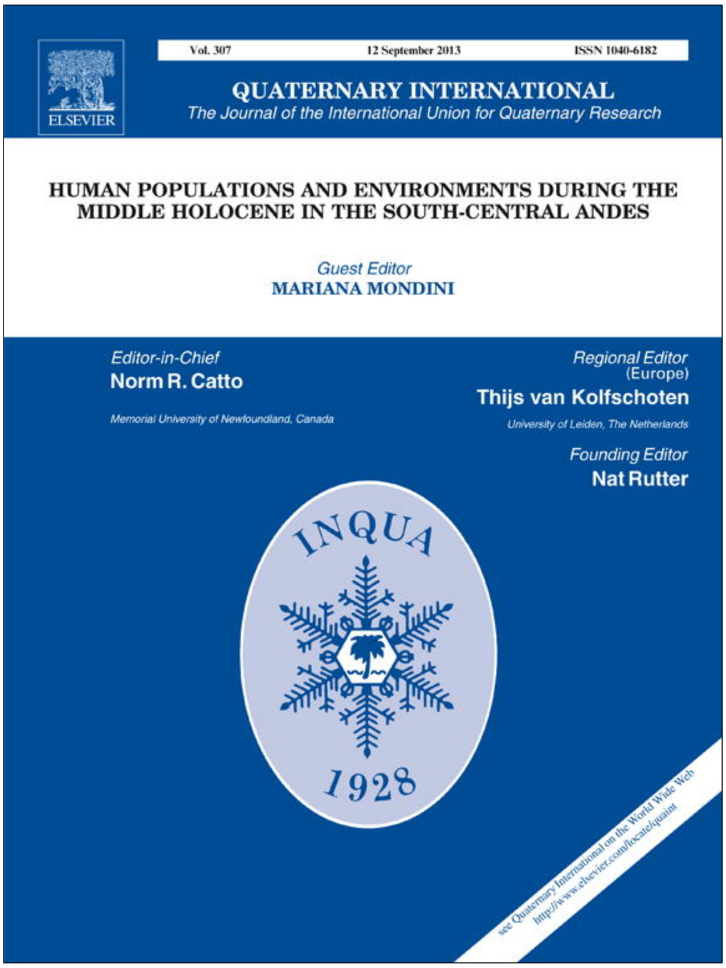
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Mid-Holocene paleoenvironments in Northwestern Argentina: Main patterns and discrepancies

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A R T I C L E I N F O

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A B S T R A C T

This paper summarizes the available paleoenvironmental information for the Mid-Holocene in Northwestern Argentina, in order to systematize a multi-scale scenario for human adaptation in the area. The main results of the studies carried out by several research teams that have studied the conditions during this period in the tropical Andean region are described and compared, taking into account their geographical setting, the proxies involved and their particular space–time resolution. The paleoenvironmental situation prior to the onset of Mid-Holocene conditions (i.e. starting at the Late Glacial Maximum) is summarized to estimate the nature and extent of the changes occurred during this period. Paleoenvironmental results, their characteristics and interpretation, are also considered.

A general trend towards an aridization process that fostered a hydrologic stress process is traceable along the Mid-Holocene in Northwestern Argentina and the Tropical Andes. However, several localities seem to have retained wetter conditions, increasing the contrast between highly productive environments and the generally dry landscape. This paper is only a first step towards a full understanding of the diversity and complexity of the Mid-Holocene in different space–time scales, but a necessary one in order to start to model the resources structure available for human groups in the past in the Andes.

1. Introduction

Over the last two decades, the amount and diversity of paleoenvironmental information available for the Tropical Andes has increased, allowing tracing of general environmental trends and its variability in broad scales. However, discrepancies between records or particular responses to large climatic shifts have been observed in several localities on both Andean slopes. These discrepancies have fostered a particular debate related to the nature of Mid-Holocene climatic conditions and their impact in the Andean landscape (e.g. Grosjean, 2001; Rech et al., 2002, 2003; Latorre et al., 2003, 2006; Servant and Servant-Vildary, 2003; Quade et al., 2008).

The available paleoenvironmental information in the Andes is marked by disparities in the amount of information and the research scales among different regions of the Tropical Andes. For example, the available data in the Puna of Argentina (e.g. Valero-Garcés et al., 1996; Lupo, 1998; Grana and Morales, 2005; Yacobaccio and Morales, 2005; Olivera et al., 2006; Morales and Schittek, 2008; Morales et al., 2009; Tchilinguirian, 2009; Oxman, 2010; Morales, 2011, and others) are considerably limited in comparison with research carried out in Northern Chile, Bolivia and Peru (for a general review see Tchilinguirian, 2009; Morales, 2011, main trends and patterns are summarized below).

A key concept involved with Mid-Holocene paleoenvironmental conditions has influenced the archaeology of the Andes highlands of northern Chile and northwestern Argentina during the past two decades: the "Silencio Arqueológico del Holoceno Medio" hypothesis (Mid-Holocene Archaeological Silence). This idea, initially proposed by Lautaro Núñez and Calogero Santoro in the early 1980s, refers to an occupational hiatus in the Atacama region generated as a consequence of the hyper-arid conditions established during the Mid-Holocene (Nuñez and Santoro, 1988). This concept was basically sustained by an empirical generalization derived from the concurrence of an arid signal in the Salar the Atacama area with a discontinuity in the radiocarbon dates series in the archaeological record of this region during the 8000–4800 BP span (Grosjean et al., 2005). However, in recent years, the "Archaeological Silence" hypothesis has been challenged in theoretical and empirical terms. Moreover, as soon as this idea was enunciated, some data that did not fit this empirical generalization appeared in both Andean slopes. These data included the Quebrada de Puripica record (northern Chile, Nuñez, 2005; Grosjean et al.,

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2007) that showed short but frequent Mid-Holocene occupations coinciding with wetland phases in the quebrada (Nuñez et al., 2002) and Quebrada Seca 3 rockshelter (Catamarca province, northwestern Argentina) that include several Mid-Holocene archaeological layers (Aschero, 1988).

