

MODERN ANALOGUES AND PAST ENVIRONMENTS IN CENTRAL TIERRA DEL FUEGO, ARGENTINA

ANÁLOGOS MODERNOS Y PALEOAMBIENTES EN EL CENTRO DE TIERRA DEL FUEGO, ARGENTINA

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ABSTRACT

During the Holocene a vegetation shift occurred in Tierra del Fuego from a grass-dominated steppe to a *Nothofagus* dominated forest. Here, the vegetation changes occurred in the second half of the Holocene in the centre of Isla Grande de Tierra del Fuego are analysed. We propose the hypothesis that from 4,420±110 years BP to now, the forest dominated the centre of the island. Pollen spectra from a core sample of a peat bog at Estancia Río Claro (54°22'S, 68°W) and a modern pollen dispersal model, previously published by the authors, were used for the identification of modern analogues. Changes in the composition of the pollen spectra along the peat bog profile show vegetation changes both at regional and local scales. Modern analogues showed the dominance of forest vegetation during the last 4,420 years in the central part of Isla Grande de Tierra del Fuego. However, an alternation of open and closed deciduous forests, and also water-filled and drier bog conditions were found throughout this period. The open forest was probably associated with lower precipitation and cold temperatures.

Key words: Modern analogues, Palaeoenvironments, Pollen analysis, Tierra del Fuego, Holocene.

RESUMEN

Durante el Holoceno hubo en Tierra del Fuego cambios en la vegetación, de una estepa dominada por gramíneas a un bosque dominado por *Nothofagus*. En este trabajo se analizan los cambios ocurridos en la vegetación en la segunda mitad del Holoceno en el centro de la Isla Grande de Tierra del Fuego. Se plantea la hipótesis que desde 4.420±110 años AP hasta la actualidad, en el centro de la isla dominó el bosque. Se utilizaron los espectros polínicos de un perfil de una turbera en estancia Río Claro (54°22'S, 68° W) y un modelo de la dispersión actual de polen, previamente publicado por los autores, para la identificación de análogos modernos. Los cambios en la composición de los espectros polínicos de la turbera muestran variaciones de vegetación a escala tanto regional como local. Los análogos modernos indicaron la dominancia de la vegetación de bosque en la parte central de la Isla Grande de Tierra del

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Fuego durante los últimos 4.420 años. Sin embargo, durante este período se detectó además, la alternancia de bosque deciduo abierto y cerrado, y también condiciones de agua libre y de mayor sequedad en la turbera. El bosque deciduo abierto estuvo probablemente asociado con precipitaciones menores y temperaturas frías.

Palabras clave: Análogos modernos, Paleoambientes, Análisis de polen, Tierra del Fuego, Holoceno.

INTRODUCTION

Palaeoenvironmental studies in Tierra del Fuego have shown changes in the physiognomy of the vegetation during the Holocene. Von Post (1929) and Auer (1933, 1952, 1958, 1965) studied the pollen content of peat bogs and identified a vegetation shift from a grass- and sedge-dominated steppe to a forest dominated by *Nothofagus* Blume. More recently, Heusser & Rabassa (1987), Markgraf (1989), Borrromei (1995), Heusser (1989, 1998), Quattrocchio & Borrromei (1998), Rabassa *et al.* (2000), Borrromei & Quattrocchio (2001) and Grill *et al.* (2002), in their respective studies of the south of Cordillera Darwin found that the *Nothofagus* forest expansion started 10,000 years ago. In Paso Garibaldi (located south of the Cordillera) at 500 m a.s.l., the forest expansion occurred later than at lower sites (Markgraf 1990)¹. Around Canal de Beagle, the final forest expansion took place at mid Holocene times, with a colder and more humid climate than in the early Holocene (Rabassa *et al.* 1989). On the northern side of the Cordillera the forest expansion started even later. In Lago Yehuin, now surrounded by a deciduous forest of *Nothofagus pumilio* (Poepp. & Endl.) Krasser, the expansion started 8,000 years ago (Markgraf 1990)¹. In Cabo San Pablo, located on the Atlantic coast at the transition from forest to steppe, Heusser & Rabassa (1995) set the start point of the forest at around 3,000 BP and its final expansion at 900 BP. Finally, in La Misión, Markgraf (1988) detected forest elements from 8,000 BP to 1,000 BP when the steppe expanded to its current extension. This forest expansion in the island during the Holocene is consistent with the establishment of a south to north climatic gradient (Burry *et al.* 2006). Pendall *et al.* (2001) using pollen assemblage changes and stable hydrogen isotope analysis of mosses of a bog in Canal de Beagle found that, an intense cold period

