JOURNAL OF QUATERNARY SCIENCE (2010) **25**(6) 985–988

Published online 22 April 2010 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/jqs.1385

Early Holocene climate change and human occupation along the semiarid coast of north-central Chile

ANTONIO MALDONADO,[1,2]* CESAR MÉNDEZ,[3] PAULA UGALDE,[4] DONALD JACKSON,[3] ROXANA SEGUEL[5] and CLAUDIO LATORRE[6,7]
[1] Centro de Estudios Avanzados en Zonas Áridas, Raúl Bitrán s/n, La Serena, Chile
[2] Universidad de La Serena, Benavente 980, La Serena, Chile
[3] Departamento de Antropología, Facultad de Ciencias Sociales, Universidad de Chile, Santiago, Chile
[4] Pasaje Angelmó 2373, Saucache, Arica, Chile
[5] Centro Nacional de Conservación y Restauración, DIBAM, Santiago, Chile
[6] Center for Advanced Studies in Ecology and Biodiversity and Departamento de Ecología, Pontificia Universidad Católica de Chile, Santiago, Chile
[7] Institute of Ecology and Biodiversity, Santiago, Chile

Maldonado, A., Méndez, C., Ugalde, P., Jackson, D., Seguel, R. and Latorre C. 2010. Early Holocene climate change and human occupation along the semiarid coast of north-central Chile. *J. Quaternary Sci.*, **Vol. 25** pp. 985–988. ISSN 0267-8179.

Received 1 July 2009; Revised 30 December 2009; Accepted 5 January 2010

ABSTRACT: The brief, terminal Pleistocene archaeological site at Santa Julia (SJ, 31° 50′ S; 71° 45′ W) is the only one with fluted projectile preforms and megafauna consumption known from the Chilean semiarid coastline. Here, we present the climatic history at SJ during the early Holocene reconstructed from pollen and charcoal analyses spanning 13.2–8.6 ka (=10^3 calibrated ^{14}C yr BP). Elevated charcoal concentrations confirm human activity by 13.2 ka. Human occupation decreased in intensity and charcoal practically disappears from the record after 10.6 ka, followed by wetland expansion at SJ between 10.5 and 9.5 ka. Local dominance of coastal shrubland reveals that dry phases occurred between >11.2–10.5 and 9.5–9.0 ka. Overall, these findings imply that by modulating available resources at both local and landscape levels climate change may have played an important role in explaining the peopling of semiarid coastal Chile. Copyright © 2010 John Wiley & Sons, Ltd.

Journal of Quaternary Science

KEYWORDS: Palaeoindian; semiarid Chile; southern westerlies; pollen record; charcoal.

Introduction

Climate change can either facilitate or constrain human exploratory movements and settlement patterns, particularly in the currently arid to semiarid regions of South America (Moreno *et al.*, 2009). Documenting these changes remains crucial for understanding and even predicting the location of archaeological sites (Nuñez *et al.*, 1994; Jackson *et al.*, 2007; Santoro and Latorre, 2009). Evidence for early settlement as well as local climatic conditions have been gathered at Santa Julia (SJ, Fig. 1), an exceptional South American Late Pleistocene archaeological site located along the semiarid coast of north-central Chile (Jackson *et al.*, 2007).

Records of Holocene climate change from this area are scarce. This is further confounded by widespread drying out of many depositional environments between ca. 8.6 and 6.2 ka (Villagrán and Varela, 1990; Maldonado and Villagrán, 2006; Kaiser *et al.*, 2008). In this paper, we describe the pollen and charcoal results from a unique ca. 5 ka continuous sequence exposed along the base of the SJ section (Jackson *et al.*, 2007) and discuss the palaeoenvironmental and climate context of the early human occupation of this region.

