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# Fossil leaves from the last interglacial in Central-Southern Chile: Inferences regarding the vegetation and paleoclimate

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## | A B S T R A C T |

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The continental equivalent of the most temperate part of the last interglacial (MIS 5e) is called Valdivia in southern Chile. It is characterised by extensive terraces mostly composed of detrital sediments and pyroclastic flows. Peat deposits are found within these terraces. In this paper we analyze the leaf architecture of fossil leaves collected from a peat layer at the base of the Mancera interglacial sequence, on Mancera Island, off the coast of Valdivia (near 40°S). The stratigraphic position, the presence of in situ logs and the composition of the plant species found therein suggest that the accumulation of plant remains occurred in a continental, palustrine environment. The plant morphotypes reveal an unusual mixture of species belonging to the cool temperate North Patagonian Forest and to the more thermophilous vegetation, represented by Valdivian Rain Forest. Both types of forest are currently found in the Coastal Range at different altitudes. The Mancera flora associations suggest a gradual response of the vegetation to the glacial-interglacial transition, and indicate that this coastal area could have been a refuge during the penultimate glacial period. A similar situation has been described for the last glaciation-Holocene transition.

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**KEYWORDS** | Interglacial. Flora. Leaves. Chile. South America.

## INTRODUCTION

Since the Middle Pleistocene, the world climate has been characterized by a succession of at least eight glacial cycles in which relatively short, warm interglacial periods alternate with longer cold events or glaciations (Spahni et al., 2005). The mechanisms controlling these climate oscillations are generally linked to changes in the astronomical configuration of the Earth's orbit around the Sun (Berger and Loutre, 1991).

This climatic variability has left sedimentological, stratigraphic and paleontological imprints that are widely used for global-scale interpretations of the Pleistocene climate. The study of local sedimentary sequences gave rise to the first climate descriptions of the last interglacial. In North America, the Sangamon Interglacial (Leverett, 1898) was originally described as a warm period and its sedimentary, geomorphological, and soil formation features revealed an absence of large ice masses (Kukla et al., 2002). In the classical chronostratigraphical subdivision of the Alps

(Penck and Brückner, 1909), the Riss-Würm Interglacial was identified based on geomorphological observations. The Eemian Interglacial (Harting, 1874; Nordmann, 1908) in the valley of the Eem River, Netherlands, has been described as a marine deposit rich in temperate water mollusks. In southern Chile, the Valdivia Interglacial (Latorre et al., 2007) was proposed based on the presence of fluvial and volcanoclastic deposits forming extensive terraces around the Valdivia area. These sediments are interbedded between the outwash deposited during the last and penultimate glaciations, contain abundant paleoflora and a moderate degree of weathering.

Globally an interglacial period is understood as a temperate episode, with a climatic optimum at least as warm as the present interglacial (Gibbard and Van Kolfshoten, 2004).

Since the early Von Post contribution (1946), many authors agree that interglacial vegetation developed in a similar way as it does today. This author described a series of vegetation changes in European postglacial sediments, starting from open glacial vegetation dominated by grasses, which lead to maximum forest conditions and ended with declining forests and increasing herbaceous species. Von Post also stated that postglacial pollen sequences in New Zealand and Tierra del Fuego show essentially the same series of vegetation changes (Von Post, 1946; Colhoun, 1996).

Peat deposits containing plant remains can be observed as part of the interglacial terrace at different sites on Mancera Island, off the coast of Valdivia. Such deposits offer a valuable opportunity to rebuild the interglacial flora.

In this study, we report and describe fossil leaves and fruits from one of such peat deposit at the base of Valdivia Interglacial sediments. Due to the basal stratigraphic position of the peat, we propose the following questions. Does the fossil flora found in Mancera Island represent a full interglacial condition? Or rather does it represent the glacial-interglacial transition?

### Geological setting of the Valdivia Interglacial

In southern Chile, the equivalent of the Eemian is the Valdivia Interglacial depicted in large terraces near the coast (Latorre et al., 2007). These terraces can be observed along the banks of the estuary formed by the Valdivia and Calle-Calle rivers from the Pacific coast towards the Andes (Brüggen, 1944; Fuenzalida et al., 1965; Rojas, 1990; Arenas et al., 2005; Latorre et al., 2007). The deposits were formed in the last interglacial period of the Late Pleistocene according to the following evidence: stratigraphic observations, the degree of weathering, and the elevation of the terraces (Lauer, 1968; Illies, 1970).

Arenas et al. (2005) confirmed this age, indicating that the deposits comprising the interglacial terrace are inserted between glaciofluvial sediments from the penultimate and ultimate glaciations, known as Santa María (Porter, 1981) and Llanquihue (Mercer, 1976) respectively.

