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PHYSIOGNOMICAL ANALYSIS AND PALEOCLIMATE OF THE LIGORIO MÁRQUEZ FOSSIL FLORA, LIGORIO MÁRQUEZ FORMATION, 46º45'S, CHILE

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Introduction

Present-day rain forests of southern South America are separated from other forested regions in the continent by more than 1,000 km of arid and semiarid lands (Villagrán, 1993; Villagrán, 1995; Villagrán and Hinojosa, 1997). This vicariant distribution dates back to the development of hyperarid climates in the western margin of South America during the Plio-Pleistocene transition, resulting from the strong rain shadow produced by the Andean uplift (Villagrán, 1993; Villagrán, 1995; Villagrán and Hinojosa, 1997).

Geographic distributions of forest taxa indicate that Chilean forests have conserved ancient historical links with widely disjunct floras. Hence, the blend of phytogeographic elements that characterizes contemporary forests of south-central Chile can be traced back to the ancient Palaeofloras that had occupied southern South America during the Paleogene and early Neogene periods, under markedly different climatic and geologic settings from those of present days (Hinojosa, 2003, 2005; Hinojosa and Villagrán, 1997; Schmithüsen, 1956; Villagrán and Hinojosa, 1997). Several models (Hinojosa, 2003, 2005; Hinojosa and Villagrán, 1997; Romero, 1978, 1986; Troncoso and Romero, 1998; Villagrán and Hinojosa, 1997) have proposed a succession of Palaeofloras in southern South America during the Paleogene-Early Neogene. The paleofloras suggest that in the late Paleocene and early Eocene, the mid-latitudes in South America were covered by tropical-humid forest (Gondwanica flora). The climate then shifted towards more temperate and dry conditions, and the tropical-humid forest was replaced by subtropical-humid forest (Subtropical Gondwanica flora), and then warm-temperate forest (Mixed flora). This trend culminated in the late Eocene/Oligocene climate deterioration, a marked drop of temperature that occurred around 33-35 Mya. The climate then warmed and became wetter, culminating in the mid-Miocene climatic optimum, during which the cold-temperate dry forest of the early Oligocene was replaced by subtropical dry forest (Subtropical Neogene flora). Climatically, different temperature and precipitation scenarios can be established, such as the Paleocene-Eocene warm optimum, the Eocene-Oligocene cold event and the mid-Miocene warm climatic optimum (Zachos *et al*., 2001). All these climate scenarios are related, among other aspects, to the glacial history of Antarctica and the uplift history of the Andes (Hinojosa, 2005; Hinojosa and Villagrán, 1997).

Currently there are few quantitative data on the Tertiary terrestrial paleoclimate of southern South America. Such data are critical yet, because they can be used to better understand the evolution of the flora and fauna, to provide boundary conditions for tectonic models, and to evaluate the output of general circulation models. Under this context we made a physiognomical analysis and paleoclimate estimate based on the fossil assemblage from the Ligorio Márquez Formation of southern Chile.

Ligorio Márquez Formation

This formation is characterized by a sequence of subhorizontal succession of quartz-sandstones, 60 m thick, with interbedded shales, some carbonaceous shales, and thin coal horizons, exposed in the southern hills to the north of Laguna Los Flamencos, 25 Km south of Chile Chico (46º 46' S) (Suárez *et al*., 2000). It was assigned to the middle Eocene or earlier, most probably to the Paleocene, based on K-Ar dates of the basalt above the formation and plant fossil compositions (Suárez *et al*., 2000; Yabe *et al.*, in this volume). Plant fossils (including leaves and pollen) have been studied by Uemura (1988), Yoshida (1990) and recently by Troncoso and collaborators (2002). Yabe *et al.* (2006, in this volume) and Okuda *et al.* (2006, in this volume) provide some new information from the same formation on megafossils and palynomorphs, respectively.

