Quaternary Research **58**, 130–138 (2002)
doi:10.1006/qres.2002.2353

Paleoenvironmental Changes in the Semiarid Coast of Chile (~32°S) during the Last 6200 cal Years Inferred from a Swamp–Forest Pollen Record

Antonio Maldonado[1] and Carolina Villagrán

Laboratorio de Palinología, Departamento de Biología, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago, Chile

E-mail: amaldona@icaro.dic.uchile.cl

Received October 3, 2001; published online August 22, 2002

Pollen analysis of two sediment records from a coastal swamp forest site in the Chilean semiarid region (31°50′S; 71°28′W) shows an alternation of dry and wet phases during the past ~6100 cal yr B.P. The most prominent vegetation changes occur at ~4200 cal yr B.P., with the expansion of the swamp forest taxa *Luma chequen* and *Escallonia sp.*, followed by a regression of the forest beginning at ~3200 cal yr B.P. and ending with its replacement by a xerophytic scrub, between ~1800 and 1300 cal yr B.P. The swamp forest reexpanded after ~1300 cal yr B.P. and persisted, with minor variation, until the present. We interpret the establishment of the swamp forest at the study site to be the result of a rising watertable in response to increased rainfalls from ~4200 cal yr B.P. onward. Our results indicate that in north-central Chile the second half of the Holocene was climatically more variable than previously thought, suggesting significant changes in the position and/or intensity of the westerlies wind belt and possibly in the frequency of El Niño–Southern Oscillation events.

Key Words: **Chile; Holocene; environmental change; pollen; paleoclimate.**

INTRODUCTION

The semiarid district of Chile (Norte Chico, 30°–32°S) represents a vegetation and climatic transition between the Mediterranean-climate region and the Atacama Desert. This zone is characterized by dry summers and relatively wet winters with sporadic drought intervals (VanHusen, 1967). The extreme interannual variability of rainfall in Norte Chico is strongly associated with El Niño–Southern Oscillation (ENSO) events, with pluviometric excesses, and temperature increases, during the negative phases of the Southern Oscillation (El Niño), and the opposite conditions during the positive phase (La Niña; Aceituno, 1988). The transitional character of climatic conditions confers greater relevance to paleoclimatic studies in this region, because we can predict a greater sensibility to past changes in climate and vegetation (Ota and Paskoff, 1993; Villagrán and Varela, 1990; Villa-Martínez and Villagrán, 1997). The existence of scattered swamp forests in the coastal region of the Norte Chico allows for the accumulation of organic sediments, thus offering an excellent opportunity for paleoenvironmental studies, through the stratigraphic analysis of fossil pollen or other paleoenvironmental indicators in the sediments. Previous studies of coastal swamp forests in central Chile and Norte Chico (31°–33°S) (Villagrán and Varela, 1990; Villa-Martínez and Villagrán, 1997) have documented important vegetation and climatic fluctuations during the Holocene and emphasized the very recent onset of the wet climatic conditions that originated the swamp forest at ~2000 cal yr B.P., in the case of Quintero swamp forest (32°47′S; 71°30′W). Additionally, studies of paleosols in a broader region of Norte Chico (Veit, 1996), and limnological and geomorphological studies in the Andes of Norte Chico (Grosjean *et al.*, 1997, 1998) provide evidence for pronounced climatic variability during the Holocene. Such variability can be associated with changes in the influence of the westerly winds in this region.

However, there are important regional differences in the number, age, and frequency of wet and dry events recorded during the Holocene. In this work we seek to establish more precisely the paleoclimatic evolution during the second half of the Holocene in the coast of the semiarid region of Norte Chico (31°50′S) by examining fossil pollen assemblages obtained from swamp forest sediments.

STUDY AREA

Swamp forests, dominated by Myrtaceae trees and shrubs species, are distributed along the Chilean coast between 30° and 36°30′S (Fuenzalida, 1965). They are a discontinuous vegetation formation, restricted to hygrophilous habitats subjected to periodic or permanent flooding. On the coast of Los Vilos (31°50′S), we identified seven gullies bearing swamp forests (Fig. 1), all of them located on the gentle relief of the coastal plains, associated with small hydrographic basins. The zone of groundwater recharge is located in the foothills of the Coastal Range bordering the coastal plain. Groundwater recharge, which determines

[1] To whom correspondence should be addressed.