For this reason, based on the evidence recovered at Puripica, Grosjean and Nuñez (1994) suggested the existence of "ecological refuges" that might have allowed human occupation in the region during this hyper-arid period. Pintar (2009) proposed a similar situation to explain the evidence recovered from Cueva Salamanca 1 (Antofagasta de la Sierra, Catamarca province, Argentina). Other localities with different environmental characteristics have also started to produce evidences of Mid-Holocene occupations in both slopes of the Andes: several sites in the Upper Loa Basin, Chile (De Souza, 2004); and Alero Cuevas in the Puna of Salta Province (López, 2008), and Hornillos 2 in the Puna of Jujuy (Yacobaccio et al., 2000), both located over 4000 m asl in the Argentinan Andes highlands. This situation started to suggest that the extremely arid conditions of Mid-Holocene were overestimated, or at least that the complex Mid-Holocene paleoenvironmental scenarios were oversimplified (Fig. 1).

In order to gain more detailed knowledge about past environmental conditions during Mid-Holocene, an effort towards reviewing and systematically synthesize the broad corpus of information about this period must be made. This paper presents a first attempt in this direction that has focused on those elements that could be particularly important for future archaeological models and hypotheses.

2. Key elements of moisture dynamics in the Tropical Andes and signals in paleoenvironmental records

In general terms, the climate is the main driver of moisture dynamics in the area. Garreaud et al. (2003) have stated that climatic conditions in the tropical Andes and neighboring areas are strongly related to high level circulation (i.e. tropospheric), particularly the balance between easterlies and westerlies. This means that, while easterlies' intensification fosters the Amazon moisture input towards the continent and ultimately upwards to the highland Andes during the austral summer (Dec–Mar), the westerlies' intensification (or northward shifts of these winds) moderate or even block the eastern moisture input, producing dry periods in the region. The seasonal precipitation amounts in the Andes highlands are also related to the position and intensity of the Bolivian High, weaker during westerly intensification (dry phases) and stronger and southward-displaced when easterly circulation is favored (wet phases) (Aceituno and Montecinos, 1993).

On the other hand, the moisture dynamics in particular localities in the tropical Andes is conditioned by other elements related to the hydrological, geomorphologic, and geographical features. For example, the orographic rains are the main factor of the spatial variability of moisture across an east–west transect over the Andes. The altitude, catchment areas of lakes and rivers, slope isolation, and the orientation of slopes to prevailing wet winds are also key factors in spatial moisture variability (Fig. 2).

Finally, another variable to keep in mind when dealing with paleoenvironmental archives is that the variety of variables included in any paleoenvironmental record could magnify or underestimate moisture regime for several reasons. Grosjean et al. (2003) suggested that these reasons are related to the fact that a sedimentary sequence could include several facets of weather and climate, but also the information about other environmental proxies, such as flora and fauna, on different space–time scales. Other variables besides the climate must be considered to properly understand the paleoenvironmental records and their signals when several localities are considered.

3. Paleoenvironmental conditions prior to Middle Holocene

Understanding the dimensions of paleoenvironmental changes during the Mid-Holocene requires a review of the estudies in the region beginning in the Last Glacial Maximum (LGM). This

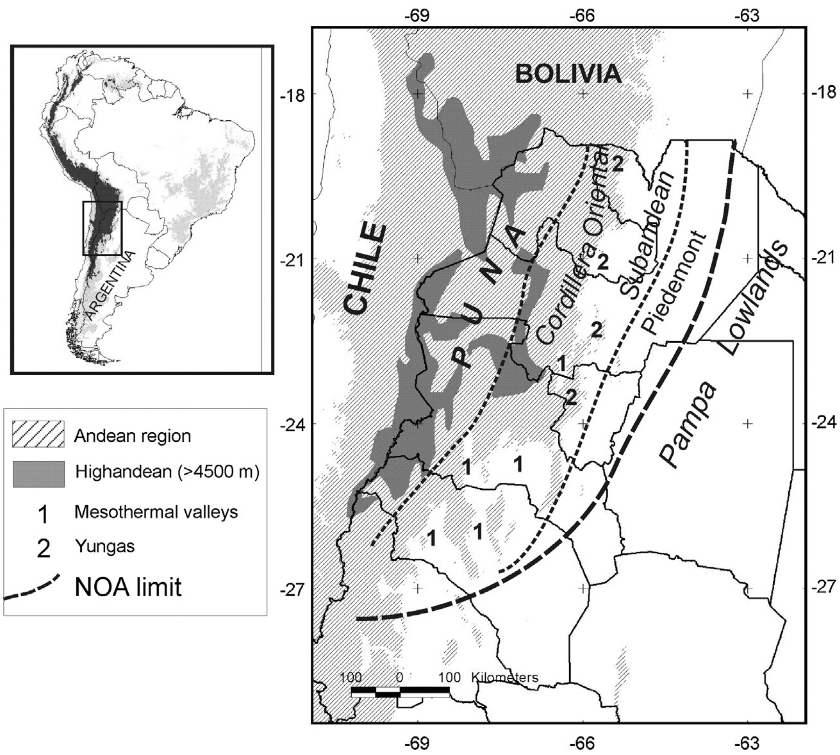

Fig. 1. Study area and main geographic references.