The varying heights of the terraces (10 - 67m) have been explained through block neotectonics (Illies, 1970). Despite different magnitudes of neotectonic uplift, the surfaces of these terraces represent the sea level during the last interglacial, which was no more than 8m above its current level according to global estimates (Esat et al., 1999; Blum and Törnqvist, 2000; Esat and Yokoyama, 2000; Lambeck et al., 2002; Shackleton et al., 2003). The deposits of the interglacial terrace are composed of two markedly different detrital and volcanoclastic sediment types, namely allochthonous and autochthonous sediments, which are from regional and local origin respectively (Latorre et al., 2007). Allochthonous sediments are composed mainly of medium and fine-grained, immature, volcanic sands locally known as “cancagua”, interbedded with silt-sized volcanic ashes partially weathered to clay. These deposits have been described by Brüngen (1944), Illies (1970), Pino (1987), and Rojas (1990). Autochthonous sediments consist of gravel, sand, and silt derived from the local metamorphic basement. Peat deposits associated with these sediments can be recognized at different sites on the island.

Palustrine deposits were temporally and spatially frequent during the Valdivia Interglacial. Hidalgo (2007) described three levels of peat. The first, as on Mancera Island, is located almost at sea level and contains *in situ* logs, numerous plant and insect remains, and sometimes the imprints of estuarine mollusks. The second and third levels can be found near Los Molinos (Fig. 1), located at 13 and 7m below the terrace surface at 47 m a.s.l.

There are several interpretations of the depositional models for interglacial deposits on the Valdivian coast. According to Rojas (1990), during this period the Valdivia basin was a gently sloping flood plain. In contrast, Latorre et al. (2007) proposed that pyroclastic flows advanced from the Andes to the coast, moving east to west across an alluvial plain that ran parallel to the coastline (north-south) several kilometers west of its current position. According to Lambeck (2002), sea levels during MIS 5e were close to current levels of around 130ka and peaked around 125ka. However, it is likely that interglacial temperatures at mid-latitudes had increased approximately 6ka before the sea level approached its present level (Lambeck et al., 2002), thereby promoting the observed change in vegetation composition.

One of the most detailed records of the last interglacial climate, obtained from the Vostok ice core (Petit et al.,

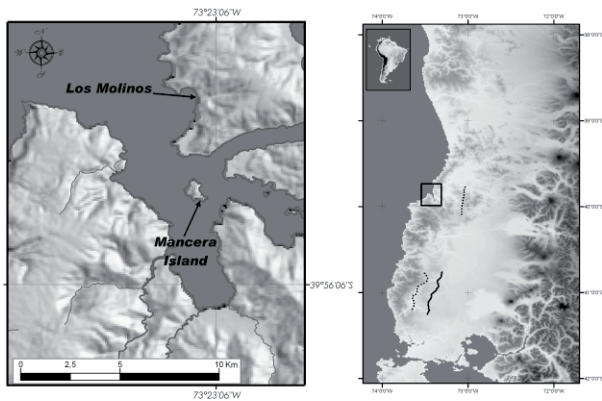


FIGURE 1 | Left map: Location of Mancera Island. Right map: the solid thick, solid thin and dotted lines represent the limit of drift during maximum Llanquihue, Santa María and Llico Glaciations (modified from Porter, 1981) respectively.

1999), also revealed a gradual increase of temperatures from the glacial minimum around 138ka, reaching similar values to those at present around 132ka, and then remaining high or increasing for the next 13ka (Kukla et al., 2002).

### Vegetation setting of the Valdivia Interglacial

Through the interpretation of palynoflora, Heusser (1974, 1981) inferred that the climatic conditions and forest composition of the last interglacial were comparable to those presently found at low-altitude sites in the region. According to this author, ice retreat was followed by an early colonization of grasslands and later by *Nothofagus* forests with small clearings of grass, forbs, and shrubs. The climate was relatively drier than present conditions, becoming more humid as forest populations were established in the area. Changes in the weather and vegetation patterns of the Chilean Lake District (Heusser, 1974; 1981) during the last interglacial-glacial cycle were synchronous with other mid-latitude records from the Southern Hemisphere (Heusser, 1981). This was demonstrated by studies conducted in Tasmania and New Zealand (Nathan and Moar, 1975; Colhoun, 2000) that revealed similar changes in terms of timing and direction to those recorded in Chile.