0033-5894/02 $35.00

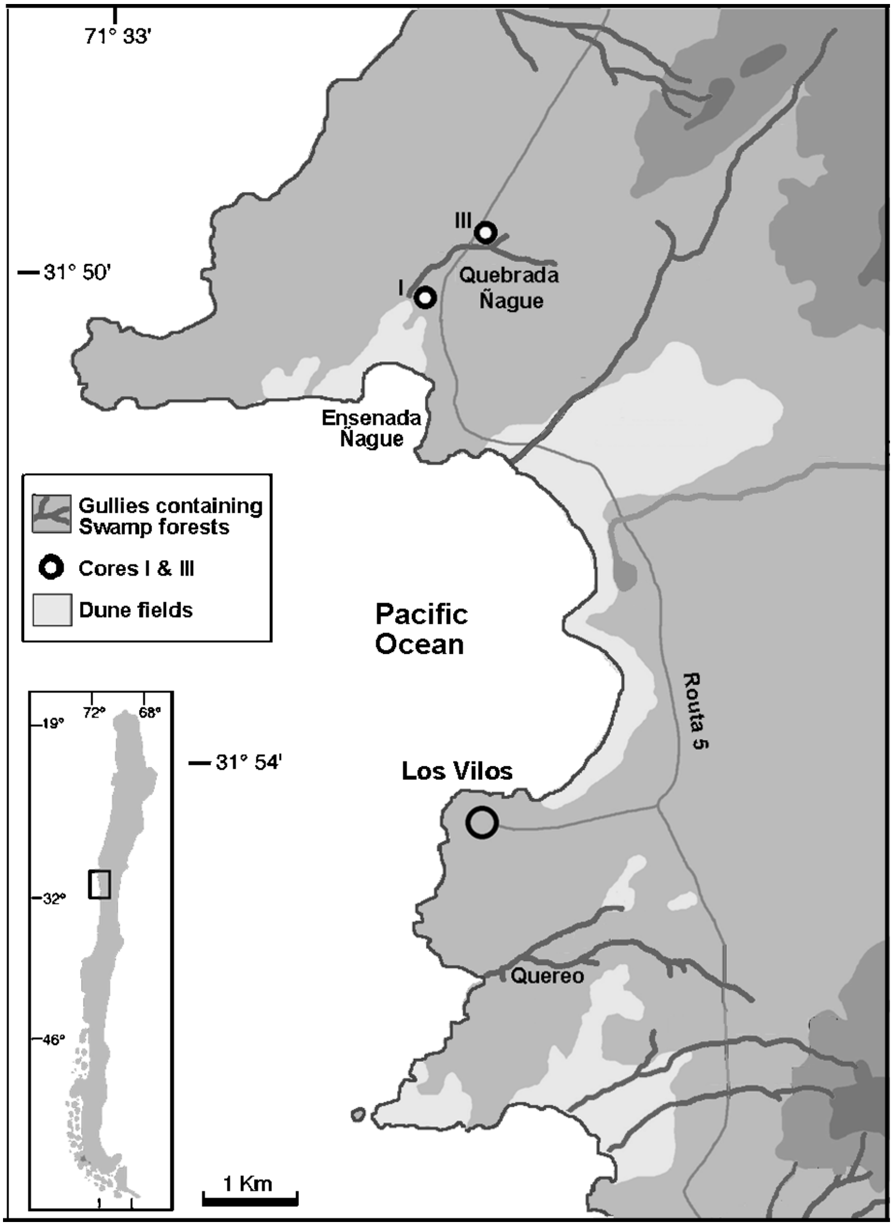

FIG. 1. Map of the study area showing the geographic location of the sediment profiles obtained for pollen analysis and the gullies containing swamp forests in the area of study. 200-m elevation zones are shaded.

the hydrology of these forests, depends to a large extent on local rainfall. Therefore, it is expected that the interannual variability in precipitation that characterizes Norte Chico will strongly influence the hydrology of these coastal swamp forests. Some of these forests are associated with Holocene swales that developed after the last marine regression, which in our study area has been dated between ~6800 and 5700 cal yr B.P. (Caviedes, 1972; Ota and Paskoff, 1993; Varela, 1981).

The dominant vegetation in the coastal semiarid region is the Jaral Costero. It corresponds to an open scrub, dominated by *Baccharis vernalis* and *Schinus polygama*. Other vegetation formations present in the coastal plain are sand dune and salt marsh herbaceous vegetation, occurring near low energy water courses. Trees dominate the vegetation in humid gullies, forming a dense woodland that contrasts strongly with the sparse cover of Jaral Costero. Discrete swamp forest patches develop in restricted zones of these gullies, in areas where the watertable rises close to the surface (Varela, 1981). Dominant species in these swamp forests are *Luma chequen, Drimys winteri*, and *Escallonia revoluta*. Other woody formations present in these gullies are sclerophilous forests and mixed shrubland, with deciduous and evergreen elements.

TABLE 1
Radiocarbon Ages, Calibrated "Calendar" Ages, and δ ^{13}C

Site	Depth, cm	Age, ^{14}C yr B.P.	Age, cal yr B.P.	Age, max & min range cal yr B.P.	Age, midpoint cal yr B.P.	δ ^{13}C‰	Material	Laboratory no.
Ñague I	42–46	1400 ± 50	1296	1381–1254	1296	−29.4	Bulk	Beta-118854
Ñague I	47–48	2480 ± 35	2704-2635-2481	2730–2357	2635	−26.3	Bulk	NSRL-11172
Ñague I	56–57	3030 ± 35	3214	3343–3081	3214	−27.2	Bulk	NSRL-11131
Ñague I	58–65	3810 ± 40	4221-4207-4153	4347–4003	4207	−28.4	Bulk	Beta-118855
Ñague I	88–89	5340 ± 70	6173-6136-6110	6290–5935	6136	−25.7	Bulk	NSRL-11052
Ñague III	66–68	5200 ± 40	5935	6162–5902	5935	−25.8	Bulk	NSRL-11052

* Errors for ages are all 2 sigma.

MATERIAL AND METHODS

We obtained three sediment cores from the swamp forest known as Ñague (Fig. 1), using a Dachnowsky soil corer. Pollen analysis was carried out in two cores, Ñague I and III, obtained from the drainage and source of the gully respectively. The samples consisted of 3 cm^3 of sediment and were taken at intervals that fluctuated between 2 and 5 cm, along the stratigraphic columns. The chemical processing and the microscopic pollen inventory followed conventional palinological methods (Faegri and Iversen, 1989). Tablets of *Lycopodium* (Stockmarr, 1971) were used to calculate the pollen concentrations. The zoning of the diagrams was defined according to the major pollen changes and the Coniss ranking (Grimm, 1987). Vegetational interpretation of fossil pollen spectra was accomplished on the basis of current pollen–rain analogues of the different plant formations present in the study area (Maldonado, 1999). Considering that the studied swamp forest is an azonal plant formation immersed in a coastal shrubby matrix, any expansion of the forest indicator taxa is interpreted as a moisture raise, while the withdrawal of those indicators and an expansion of the shrub indicator taxa are interpreted as reduced moisture. Plant nomenclature follows Marticorena and Quezada (1985).