* Correspondence to: A. Maldonado, Centro de Estudios Avanzados en Zonas Aridas, La Serena, Chile.
E-mail: amaldona@userena.cl

Study area and methods

SJ Site LV. 221 (31° 50′ S, 71° 30′ W) is exposed along the rim of a small, E–W oriented arroyo that drains into the Pacific Ocean near Los Vilos (Fig. 1). The site was exposed by down-cutting of former sandy and wetland sediments along the south bank during the late Holocene. Continuous, fine-grained sediments occur along the base of the section (Fig. 2).

The region lies within the subtropical zone of central Chile, receives 260 mm a^{-1} of frontal winter rainfall and mean annual temperature is 14°C (Almeyda and Saez, 1958; Miller, 1976; Fuenzalida, 1982; Montecinos *et al.*, 2000). Semiarid, Asteraceae-dominated shrublands populate the adjacent coastal plains. Sclerophyll and local swamp forests (<0.1 km^2) occur alongside wetlands in the deepest, wettest gullies.

We measured, described and sampled the lowermost 68 cm of sediment from the western profile of the archaeological

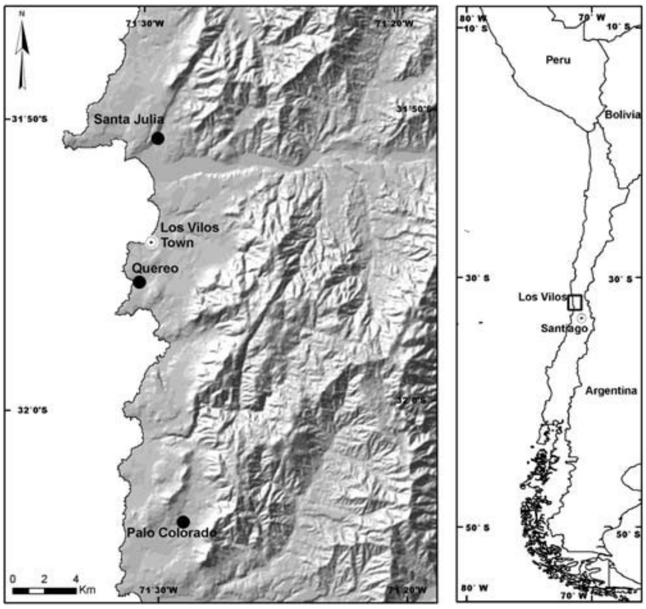

Figure 1 Map of the study area indicating the locations of Santa Julia (SJ), Quebrada Quereo and Palo Colorado

excavation at SJ (strata 36–38) (Jackson *et al.*, 2007). Three accelerator mass spectrometry (AMS) radiocarbon dates were previously obtained on organic matter (Jackson *et al.*, 2007) (Table 1). Loss-on-ignition was done at 1 cm intervals using conventional methods (Dean, 1974; Heiri *et al.*, 2001). Pollen was sampled at 5 cm intervals but was preserved only in the upper 40 cm. Samples were treated with conventional extraction and identification methods (Faegri and Iversen, 1989). Charcoal particle counts were analysed continuously along the profile in 1 cm thick sections with 1 cm^3 subsamples (Whitlock and Larsen, 2001; Whitlock and Anderson, 2003). Charcoal influx (particles cm^{-2} a^{-}) was calculated using CHAPS software (P. Bartlein, unpublished).

Without local data, fire event calibration is difficult. Extrapolation from calibration studies obtained from temperate forests (e.g. Higuera *et al.*, 2005; Whitlock *et al.*, 2006, 2007; Carcaillet *et al.*, 2007) is not warranted, given that SJ lies within semiarid scrub with considerably less biomass. We thus utilise our charcoal record for visualising broad-scale relationships between fire/climate change/human activity rather than estimate individual fire events or local fire activity (Whitlock *et al.*, 2006; Higuera *et al.*, 2007).

Figure 2 Photograph of the SJ site, showing archaeological excavation and stratigraphy. Note the abundant laminations of light-coloured sands and dark organic sediments at the base of the section. This figure is available in colour online at www.interscience.wiley.com/journal/jqs

Results

The stratigraphy records intercalated clayey silt layers to fine sands. Variable clay amounts occur and the overall organic content is low (<10%) (Fig. 3). The chronology reveals a linear increase in age vs. sediment depth from 13.2 to 8.6 ka (Table 1). Average accumulation rate is 65–70 a cm^{-1} and pollen samples are spaced at approximately 280 years.