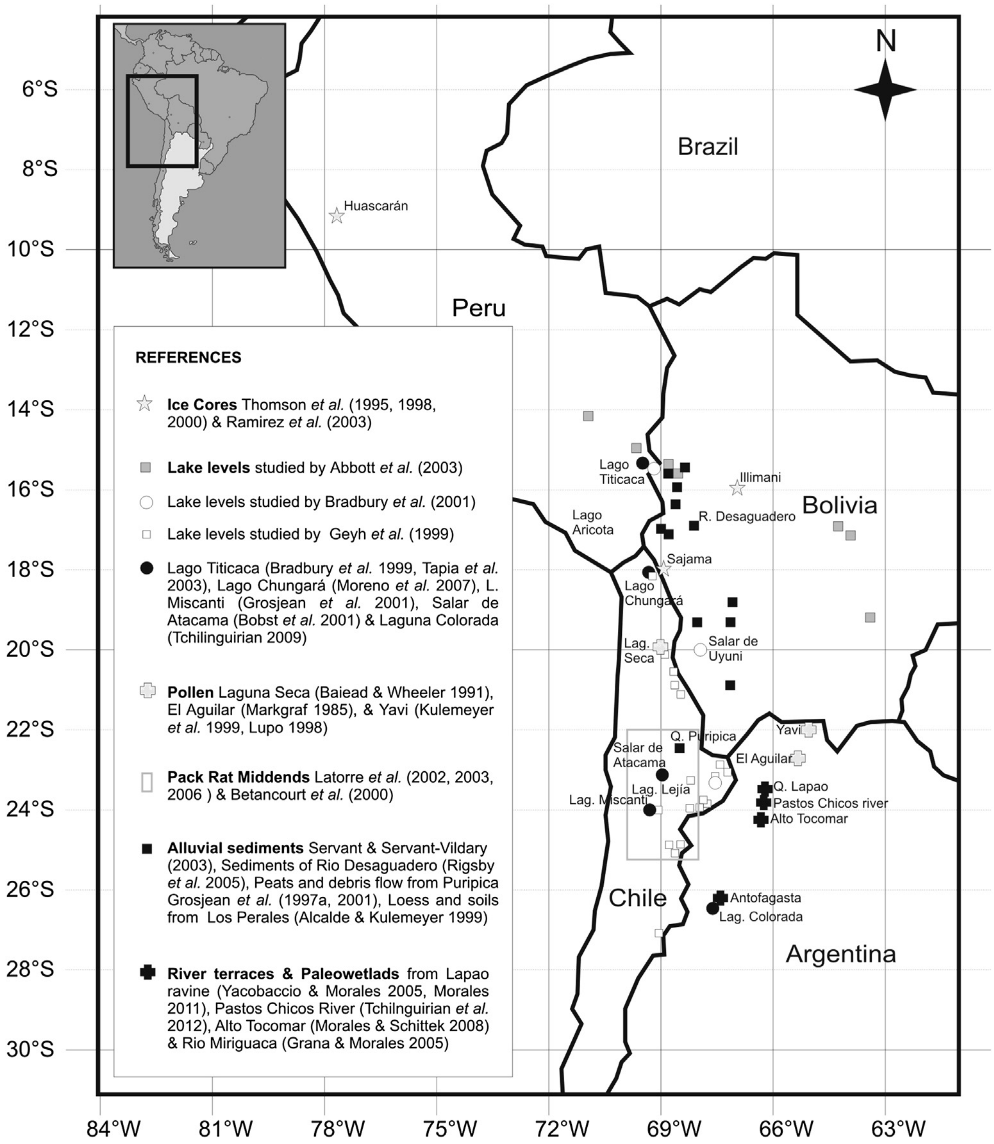

Fig. 2. Paleoenvironmental archives mentioned along this work.

information frames the Mid-Holocene in the general context of the last major climatic change on a global scale, from cold conditions towards the current state of glacier retreat. The LGM has left strong signals in Northwestern Chile (Ammann et al., 2001) and Argentina, especially in the eastern border of the Puna region, in Sierra Aconquija and in the Cordillera Oriental (Igarzabal, 1981; Ahumada et al., 2006). At the same time that glacial retreat was occurring, large endorheic basins in the Puna were filled with meltwaters, forming lakes and lagoons, currently present as salt lakes, pans and playas. The lake formation process showed two major periods of high stand levels, one during late Pleistocene and the other at the beginning of the early Holocene, usually denominated with the names of the Bolivian lakes where these events were studied: the "Tauca" phase (between ~16,000 and ~12,000 BP) and the "Coipasa" event (between 9500 and 8500 BP) (Sylvestre et al., 1999). These phases were also observed in several other lakes between 20° and 23° S including Titicaca, Salar de Uyuni, and Salar de Atacama (Bradbury et al., 2001). The transition to Mid-Holocene conditions between 8500 and 7500 BP seems to have coincided with the end of the end of Coipasa event, probably indicating a steady trend towards a more arid environment, as indicated by the final drying up of some lakes (Salar de Uyuni and Salar de Atacama).

In Northwestern Argentina, several studies recognized moister conditions during the Early Holocene. Pollen studies (Markgraf, 1985) in alluvial sequences detected a wet phase in El Aguilar (23° 5′S, 65° 45′ W, 4000 m asl) between 10,000 and 7000 BP, and in Barro Negro (Fernández et al., 1991) starting before 11,000 BP and ending around 7500 BP. Kulemeyer et al. (1999) have also detected humid conditions in Yavi (22° S, 65° W, 3400 m asl) between 10,500 and 8100 BP. Soil formation under wet conditions occurred at Los Perales, eastern Andean zone of Jujuy, at 8180 ± 130 BP and 8930 ± 130 BP (Alcalde and Kulemeyer, 1999). In the Susques area (Dry Puna of Jujuy), a wetland environment was detected in the current dry ravine of Lapao (23.2° S, 66.2° W, 3650 m asl), between 9300 and 7500 BP (Yacobaccio and Morales, 2005; Morales, 2011). Near this locality, 35 km south, a signal of wetter than present day conditions was detected in Pastos Chicos (23.6° S, 67.4° W, 3527 m asl) between 9300 and 7000 BP (Morales, 2011; Tchilinguirian et al., 2012). Further north, in Laguna Pozuelos (22.1° S, 66° W, 3700 m asl) an argillic horizon formed under wetter conditions ca. 12,400 ± 110 BP (Camacho, 2001). Towards the southern boundary of the Puna, in the Salt Puna of Catamarca, evidence of soil developments under wetter conditions have been recorded at 8839 ± 69, 8410 ± 50, and 8230 ± 60 BP by Ratto et al. (2008), and in Antofagasta de la Sierra several lake transgressions of Laguna Colorada seem to have developed between 10,700 and 7900 BP (Olivera et al., 2006; Tchilinguirian, 2009). Finally, in the valleys of the Cordillera Oriental of Jujuy, several glacial advances have been recognized between 9500 and 8500 BP (Zipprich et al., 2000).

The studies mentioned in the previous lines suggest a possible correlation between the wet phase detected during the Early Holocene in Northwestern Argentina and the Coipasa event proposed for the rest of the Tropical Andes. A marked variability ranging over almost 1000 years in the chronology of the onset of arid conditions, between 8500 and 7500 BP, was detected in the area.