The core Ñague I was obtained in the southern end of the swamp forest, near the coastal drainage of the gully (Fig. 1). We obtained five radiocarbon dates for this core (Table 1, Fig. 2). All the dating was done on humic acids from full samples of sediments, because it was not possible to obtain organic macroscopic remains to date. Nevertheless, while observing the sediments on the dissecting scope (10×), there were neither algal remains nor carbonate evidence as results of the hydrochloric acid treatment of the sediments. This, together with the close fitting between the obtained dates, makes us believe that a "hard-water" effect is unlikely. Possibly, the age of the most recent sample, 46–42 cm in the profile (1400 ± 50 ^{14}C yr B.P., Beta 118854, Table 1), corresponded only to the upper fraction of the sample (42 cm), since its organic matter content was very low, except for the top. The great difference in age between this sample and that of the next sample in the profile (2480 ± 35 ^{14}C yr B.P., 47–48 cm; Table 1), and the sharp contact between clay and organic limestone observed at 47-cm depth led us to postulate a hiatus in sediment deposition ~2500–1900 ^{14}C yr B.P. The core Ñague III was obtained in the northeast end of the forest, east of Route 5 (Fig. 1). We obtained ^{14}C a date for the lowest portion of this column (Table 1).

Additionally, under a dissecting scope, macroscopic remains of plant material were recovered from the same stratigraphic levels of the sediment column Ñague I.

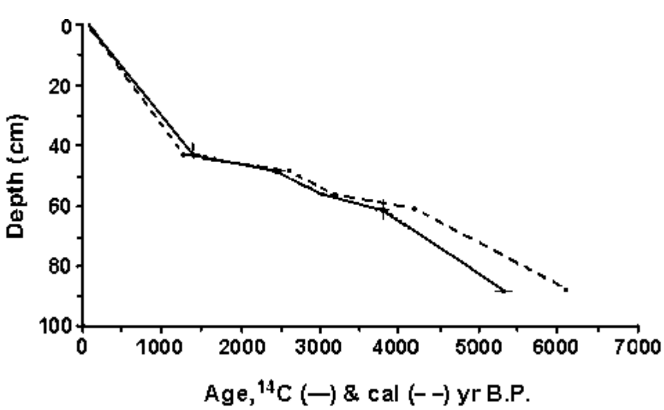

FIG. 2. Age versus depth for the column Ñague I. Bars represent two standard deviations for radiocarbon dates.

RESULTS

Core Ñague I

Zone Ñ-1A (~6100–5300 cal yr B.P.) is characterized by a predominance of nonarboreal pollen, mainly Asteraceae (ca. 46%), Poaceae (ca. 49%), and Apiaceae (ca. 33%), containing also pollen of halophytes (Frankeniaceae and Chenopodiaceae), and high proportions of marshy taxa (Cyperaceae ca. 42% and *Typha* ca. 9%; Fig. 3).

Zone Ñ-1B (~5300–4200 cal yr B.P.) contains small proportions of *Luma chequen* (<7%) and nonarboreal pollen (Frankeniaceae and Chenopodiaceae), which increase in abundance toward the upper end of the zone (Fig. 3).

Zone Ñ-2A (~4200–3200 cal yr B.P.) shows a marked increase in the abundance of arboreal pollen, mainly *Luma chequen* (21–54%) and *Escallonia* (7–24%; Fig. 3).

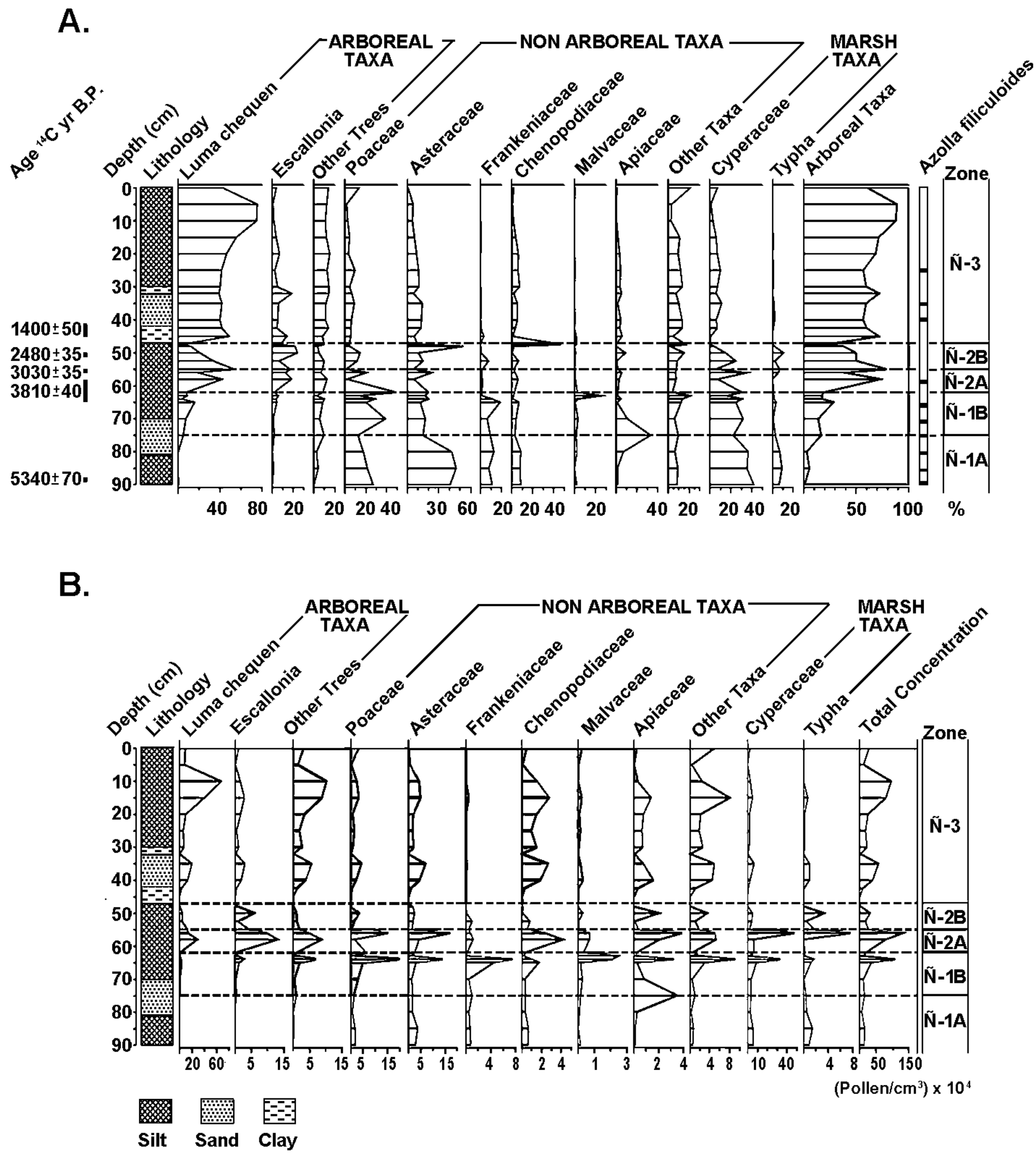

FIG. 3. A. Stratigraphy and percentage pollen diagram of Ñague I profile. Radiocarbon dates are shown on the left side of the diagram. B. Pollen concentration diagram.