Pollen was retrieved from samples dated between ca. 11.2 and 8.6 ka. The resulting analyses were divided into three zones. Zone 1 (SJ-1: 40–30 cm; ca. 11.2–10.5 ka) is dominated by shrub and herbaceous taxa, mostly Poaceae (8–30%) and Asteraceae–Tubuliflorae (15–34%), representing the shrub component. Zone 2 (SJ-2: 30–15 cm; ca. 10.5–9.5 ka) has the highest percentages of the wetland obligate *Gunnera tinctorea* (50–70%) and low percentages of Poaceae (9–18%), Asteraceae–Tubuliflorae (7–12%) and Chenopodiaceae (1–3%). Other wetland indicators, such as Cyperaceae (42%) and *Typha* (24%), also reach maximum values. Zone 3 (SJ-3: 16–0 cm; ca. 9.5–8.6 ka) shows increases in Poaceae (16–27%) and Asteraceae–Tubuliflorae (12–38%) and a concomitant decrease in *Gunnera tinctorea* (16%) and *Typha* (6%) at 9.2 ka, although these increase afterwards until the end of the record.

Charcoal amounts are low (~0–70 particles >250 μm and ~0–700 particles <250 to >125 μm). We regard the general trend in charcoal influx as a measure of local fire activity, so only particles >125 μm were examined (Whitlock and Anderson, 2003; Higuera *et al.*, 2007; Ali *et al.*, 2009). Two distinct periods with charcoal occur (Fig. 3). The most prominent is at ca. 13–12.3 ka, coeval with the archaeological occupation at SJ (Jackson *et al.*, 2007). A second period occurs at 11.8–10.6 ka, after which charcoal levels fall to almost zero for the rest of the record (Fig. 3).

Palaeoecology, regional palaeoclimate and human occupation

Very high charcoal influx values occur between ca. 13 and 12.3 ka. Yet regional climate was either wetter/cooler, as documented by swamp forest expansion at nearby Quebrada Quereo (Villagrán and Varela, 1990) and by cold sea surface temperatures (SSTs) in an offshore marine core (Kaiser *et al.*, 2008). Furthermore, low regional plant cover values and absence of natural ignition sources are not conducive to natural fires under modern conditions. Hence it is highly probable that the charcoal is of local human origin. Our maximum charcoal peak is also coeval with the SJ occupation (Jackson *et al.*, 2007).

From 11.2 ka onwards, dominance of coastal shrub pollen indicates a climate drier than today until 10.5 ka, in agreement with other records (Villagrán and Varela, 1990; Kaiser *et al.*, 2008). Persistent human presence (though not likely at the site itself) is revealed by the relatively high charcoal influx from 11.8 to 10.6 ka (Fig. 3) as well as the presence of other, slightly younger settlements in the area (Jackson and Mendez, 2005). Local human subsistence strategies associated with coastal adaptations persisted until 10.8 ka (Jackson and Mendez, 2005). This subsistence strategy is significantly different from that at SJ, which is characterised by megafauna consumption and a lack of marine resources (Jackson *et al.*, 2007).

Increased percentages of *Gunnera tinctorea* and Cyperaceae herald wetland expansion between 10.5 and 9.6 ka. Small, local wetlands (<1 ha) expand primarily as a response to heightened groundwater levels, which are associated with local

Table 1 Radiocarbon (AMS) dates from Quebrada Santa Julia (31° 50′ S, 71° 30′ W) (from Jackson *et al.*, 2007)