The results of the correlation between  $\delta^{18}\text{O}$  and high-resolution pollen obtained at 36°S offshore the Chilean continental transition, between the Mediterranean and the rainy temperate climate zones, indicated a complex sequence of changes in climate and vegetation during the past 140ka (ODP Site, 1234; Heusser et al., 2006). The isotope stage MIS 5e was reported to be more arid and possibly warmer than the current interglacial (MIS 1). These warm, semi-arid conditions held until the beginning

of a cold pulse in MIS 5d, when they gradually deteriorated to near-glacial levels in MIS 5b. The interglacial lowland deciduous forest returned to prominence in MIS 5a. The development of this forest over time and its expansion in the area coincided with the decline of the ice volume. The changes in vegetation at the end of the two last glaciations were markedly similar. In both cases, forests dominated by *Nothofagus dombeyi* declined sharply and were replaced by interglacial lowland deciduous forest. The decline in *Nothofagus dombeyi* correlated negatively with  $\delta^{18}\text{O}$ ; the former peaked in MIS 6 (equivalent to the Santa María Glaciation) and fell to its lowest point in MIS 5e. Essentially, the same inverse relationship was observed in the transition from the Llanquihue glaciation to the current interglacial conditions (Heusser et al., 2006).

Coastal forests were only slightly affected during the Pleistocene ice ages, unlike the Andes and southern Patagonia forests (Villagrán et al., 1995; Villagrán and Hinojosa, 1997; Villagrán and Armesto, 2005; Hinojosa et al., 2006). Thus, the Coastal Range became a flora refuge (Heusser, 1981; Villagrán et al., 1995; Villagrán and Armesto, 2005). According to the model proposed by Villagrán (2001), the coast of south-central Chile between 40° and 42°S, served as a refuge for the North Patagonian forest during the last ice age. Simultaneously, the middle and lower slopes of the range (36°- 40°) provided refuge to the warmer elements of the Valdivian Rain Forest. Studies of fossil wood found in the Valdivia interglacial peats are consistent with this model, reporting *Nothofagus* sp., *Fitzroya cupressoides*, *Pilgerodendron uviferum*, and *Saxegothaea conspicua*, all species belonging to the North Patagonian Forest (Hidalgo, 2007).

### Current climate and vegetation of the Coastal Range

Luebert and Plissock (2006) reported a temperate macrobioclimate for the coast of Valdivia, under the specific influence of the hyperoceanic temperate bioclimate. These authors also indicated a vegetation floor that corresponds to the coastal temperate evergreen forest of *Weinmannia trichosperma* and *Laureliopsis philippiana*, located between 0 and 700m a.s.l on the western slope of the Coastal Range (Luebert and Plissock, 2006). The warmest range or lowest level (up to 300 m a.s.l.) of this floor consists of a coastal Olivillo forest with communities dominated by *Aextoxicon punctatum* and *Eucryphia cordifolia*. The vegetation in the coldest range or upper level (500-800 m a.s.l.) is a forest of tepa, tineo and mañío, with communities dominated by *Eucryphia cordifolia* and *Weinmannia trichosperma* (Pisano, 1956; Schmithüsen, 1956; Oberdorfer, 1960; Veblen and Schlegel, 1982; Ramírez et al., 1996; Ramírez and San Martín, 2005; Luebert and Plissock, 2006).

## MATERIAL AND METHODS

Mancera Island is located in Corral Bay, off the coast of Valdivia (39°53'S - 73°23'W). The island has a central hill composed of rocks belonging to the Bahía Mansa Metamorphic Complex (Duhart et al., 2001). Three levels of terraces of different ages occur in the slopes of the central hill. The Valdivia Interglacial terrace covers nearly half of the island's surface (Villalobos, 2005).

The fossil leaves analyzed in this study were obtained from a peat deposit on the SE side of the island (Fig. 1) that crops out at high tide level and is seasonally covered by beach sand. This layer can be followed to the beach scarp where it forms part of the interglacial terrace (Fig. 2).

The layer containing the fossils is a dark gray, Muscovite-rich, slightly silty peat of undetermined thickness, interbedded with fine sand rich in organic detritus. The peat includes a large amount of leaves, charred wood, elytra of coleoptera, mollusk valve imprints and in situ logs.

The peat was cut into decimetric fragments, which were transported in boxes to the laboratory and sectioned into slices (approx. 5mm) following the disposition of the lamination and the fossil leaves. Each obtained specimen was cleaned with a brush under a binocular microscope in order to reveal the largest possible number of foliar characteristics. Later, each specimen was washed with a mixture of alcohol and distilled water in equal amounts. Due to the good state of conservation of the fossils, the macroscopic features of the leaves architecture were enough to determine the morphotypes. The obtained specimens were photographed and labelled using the acronym GEOUACH-P-IM followed by a sequential number. These specimens were then added to the fossil collection of the Instituto de Geociencias. A total of 80 leaves were obtained, of which 50 complete or relatively large, well-preserved fragments were used in this study.