The fossil assemblage show a blend of tropical-subtropical taxa dominated by Lauraceae familiy with the presence of Sapindaceae, Myrtaceae, Melastomataceae, Monimiaceae, Proteaceae, and Podocarpaceae. Based on the plant assemblage, Troncoso and collaborators (2002) suggested a strong relationship with the fossil flora of Concepción - Arauco (Paleocene-Eocene, ~37°S) of central Chile, which is characterized by warm-humid Neotropical or Gondwanic flora (Hinojosa, 2005; Romero, 1986).

Paleoclimatically, Troncoso and collaborators (2002) suggested warm and humid conditions during the depositional time; on the other hand, Hinojosa (2005), using the taxa described by Troncoso, estimated values of mean annual temperature between 24-26±2.1ºC and precipitation with values higher than 200 cm. However, the number of the considered taxa was very low to expect reliable environmental reconstruction, so in this report newly collected 55 morphotaxa were analyzed using both univariate and multivariate models. The main objective is to obtain more reliable estimate about the paleoclimate in Ligorio Márquez Formation.

Materials and methods

Leaf - Physiognomic Analyses

This type of analyses is based on the correlation between woody dicotyledonous leaf morphology and climatic variables that take into account temperature and moisture. The percentage of leaves with smooth margins, for example, is positively correlated with mean annual temperature, whereas leaf size is correlated with mean annual precipitation. This modern relationship constitutes the analogue for inferring paleoclimate based on certain association of fossil leaves (Bailey and Sinnot, 1916; Dilcher, 1973; Dolph and Dilcher, 1979; Kovach and Spicer, 1996; Sinnott and Bailey, 1915; Wiemann *et al*., 1998; Wilf, 1997; Wing and Greenwood, 1993; Wolfe, 1971, 1979, 1993).

By using the modern relation between climate and vegetation, many numeric models have been proposed for estimating temperature and moisture based on fossil leaves. These methods are based on univariate (Single Linear Regression (SLR)) and multivariate (Multiple Linear Regression (MLR) analyses, and Canonical Correspondence Analyses (CCA)) of modern leaf traits with their respective climates. The most widely used data set is that of CLAMP (Climate-Leaf Analysis Multivariate Program) developed by Wolfe (1993), based on a systematic collection of plant and climate data from North America and Asia. In this work we used the last version of CLAMP data set, called CLAMP3 SA (Hinojosa, 2005; Hinojosa *et al*., 2006; Hinojosa and Villagrán, 1997), which include data from seventeen localities from Bolivia and Chile. For our analyses we have used a more restricted version, CLAMP3B SA (161 locs.), which excluded the data from the coldest and driest localities, where attention was drawn to exclude the sites with coldest mean month temperatures <2°C (Wilf, 1997; Wing and Greenwood, 1993), values not registered for South American climates, which are mostly under oceanic influence (Schwerdtfeger, 1976).

In this paper we used SLR; MLR and CCA models to infer quantitatively the paleoclimate of

Ligorio Márquez fossil flora. The values were obtained using the equations published by Hinojosa (2005), and Gayó and collaborators (2005).

Multiple linear Regression (MLR) models are an extension of Single Linear Regression Models (SLR), in which a climatic variable can be predicted by more than one leaf physiognomic characters (Gregory-Wodzicki and McIntosh, 1996; Jacobs, 1999; Wiemann *et al*., 1998; Wing and Greenwood, 1993). CLAMP, on the other hand, uses Canonical Correspondence Analysis (CCA) to estimate climate parameters based on 31 woody angiosperm leaf characters (Gregory-Wodzicki, 2000; Herman *et al*., 1996; Wiemann *et al*., 1998; Wolfe, 1993, 1995). CCA ordinations were performed using CANOCO v.4 for Windows (ter Braak and Smilauer, 1998). We applied CCA to eight different climate variables as per the CLAMP3B SA data set. The environmental variables used in the CCA analysis were: mean annual temperature (MAT); cold-month mean temperature (CMMT); warm-month mean temperature (WMMT); length of the growing season, i.e. those month with mean temperature (LGS); mean growing season precipitation (MGSP); mean monthly growing season precipitation (MMGSP); precipitation of the three consecutive wettest month (or Mean Precipitation of Wet Season, MPW). and precipitation of the three consecutive driest months (or Mean Precipitation of Dry Season, MPD).