developed around 2,000 BP and lasted approximately 200 years. On the other hand, Mayoral *et al.* (1991) studied the palaeotemperatures in the profile of Estancia Río Claro by analysing amino acid racemisation in fossil plant proteins. Their preliminary results suggest a temperature rise between 3,800 BP and 2,600 BP and from 500 BP to the present. There is also indication of a temperature decrease between 2,600 and 1,500 BP. Lately, Huber *et al.* (2004) studied the postglacial fire history along two transects in southern Patagonia and Tierra del Fuego, showing distinct geographical and temporal trends that reflect changes in effective moisture.

With reference to modern pollen studies in the island, D'Antoni & Spanner (1993) have developed models for palaeoecology through remote sensing and modern pollen dispersal in southern Patagonia and Tierra del Fuego. More recently, a model was developed to study a transect running from the southwest through the northeast of the island (Trivi *et al.* 2006).

The aim of this work is to reconstruct the vegetation history of the surroundings of Estancia Río Claro, in the central part of Tierra del Fuego, from the mid Holocene to the present using the method of modern analogues. This method compares fossil pollen spectra with modern spectra from a range of vegetation types and environments; when a fossil spectrum is associated to one or more modern pollen spectra, it is possible to infer that the ecosystem around the modern pollen sampling site is analogue for the past ecosystem centred on the fossil pollen sampling site (Overpeck *et al.* 1985). We propose the hypothesis that from 4,420 years BP to present times, forest vegetation has dominated the centre of the island.

Study Area.

The study area is in the Argentine sector of Isla Grande de Tierra del Fuego in a large flat with a lagoon with a *Sphagnum* L. bog at Estancia Río

¹ Markgraf, V. 1990. Paleoclimates in Tierra del Fuego. *Programs and Abstracts American Quaternary Association*, p 24.

Claro (54°22'S, 68°W, 300 m a.s.l.). The bog is located in the deciduous forest in the centre of the island (Fig. 1), with a landscape of hills and plains. On the southern side is the Cordillera Darwin, the island's most prominent geographical feature that gives the area its drastic local variations of topography and climate.

There are few weather stations in Tierra del Fuego, generally placed in coastal zones, so that no data is available for the interior of Isla Grande. The most outstanding temperature feature of the region is the absence of warm summers. In winter, the climate is influenced by Antarctic cold air intrusions coming from the south. The predominant winds are from the south and southwest (Rabassa *et al.* 2000). In the mountains and in the interior of Isla Grande, winter snow is permanent. A strong annual precipitation gradient from 250 mm in the northeast to more than 2000 mm in the southwest (Fig. 2), and the effects of the north to south and northwest to southeast wind barrier set by the Fue-