Zone Ñ-2B (∼3200–2600 cal yr B.P.) shows a pronounced decrease in the percentages and concentration of arboreal pollen and, toward the end of the zone, most of the taxa (Fig. 3).

Zone Ñ-3 (∼1800–0 cal yr B.P) is characterized at its base by a noticeable and short-lived increase in the percentages of Chenopodiaceae, reaching up to 50%. A subsequent decline in the abundance of Chenopodiaceae pollen is matched by an associated increased abundances of woody taxa (ca. 56%). The common arboreal taxon *Luma chequen* maintains a high and relatively stable abundance until the present. Pollen concentrations of all taxa show strong fluctuations, probably related to lithological changes. A decrease in the abundance of arboreal pollen and a mild increase in that of Poacae is observed near the surface, probably due to anthropogenic disturbance (Fig. 3).

Observation of sediments from the Ñague I column at 20× permitted identification of macroremains (sporocarps) of *Azolla filiculoides*, a small aquatic fern, at depths of 90–65, 58, 40–35, and 25 cm. The greatest abundance of this fern was recorded between 90 and 65 cm, corresponding to zone Ñ-1, particularly in the 65 cm level (23 sporocarps; Fig. 3). The presence of *Azolla filiculoides* is an indicator of a low-energy depositional environment when these sediments were deposited.

Core Ñague III

Zone Ñ-1 (65–45 cm depth) is characterized by the dominance of nonarboreal pollen, mainly Apiaceae (ca. 60%) and

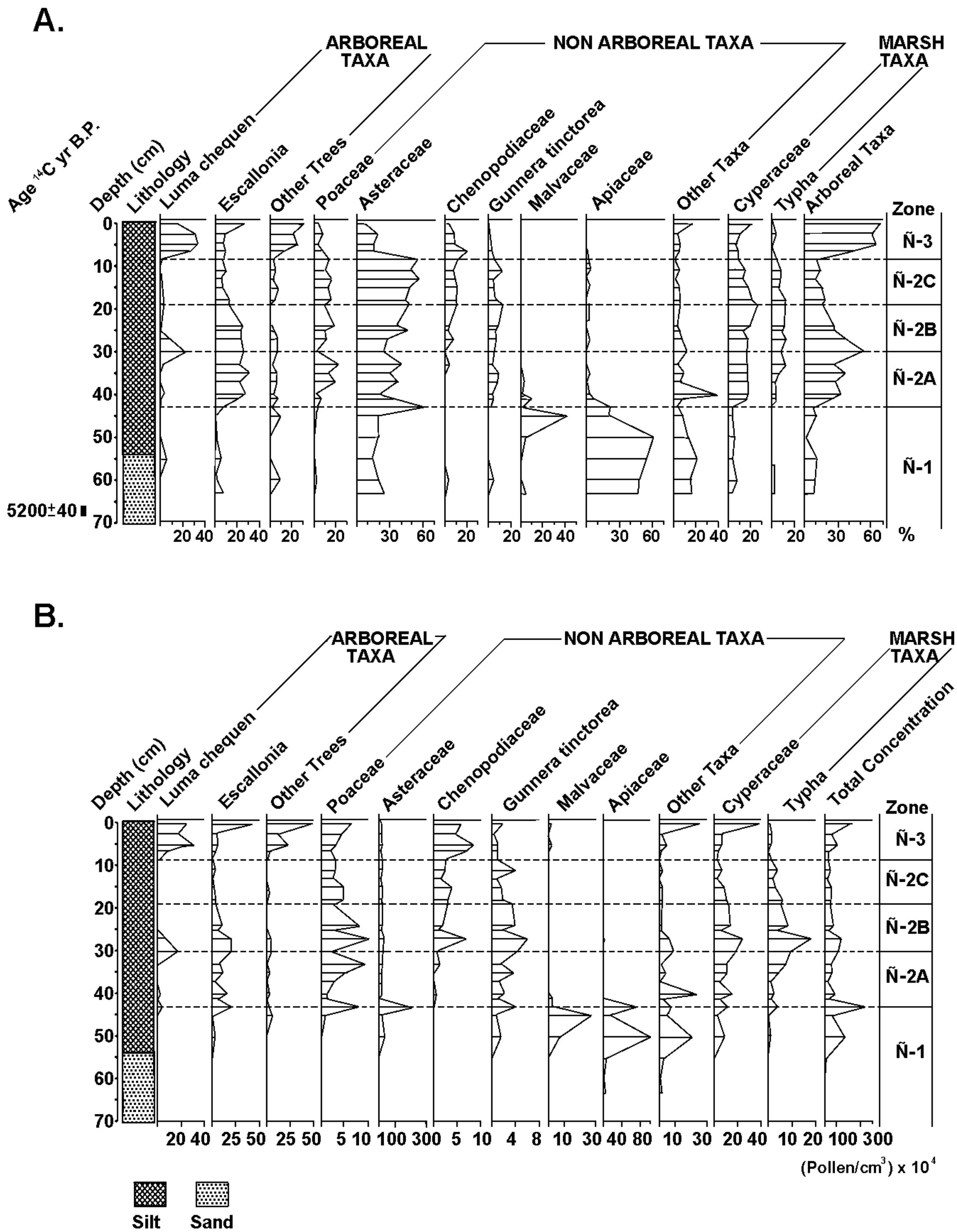

FIG. 4. A. Stratigraphy and pollen diagrams of the profile Ñague III. Calibrated radiocarbon dates are shown at the left of the diagram. B. Stratigraphy and pollen concentration diagram.