Table 1 provides a list of the most representative families and species composing the vegetation of the coastal temperate evergreen forest of *Weinmannia trichosperma* and *Laureliopsis philippiana*, and that of the interior temperate evergreen forest of *Nothofagus dombeyi* and *Eucryphia cordifolia* in the Coast Ranges around Valdivia (Luebert and Plischoff, 2006 and citations therein). These species were collected, herborized, and photographed in order to establish a database with which to describe, compare, and finally relate the fossil species.

We used the morphotype system proposed by Johnson (1992) to study the fossil leaves. Thus, the fossil leaves

were grouped into categories defined by the characteristics of their leaf architecture. For each category, we selected the most complete, best-preserved specimen as the holomorphotype. We analyzed photographs of current and fossil leaves to describe, compare, and determine the taxonomic level (family, genus, or species) to which the

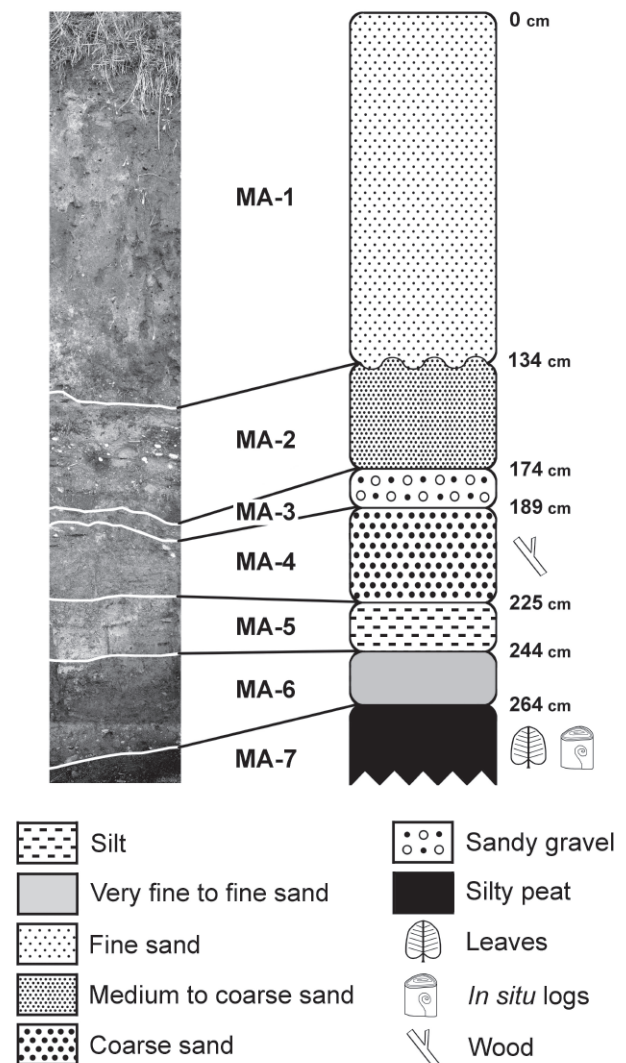


FIGURE 2 | Stratigraphic section of the Mancera Island Quaternary deposits. MA-1: (0-134cm). Medium-grained sand; well sorted, with incipient soil development. This layer corresponds to a Holocene terrace. The contact at the base corresponds to an erosive unconformity; MA-2: (134-174cm). Medium to coarse-grained sand, no matrix, highly weathered, including some gravel lenses also without a matrix. The gravel is barely rounded and composed of fragments of metamorphic rocks and quartz; MA-3: (174-189cm). Gravel with a sandy matrix, weathered, with iron oxide deposits; MA-4: (189-225cm). Coarse sand with isolated gravel clasts; MA-5: (225-244cm). Muscovite-rich silt with levels rich in organic plant matter and wood fragments; MA-6: (244-264cm). Fine to very fine-grained sand with high contents of fine organic wood; MA-7: (264cm and over). Fossil-bearing layer. Peat intermixed with very fine and organic sands. This layer is exposed on the beach floor due to the erosion of the waves. All fine sediments with or without organic matter contain plant fossils.