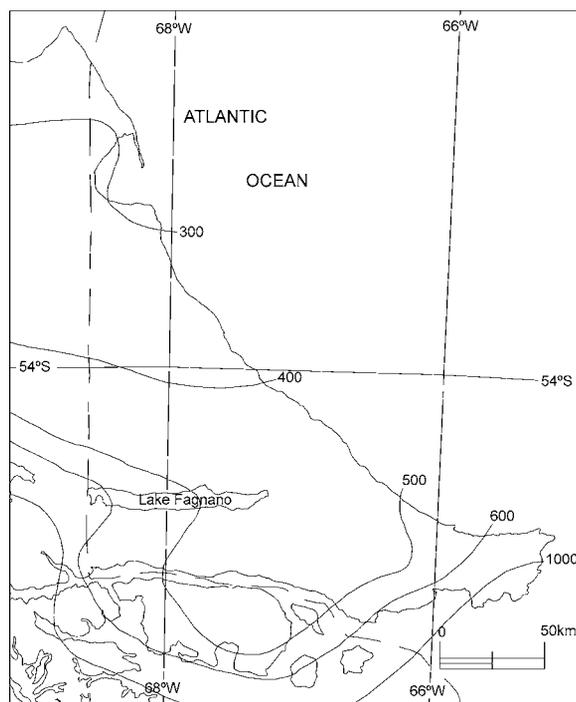


Fig. 2. Annual precipitation isohyets (in mm's) for Tierra del Fuego.

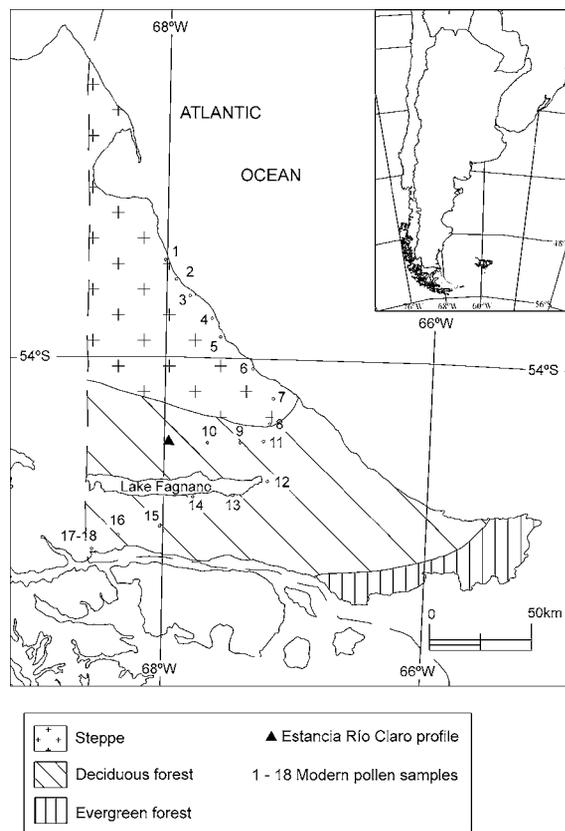


Fig. 1. Tierra del Fuego, Argentine sector. Phytogeographic regions (Moore 1983).

gian Andes Cordillera are related to vegetation and soils (Tuhkanen 1992).

Nowadays, the phytogeographic units of the Argentine sector of the island are the evergreen and deciduous forests, and the steppe (Moore 1983). The southernmost unit of the region, the evergreen forest, is out of the scope of this work. The deciduous forest is dominated by the tree *Nothofagus pumilio*, with a few undergrowth species. In windy lowlands with soils poor in nutrients of the interior of Isla Grande the vegetation is composed of dwarf shrubs, such as *Empetrum* L. and *Apiaceae*. In the northern border of the deciduous forest ecotone, bogs are found characterised by *Cyperaceae* and genera such as *Sphagnum*, *Myriophyllum* L. and *Empetrum*. In the hummocks, the driest portion of the bog, grow *Sphagnum* and *Empetrum*, while the *Cyperaceae* and *Myriophyllum* live in sub-aquatic habitats. When conditions are favourable for bog expansion the surrounding vegetation becomes affected and other taxa may occur (*e.g. Pilgerodendron uviferum* Florin (1930) *Cupressaceae*). In the deciduous forest, the mean temperature for the warmest month is 10°C, and for the coldest month

between -3.5° - $+2^{\circ}\text{C}$; precipitation varies between 450–650 mm. The steppe, situated in the northern portion of the island is a heavily grazed semiarid region characterised by grasslands and shrubs, with *Festuca gracillima* Hooker f. as a dominant species. The mean temperature for the warmest month is 11°C and for the coldest month between -4° - $+2^{\circ}\text{C}$; precipitation ranges 250–400 mm. An ecotone forming a woodland between forests and steppes occurs (Tuhkanen *et al.* 1989–1990).