Asteraceae (ca. 70%). Only traces of arboreal pollen such as *Luma chequen* and *Escallonia* were observed. Marshy taxa were also poorly represented. The pollen concentration diagram shows low values of all the taxa at the beginning of the zone (Fig. 4). We obtained an age of 6000 cal yr B.P. (Table 1) for the bottom of core Nague III.

Zone Ñ-2A (45–30 cm depth) is characterized by an increase in swamp forest taxa, mainly *Escallonia* and, to a smaller degree, *Luma chequen, Drimys winteri*, and other arboreal taxa. Together, these swamp forest taxa reach a maximum of 60% at the top of the zone. Among the nonarboreal taxa the expansion of Poaceae (ca. 20%) and *Gunnera tinctorea* (ca. 18%) and the significant decrease of the Apiaceae is relevant. In this zone there is also an increase of marshy taxa, reaching 40%. The pollen concentration diagram corroborates the trends observed in the percentage diagram (Fig. 4).

Zone Ñ-2B (30–20 cm depth) shows an initial decrease in the percentages, as well as in the concentrations of arboreal taxa, and an expansion of Chenopodiaceae. Marshy taxa have similar values as in the previous zone (Fig. 4).

Zone Ñ-2C (20–10 cm depth) is characterized by an increase in the proportion of herbaceous taxa mainly the Asteraceae family (ca. 50%). Marsh taxa remain as abundant as in the previous zone. The pollen concentration diagram shows a decrease in pollen concentration of all the taxa. This zone possibly corresponds to the sedimentation hiatus observed in the stratigraphic column Ñague I.

Zone Ñ-3 (10–0 cm depth) is characterized by the reappearance and dominance of the forest taxa and a decline of Poaceae, Asteraceae, *Gunnera tinctorea, Typha*, and fern spores. The pollen concentration diagram corroborates this increase in woody taxa (Fig. 4).

DISCUSSION

Pollen records from two Ñague sites show that between ~6100 and 4200 cal yr B.P. an open and herbaceous vegetation prevailed, with dominance by xerophytic taxa, in an area that is now occupied by swamp forests. The pollen record of marshy and aquatic vegetation, for the lower course of the gully (Ñague I), suggests the presence of relatively shallow water bodies. In the upper course of the gully (Ñague III) a vegetation of xeric character was present at this time, without marshy taxa and with the predominance of herbaceous Asteraceae and Apiaceae. These results lead us to believe that before ~4200 cal yr B.P., conditions drier than the present existed in the coastal Norte Chico.

According to both pollen records, the expansion of the current swamp forests taxa of Ñague site begin ~4200 cal yr B.P., when the establishment of arboreal elements, dominated by *Luma chequen* and *Escallonia revoluta*, was first recorded. We interpret the establishment of swamp forest trees in the area as the result of a rise close, to the surface of permanent or semipermanent groundwater, in response to an increase in rainfall. Since forests became established in the area, two major vegetational–climatic fluctuations were recorded, which are outlined below.

A reversion of the trend toward increasing arboreal pollen is observed in this area, at ~3200 cal yr B.P., with a predominance of herbaceous pollen of Chenopodiaceae and Asteraceae at the peak, ~2600 cal yr B.P. The subsequent decline in abundance of forest taxa could represent a period of lower rainfall that has its maximum expression with the development of Jaral Costero (core Ñague III), and the predominance of herbaceous taxa (Asteraceae, Poaceae, Chenopodiaceae), revealing conditions of great aridity. Carbon dating limits the duration of the dry phase to a period between ~2600 and 1300 cal yr B.P. During this phase a significant drop in the slope of the sediment accumulation curve was recorded (Fig. 2), in addition to an abrupt change from organic to inorganic sediments, with a probable loss of sediments. An interpolated age of ~1800 cal yr B.P. marks the replacement of swamp forest by Jaral Costero, suggesting increasing aridity.

By the end of this arid phase, at ~1300 cal yr B.P., pollen records reveal a sustained new expansion of the forest, probably reaching a state that persists through the present. The increase in swamp forest indicators after ~1300 cal yr B.P. suggests increased humidity in the area, equivalent to the current climatic conditions. The upper 5 cm of sediments show an alteration of this trend, probably due to anthropic disturbance during historical times, which is consistent with the presence of exotic pollen indicators.

Figure 5 compares the pollen data of Ñague site with the results from the nearby site of Quebrada Quereo (Nuñez *et al.*, 1994; Villagrán and Varela, 1990). The chronology of human occupation postulated by Jackson (1997) for the study area and the pollen record for Quintero II (Villa-Martínez and Villagrán, 1997), at approximately 33°S, are also compared.

The record of Quereo creek shows wet climatic conditions at the beginning of the Holocene, changing to arid conditions from ~10,570 cal yr B.P. onward. The occurrence of sediment levels with high organic contents, associated with pollen evidence of marshy vegetation and traces of arboreal pollen starting from ~3200 cal yr B.P. on, have been interpreted as evidence for an increase in rainfall during the late Holocene (Nuñez *et al.*, 1994; Villagrán and Varela, 1990).

The archaeological chronology shows two contrasting settlement patterns of hunter–gatherer groups in the region of Los Vilos discriminated by the density and diversity of the utilized resources and for the variety of artifacts present in each site, showing the functional differences between the sites and the duration of the human settlements (Jackson, 1997; Jackson and Ampuero, 1992; Jackson *et al.*, 1996; Jackson and Rodríguez, 1998). The first pattern is characterized by seasonal occupation for extended periods, and it occurred between ~13,400 and 10,200 and between ~4400 and 1800 cal yr B.P., denoting an specialized exploitation of marine resources.