The ultimate reason of the wet phase detected along the tropical Andes remains unclear because several causes could be involved. On the one hand, some researchers invoke an increased importance of meteoric waters as the main source due to the changes in the atmospheric circulation patterns of South America that affected annual precipitation amounts and their seasonal distribution. Villagrán (1993) suggested that these changes were related to a major change in the position and intensity of the anticyclonic and cyclonic centers during most of the Tauca phase. This situation was finally modified at the end of Coipasa event with the onset of current prevailing atmospheric patterns. On the other hand, the extreme overflowing stages observed in several lake systems and soil development lapses could not be explained without taking into account the role of melt water related to the deglaciation process and the low temperatures that prevailed until 9500 BP, as suggested by ice core studies such as those carried out at Huascarán by Thompson et al. (1995, 1998, 2000, 2003).

Whatever the ultimate reason for the moist Early Holocene, the results presented above could only be explained by the conjoining of several factors such as an increase in the total amount of non-stormy type precipitation, reduced seasonality in the rainfall and lower than present temperatures, all pointing towards wetter and more stable conditions. Regarding the chronological variability in the onset of the subsequent arid conditions, the variability and amount of moisture supply combined with the nature (i.e. wetland, river, lagoon, salt pan, playa, lake, etc.), geographical location and catchment area of each system generated a particular buffer effect that could have triggered diachronically the installation of dry conditions in each system.

4. Mid-Holocene paleoenvironmental data (8000–3500 BP)

Mid-Holocene paleoenvironmental results have been the subject matter of a strong and fluid debate between scholars during the first decade of the 21st century. In this debate, two positions can be easily differentiated: one supporting a “Dry” Mid-Holocene (i.e. Grosjean, 2001; Grosjean et al., 2003), and the other stressing a “Wet” Mid-Holocene (i.e. Betancourt et al., 2000; Latorre et al., 2003, 2006; Rech et al., 2003; Quade et al., 2008). It was during the progress of this discussion that a more complex and accurate picture of Mid-Holocene conditions and its internal space-time variability started to emerge. The following tables summarize the results of the available paleoenvironmental research that sustain the idea of an arid Mid-Holocene (Table 1) and the presence of moist conditions (Table 2), at least during a discrete span of this period. A graphic summary of the main trends of the continuous records mentioned in both tables is presented in Fig. 3. Finally, in order to easily analyze the spatial pattern of these results, Fig. 4 displays the moisture conditions during the 10,000–4500 BP time-span suggested by the compiled records, bracketed every 1000 yr (except for the last case, the 6000–4500 BP span, that represents 1500 years).

Table 1
Paleoenvironmental studies suggesting prevailing extremely dry conditions during Mid-Holocene.

	Proxy	Paleoenvironmental signal	Location		Source
			Coordinates	Country	
Middle Holocene's arid conditions markers	Pollen and geomorphology	Progressive desiccation of Laguna Seca, including peat accumulation at 7030 ± 245 BP	18° 11′ S, 69° 15′ W, 4500 m asl	Chile	Baied and Wheeler, 1993
	Geomorphology (Sediments)	Sediments indicating short events of drought and desiccation between 6000 and 3600 BP in the sequence of Laguna del Negro Franciscom, Northern Chile	27° 13′ S, 69° 11′ W, 4125 m asl	Chile	Grosjean et al., 1997b
	Geomorphology (Sediments)	Debris flow sediments in the alluvial sequence of Quebrada Puripica between 6200 and 3100 BP	22° 15′ S, 68° 10.5′ W, 3250 m asl	Chile	Grosjean et al., 1997a
	Geomorphology (Multiproxy)	Arid conditions (max. dryness between 6000 and 5000 BP) in Laguna del Negro Francisco, Laguna Miscanti and Laguna Seca	Negro Francisco 27° 28′ S 69° 14′ W, 4125 m asl Laguna Miscanti 22° 45′ S, 67° 45′ W, 4140 m asl Laguna Seca 18° 11′ S, 69° 15′ W, 4500 m asl	Chile	Schwalb et al., 1999
	Multiproxy	Very shallow hypersaline lacustrine conditions prevailed during the Mid-Holocene until 3600 BP in Laguna Miscanti	18° 11′ S, 69° 15′ W, 4500 m asl	Chile	Grosjean, 2001
	Ice cores (Multiproxy)	Rise in the dust particle concentration, depleted oxygen isotopic values and lower rates of ice accumulation in the Sajama Ice cores between 9000 and 3500 BP, particularly during the periods 6600–6000 and 4100–3800 BP	18° 7′ S, 68° 53′ W, 6542 m asl	Bolivia	Thompson et al., 1998
	Diatoms	Dry phase in the Titicaca that started at 8500 BP and ended at 3400 BP with strong water level fluctuations between 5300 and 3400 BP	15° S, 16.5° S, 3810 m asl	Peru and Bolivia	Tapia et al., 2003
	Multiproxy	Dry phase in the Titicaca indicated by two major low stands: between 8500 and 7000 BP and between 6000 and 5000 BP, interrupted by a brief high stand between 7000 and 6000 BP	15° S, 16.5° S, 3810 m asl	Peru and Bolivia	Baker et al., 2001
	Multiproxy	Glacial retreat in the Paco Cocha basin between 10,000 and 4800 BP, in the Taypi Chaka Kkota basin between 9600 and 2300 BP and in the Laguna Potosí starting at 9000 BP	Paco Cocha 13° 54′ S, 71° 52′ W 5580 m asl Taypi Chaka 16° 12′ S, 68° 21′ W 5650 m asl Laguna Potosí 19° 38′ S, 65° 41′ W 5025 m asl	Peru and Bolivia	Abbott et al., 2003

(*continued on next page*)

Table 1 (*continued*)