The materials were collected at the "Mina Ligorio Márquez" in the summer of 2004. Fossil plants were cleaned by hand and photographed with digital camera. Morphotypes were classified by both leaf architectonic venation pattern and morphology (Hickey, 1974).

Results

Table 1 shows the morphological score obtained for 55 morpho-taxa, which include 36 new taxa in compared with the previous physiognomic analysis (Hinojosa, 2005). Table 2 shows the results of both univariate and multivariate models, and Table 3 shows the estimate for each environmental variable considered. According to the univariate models, the estimate obtained for mean annual temperature was 19 (± 2.1) ºC; while multivariate models predicted values from 16.9 (± 2.1) ºC and 19.5 (± 2.1) ºC (Table 3). For cold-month mean temperature and warm-month mean temperature, multivariate models estimated values between 10.3 (± 3.7) ºC - 13.6 (±3.8) ºC, and 23.6 (±3.2) ºC - 24.5 (±3.3) ºC, respectively, with a temperature range of 13.4 ºC - 10.8 ºC (Table 3). According to the data, the length of the growing season was permanent in Ligorio Márquez, just CCA model showed a value of 10 (±1) month; while, the lowest CMMT obtained by CCA gave a value of 10 ºC in the limit of the definition of growing season (Table 3).

Mean annual precipitation obtained by univariate model (Table 2) was a value of 157 (+101.8; -61.8) cm (Table 3). Mean growing season precipitation estimate by CCA and MLR models were 153.7 (± 42.6) cm and 169.4 (±58.2) cm, respectively (Tables 2 and 3). Finally, Mean Precipitation of Dry Season values oscillated between 39.7 (±15.3) cm and 29.1 (±15.6) cm (Tables 2 and 3). Thus, precipitation during MPD was practically equivalent to a quarter of the annual precipitation values (Table 3).

Discussion and conclusion

The higher number of morpho-taxa considered in this study allowed a more reliable estimate of the environmental conditions where Ligorio Márquez fossil flora was developed. All variables associated with temperature exhibited values lower than the previous data published (e.g. Hinojosa, 2005, table 3). On the other hand, values associated with precipitation variables did not show statistical differences from those published by Hinojosa (2005, table 3).

According to Di Castri and Hajec (1976), the present location of Ligorio Márquez exhibits the mean annual temperature oscillating between 7.3 °C and 11.5 °C, and the mean annual precipitation between 57.2 cm and 192.5 cm. The lowest precipitation values correspond to those of Balmaceda (45º54'S, 71º43'W) and Chile Chico (46º36'S, 71º43'W) meteorological stations, which are placed under rain shadow conditions of mountain range, while the higher values correspond to those of Cabo

Raper station (46º50'S, 73º36'W) located near the Pacific coast with direct influence of humid westerlies. All the above stations exhibit a length of the growing season less than 7 month (range 7-3).

The paleoclimatic estimates obtained for LM, suggested a MAT difference >8°C compared to the current temperature; the precipitation amount (>150 cm) similar to that recorded in the area under influence of humid westerlies; and a length of growing season 10-12 month.

When we compare the estimates from Ligorio Márquez with those from other Paleocene/Eocene or Eocene floras (Table 3), previous estimate values for LM (Hinojosa, 2005) were in accordance with those of the paleofloras under warm and humid conditions, for example, subtropical fossil floras of Concepción - Arauco and Caleta Cocholgue of central Chile (~ 37°S; Hinojosa 2005; Gayó *et al.* 2005). However, new estimates for LM in this study are comparable to those of Laguna del Hunco and Rio Pichileufu floras of Argentine Patagonia (~ 42 °S; Wilf *et al.* 2005), rather locating LM floras cooler than the central Chile floras (Table 3). On the other hand, high precipitation values obtained suggest very wet conditions in LM, probably with rainfall throughout the year (Table 3). These warm and humid conditions estimated in Ligorio Márquez, support the idea that subtropical climate extended at least to the location of this fossil flora during the early Paleogene, under a very low equator-pole temperature gradient, as have been suggested in earlier studies (Hinojosa 2005; Hinojosa and Villagrán 1997; Romero, 1978; Troncoso and Romero 1997).

