BP brought T1 to an end in central-west Patagonia. The earliest of these events overlaps in timing with the culmination of Patagonian (Garcia et al., 574 575 2012; Moreno et al., 2009; Strelin et al., 2011; Strelin and Malagnino, 2000) and New Zealand 576 glacier advances (Kaplan et al., 2010; Putnam et al., 2010) during the Antarctic Cold Reversal. Our data suggest that the subsequent warm pulse, which was accompanied by a decline in 577 SWW strength at ~11,000 yr BP (Moreno et al., 2010; Moreno et al., 2012), was the decisive 578 579 event that led to the end of T1 in the study area.

580

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- 589
- 590

591 FIGURE AND TABLE CAPTIONS

Table 1. Radiocarbon dates from the Lago Edita core. The radiocarbon dates were calibrated tocalendar years before present using the CALIB 7.0 program.

594

595 Figure 1. Sketch map of the study area showing the location of central-west Patagonia, the position of Valle Chacabuco relative to the Río Blanco, María Elena, Lago Columna (LC) and Lago 596 597 Posada (LP) ice limits east Lago of Cochrane, and the North Patagonian icefield and Peninsula 598 Taitao to the west. We also included Sierra Colorado, Lago Esmeralda and Cerro Oportus for reference. The lower portion of the figure shows a detail on the Cerro Tamango area and the 599 600 portion of Valle Chacabuco where Lago Edita and Lago Augusta are located. Also shown are 601 palynological sites discussed in the main text (Canal de la Puntilla, Huelmo, Mallín Lago Shaman, 602 Mallín Pollux, Lago Stibnite, Lago Augusta).

603

Figure 2. Stratigraphic column, radiocarbon dates and loss-on-ignition data from the Lago Edita
record. The labels on the right indicate the identity and stratigraphic span (dashed horizontal
lines) of each core segment.

607

Figure 3. Age model of the Lago Edita record, the blue zones represent the probability
distribution of the calibrated radiocarbon dates, the grey zone represents the calculated
confidence interval of the Bayesian age model.

611

Figure 4. Percentage pollen diagrams from the Lago Edita core. The labels on the right indicate

the identity and stratigraphic span (dashed horizontal lines) of each pollen assemblage zone.

The black dots indicate presence of *Drimys winteri* pollen grains, normally <2%.

615

Figure 5. Macroscopic charcoal record from the Lago Edita core and results of CharAnalysis:

blue line: background component, red line: locally defined threshold, triangles: statistically

618 significant charcoal peaks, magnitude: residual abundance that supersedes the threshold.

620 Figure 6. Selected palynomorph abundance of the Lago Edita record shown in the time scale 621 domain. The red lines correspond to weighted running means of seven adjacent samples with a 622 triangular filter. The taxa shown in the left panel are characteristic of humid environments 623 currently found in sectors adjacent to the Pacific coast and/or the Andean treeline in the study 624 area. The taxon Nothofaqus dombeyi type, which includes multiple species with contrasting 625 climatic tolerances, is also found in (relatively) humid sectors east of the Andes. The herbs and 626 shrubs shown in the right panel are either cosmopolitan or present in the Patagonian Steppe 627 and sectors located at or above the Andean treeline in central-west Patagonia.

628

Figure 7. Comparison of selected tree pollen recorded in Lago Fácil, Lago Oprasa, Lago Stibnite
(Lumley and Switsur, 1993) and Lago Edita. The red line corresponds to a weighted running
mean in each record of seven adjacent samples with a triangular filter. The lower panels show
the curves from all sites expressed in a common percent scale (Lago Fácil: purple line, Lago
Oprasa: blue line, Lago Stibnite: black line, and Lago Edita: red line).

634

Figure 8. Comparison of the percent sum of arboreal pollen (AP) in records from Lago Edita, 635 636 Lago Stibnite (Lumley and Switsur, 1993) and the spliced Canal de la Puntilla-Huelmo time 637 series (Moreno et al., 2015), as proxies for local rise in treeline driven by deglacial warming. These data are compared against the δ Deuterium record from the Antarctic Epica Dome 638 Concordia (EDC) ice core (Stenni et al., 2010), and hydrologic estimates from northwestern 639 640 Patagonia. The latter consist of the percent abundance of Magellanic Moorland species found in the spliced Canal de la Puntilla-Huelmo record (Moreno et al., 2015), indicative of a 641 642 hyperhumid regime, and the percent abundance of the littoral macrophyte *Isoetes savatieri* 643 from Lago Lepué (Pesce and Moreno, 2014), indicative of low lake level (LL) during the earliest 644 stages of T1 and the early Holocene (9000-11,000 yr BP). The vertical dashed lines constrain the 645 timing of the early Holocene SWW minimum at 41°-43°S (9000-11,000 yr BP) (Fletcher and Moreno, 2011), a low-precipitation phase during the early termination at 41°-43°S (16,800-646 17,800 yr BP) associated with a southward shift of the SWW (Pesce and Moreno, 2014), the 647 648 final LGM advance of piedmont glacier lobes (17,800-19,300 yr BP) and the final portion of the

- Varas interestade (19,300-21,000 yr BP) in the Chilean Lake District (Denton et al., 1999;
- Moreno et al., 2015). The dashed green horizontal lines indicate the mean AP of each pollen
- record prior to their increases during T1 (Lago Edita: 17%, Lago Stibnite:2%, spliced Canal de la
- 652 Puntilla-Huelmo: 31%). The ascending oblique arrow represents a northward shift of the SWW,
- the descending arrow a southward shift of the SWW at the beginning of T1.

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790 Table 1

Laboratory code	Core	Material	Length (cm)	¹⁴ C yr BP±1σ	Median probability (yr BP)	2σ range (yr BP)
UCIAMS-133501	PC0902AT7	Bulk	660-661	8935±25	10,029	9794-10,177
UCIAMS-133416	PC0902AT8	Bulk	705-706	11,350±60	13,229	13,109-13,350
UCIAMS-133417	PC0902AT8	Bulk	757-758	13,740±70	16,863	16,684-17,055
UCIAMS-133418	PC0902AT8	Bulk	795-796	16,250±90	19,414	18,934-19,779
CAMS-144454	PC0902BT8	Bulk	795-796	16,020±50	19,164	18,922-19,408













806 Figure 5