The second pattern, identified between ~7600 and 4400 and between ~1800 and 940 cal yr B.P., is characterized by occasional occupations, with short periods of permanence in the area,

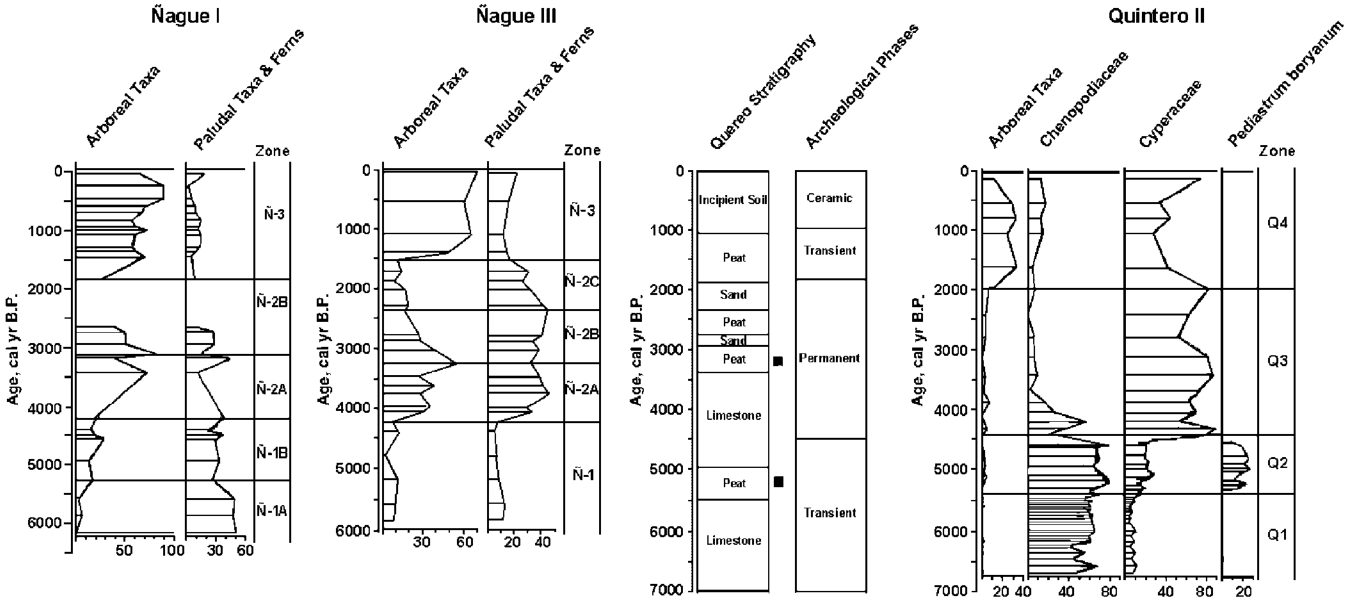

FIG. 5. Temporal series for Ñague I and III and their relationship with local stratigraphy of the Quereo site (Villagrán and Varela, 1990), the Quintero II pollen record (Villa-Martinez and Villagrán, 1997), and archeological sequences (Jackson, 1997) for Holocene of Los Vilos, Chile. Ages are linear extrapolations between the adjacent dates of the Ñague I profile, a basal date and by stratigraphic pollen correlations for the profile Ñague III. The black squares on the right side of the Quereo profile represent presence of pollen indicators of humidity.

associated with opportunistic exploitation of marine resources (Jackson and Ampuero, 1992; Jackson *et al.*, 1996). The period between ~10,200 and 7600 cal yr B.P. lacks archaeological records. According to Jackson (1997), the period that shows transient and occasional occupation of the area could be associated with a decrease of food supply in the interior valleys, under more arid conditions, which would force hunter–gatherer groups to descend to the coast, searching for more stable marine resources. Our results at Ñague site show two arid phases, with a prevalence of xeric, open vegetation occurring between ~6100 and 4200 cal yr B.P. and again between ~1800 and 1300 cal yr B.P. These time periods are coherent with the chronology for occasional human occupation of the area. In contrast, the first phase of forest development in Ñague site (~4400 and 1800 cal yr B.P.), coincides with the period of more permanent human settlement in the area.

Carbon records of the Ñague I profile (evidence not shown) indicate only one important maximum around 3200 cal yr B.P., coincident with a permanent human settlement period.

Regional Significance

Paleoclimatic studies for the Holocene of north-central Chile, have revealed substantial climatic oscillations, with alternation of dry and wet periods during the last ~11,400 cal yr. The most significant change outlined in the literature, for its wide spatial and temporal extension, is the record of an arid and/or warm phase during the early and mid Holocene, probably associated with an important southward displacement of the westerly winds belt. Accordingly, the granulometric, geochemical, fossil pollen, and microalgal analysis of the sediments of the Lagoons of Tagua Tagua (34°30′S) (Heusser, 1983) and Aculeo (33°50′S) (Jenny *et al.*, in press), which are representative of the scarce lacustrine reservoirs of the central valley of Central Chile, show that arid and warm conditions prevailed in the area before 4000 cal yr B.P. as suggested by the high proportions of halophytes (Chenopodiaceae), absence of microalgae and diatoms, and sediments indicative of strong evaporation. Geomorphological and paleopedological evidence (Veit, 1996), as well as archaeological data (Jackson, 1997; Nuñez *et al.*, 1995–96; Nuñez *et al.*, 1994) for the coast of north-central Chile also show increased aridity, compared with the present conditions, between ~6800–5700 cal yr B.P. This arid phase is in synchrony with the marine transgressive maximum (Ota and Paskoff, 1993). The palynological record for site Quintero II (Villa-Martínez and Villagrán, 1997) shows the end of the maximum aridity phase and the tendency of increased moisture availability. The Quintero data are consistent with the timing of the termination of marine transgresion and associated phases of dune activity at ~5700 cal yr B.P. The later history of Quintero II documents the development of shallow lagoons and rich in herbaceous, hallophytic vegetation until ~4400 cal yr B.P. (Fig. 5). Likewise, the profiles for Quereo (Villagrán and Varela, 1990) and Ñague swamp forest, show dominance by nonarboreal pollen and shallow lagoons (with marshy taxa and *Azolla filiculoides*) between ~6100–4200 cal yr B.P., suggesting arid conditions. In the Andes of Norte Chico, between 27° and 29°S, geomorphological evidence indicates pronounced aridity for the same period (Grosjean *et al.*, 1997).