According to our physiognomical analysis, we can conclude that Ligorio Márquez flora would represent a subtropical, frost-free and humid vegetation, which in accordance with that postulated by Troncoso and collaborators (2002) and Uemura (1988). The vegetation was probably established at southern periphery of the subtropical climatic belt in South America during early Paleogene. This condition favors the absence of extensive ice sheet in Antarctica, and the different obliquity of the earth axis during the early Cenozoic (Hinojosa and Villagrán, 1997; Sewall and Sloan, 2004).

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Table 1. Morphological score of the morphotaxa used in this study. Sp 1-55 Morphotaxa. Leaf characters according to Wolfe (1993) and Herman and collaborators (1996). Column Average: Average score (in %) used in the physiognomic models.

	Taxa	Sp 1	Sp 2	Sp 3	Sp 4	Sp 5	Sp 6	Sp 7	Sp 8	Sp 9	Sp 10	Sp 11	Sp 12	Sp 13	Sp 14	Sp 15	Sp 16	Sp 17	Sp 18
Form	**Lobed**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Teeth	**no teeth**	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Regular	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Closed	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	rounded	0.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Acute	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	compose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Size	**nanophyll**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	leptophyll 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	leptophyll 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	microphyll 1	0	0	0.5	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	microphyll 2	1	1	0.5	0	1	1	0.5	1	0	1	1	0	0	1	0	0	1	1
	microphyll 3	0	0	0	0	0	0	0.5	0	0	0	0	1	1	0	0	1	0	0
	mesophyll 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	mesophyll 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	mesophyll 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apex	**Emarginate**	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	
	rounded	0	0	0	1	0	0	0	0	0	0		0	0	1	0	0	0	
	acute	1	1	0	0	0	1	1	1	0	1		0	1	0	1	1	0	
	attenuate	0	0	1	0	0	0	0	0	1	0		0	0	0	0	0	1	
Base	**cordate**		0	0	1	0	0	0		0	0	0	0	0	0	0	0	0	0
	rounded		1	0	0	0	0	0.5		0	0	0	0	0	0	0	0	0	0
	acute		0	1	0	1	1	0.5		1	1	1	1	1	1	1	1	1	1
L/W Ratio	**<1:1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1-2:1	0	0	0	1	0	0	0.5	0	0	0	0	0	0	0	0	1	0	0
	2-3:1	1	1	0	0	1	1	0.5	1	0	0	1	1	1	1	0	0	0.5	0
	3-4:1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	0.5	0
	>4:1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Shape	**obovate**	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	elliptic	1	1	0.5	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1
	ovate	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0

Table 1. (continuation).