MATERIALS AND METHODS

Since the method of modern analogues is most likely to succeed in regions with extensive, representative collections of modern pollen data (Birks & Birks 1980) and definitive statements about the analogue status of a fossil pollen spectrum requires that samples from all the vegetation units of the region be in the modern data base (Delcourt *et al.* 1984), we examined a modern pollen transect and a fossil peat bog. The modern transect runs from southwest to northeast in the Argentine sector of Isla Grande (Trivi *et al.* 2006), through deciduous forest and steppe vegetation (Fig. 1).

(1) Sampling – A 2.25 m depth *Sphagnum* bog core was taken with a Dachnowski (1924) corer. Fourteen peat samples were taken equidistantly from the surface to 1.92 m. The profile was dated 625 ± 35 at 0.49 m, 825 ± 35 at 0.59 m, $1,210\pm 35$ at 0.74 m, $2,235\pm 35$ at 1.19 m by AMS and $4,420\pm 110$ BP at 1.92 m by conventional ^{14}C (University of Arizona) on a *Sphagnum* peat sample; further, the profile has preliminary data of palaeotemperature variations between 1° and 3°C (Mayoral *et al.* 1991). The bog material was tightly packed in aluminium foil. Depending on the composition of the samples, 1.3 to 8.0 g subsamples were taken in the laboratory.

(2) Extraction – In order to recover the pollen grains from fossil sediments the following sequence of physical and chemical treatments (Faegri & Iversen 1989) was performed:

a) Five Stockmarr tablets of *Lycopodium clavatum* L. (1753) spores were added to each sub-sample for a reassurance that no part of the sample has been lost during the extraction process and the making of minimum area curves (Bianchi & D'Antoni 1986)²; b) the samples were sieved through

a 260 μm mesh; c) the material was deflocculated with warm 10% potassium hydroxide to neutralise humic acids and to bring the sample to particle-size; d) several water rinses were performed and then, room temperature hydrochloric acid was added to neutralise carbonates; e) differential flotation was practised using an aqueous solution of zinc chloride calibrated at a 1.9 g/l density, thus permitting the separation of organic compounds ($d < 1.7$) from the inorganic ones ($d > 2.0$); f) hydrofluoric acid washings were done to remove residual silicates; g) acetolysis was applied in order to break the cellulose molecule into soluble fragments that were successively washed with water; h) residues were included in glycerine and transferred to 5 ml room temperature vials.

(3) Determination and Counting – Pollen types of each of the samples were determined with reference to several published texts (Erdtman 1943, 1969, Heusser 1971, Markgraf & D'Antoni 1978, Moore *et al.* 1991) and by comparison with the pollen collection at the Laboratorio de Palinología (Universidad Nacional de Mar del Plata). The diverse pollen types were counted at 400 to 1000x magnification until an adequate pollen sum was achieved by means of minimum area curves (Bianchi & D'Antoni 1986)².

(4) Statistical Analyses – A joint modern and fossil pollen sample correspondence analysis (CA programme), Tilia pack, version 1.12 (Grimm 1992) was performed in order to detect modern analogues. Modern pollen samples were those from a modern pollen model (Trivi *et al.* 2006) (Fig. 3) that shows the pollen types found on surface and its abundance along a SW-NE transect. The composition of the pollen samples and the relationship of the dominant types *Nothofagus* and Poaceae, allowed for the identification of the open and closed deciduous forests, the woodland (a transitional zone) (Tuhkanen *et al.* 1989–1990) and the steppe. Taxa presenting frequencies greater than 2% in the fossil record were considered for the statistical analyses in order to reduce the statistical noise introduced by minor components of the pollen sum (Howe & Webb 1983).