	Proxy	Paleoenvironmental signal	Location		Source
			Coordinates	Country	
	Geomorphology (Lake levels)	Low water table levels and a replacement of organic soils with mineral ones in several localities such as Rio Baja (between ~7400 and 5800 BP) and Río Blanco (between ~4500 and 2800 BP)	16°–21° S, 65°–69° W, 3500–4200 m asl	Peru and Bolivia	Servant and Servant-Vildary, 2003
	Geomorphology	Extremely dry conditions verified at Rio Desaguadero between ~7100 and 4100 BP	16.5° S, 69.9°W, 3810 m asl	Bolivia	Rigsby et al., 2005
	Diatoms and carbonates	Greater carbonates content and bentic diatoms abundances associated to dry phases between ~7800 and 5700 BP in Lago Chungará	18° 14'S, 69° 09'W, 4570 m asl	Chile	Moreno et al., 2007
	Paleosols	Drop in Middle Holocene dated paleosoils frequency (30% less abundant than those of Early Holocene in the Tropical Andes)	15°–26° S, 65°–70° W, 2800–4250 m asl	Per. - Bol. -Chi. - Arg.	Morales, 2011
	Pollen	Presence of pollen taxa associated to dry conditions between 7500 and 4000 BP in El Aguilar, Jujuy	23.83° S, 65.75° W, 4000 m asl	Argentina	Markgraf, 1985
	Pollen and geomorphology	Presence of eolian sediments and the abundance of pollen from shrubland steppe between 7995 ± 130 and 6160 ± 190 BP in a sequence near Yavi, Jujuy	22° S, 65.3° W, 3200 m asl	Argentina	Kulemeyer et al., 1999
	Geomorphology	Loess sediments (dry event) overlaying an argilic paleosoil layer (wet event) dated at 6470 ± 100 BP in the sequence of Los Perales, Jujuy, Argentina	24° S, 65.4° W, 1700 m asl	Argentina	Alcalde and Kulemeyer, 1999
	Geomorphology	Loess deposit dated at 6290 ± 120 BP located in the Llanura Oriental (i.e. eastern planes), Tucuman	26.9°S, 65.2°W, 700 m asl	Argentina	Sayago, 1999
	Geomorphology	Sediments associated to lake low-stands between 7900 and 6300 BP, and between 5800 and 4500 BP in Laguna Colorada, Antofagasta de la Sierra, Catamarca	26.0°S, 67.4° W, 3400 m asl	Argentina	Tchilinguirian, 2009

Table 2
Paleoenvironmental studies suggesting moist conditions spans during Mid-Holocene.

	Proxy	Paleoenvironmental signal	Location		Source
			Coordinates	Country	
Middle Holocene wet conditions markers	Pollen	A brief rise in the abundance of aquatic plants pollen between 5000 and 4800 BP in Laguna Seca	18.1°S, 69.1° W, 4500 m asl	Chile	Baied and Wheeler, 1993
	Rodent middens (isotopes and macroremains)	High water table levels in northern Chile in the localities of: Río Loa between 4400 and 3200 BP, Río Salado between 5900 and 3800 BP, Río Puripica between 6200 and 4000 BP, and in Río Tulán between 8200 and 3000 BP	22°–25° S, 68.5°W, 2900–3100 m asl	Chile	Betancourt et al., 2000
	Rodent middens (isotopes and macroremains)	Wet phase between ~6400 and 5900 BP (7330 and 6720 cal BP) and an arid event around 4300 BP (4865 yrs cal BP) in at different altitudes along the Rio Salado	22°–25° S, 68.5°, 2900–3100 m asl	Chile	Latorre et al., 2006
	Geomorphology	An argilic paleo-horizon formed under wetter conditions at 6470 ± 100 BP and several paleosols (peat deposits) dated at 7610 ± 130, 6970 ± 100, 6470 ± 110 BP	24° S, 65.4° W, 1200 m asl	Argentina	Alcalde and Kulemeyer, 1999
	Geomorphology and Sediments	Sediments indicating the presence of shallow saline lakes formed during short wet periods in the Salar the Atacama between 5400 and 3200 BP	23°S, 68°W, 2300 m asl	Chile	Bobst et al., 2001
	Geomorphology (multiproxy)	A brief high-stand detected in Laguna Miscanti between 5300 and 4800 BP	23.6°S, 67.6°W, 4100 m asl	Chile	Grosjean et al., 2003
	Multiproxy	At least twenty nine paleosol layers in Alto Tocomar where C:N ratios and diatom analysis have showed the occurrence of frequent wet events between 8250 and 5700 BP, particularly during the 6400–5700 BP span.	23.1° S, 66.2° W, 4200 m asl	Argentina	Morales and Schittek, 2008; Morales, 2011
	Sediments and soils	Peat deposits dated at 5960 ± 100 and 5480 ± 40 BP in the Quebrada de las Papas	28° S, 67.8°W, 2700–3000 m asl	Argentina	Ratto et al., 2008
	Sediments and soils	Littoral facies with diatoms and organic matter in Laguna Colorada dated at 6360 ± 60 BP that indicate short wet events around this date	26° S, 67.5°O, 3424 m asl	Argentina	Olivera et al., 2006; Tchilinguirian, 2009
	Geomorphology and diatoms	A paleosol dated at 5880 ± 50 BP and the diatoms record that indicate wet conditions during the formation of the alluvial deposits of Río Mirihuaca where it is include	25.9°S, 67°23.2″ O, 3487	Argentina	Grana and Morales 2005
	Multiproxy (pollen, diatom, fluvial facies)	A wetland environment in Quebrada Lapao that have developed paleosols and a water body between 8500 and 7500 BP	23.1°S, 66.1°W; 3650 m asl	Argentina	Morales, 2011
	Multiproxy (diatom, pollen, fluvial facies)	A wetland environment in the middle course of Pastos Chicos river that developed paleosols between 8900 and 7500 and a highly variable water body between 7500 and 6000 BP	23.6°S; 66.4°W; 3890 m asl	Argentina	Tchilinguirian et al., 2012
	Sediments and soils	Peat deposits dated at 5387 45 BP in the El Bolsón de Fiambalá paleolake	27.6°S, 67.6°, 1700 m asl	Argentina	Ratto et al., 2008