	Taxa	Sp 19	Sp 20	Sp 21	Sp 22	Sp 23	Sp 24	sp 25	Sp 26	Sp 27	Sp 28	Sp 29	Sp 30	Sp 31	Sp 32	Sp 33	Sp 34	Sp 35	Sp 36
Form	**lobed**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Teeth	**no teeth**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	regular	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	closed	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	rounded	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	acute	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	compose	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Size	**nanophyll**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	leptophyll 1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	leptophyll 2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	microphyll 1	**0**	**0**	**0**	**0**	**1**	**0.5**	**0.5**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0.33**	**0**	**1**
	microphyll 2	**1**	**1**	**1**	**1**	**0**	**0.5**	**0.5**	**1**	**1**	**1**	**0.5**	**0.5**	**0**	**1**	**1**	**0.33**	**0**	
	microphyll 3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**
	mesophyll 1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.33**	**1**	**0**
	mesophyll 2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	mesophyll 3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Apex	**Emarginate**	**0**	**0**	**0**		**0**	**1**	**0**			**0**	**1**		**0**	**0**	**0**	**0**	**0**	
	rounded	**0**	**0**	**0**		**0**	**1**	**0.5**			**0**	**1**		**0**	**0**	**0**	**0**	**1**	
	acute	**1**	**1**	**0**		**1**	**0**	**0.5**			**1**	**0**		**1**	**1**	**1**	**1**	**0**	
	attenuate	**0**	**0**	**1**		**0**	**0**	**0**			**0**	**0**		**0**	**0**	**0**	**0**	**0**	
Base	**cordate**	**0**	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	
	rounded	**0**	**0**	**0**	**0**		**0.5**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	
	acute	**1**	**1**	**1**	**1**		**0.5**	**1**		**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	
L/W Ratio	**<1:1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	1-2:1	**0**	**0**	**0**	**0.5**	**0**	**1**	**0.5**	**0**	**1**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
	2-3:1	**0**	**0**	**0.5**	**0.5**	**1**	**0**	**0.5**	**0**	**0**	**1**	**0.5**	**0.5**	**1**	**1**	**0**	**0**	**0**	**0**
	3-4:1	**1**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0**	**0**	**1**	**0.5**	**0**	**0**
	>4:1	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0**	**0**
Shape	**obovate**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0.5**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	elliptic	**1**	**0**	**1**	**0.5**	**0**	**0.5**	**0.5**	**0**	**1**	**0**	**1**	**0.5**	**1**	**0**	**0**	**1**	**0**	**1**
	ovate	**0**	**1**	**0**	**0.5**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0**	**1**	**1**	**0**	**1**	**0**

Table 1. (continuation).

	Taxa	Sp 37	Sp 38	Sp 39	Sp 40	Sp 41	Sp 42	Sp 43	Sp 44	Sp 45	Sp 46	Sp 47	Sp 48	Sp 49	Sp 50	Sp 51	Sp 52	Sp 53	Sp 54	Sp 55	Average
Form	**lobed**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**11**
Teeth	**no teeth**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**62**
	regular	**0**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**33**
	closed	**1**	**0.5**	**1**	**1**	**0.5**	**0**	**1**	**0**	**0**	**0.5**	**1**	**0.5**	**1**	**1**	**0.5**	**1**	**1**	**1**	**0**	**26**
	rounded	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0**	**0.5**	**0**	**0**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0**	**0.5**	**0.5**	**0.5**	**0**	**15**
	acute	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0**	**0.5**	**1**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**0.5**	**0.5**	**0.5**	**1**	**23**
	compose	**0**	**0**	**0**	**0**	**0.5**	**0**	**0.5**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**9**
Size	**nanophyll**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	leptophyll 1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	leptophyll 2	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
	microphyll 1	**0**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0.33**	**0**	**18**
	microphyll 2	**0**	**1**	**0**	**0.5**	**0.5**	**0**	**0.5**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0.33**	**0.33**	**1**	**55**
	microphyll 3	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0.5**	**1**	**0**	**0**	**0**	**0.33**	**0.33**	**0**	**15**
	mesophyll 1	**1**	**0**	**0.5**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0.33**	**0**	**0**	**9**
	mesophyll 2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
	mesophyll 3	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
Apex	**Emarginate**		**0**	**0**		**0**			**0**	**0**	**0**			**0**	**0**		**1**	**0**	**0**	**0**	**7**
	rounded		**0**	**0**		**0**			**0**	**0**	**0**			**1**	**0**		**0**	**0**	**0**	**0**	**16**
	acute		**1**	**0.5**		**0.5**			**0**	**1**	**1**			**0**	**0**		**0.5**	**0.5**	**0**	**1**	**57**
	attenuate		**0**	**0.5**		**0.5**			**1**	**0**	**0**			**0**	**1**		**0.5**	**0.5**	**1**	**0**	**22**
Base	**cordate**				**0**	**0**	**0**	**0**	**0**	**0**	**0**			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**
	rounded				**0**	**0**	**0**	**0**	**0**	**0**	**1**			**0**	**1**	**0**	**0**	**0.5**	**0**	**0**	**14**
	acute				**1**	**1**	**1**	**1**	**1**	**1**	**0**			**1**	**0**	**1**	**0**	**0.5**	**1**	**0**	**79**
L/W																					
Ratio	**<1:1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	1-2:1	**0**	**1**	**0.5**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0.5**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**22**
	2-3:1	**1**	**0**	**0.5**	**0.5**	**1**	**0**	**1**	**1**	**0**	**0**	**0.5**	**0**	**0**	**0**	**1**	**0**	**0.33**	**0**	**0**	**42**
	3-4:1	**0**	**0**	**0**	**0.5**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0.5**	**0.33**	**0.5**	**0**	**23**
	>4:1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.5**	**0.33**	**0.5**	**1**	**9**
Shape	**Obovate**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**
	Elliptic	**1**	**1**	**1**	**0.5**	**1**	**1**	**1**	**0**	**0**	**0.5**	**0**	**0**	**1**	**0**	**0**	**0.5**	**1**	**1**	**1**	**60**
	Ovate	**0**	**0**	**0**	**0.5**	**0**	**0**	**0**	**1**	**1**	**0.5**	**1**	**1**	**0**	**1**	**1**	**0.5**	**0**	**0**	**0**	**28**