After ~4400 cal yr B.P., more humid and/or warmer climatic conditions than the present are inferred, based on evidence provided by different indicators. In the first place, wetter and cooler conditions have been postulated for this period on the basis of the abundant presence of the terrestrial mollusc *Radiodiscus sp.* at nearby archaeological sites. This species is currently distributed south of 40°S and is restricted to terrestrial leaf-litter habitats (D. Jackson, unpublished data). Geomorphological studies in the Andes of Norte Chico (27°–29°S), for the period between ~4200 and 2430 cal yr B.P. (Grosjean *et al.*, 1997, 1998), paleopedological evidence for Norte Chico, between ~3200 and 2430 cal yr B.P. (Veit, 1996), and δ^{18}O analysis of mollusc shells from El Peral Lagoon, ~33°30′S (Falabella *et al.*, 1991), are all consistent with the previous evidence. All these studies agree with our results and suggest that the increase in humidity, recorded in Ñague site ~4200 cal yr B.P., had a regional rather than local character, pointing to an increase in rainfall frequency associated with the westerly winds belt.

The retreat of the forest observed in Ñague site, its near disappearance from the record between ~1800 and 1300 cal yr B.P., can be interpreted as an indicator of increased temperatures and/or a marked decrease in precipitation. This dry phase has also been documented in the Andes of the Norte Chico, in Laguna del Negro Francisco (Grosjean *et al.*, 1997), where it was expressed as an increase in salinity ~1720 cal yr B.P. A similar event is recorded in radioisotopic studies on the coast of Central Chile, 33°30′S, with evidence of warmer-than-present temperatures at ~1400 cal yr B.P. (Falabella *et al.*, 1991). These data are consistent with a southward displacement of the belt of westerly winds, first postulated by Veit (1996), for the period between 1580 and 670 cal yr B.P. The later rapid expansion and persistence of the forest vegetation in Ñague site beginning at ~1300–0 cal yr B.P., is almost synchronous with the swamp forests development in the palynological site Quintero I (Villagrán, 1982) and with the upper arboreal level of the profile Quintero II, with an interpolated age of ~1500 cal yr B.P. (Villa-Martínez and Villagrán, 1997).

CONCLUSIONS

Results of the Ñague analysis show swamp forests occurring during two wet phases in the late Holocene, ~4200–3200 and after ~1300 cal yr B.P. Two distinctive arid phases, with predominance of herbaceous taxa, are also documented for the period ~6100–4200 and ~1800–1300 cal yr B.P. Human settlement patterns in the study area show chronological correspondence with the climatic–vegetational changes suggested by our pollen records. Temporary and opportunistic occupation phases prevailed during the dry periods, and more stable and specialized settlements occurred during the wetter periods.

Our results are also coherent, in trend and chronology, with most paleoclimatic studies in north-central Chile, strongly suggesting that important fluctuations in rainfall characterized the last ~6000 cal yr of the Holocene. We think that changes in rainfall frequency were due to changes in the influence of the westerly winds in the region, due to either intensification/weakening or latitudinal displacement of this system.

Although Rodbell *et al.* (1999) find evidence for the establishment of the current periodicity of El Niño phenomena from ~5000 cal yr B.P. onward in the Andes of Ecuador, other data suggest a more complex history. Geoarchaeological studies on the Peruvian coast show the beginning of El Niño toward ~5700 cal yr B.P. and the onset of its current periodicity toward ~3200 cal yr B.P. (Sandweiss *et al.*, 1996, 2001). Furthermore, foraminifers records in deep sea cores off the coast of central Chile (32°45′S) suggest an intensification in the frequency of El Niño system starting ~3200 cal yr B.P. (Marchant *et al.*, 1999). El Niño events have had a significant influence in our study area and it can be expected that sensitive paleoenvironmental records, with high rates of sediment accumulation, will show at least the most extreme variations of this system. Even though our results at Ñague do not have the necessary chronological resolution to identify high-frequency climatic variability within the ENSO range, they have clearly identified major changes in the rainfall pattern ~5700 cal yr B.P. (beginning of a marshy phase in the coast of central Chile), ~4400–4200 cal yr B.P. (substitution of Chenopodiaceae prairies by Cyperaceae swamps in Quintero and beginning of the swamp forest in Ñague) and ~3200 cal yr B.P. (contraction of the swamp forest in Ñague, under conditions of increased aridity). Consequently, it is reasonable to propose that important changes in the climatic system of the subtropical Pacific took place during the late Holocene, which could have affected the frequency and/or magnitude of ENSO-type events in the coast of north-central Chile.

ACKNOWLEDGMENTS

The authors thank D. Jackson, R. Villa, F. Falabella, N. Pohl, and C. Latorre. We are especially grateful to Dr. P. Moreno for his editorial comments and Dr. J. Armesto for assistance with the English translation. Funding was provided by project No. PG/028/97 of Universidad de Chile and FONDECYT grants 1950372, 1990699, and 1000905.

REFERENCES

Aceituno, P. (1988). On the functioning of the Southern Oscillation in the South American sector. Part I. Surface climate. *Monthly Weather Review* **116,** 505–523.

Caviedes, C. (1972). "Geomorfología de Cuaternario del valle de Aconcagua, Chile Central." Freiburger Geographischa Hefte No. 11, 153 pp. Universitat Freiburg I. BR [In Spanish]

Faegri, K., and Iversen, J. (1989). "Textbook of Pollen Analysis." Blackwell Sci., Oxford.