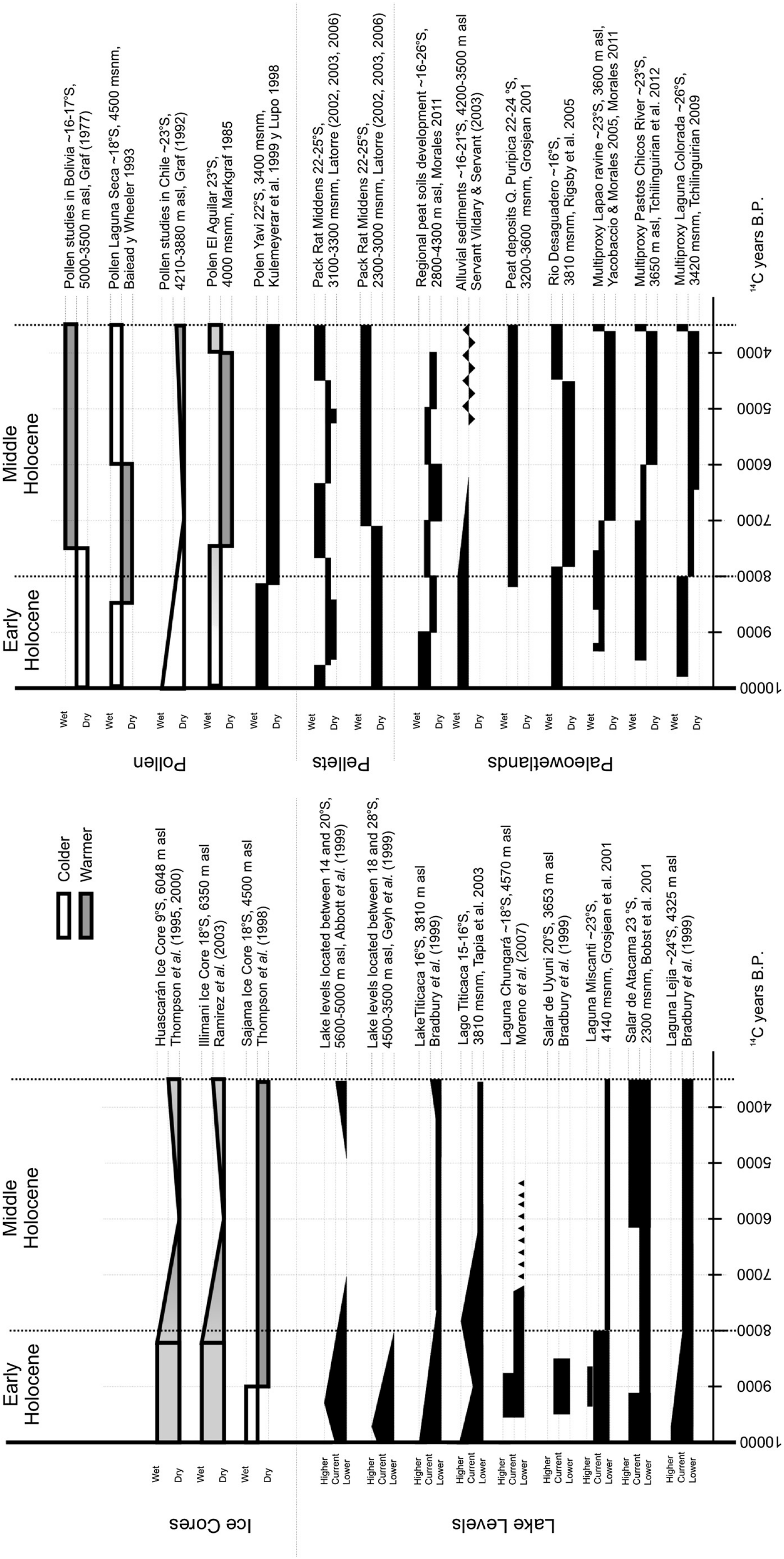

Fig. 3. Graphic summary of the continuous records mentioned in this review.