Table 2. Equations used to estimate values of environmental variables MAT: Mean annual temperature; CMMT: Cold-month mean temperature; WMMT: Warm-month mean temperature; GSL: length of the growing season; MGSP: Mean growing season precipitation and MPD: precipitation of the three consecutive driest months (or Mean Precipitation of Dry Season). 1.- Equations derived by Gayó and collaborators (2005). 2 and 3.- Equations derived by Hinojosa (Hinojosa 2005; Hinojosa and Villagrán 2005). MATv; CMMTv; WMMTv; GSLv; MGSPv; MPDv are environmental vectors from CCA analysis. All equations are significant with p< 0.001. Data set CLAMP3BSA (161 loc.) from Hinojosa 2005; Hinojosa and Villagrán 2005 and Hinojosa *et al.* 2006.

Parameter	Equations	SE	R^2
MAT	[1] MAT=1.8116+(0.24*% no teeth)+(0.06795*L:W 2-3:1)	2.1°C	0.9
	[2] MAT=3.25+0.24*% no teeth	2.1°C	0.9
	[3] $MAT=-8.1+exp^{(3.1+(0.24*MATvector))}$	2.1 °C	0.9
CMMT	[1] CMMT= -12.1013+(0.3182*% no teeth)+(0.1433*L:W2-3:1)	3.8°C	0.8
	[2] $CMMT= -35.2+exp^{(3.7+(0.2CMMTv))}$	3.8°C	0.8
WMMT	[1] WMMT=16.9076+(0.1218*% no teeth)+(0.1433*nanophylla)	3.2°C	0.5
	[2] $WMMT=23.6+4.42*WMMTv-0.4WMMTv^2$	3.3°C	0.5
GSL	[1] GSL=2.5238+(0.09765*% no teeth)+(0.08584*L:W3-4:1)+(0.02334*L:W 2-3:1)	1.2 month	0.83
	[2] $GSL=-14.2108+exp^{3.1147+(0.1098*GSLv)}$	1.2 month	0.83
MAP	[2] LnMAP=1.6355+0.492*MLnA	Ln 0.5 cm	0.6
MGSP	[1] MGSP=-180.5805+(4.2098*% L:W 2-3:1)+(2.8854*% elliptic)	58.2 cm	0.6
	[2] $MGSP=75.5*exp^{(0.53*MGSPv)}$	42.6 cm	0.8
MPD	[1] MPD=-47.5145+(1.032*% elliptic)+(0.9776*% microphylla 3)	15.6 cm	0.6
	[2] $MPD=17.5*exp^{(0.7*MPDv)}$	15.3 cm	0.6

Table 3. Environmental estimate base on physiognomical analysis from southern South American fossil floras. LM: Ligorio Márquez; LC: Concepción – Arauco; CC: Caleta Cocholgüe; LH: Laguna del Hunco; RP: Rio Pichileufu. 1: Data from this study; 2: Data from Hinojosa (2005); 3: Data from Gayó *et al.* (2005); 4: Data from Wilf *et al*. (2005). a. Multiple linear Regression; b. Single linear Regression and c. Canonical correspondence analysis