Laboratory no.	Depth (cm) or level	Age (^{14}C a BP)	Age, midpoint (cal. a BP) ($P>95\%$, 2σ)	δ^{13}C‰	Material
Beta-204523	0–1	7 830 ± 40	8 633 ± 95	−26.0	Bulk
Beta-204524	36–37	9 640 ± 50	10 985 ± 205	−26.7	Bulk
Beta-194725	60–62 (archaeological level)	10 920 ± 80	12 920 ± 113	−27.0	Charcoal

Dates were calibrated using CALIB 5.0.1/INTCAL04 (Stuiver *et al.*, 2005).

precipitation increases (Maldonado, 1999). Charcoal influx dwindled practically to zero (Fig. 3) and human settlements moved towards ravines and interior valleys, only sporadically reaching the coast between ca. 10.5 and 8.8 ka as climate became wetter (Jackson and Mendez, 2005).

Herbaceous and shrubland taxa, all indicative of drier conditions at SJ, increased in importance after 9.6 ka. This trend was interrupted by a dry period at ca. 9.2 ka, after which wetland indicators gradually increased until 8.6 ka. Wetland formation ended abruptly with the subsequent onset of aeolian sand deposition, suggesting increased aridity. The Palo Colorado record also provides evidence for drought at 9.2 ka as well as corroborating that the driest period began by 8.6 ka and lasted until 6.2 ka (Maldonado and Villagrán, 2006).

Marine and continental records show SST increases after ca. 15 ka, with maximum temperatures probably peaking around 7.5 ka (Veit, 1996; Kim *et al.*, 2002; Kaiser *et al.*, 2008). The last regional major glacial advance in the high Andes, however, occurred between 13 and 11 ka (Zech *et al.*, 2008). This advance was coeval with the latter half of the Central Andean Pluvial Event documented in the Atacama Desert and adjacent Altiplano, when summer rainfall was significantly higher between ca. 17.5 and 9.5 ka (Betancourt *et al.*, 2000; Latorre *et al.*, 2005, 2006; Maldonado *et al.*, 2005; Quade *et al.*, 2008; Placzek *et al.*, 2009).

In semiarid Chile, a palaeopedological study shows wet conditions between ca. 10 and 8 ka, followed by drought (Veit, 1996). Further south, the Tagua Tagua record (35° S) suggests wetter conditions until 11.5 ka (Valero-Garcés *et al.*, 2005). Along with the Laguna Aculeo record (33° S), both evince increased aridity that culminated by ca. 8 ka (Jenny *et al.*, 2002; Valero-Garcés *et al.*, 2005). Rapid facies shifts in the Aculeo record between >9.4 and 8.4 ka could also be related to moisture changes seen in our record.

In summary, our pollen and charcoal records from SJ reveal a series of wet–dry intervals during the Late Pleistocene/early Holocene. Initial occupation of SJ at ca. 13 ka occurred under wetter conditions, in agreement with other records. Climate became drier after 11.2 ka and perhaps even as early as 11.8 ka (as inferred from charcoal trends). Wetland expansion at 10.5 ka along with evidence for increased available regional