TABLE 1 | Most representative species from the vegetation floor of the coastal temperate evergreen forest of *Weinmannia trichosperma* and *Laureliopsis philippiana*. The list also includes some species from the vegetation floor of the interior temperate evergreen forest of *Nothofagus dombeyi* (compiled by Ramírez et al., 1985 and Luebert and Pliscoff, 2006)

Families	Species	Common names
Aextoxicaceae	<i>Aextoxicon punctatum</i> Ruiz & Pav.	Olivillo
Araliaceae	<i>Pseudopanax valdiviensis</i> (Gay) Baill.	Voqui naranjillo
Araliaceae	<i>Pseudopanax laetevirens</i> (Gay) Baill.	Sauco del diablo
Asteraceae	<i>Dasyphyllum diacanthoides</i> (Less.) Cabrera	Trevo
Berberidaceae	<i>Berberis darwinii</i> Hook	Michay
Cunoniaceae	<i>Caldcluvia paniculata</i> D. Don	Tiaca
Cunoniaceae	<i>Weinmannia trichosperma</i> Cav.	Tineo
Eucryphiaceae	<i>Eucryphia cordifolia</i> Cav.	Ulmo
Fagaceae	<i>Nothofagus dombeyi</i> (Mirb.) Oerst.	Coihue común
Fagaceae	<i>Nothofagus obliqua</i> (Mirb.) Oerst.	Roble
Flacourtiaceae	<i>Azara lanceolata</i> Hook. f.	Corcolén
Griselinaceae	<i>Griselinia jodinifolia</i> Taub.	Yelmo chico
Lauraceae	<i>Persea lingue</i> Nees	Lingue
Monimiaceae	<i>Laurelia sempervirens</i> (Ruiz & Pav.) Tul.	Laurel
Monimiaceae	<i>Laureliopsis philippiana</i> (Looser) Schodde	Tepa
Myrtaceae	<i>Amomyrtus luma</i> (Molina) D. Legrand & Kausel	Luma
Myrtaceae	<i>Amomyrtus meli</i> (Molina) D. Legrand & Kausel	Meli
Myrtaceae	<i>Luma apiculata</i> (DC.) Burret	Arrayán
Myrtaceae	<i>Myrceugenia planipes</i> O. Berg	Patagua de Valdivia
Myrtaceae	<i>Ugni molinae</i> Turcz.	Murta
Philesiaceae	<i>Lapageria rosea</i> (Ruiz & Pav.)	Copihue
Podocarpaceae	<i>Podocarpus nubigenus</i> Lindl.	Mañío macho
Podocarpaceae	<i>Podocarpus salignus</i> D. Don	Mañío de hoja larga
Podocarpaceae	<i>Saxegothaea conspicua</i> Lindl.	Mañío hembra
Proteaceae	<i>Aristotelia chilensis</i> Stuntz	Maqui
Proteaceae	<i>Embothrium coccineum</i> J.R. Forst. & G. Forst.	Notro
Proteaceae	<i>Genuina avellana</i> Molina	Avellano
Proteaceae	<i>Lomatia ferruginea</i> R. Br.	Romerillo
Proteaceae	<i>Lomatia dentata</i> R. Br.	Avellanillo
Proteaceae	<i>Lomatia hirsuta</i> (Lam.) Diels	Radal
Solanaceae	<i>Latua pubiflora</i> Baill.	Palo brujo
Thymelaeaceae	<i>Ovidia pillo-pillo</i> Hohen. ex Meissn.	Pillo- pillo
Verbenaceae	<i>Rhaphithamnus spinosus</i> (Juss.) Moldenke	Espino blanco
Winteraceae	<i>Drimys winteri</i> J.R. Forst. & G. Forst.	Canelo

fossil leaves from Mancera Island could be connected. The descriptions consist of easily observable macroscopic botanical parameters, following the nomenclature of Hickey (1973) and the Leaf Architecture Working Group (1999).

## RESULTS

### Stratigraphy

The base of the stratigraphic section corresponds to the fossiliferous layer and is located at the high tide sea level (Fig. 2). The section is 2.64m in depth. Seven main layers have been described from top to bottom. The youngest layer is a medium-grained sand that belongs to a terrace, which was deposited during the Holocene climate optimum. A radiocarbon date was obtained from a piece of charcoal collected in a hearth (GEOUACH-20 / TO-11482, 6240 ± 60 BP). The underlying beds belong to the Pleistocene and are composed by detrital and organic sediments (Fig. 2).

### Paleobiological content

The analyzed fossil leaves (Fig. 3) showed no signs of transport-related damage. In general terms, they were well-preserved with complete blades disposed horizontally within the laminae.

The samples were grouped into eight different categories. The eight morphotypes found in the peat of Mancera Island and the number of samples described for each morphotype is given below.

#### *Geouach-p-im-001*

Symmetrical and ovate-shaped blade, 3.3cm long and 2.3cm wide. Pinnate semi-craspedodromous venation. Slightly wavy entire margin, with an obtuse apex and cordate base (Figs. 3a and b). The description given by Hill (1991) includes the ovate shape with a cordate to lobate base and obtuse apex. The author also informs a complete fimbrial vein and weakly semicraspedodromous venation pattern. The presence of prominent rosoid teeth

on the leaf margin is reported by other authors (Dickison, 1978; Hickey and Wolfe, 1975). Based on the previously described characteristics, this morphotype can be related to the current species *Eucryphia cordifolia* Cav. A large number of recovered fruits (Fig. 3c) also belong to this species. Samples 1 to 34 may be linked to this morphotype (Fig. 3a and b).