Falabella, F., Planella, M. T., and Pollastri, A. (1991). Análisis de oxigeno 18 en material malacológico de Chile central. *Actas del XI Congreso Nacional de Arqueología Chilena. Stgo de Chile*, 105–121. [In Spanish]

Fuenzalida, P. (1965). Biogeografía. *In* "Geografía Económica de Chile" (CORFO, Ed.). Editorial Universitaria S.A., Santiago, Chile. [In Spanish]

Grimm, E. (1987). CONISS: A fortran 77 program for stratigraphically constrained cluster analisys by the method of incremental sum of squares. *Computers and Geociences* **V,** 13–35.

Grosjean, M., Valero-Garcés, B. L., Geyh, M. A., Messerli, B., Schotterer, U., Schreier, H., and Kelts, K. (1997). Mid- and late-Holocene limnogeology of Laguna del Negro Francisco, northern Chile, and its palaeoclimatic implications. *The Holocene* **7,** 151–159.

Grosjean, M., Geyh, M. A., Messerli, B., Schreier, H., and Veit, H. (1998). A late-Holocene (<2600 B.P.) glacial advance in the south-central Andes (29°S), northern Chile. *The Holocene* **8,** 473–479.

Heusser, C. (1983). Quaternary pollen record from Laguna de Tagua Tagua, Chile. *Science* **219,** 1429–1431.

Jackson, D. (1997). Coexistencia e interacción de comunidades cazadores-recolectores del arcaico temprano en el semiárido de Chile. *Valles. Revista de estudios regionales, Museo de la Ligua-Chile* **3,** 13–36. [In Spanish]

Jackson, D., and Ampuero, G. (1992). Comentario a una datación radiocarbónica para el Arcaico medio del Norte Chico. *Boletín Sociedad Chilena de Arqueología* **15,** 11–13. [In Spanish]

Jackson, D., and Rodríguez, A. (1998). Ocupación del Complejo El Molle en la costa de Los Vilos, provincia del Choapa. *Boletín Sociedad Chilena de Arqueología* **26,** 19–21. [In Spanish]

Jackson, D., Baez, P., Seguel, R., and Arata, J. (1996). Campamento arcaico para la explotación del intermareal: Significado del desconche local de moluscos. *Valles. Revista de estudios regionales, Museo de la Ligua-Chile* **2,** 89–109. [In Spanish]

Jenny, B., Valero-Garces, B., Villa-Martínez, R., Urrutia, R., Geyth, M., and Veit, H. (in press). Early to mid-Holocene aridity in Central Chile (34°S) related to the Southern Westerlies: The Laguna Aculeo record. *Quaternary Research*.

Maldonado, A. (1999). "Historia de los bosques pantanosos de la costa de Los Vilos (IV Región, Chile) durante el Holoceno medio y tardío." Unpublished Magíster thesis, Facultad de Ciencias, Universidad de Chile. [In Spanish]

Marchant, M., Hebbeln, D., and Wefer, G. (1999). High resolution planktic foraminiferal record of the last 13,300 years from the upwelling area off Chile. *Marine Geology* **161,** 115–128.

Marticorena, C., and Quezada, M. (1985). Catálogo de la flora vascular de Chile. *Gayana (Botánica) (Chile)* **42,** 5–155. [In Spanish]

Nuñez, L., Grosjean, M., Messerli, B., and Schrelier, H. (1995–96). Cambios ambientales holocénicos en la puna de Atacama y sus implicancias paleoclimáticas. *Estudios Atacameños* **12,** 31–40. [In Spanish]

Nuñez, L., Varela, J., Casamiquela, R., and Villagrán, C. (1994). Reconstrucción Multidiciplinaria de la Ocupación Prehistórica de Quereo, Centro de Chile. *Latin American Antiquity* **5,** 99–118. [In Spanish]

Ota, Y., and Paskoff, R. (1993). Holocene deposits on the coast of north-central Chile: Radiocarbon ages and implications for coastal changes. *Revista Geológica de Chile* **20,** 25–32.

Rodbell, D. T., Seltzer, G. O., Anderson, D. M., Abbott, M. B., Enfield, D. B., and Newman, J. H. (1999). An ∼15,000-year record of El Niño-driven alluviation in southwestern Ecuador. *Science* **283,** 516–520.

Sandweiss, D. H., Richardson, J. B., III, Reitz, E. J., Rollins, H. B., and Maasch, K. A. (1996). Geoarchaeological evidence from Peru for a 5000 years B.P. onset of El Niño. *Science* **273,** 1531–1533.

Sandweiss, D. H., Maasch, K. A., Burger, R. L., Richardson, J. B., III, Rollins, H. B., and Clement, A. (2001). Variation in Holocene El Niño frequencies: Climate records and cultural consequences in ancient Peru. *Geology* **29,** 603–606.

Stockmarr, J. (1971). Tablets with spores used in absolute pollen analysis. *Pollen et Spores* **13,** 615–621.

VanHusen, C. (1967). "Klimagliederung in Chile auf der Basis von Häufigkeitsverteilungen der Niederschlagssummen." Freiburger Geographischa Hefte 4, 113 pp. Universitat Freiburg I. BR [In German]

Varela, J. (1981). Geología del Cuaternario del Area de Los Vilos-Ensenada El Negro (IV Región) y su Relación con la Existencia del Bosque "Relicto" de Quebrada Quereo. *Comunicaciones* **33,** 17–30.

Veit, H. (1996). Sourthern Westerlies during the Holocene deduced from geomorphological and pedological studies in the Norte Chico, Northern Chile (27–33°S). *Palaeogeography, Palaeoclimatology, Palaeoecology* **123,** 107–119.

Villagrán, C. (1982). Estructura floristica e historia del bosque pantanoso de Quintero (Chile, V Región) y su relación con las comunidades relictuales de Chile Central y Norte Chico. *Actas del III Congreso Geológico Chileno*, 377–402. [In Spanish]

Villagrán, C., and Varela, J. (1990). Palynological evidence for increased aridity on the central Chilean coast during the Holocene. *Quaternary Research* **34,** 198–207.

Villa-Martínez, R., and Villagrán, C. (1997). Historia de la vegetación de bosques pantanosos de la costa de Chile central durante el Holoceno medio y tardío. *Revista Chilena de Historia Natural* **70,** 391–401. [In Spanish]