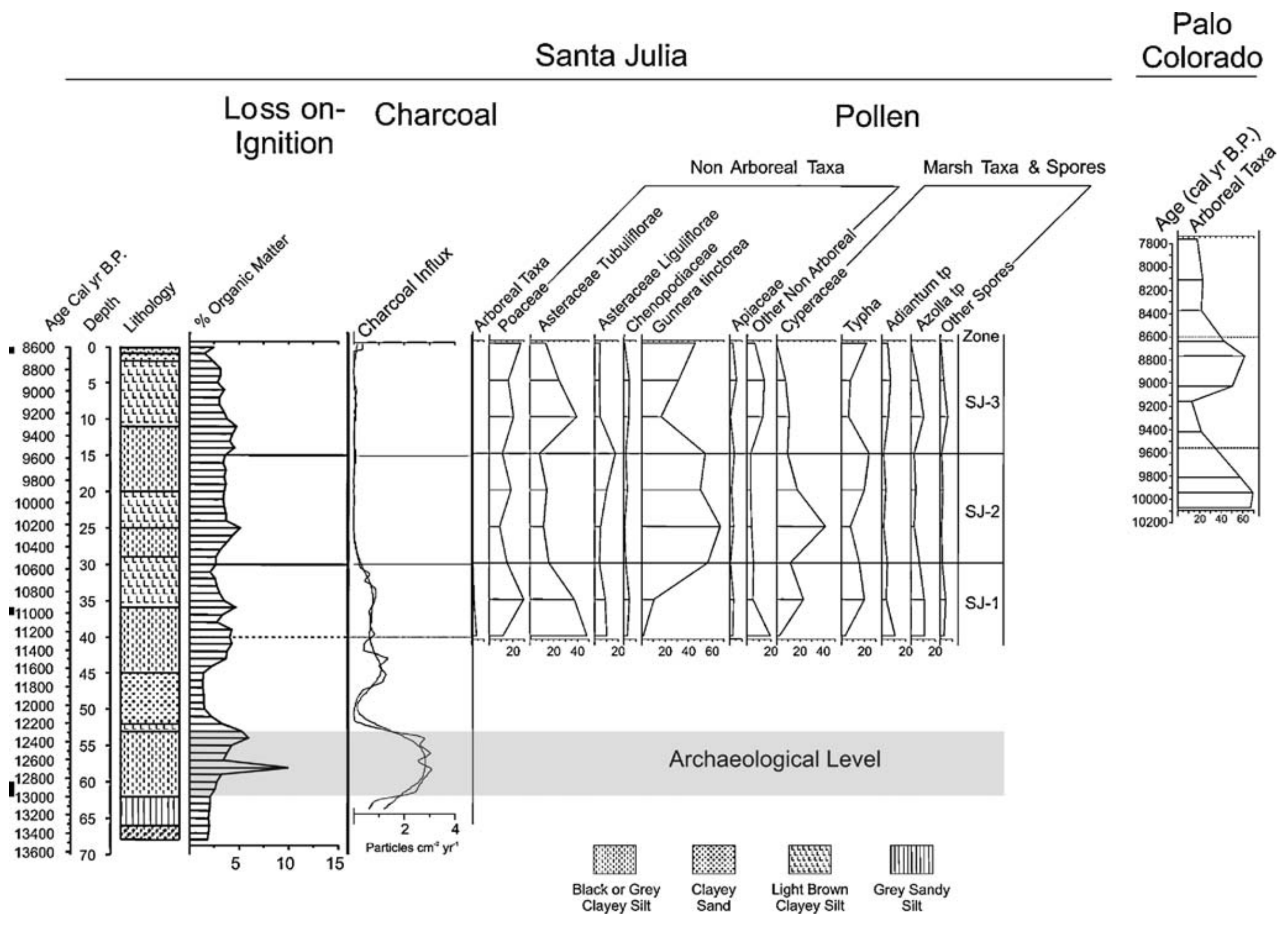

Figure 3 Stratigraphic sequence of SJ, indicating depth, lithology, percent organic matter, charcoal influx, pollen percentages of main taxa and pollen zones determined by cluster analysis (Grimm, 1987). Grey shading indicates the archaeological level. Arboreal taxa are the main wetland indicators for the lower section of the Palo Colorado record (see Maldonado and Villagrán, 2006)

moisture, and an almost complete lack of charcoal in the record, imply that climate was wet enough to inhibit fire propagation. Fire activity is thus linked to interactions between climate (facilitated by drought), with local human activity as the ignition source. Arid conditions prevailed again from 9.6 to 9.2 ka, followed by wetland expansion until 8.6 ka. Widespread regional aridity followed, perhaps resulting in a paucity of early to mid Holocene archaeological sites and implying a major shift in settlement patterns.

Acknowledgements We thank Cathy Whitlock, Macarena Cardenas, Julio Betancourt, an anonymous reviewer and the editor. Research was funded by FONDECYT grants # 3040032, # 1060496, # 11070016, # 1090044 and NGF-8122-06. CL acknowledges funding by PFB-23 and P05-002 ICM to the IEB and FONDAP 1501-0001 to CASEB.