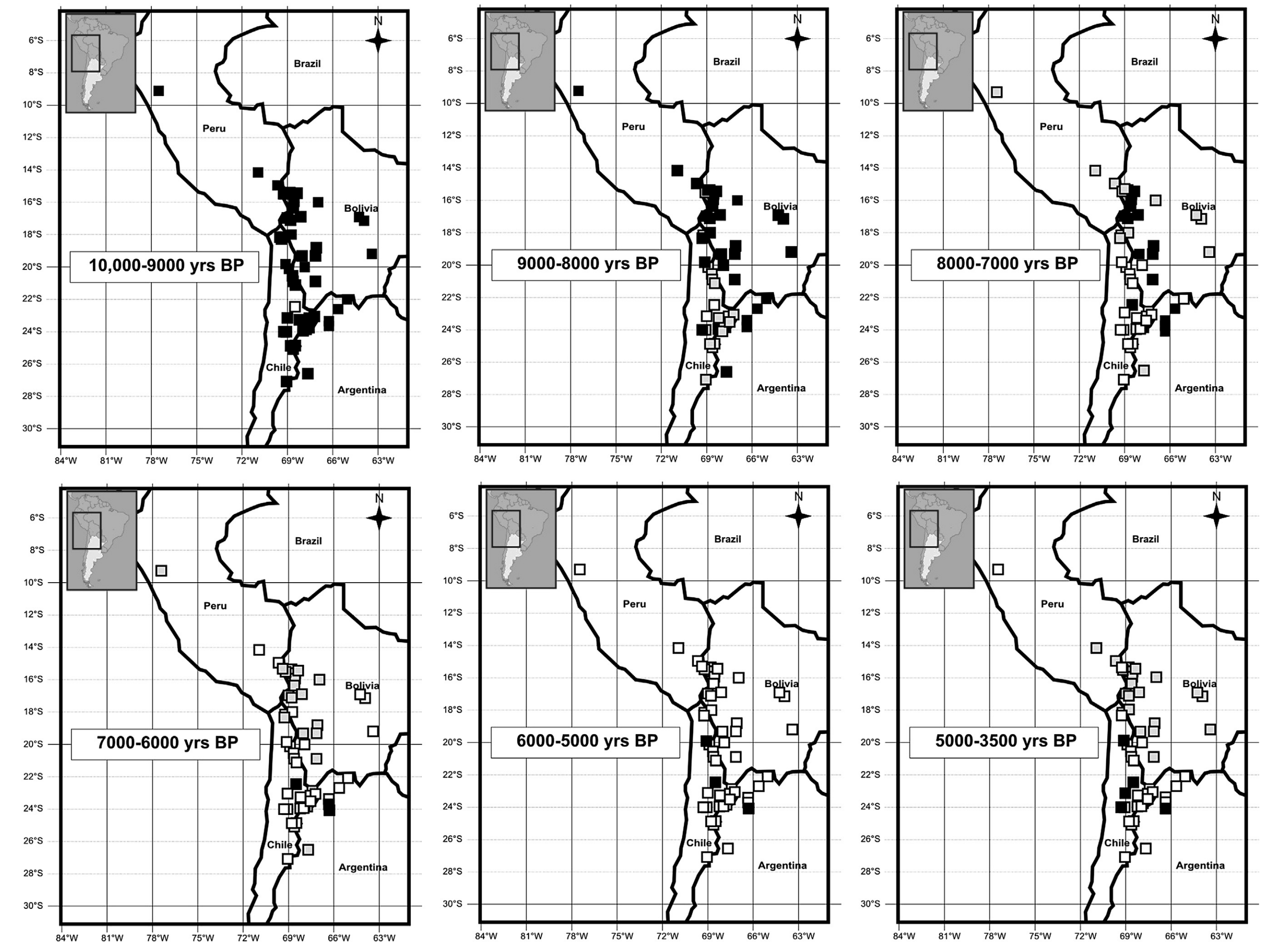

Fig. 4. Graphic summary of the spatial patterning of the signals of the paleoenvironmental records reviewed, bracketed every 1000 years (except for 6000–4500 BP). The squares indicate the moisture signal nature: black = wetter, grey = variable or transitional, and white = dry.

5. Discussion: was the Mid-Holocene a wet or dry phase?

Almost a decade after its enunciation, a key question (Grosjean, 2001) remains current: was the Mid-Holocene a wet or dry period?

More than the 85% of the data compiled come from the arid and semiarid regions of Bolivia, Northern Chile, and the Puna of Argentina. For this reason, any paleoclimatic interpretation of the Mid-Holocene in Northwestern Argentina will be partially biased due to the lack of important information from the Yungas (Foggy Forests, east of Andes) and the Transition Forests of the Eastern Andean Piedmont. This lack of information makes it difficult to understand the variability of moisture dynamics over other important sectors of Northwestern Argentina such as the Sub-andean Highlands, where the impact of the South Atlantic Anticyclone on the Andean moisture is greater than in the Puna region. This leads to a question: Did the Mid-Holocene climatic changes have a similar intensity and sign in the Yungas, the Mesothermal Valleys, the Puna and the High Andes? Probably not, given that the eastern sector of Northwestern Argentina is closer to the Atlantic moisture sources, whereas the western parts are also influenced by the South Pacific Anticyclone, the intensity and position of which frequently blocks or reduces the abundance of the easterly moisture input in the area, for example during ENSO events. A clear example of this spatial heterogeneity of the signal due to the proximity of the moisture source area (i.e. Amazon) emerges from the diachronic analysis of Fig. 4, where the records located to the NE show wetter conditions until 7000–6000 BP, whereas in Northern Chile they end sharply at 8000 BP. Dry conditions started somewhat earlier in the southern sites, located far from the Equator and the trade winds (Figs. 3 and 4).

Other questions are related to the intensity and the grade of synchronicity between climatic variability and its effects on the vegetation and the erosion/sedimentation processes in the different geo-ecological regions. For example, how were the arid signals expressed in hydrological, hydro-geological and vegetation records in each region? This question started to be answered a quarter-century ago, with the studies carried out by Markgraf (1985) in El Aguilar and Barro Negro sequences (Dry Puna, Jujuy Province, Argentina). In those records, the broad scale climatic changes such as the Pleistocene–Holocene transition or Mid-Holocene arid onset are expressed as displacements of the altitudinal belts of vegetation: downslope migration of highland grassland steppes during wet phases, and upward displacement of grassland combined with proliferation of shrubland steppe during droughts. These altitudinal movements of the vegetation belts reached 300 m during the Early to Mid-Holocene transition. However, this was not synchronic along the Andes, and the topography could have played a major role in the extent of the changes in each region (Tchilinguirian, 2009; Morales, 2011; Tchilinguirian et al., 2012). For instance, whereas in localities with smooth slopes the changes in the vegetation have affected huge areas, these modifications have had an exiguous impact on places with steep relief. The nature of the impact of the arid events in the vegetation of the Yungas and the Mountain Forests remains unclear. However, a signal that could be expected as a result of this kind of event on this type of landscape is forest fragmentation, due to the increase of natural fire events favored under water stress.

Not only the vegetation was affected during Mid-Holocene: the climatic variability also left a clear signal on geomorphologic processes. The aridization process at the beginning of the Mid-Holocene triggered the desiccation of ponds and lakes, their erosion and the formation of dune fields to windward. Examples of these processes are evident in the large dune field formations of Salinas Grandes and Río Las Burras in the Dry Puna of Jujuy Province, Argentina, also related with the erosion of several soils of the late Pleistocene and early Holocene. Other dune fields related to Mid-Holocene aridity are located windward of Laguna Purulla and Laguna Blanca in Catamarca Province, and the Salar de Olaroz-Cauchari system in Jujuy Province, both in Argentina (Tchilinguirian, 2009). Other processes related to Mid-Holocene aridity seems to have been the upwards displacement of permafrost and the deactivation of cryogenic or glacigenic rock glaciers in the High Andes. These processes certainly have affected the hydrology of numerous major basins (for example Pastos Chicos-Las Burras, Jujuy, Argentina) and some rivers and wetlands could have been desiccated (for example Quebrada Lapao and Río Mirihuaca in the Dry and Salt Puna of Argentina, respectively; Grana, 2007; Grana and Morales, 2005; Morales, 2011; Tchilinguirian et al., 2012; Yacobaccio and Morales, 2005).

Another variable in Mid-Holocene paleoenvironmental characteristics is the impact of short term catastrophic events such as the volcanic ashfall (Ratto et al., 2008) and tectonic activity (Trauth et al., 2003). The volcanic events generated deep ecological and hydrological impacts that have razed thousands of square kilometers in some localities in Northwestern Argentina during the Holocene. Some examples are the Holocene ash mantles located in the eastern region of Caldera of Cerro Blanco and Campo de Piedra Pomez in the southern Salt Puna. The ashes have caused severe loss of vegetation, and also have covered several permanent streams, ponds and springs.