² Bianchi, M.M. & H.L. D'Antoni 1986. Deposición del polen actual en los alrededores de Sierra de los Padres (pcia. de Buenos Aires). *Contribuciones al IV Congreso Argentino de Palinología y Bioestratigrafía. (Apéndice de las Actas del Congreso)*. Mendoza, Argentina.

Modern Pollen
Tierra del Fuego
(52° 40' S - 65° 5' W / 55° 7' S - 68° 40' W)

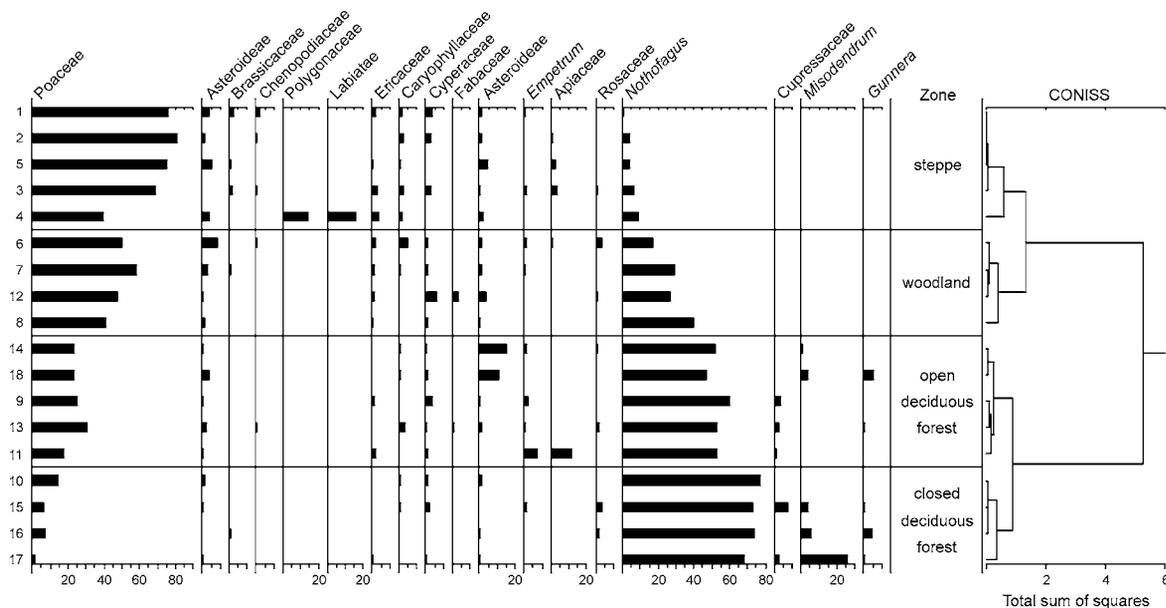


Fig. 3. Unconstrained cluster analysis of modern pollen samples (Trivi *et al.* 2006).

RESULTS

Fossil pollen samples.

Pollen sums from the bog samples ranged between 300 and 570 grains. In our palynological analysis we determined 27 pollen types, having discarded 18 of them for the statistical analysis (Fig. 4). Thus, the following taxa were not taken into account: Myrtaceae, *Ephedra*, Fabaceae, Apiaceae, Juncaginaceae, Papaveraceae, *Nassauvia*, Polygonaceae, Asteraceae subfam. Asteroideae, Juncaceae, *Plantago*, Berberidaceae, Convolvulaceae, Labiatae, Chenopodiaceae, *Weinmania* Cav. (1801), Ranunculaceae and *Gunnera*. *Nothofagus* predominated over the rest of the taxa in the pollen profile with percentages between 44% and 85% of the total pollen sum. The family Poaceae showed percentages between 3% and 36% (Fig. 4). The older samples (XIV through VII) were also characterised by the Cupressaceae, Rosaceae and aquatic taxa such as *Myriophyllum* and Lemnaceae, and the younger samples (VI through I) by *Empetrum*.