#### *Geouach-p-im-002*

Symmetrical and ovate-shaped blade, 2.0cm long and 1.0cm wide. Dentate margin with compound teeth, acute apex, asymmetrical and acute base. The first venation order is pinnate. The second order could not be determined; however, similarities in its characteristics such as size, blade shape, tip and base, allow us to link this morphotype to the species *Nothofagus dombeyi* (Mirb.) Oerst. Gandolfo and Romero (1992) have informed an acute and asymmetrical base, dentate margin, composite teeth, and pinnate craspedodromous venation, for this species. The morphotype corresponds to sample 36 (Fig. 3d).

#### *Geouach-p-im-003*

Suborbiculate shaped blade, 3.0cm long and 2.5cm wide. Acute apex, asymmetrical and truncate base. Serrate margin with uniform compound teeth, separated by a rounded sinus. Primary teeth are concave and supported by the branch of a secondary vein. Convex secondary teeth. The venation pattern is pinnate, semi-craspedodromous. Based on these characteristics, this morphotype can be related to the leaflets of the species *Gevuina avellana* Molina (Fig. 3e, e'). Three large spherical fruits are also linked to this species (Fig. 3f). The morphotype is associated with samples 37 and 38.

The features mentioned by González et al. (2004) indicate that the leaves of *Gevuina avellana* are ovate to suborbiculate in shape, 2-6cm long and 1.5-3.5cm wide. These authors have also indicated the following characteristics: asymmetric, obtuse and truncate base; acute to obtuse apex; generally compound teeth that are sometimes simple and always uniformly separated by rounded sinuses; concave/convex primary and secondary teeth with a spinose apex.

#### *Geouach-p-im-004*

Small and asymmetrical blade, 0.9cm long and 0.5cm wide. Acute base and apex. Entire margin on the lower half of the leaf, but serrate with simple teeth on the upper half. This morphotype is represented by a single sample in a poor state of conservation, making it impossible to determine the venation. However, it is likely that this morphotype is related to the current species *Lomatia dentata* R. Br. The morphotype is associated with sample 48 (Fig. 3g).

#### *Geouach-p-im-005*

Symmetrical and elliptic shape blade, 2.7cm long and 1.4cm wide. It presents a particular reddish-brown colour. Entire margin, acute base, acute and mucronate apex. The venation pattern is pinnate brochidodromous, with a prominent primary vein (middle vein) and a notorious marginal vein. Seven pairs of slightly visible secondary veins run towards the margin and are connected by a marginal vein parallel to the margin. The first pair of lower secondary veins runs upwards, whereas the upper pair runs towards the margin. The characteristics of this morphotype are related to the species *Amomyrtus luma* and *Amomyrtus meli*. According to Landrum (1988), the distinctive main feature used to differentiate both species is the number of secondary veins and the angle of insertion of the upper and lower pairs (45°) of veins. Based on this, this morphotype can be linked to the current species *Amomyrtus meli* (Phil.) D. Legrand et Kausel. The same author describes the leaves as elliptic, ovate or lanceolate, 2.0-5.0cm long and 0.7-