Parameter	L.M [1]	L.M [2]	LC [2]	CC[3]	LH [2]	RP [2]	LH [4]	RP [4]
MAT (°C)	19.5[a] ±2.1	25.7[a] ±2.1	22.8[a] ±2.1	25.5[a] ±2.1	19.6[a] ±2.1	20.9[a] ±2.1	-----	-----
	19.0[b] ±2.1	25.9[b] ±2.1	21.6[b] ±2.1	22.8[b] ±2.1	19.3[b] ±2.2	20.6[b] ±2.1	16.6[b] ±2.0	19.2[b] ±2.4
	16.9[c] ±2.1	24.7[c] ±2.1	21.9[c] ±2.1	19.3[c] ±2.1	17.5[c] ±2.1	18.3[c] ±2.1	-----	-----
CMMT (°C)	13.6[a] ±3.8	21.5[a] ±3.8	18.7[a] ±3.8	22.4[a] ±3.8	13.7[a] ±3.8	15.4[a] ±3.8	-----	-----
	-----	-----	-----	-----	-----	-----	-----	-----
	10.3[c] ±3.8	20.1[c] ±3.8	16.6[c] ±3.8	13.2[c] ±3.8	10.8[c] ±3.8	11.8[c] ±3.8	-----	-----
WMMT (°C)	24.5[a] ±3.2	27.7[a] ±3.2	25.7[a] ±3.2	27.0[a] ±3.2	24.6[a] ±3.2	25.2[a] ±3.2	-----	-----
	------	-----	-----	-----	-----	-----	-----	-----
	23.6[c] ±3.3	26.3[c] ±3.3	25.3[c] ±3.3	22.6[c] ±3.2	24.6[c] ±3.3	23.1[c] ±3.3	-----	-----
RANGE (°C)	10.8[a]	6.2[a]	7.0[a]	5.4[a]	10.9[a]	10.8[a]	-----	-----
	------	----	-----	-----	-----	-----	-----	-----
	13.3[c]	6.2[c]	9.3[c]	9.2[c]	13.8[c]	11.3[c]	-----	-----
GSL (months)	12.0[a] ±1.2	12[a] ±1.2	12[a] ±1.2	12.0[a] ±1.2	10[a] ±1.2	12[a] ±1.2	-----	-----
	-----	-----	-----	-----	-----	-----	-----	-----
	10.0[c] ±1.2	12[c] ±1.2	12[c] ±1.2	11.0[c] ±1.2	10[c] ±1.2	10[c] ±1.2	-----	-----
MAP (cm)	-----	-----	-----	-----	-----	-----	-----	-----
	157[b] +101.8 -61.8	152.9[b] +99.3 -60.2	202.9[b] +131.7 -79.9	263[b] +104.3 -171.9	193.7[b] +125.8 -76.3	166.3[b] +108 -65.5	114[b] +49.1 -34.3	-----
	-----	-----	-----	-----	-----	-----	-----	-----
GSP (cm)	169[a] ±58.2	168.5[a] ±58.2	172.1[a] ±58.2	190[a] ±58.2	120.5[a] ±58.2	130.5[a] ±58.2	-----	-----
	153.7[b] ±42.6	296.6[b] ±42.6	-----	-----	-----	-----	-----	-----
	-----	-----	364.6[c] ±42.6	268[c] ±42.6	223.7[c] ±42.6	167.3[c] ±42.6	-----	-----
MPD (cm)	29.1[a] ±15.6	39.2[a] ±15.6	33[a] ±15.6	30.0[a] ±15.6	21.5[a] ±15.6	31.3[a] ±15.6	-----	-----
	39.7[b] ±15.3	-----	-----	-----	-----	-----	-----	-----
	-----	45.0[c] ±15.3	68.2[c] ±15.3	58[c] ±15.3	49.8[c] ±15.3	34.3[c] ±15.3	-----	-----
No. Taxa	55	19	94	40	30	120	131	39