Modern and fossil pollen samples.

Ordination of modern and fossil pollen samples by means of correspondence analysis explained 52% of the variance with the first axis and 21% with

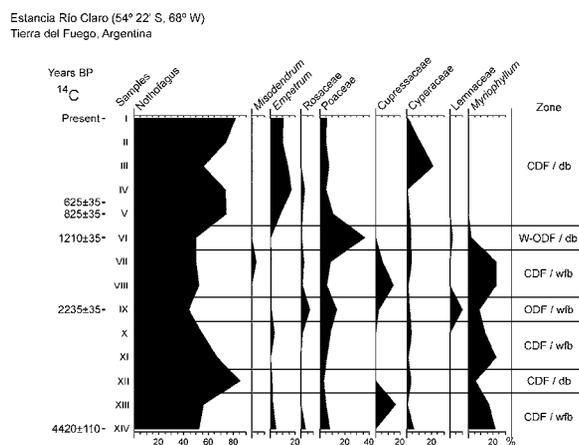


Fig. 4. Fossil Pollen Diagram. Zonation based on modern analogues. CDF: Closed Deciduous Forest, ODF: Open Deciduous Forest, W-ODF: Woodland - Open Deciduous Forest ecotone, wfb: water filled bog, db: dry bog.

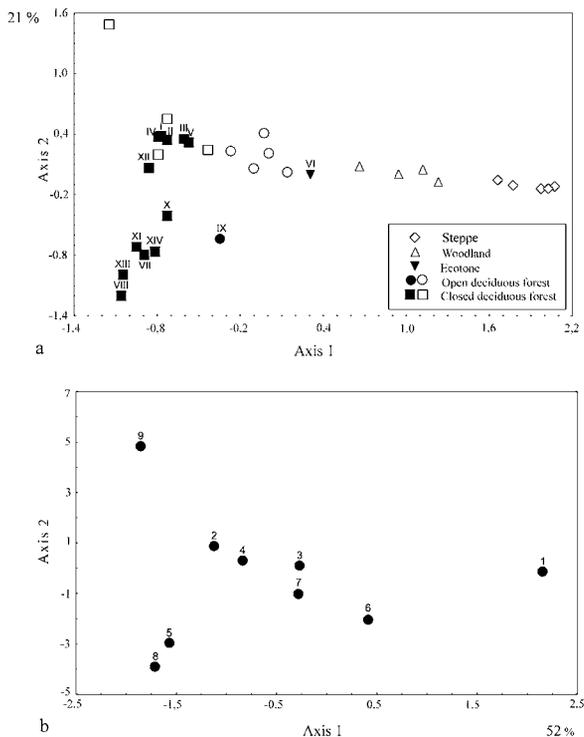


Fig. 5. a: Modern and fossil pollen samples ordination, full symbol: fossil pollen samples, empty symbol: modern pollen samples. b: Variables ordination. 1. Poaceae, 2. Empetrum, 3. Cyperaceae, 4. Nothofagus, 5. Cupressaceae, 6. Lemnaceae, 7. Rosaceae, 8. Myriophyllum, 9. Misodendrum.

the second axis (Fig. 5). The analysis showed an arrangement of physiognomic units from right to left along the first axis: steppe – woodland – open deciduous forest – closed deciduous forest (Fig. 5a). Fossil sample VI fell into the ecotone woodland-open deciduous forest; fossil sample IX, into the open deciduous forest; and the rest of the fossil pollen samples into the closed deciduous forest. The second axis separated samples belonging to the closed deciduous forest. Accordingly, the ordination of variables showed that axis 2 separated variables that belong to water filled and a drier bog, the former, mainly by *Myriophyllum* and the later by *Empetrum* (Figs. 4 and 5).

DISCUSSION

The modern pollen samples were ordinated from right to left in different plant communities belonging to the phytogeographic units steppe, woodland and deciduous forest (Trivi *et al.* 2006).