References

Ali AA, Higuera PE, Bergeron Y, Carcaillet C. 2009. Comparing fire-history interpretations based on area, number and estimated volume of macroscopic charcoal in lake sediments. *Quaternary Research* **72**: 462–468.

Almeyda E, Saez F. 1958. *Recopilación de Datos Climáticos de Chile y Mapas Sinópticos Respectivos*. Ministerio de Agricultura: Santiago, Chile; 195.

Betancourt JL, Latorre C, Rech JA, Quade J, Rylander KA. 2000. A 22,000-year record of monsoonal precipitation from northern Chile's Atacama Desert. *Science* **289**: 1542–1546.

Carcaillet C, Bergman I, Delorme S, Hörnberg G, Zackrisson O. 2007. Long-term fire frequency not linked to prehistoric occupations in northern Swedish boreal forest. *Ecology* **88**: 465–477.

Dean WEJ. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *Journal of Sedimentology and Petrology* **44**: 242–248.

Faegri K, Iversen J. 1989. *Textbook of Pollen Analysis*. Blackwell Scientific: Oxford; 1–327.

Fuenzalida H. 1982. A country of extreme climate. In *Chile: Essence and Evolution*, García H (ed.). Instituto de Estudios Regionales de la Universidad de Chile: Santiago; 27–35.

Grimm E. 1987. CONISS: a Fortran 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers and Geociences* **5**: 13–35.

Heiri O, Lotter AF, Lemcke G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology* **25**: 101–110.

Higuera PE, Sprugel DG, Brubaker LB. 2005. Reconstructing fire regimes with charcoal from small-hollow sediments: a calibration with tree-ring records of fire. *The Holocene* **15**: 238–251.

Higuera PE, Peters ME, Brubaker LB, Gavin DG. 2007. Understanding the origin and analysis of sediment-charcoal records with a simulation model. *Quaternary Science Reviews* **26**: 1790–1809.

Jackson D, Mendez C. 2005. Primeras ocupaciones humanas en la costa del Semiárido de Chile: patrones de asentamiento y subsistencia. In *XVI Congreso Nacional de Arqueología Chilena*, Tome, Chile; 493–502.

Jackson D, Mendez C, Seguel R, Maldonado A, Vargas G. 2007. Initial occupation of the Pacific coast of Chile during Late Pleistocene times. *Current Anthropology* **48**: 725–731.

Jenny B, Valero-Garcés BL, Villa-Martínez R, Urrutia R, Geyh MA, Veit H. 2002. Early to mid-Holocene aridity in central Chile and the southern westerlies: the Laguna Aculeo record (34° S). *Quaternary Research* **58**: 160–170.

Kaiser J, Schefuß E, Lamy F, Mohtadi M, Hebbeln D. 2008. Glacial to Holocene changes in sea surface temperature and coastal vegetation in north central Chile: high versus low latitude forcing. *Quaternary Science Reviews* **27**: 2064–2075.

Kim J-H, Schneider RR, Hebbeln D, Müller PJ, Wefer G. 2002. Last deglacial sea-surface temperature evolution in the Southeast Pacific compared to climate changes on the South American continent. *Quaternary Science Reviews* **21**: 2085–2097.

Latorre C, Betancourt JL, Quade J, Rech JA, Holmgren C, Placzek C, Maldonado A, Vuille M, Rylander KA. 2005. Late Quaternary history of the Atacama Desert. In *23° South: The Archaeology and Environmental History of the Southern Deserts*, Smith M, Hesse P (eds). National Museum of Australia Press: Canberra; 73–90.

Latorre C, Betancourt JL, Arroyo MTK. 2006. Late Quaternary vegetation and climate history of a perennial river canyon in the Río Salado basin (22° S) of northern Chile. *Quaternary Research* **65**: 450–466.

Maldonado A. 1999. *Historia de los bosques pantanosos de la costa de Los Vilos (IV Region, Chile) durante el Holoceno medio y tardío*. MSc thesis, Universidad de Chile.