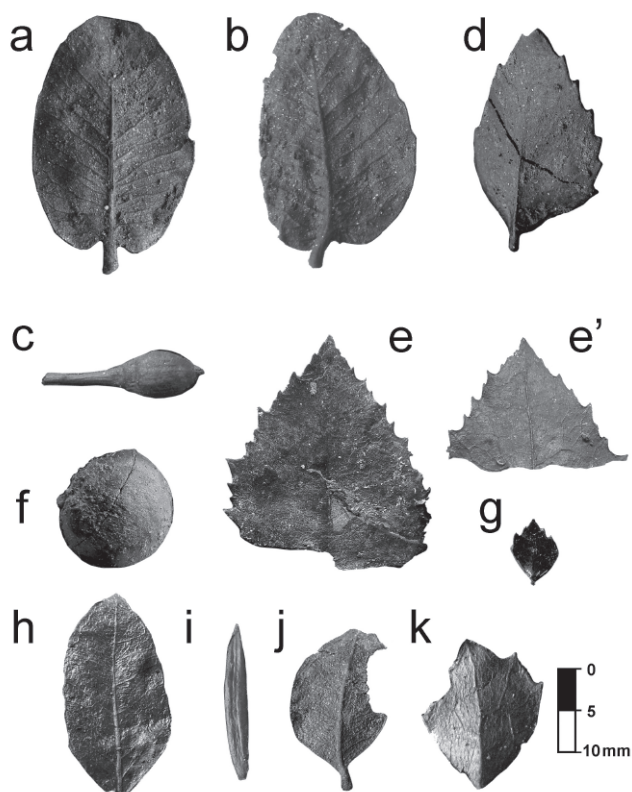


FIGURE 3 | Fossil leaves from the Mancera Island. A-B-C) *Eucryphia cordifolia* (*Geouach-p-im-001*); D) *Nothofagus dombeyi* (*Geouach-p-im-002*); E-E') *Gevuina avellana* (*Geouach-p-im-003*); G) *Lomatia dentata* (*Geouach-p-im-004*); H) *Amomyrtus meli* (*Geouach-p-im-005*); I) *Saxegothea conspicua* (*Geouach-p-im-006*); J) *Luma apiculata* (*Geouach-p-im-007*); K) *Berberis darwinii* (*Geouach-p-im-008*).

2.5cm wide, with an acute base and apex, the latter often mucronate. The morphotype is associated with sample 39 (Fig. 3h).

#### ***Geouach-p-im-006***

Linear blade, approximately 1.0cm long and 0.3cm wide. It presents an acute, mucronate apex, with a cuneate base ending in a petiole and two clearly visible stomata bands. This morphotype can be linked with the species *Saxegothaea conspicua* Lindl. The morphotype is associated with samples 40-47 (Fig. 3i).

#### ***Geouach-p-im-007***

Symmetrical and elliptic shape blade, 2.1cm long and 1.1cm wide, cuneate base. It is not possible to evaluate the characteristics of the apex because the specimen is incomplete. The leaf exhibits a pinnate brochidodromous venation pattern with a prominent primary vein, thicker than the secondary veins. The secondary veins are connected through a marginal vein. Considering the characteristics mentioned by Landrum (1988) and the present work, we have linked this morphotype to the species *Luma apiculata* (DC.) Burret. Landrum (1988) notes that *Luma apiculata* leaves are elliptic to suborbicular, less often ovate or lanceolate, 1.0-4.5cm long and 0.5-3.5cm wide, glabrous or villous along the midvein. The apex is apiculate or abruptly acuminate, terminating in an apiculum. The morphotype is associated with samples 49 and 50 (Fig. 3j).

#### ***Geouach-p-im-008***

Symmetrical and obovate shaped blade, 1.7cm long and 0.8cm wide. Slightly revolute margin with five spines. The apex is subtruncate ending in a 1mm long spine. The base of the lamina is cuneate and the venation pattern mixed pinnate craspedodromous, with two pairs of secondary veins. The foliar architecture of this morphotype allows us to relate it to the species *Berberis darwinii* Hook, described by Landrum (1999). According to this author the leaves of this species exhibit the following characteristics: ovate, sublanceolate or elliptic blade; 1.4-3.0cm long and 0.5-1.4cm wide. The margin is somewhat revolute with 1 to 4 pairs of spines. Acute to subtruncate apex terminating in a 1mm long spine. Acute, cuneate or obtuse base with a petiole. Its venation pattern is mixed craspedodromous with 2 to 4 secondary veins. The morphotype is associated with sample 35 (Fig. 3k)

## **DISCUSSION AND CONCLUSIONS**

The interglacial terrace at the sampling site was eroded to sea level, possibly due to the effect of waves in the

estuary prior to the co-seismic subsidence associated with the 1960 earthquake (Plafker and Savage, 1970) or by a river during the Llanquihue glaciation.

The fossil-bearer peat analyzed in this study belongs to the basal layer that crops out within the Valdivia Interglacial sequence on Mancera Island. This agrees with the stratigraphic position of the same peat on the west of the island, where it lies directly on the metamorphic basement (Salvadores-Cerda, 2008). The fluvial-palustrine environment represented at the basal sequence (Fig. 2) of Mancera Island, differs completely from the currently estuarine-bay conditions of the island. This idea is consistent with conifers reported by Hidalgo (2007) in nearby peats and also agrees with the hypothesis discussed by Latorre et al. (2007), suggesting that freshwater wetlands and their associated forests were widely separated from the coastline at that time.

A wood fragment recovered from the youngest peat of the interglacial sequence near Los Molinos (Fig. 1) was found to have an infinite radiocarbon age >50,000 (Poz-2728, GEOUACH 3-2003, Poznan Radiocarbon Laboratory, Instituto de Geociencias unpublished data). This age is consistent with that obtained by Arenas et al. (2005) for a basal peat 50km north of Mancera Island, and the date informed by Latorre et al. (2007). In cases like this, infinite radiocarbon ages associated to peat deposits are interpreted as equivalents of the last, or even an older interglacial (e.g. Rabassa et al., 2008; Gordillo et al., 2010).