These physiognomic units were related to a precipitation gradient in such a way that the first correspondence axis represents an annual precipitation gradient from 250-400 mm (steppe) to 450-600 mm (deciduous forest). On the other hand, the second correspondence axis separated, within the closed deciduous forest, bog environments with: a) indicators of marshy and fresh-water environments, like *Myriophyllum* and Lemnaceae, thus making evident the occurrence of open water holes in the oldest profile samples, and b) indicators of species that colonise the driest portions of the peat bog, like Cyperaceae and *Empetrum*, in the youngest profile samples (Figs. 4 and 5). The elevated values of *Empetrum* and the absence of aquatic plants growing in the more humid portion of the bog should be an indication that its surface remained dry during longer periods (Heusser 1989) making evident less humid conditions. Then, the second axis of the correspondence analysis represents differences in the hydrology of the peat bog.

No evident problem was detected while comparing modern and fossil pollen spectra from the steppe (Huber *et al.* 2004) or the forest, although modern pollen samples were taken from bogs and surface soils, and the fossil pollen profile is from a bog. Correspondence analysis through modern and fossil pollen samples detected modern analogues on a gradient ecotone woodland - open deciduous forest, open deciduous forest, closed deciduous forest, as seen in the first correspondence axis (Fig. 5a). Fossil pollen sample VI dated $1,210 \pm 35$ years BP, with the profile's highest percentage of Poaceae, was located between the woodland and the open deciduous forest modern pollen samples, thus reflecting the driest conditions recorded in the profile. On the other hand, fossil pollen sample IX, dated $2,235 \pm 35$ years BP, with lower values of Poaceae, was located near the open deciduous forest, thus representing an intermediate moist condition. The remaining fossil pollen samples were placed within the close deciduous forest unit.

In short, the method of modern analogues allowed the detection of changes in the forest communities around Rio Claro: from $4,420 \pm 110$ BP a succession of closed deciduous forest, an open deciduous forest at $2,235 \pm 35$ BP, and again a closed deciduous forest, a woodland - open deciduous forest ecotone at $1,210 \pm 35$ BP, and from

825 ± 35 BP up to now when the closed deciduous forest got established. Apart from these changes, variations in the bog's condition were registered: a dry bog was replaced by a water filled bog during a period before and after 2,235 ± 35 BP (Fig. 4). The closed deciduous forest and a dry bog currently occupies the region.

These changes within communities could be related to temperature variations detected by racemisation analyses (Mayoral *et al.* 1991) and to precipitation: the closed deciduous forest with a water-filled bog at 4,420 ± 110 BP turns into communities with a drier bog, coincident with a temperature rise. Further, the woodland - open deciduous forest at 1,210 ± 35 BP would also coincide in time with the cold event uncovered in Canal de Beagle (Mayoral *et al.* 1991, Pendall *et al.* 2001) and related to a lower precipitation. Thus, the variations observed in the pollen record of plant communities would show a relationship with different temperature and precipitation patterns.

CONCLUSIONS

Our hypothesis holding that, from 4,420 years BP to present times, forest vegetation has dominated the centre of the island, cannot be rejected based on the analysed evidence.

The distribution of the modern pollen rain and the modern pollen-vegetation relationships in the Argentine sector of Tierra del Fuego and the profile from Estancia Río Claro allowed us to recognise modern analogues for studies of vegetation history.

The comparison of modern and fossil pollen samples suggests that during the last 4,400 years, the forest was the dominant vegetation in the central part of Tierra del Fuego. Within this period there were variations from closed deciduous forest, to open deciduous forest and woodland. The latter was probably associated to lower precipitation and cold temperatures. Variations in the hydrology of the bog were uncovered. This work contributes new data to the history of vegetation in the central region of Tierra del Fuego. We demonstrate that this region responded to the general pattern of forest expansion and changes in the forest structure during the mid-Holocene timeframe.

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