Maldonado A, Villagrán C. 2006. Climate variability over the last 9900 cal yr BP from a swamp forest pollen record along the semiarid coast of Chile. *Quaternary Research* **66**: 246–258.

Maldonado AJ, Betancourt JL, Latorre C, Villagrán C. 2005. Pollen analyses from a 50,000-yr rodent midden series in the southern Atacama Desert (25° 30′ S). *Journal of Quaternary Science* **20**: 493–507.

Miller A. 1976. The climate of Chile. In *Climates of Central and South America*, Schwerdtfeger W (ed.). Elsevier: Amsterdam; 113–145.

Montecinos A, Díaz A, Aceituno P. 2000. Seasonal diagnostic and predictability of rainfall in subtropical South America based on tropical Pacific SST. *Journal of Climate* **13**: 746–758.

Moreno A, Santoro CM, Latorre C. 2009. Climate change and human occupation in the northernmost Chilean Altiplano over the last ca. 11500 cal. a BP. *Journal of Quaternary Science* **24**: 373–382.

Nuñez L, Varela J, Casamiquela R, Villagrán C. 1994. Reconstrucción multidiciplinaria de la ocupación prehistórica de Quereo, centro de Chile. *Latin American Antiquity* **5**: 99–118.

Placzek C, Quade J, Betancourt JL, Patchett PJ, Rech JA, Latorre C, Matmon A, Holmgren C, English NB. 2009. Climate in the dry central Andes over geologic, millennial, and interannual timescales. *Annals of the Missouri Botanical Garden* **96**: 386–397.

Quade J, Rech JA, Betancourt JL, Latorre C, Quade B, Rylander KA, Fisher T. 2008. Paleowetlands and regional climate change in the central Atacama Desert, northern Chile. *Quaternary Research* **69**: 343–360.

Santoro CM, Latorre C. 2009. Propuesta metodológica interdisciplinaria para poblamientos humanos Pleistoceno tardío/Holoceno temprano, precordillera de Arica, Desierto de Atacama Norte. *Andes* **7**: 11–35.

Stuiver M, Reimer PJ, Reimer RW. 2005. CALIB 5.0. http://intcal.qub.ac.uk/calib/ [30 January 2010.

Valero-Garcés BL, Jenny B, Rondanelli M, Delgado-Huertas A, Burns SJ, Veit H, Moreno A. 2005. Palaeohydrology of Laguna de Tagua Tagua (34° 30′ S) and moisture fluctuations in Central Chile for the last 46000yr. *Journal of Quaternary Science* **20**: 625–641.

Veit H. 1996. Southern 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, Varela J. 1990. Palynological evidence for increased aridity on the central Chilean coast during the Holocene. *Quaternary Research* **34**: 198–207.

Whitlock C, Anderson RS. 2003. Fire history reconstructions based on sediment records from lakes and wetlands. In *Fire and Climatic Change in the Americas*, Veblen TT, Baker WL, Montenegro G, Swetnam TW (eds). Springer: New York; 3–31.

Whitlock C, Larsen C. 2001. Charcoal as a fire proxy. In *Tracking Environmental Change Using Lake Sediments*, Last WM, Smol JP (eds). Kluwer: Dordrecht; 75–97.

Whitlock C, Bianchi MM, Bartlein PJ, Markgraf V, Marlon J, Walsh M, McCoy N. 2006. Postglacial vegetation, climate, and fire history along the east side of the Andes (lat 41–42.5° S), Argentina. *Quaternary Research* **66**: 187–201.

Whitlock C, Moreno PI, Bartlein P. 2007. Climatic controls of Holocene fire patterns in southern South America. *Quaternary Research* **68**: 28–36.

Zech R, May J-H, Kull C, Ilgner J, Kubik PW, Veit H. 2008. Timing of the late Quaternary glaciation in the Andes from ~15 to 40° S. *Journal of Quaternary Science* **23**: 635–647.