The stratigraphic position of the Valdivia interglacial sequence, between two different till deposits, and the age suggested by the local weathering analysis agree with this last interglacial infinite radiocarbon date (Brüggen, 1944; Fuenzalida et al., 1965; Lauer, 1968; Rojas, 1990; Illies, 1970 and Arenas et al., 2005).

The Coastal Range became a refuge for vegetation during the extended glacial periods of the Pleistocene (Villagrán et al., 1995; Villagrán and Armesto, 2005). During these cold events, vegetation shifts in latitude and altitude resulted from the worsening of the weather conditions, particularly declining temperatures and advancing glaciers (Villagrán and Armesto, 2005).

Latitudinal and altitudinal changes in the vegetation patterns are especially important to interpret the presence of *Saxegothaea conspicua*. The presence of *S. conspicua* could indicate that the environmental conditions during the peat formation were similar to those existing today over 500 m a.s.l. in the Coastal Range (Oberdorfer, 1960). Moreover, the presence of North Patagonian forest taxa in the peat (*Nothofagus dombeyi* and *Saxegothaea conspicua*) could indicate a similar situation to that described by Villagrán

(2001) for the Llanquihue-Holocene transition. This author suggests that the Coastal Range between 40° and 42°S, constituted a refuge during the last glacial period for the North Patagonian forest. Simultaneously elements from the Valdivian rainforest developed between 36° and 40°S. This model of glacial dynamics (Villagrán, 2001) could explain the mixture of North Patagonian and Valdivian rainforest elements found in the fossil leaves from Mancera Island. This finding agrees with studies conducted in the same area on fossil wood from *Nothofagus* sp., *Fitzroya cupressoides*, *Pilgerodendron uviferum*, and *Saxegothaea conspicua*, which are components of the North Patagonian rainforest (Heusser, 1981), as well as *Amomyrtus luma* and *Amomyrtus meli* components of the Valdivian rainforest (Hidalgo, 2007). Such could be the survival dynamics of most hygrophilous elements during glacial-interglacial cycles. These processes may have started before the last glaciation (Llanquihue), as noted by Villagrán and Armesto (2005). On the other hand, Heusser et al. (2006) indicated a transition from the end of the Santa María Glaciation (MIS6) to the more temperate conditions of the Valdivia interglacial. It should be noted that site ODP 1234 is located in the limit between northern semi-arid and southern rainy-cool temperate climate.

The most abundant leaf morphotype in the Mancera Island peat is *Eucryphia cordifolia*. The abundance of these leaves could be explained by the dominance of this species in the Valdivian rainforest or due to its high resistance to degradation, as observed in current forests. The regeneration dynamics of *E. cordifolia* depend on the occurrence of clearings in the forest (Donoso, 1993) e.g., disturbances caused by volcanic activity during the last interglacial (Latorre et al., 2007). This idea is strengthened by the presence of *Nothofagus dombeyi*, whose regeneration dynamics are closely related to the occurrence of volcanic events (Veblen and Schlegel, 1982). Landrum (1999) notes that *Berberis darwinii* is also characteristic in areas where the forest has been altered.

The imprints of estuarine mollusks, in the layer MA-7, seem to be inconsistent with a palustrine setting for the deposition of the peat layer in a floodplain environment, locally related to a creek. However, Lambeck et al. (2002) reported that the sea level approached its present level around 130ka, peaking at about 125ka. Thus, the presence of mollusk impressions in the peat may indicate the sea's first ingression into the floodplain and wetlands, as occurred during the Holocene climate optimum in the city of Valdivia (Illies, 1970). The autochthonous detrital sediments that overlies MA-7 on Mancera Island, is composed mainly by well sorted and imbricated gravel layers, clearly deposited in a fluvial setting (Villalobos, 2005). The rate of tectonic uplift on the coast of Valdivia, about 0.7mm per year (Latorre et al., 2007), may explain the absence of marine

deposits over the basal layer containing the estuarine mollusks.

Finally, the mixture of elements present in the peat deposit of Mancera Island (~40°S) could indicate both, the refuge status of the Coast Ranges, and the transition of the vegetation from the end of the Santa María Glaciation to more temperate, interglacial conditions (Villagrán, 2001). Nevertheless we did not find vegetation evidence of full interglacial conditions.

Further paleobiological studies, with additional interpretations based on proxies such as diatoms, ostracods, pollen, and dendroecology, will offer a more complete overview about the environmental conditions of the Valdivia Interglacial, including the possible consequences of volcanism on the landscape.

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