Finally, a problem to be addressed is the effect of the proxy sensibility on the signal of a record. The effect of the proxy scale on some of the resulting paleoenvironmental signals seems to be evident in the cases reviewed. A clear example is the data provided by the pack rat midden studies which are extremely sensitive to short-term (i.e. sub-decadal) wet events. They underestimate the dry periods due to the nature of these deposits (Grosjean et al., 2003, 2007). Perhaps, as suggested by Grosjean et al. (2003), a good broad scale paleoenvironmental signal to keep at sight when considering the pellet record, is their regional abundance by period. As Grosjean et al. (2003) mentioned, the abundances of pellets registered by Latorre et al. (2003) fall during Mid-Holocene, possibly indicating less frequent wet events.

Another disagreement is related to the cause of paleosols developments in some localities of the Andes highlands, such as those peat deposits recorded at Quebrada de Puripica. Grosjean et al. (2001) have interpreted their formation as related to local developments due to particular geomorphic processes, including variations in moisture triggered by rises in water table levels. In contrast, Rech et al. (2002, 2003) interpret these peat deposits as a result of regional increase in moisture availability due to climatic conditions. Regarding this position, the present authors share the Grosjean et al. (2001) position in considering that local geomorphologic features are key elements in soil development, but the regional frequencies of soil development in large areas could only be explained by climate (Barber and Charman, 2003). The results obtained by the study of peat soil development frequencies and their distribution during the Holocene in the tropical Andes have demonstrated a clear signal of reduced soil formation during the Mid-Holocene, particularly during 7000–6000 BP (Morales, 2011).

Summing up, the moisture dynamics in particular localities of the Tropical Andes, and consequently in Northwestern Argentina, are mainly controlled by the conjoining of several elements such as the hydrological nature of the system and their geomorphology, hydrogeologic or geographical setting, and catastrophic events. On the other hand, the paleoenvironmental signal in a particular record also depends on the space-time scales of the information offered by the proxies studied and the sampling method. Thus, other elements apart from climate must be considered to properly understand the paleoenvironmental records and their signals in particular localities (Grosjean et al., 2003).

6. Concluding remarks

In general terms, the information reviewed as a whole supports the "Dry Mid-Holocene" hypothesis, with some reservations. This trend is only relevant for broad space–time (i.e. regional-millennial) climatic and/or archaeological patterns. On this scale, the available evidence showed that several lakes and lagoons have dried, that numerous wetlands disappeared, and the grassland steppe was displaced upwards, over the 4000 m asl contour.

However, for problems that deal with short-term processes or particular organizational strategies in archaeological studies, such as mobility or subsistence changes, several paleoenvironmental patterns must be mentioned. For example, during the Mid-Holocene, several localities show wetter conditions than present. These places were mostly located at high elevations (i.e. Alto Tocomar) or are related to rivers and lakes with large moisture catchments in Chile (i.e. Loa, Salado) and Argentina (i.e. Pastos Chicos). Why did these locations remain wet during the dry Mid-Holocene? The answer is related to those elements associated to the hydrogeology, geomorphology and geographical setting of the systems. Those places located at high elevations (above 4000 m asl) and/or with large catchment areas and draining basins, and those with frequent melt water input, have retained moisture in the basins (Tchilinguirian, 2009; Morales, 2011). In the case of Mesothermal Valleys, rivers fed by glaciers or by rock glaciers and permafrost received more regular and steady water supply during dry phases (i.e. Río Bolsón, Catamarca).

In summary, a general trend towards an aridization process that fostered a hydrologic stress process in the Tropical Andes, and consequently in Northwestern Argentina, is traceable through the Mid-Holocene. However, several localities seem to have retained wetter conditions, increasing the contrast between highly productive environments, from an archaeological point of view, and the generally dry landscape. Beyond this characterization, much effort remains to get a comprehensive knowledge of the internal variability of this period. The implementation of new multi-disciplinary and multi-proxy studies in several space–time scales is a key task in order to better understand the Mid-Holocene complexity and their impact in the resource structure modifications that affected the life-way of human populations that inhabited Northwestern Argentina during this period.

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References

Abbott, M.B., Wolfe, B.B., Wolfe, A.P., Seltzer, G.O., Aravena, R., Mark, B.G., Polissar, P.J., Rodbell, D.T., Rowe, H.D., Vuille, M., 2003. Holocene paleohydrology glacial history of the Central Andes using multiproxy lake sediment studies. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 123–138.

Aceituno, P., Montecinos, A., 1993. Stability analysis of the relationship between the southern oscillation and rainfall in South America. Bulletin, Institut Francais pour l'Etudes Andines 22, 53–64.

Ahumada, A.L., Páez, S.V., Ibañez Palacios, G.P., 2006. Rock Glaciers in the Andean Criolithozone at the 27°S. Symposium on Climate Change: Organizing the Science for the American Cordillera (CONCORD), Mendoza, Argentina, pp. 51–52.

Alcalde, J.A., Kulemeyer, J.J., 1999. The Holocene in the south-eastern region of the province Jujuy, north-west Argentina. Quaternary International 57–58, 113–116.

Ammann, C., Jenny, B., Kammer, K., Messerli, B., 2001. Late Quaternary glacier response to humidity changes in the arid Andes of Chile (18°–29°S). Palaeogeography, Palaeoclimatology, Palaeoecology 172, 313–326.

Aschero, C.A., 1988. Arqueología precerámica de Antofagasta de la Sierra. Quebrada Seca: una localidad de asentamiento. In: Informe al CONICET período 1986–87. Ms.

Baker, P.A., Rigsby, C.A., Seltzer, G.O., Fritz, S.C., Lowenstein, T.K., Bacher, N.P., Veliz, C., 2001. Tropical climate changes at millennial and orbital timescales on the Bolivian Altiplano. Nature 409, 698–701.

Baied, C.A., Wheeler, J.C., 1993. Evolution of High Andean Puna ecosystem environment, climate and culture change over the last 12,000 years in the Central Andes. Mountain Research and Development 13, 145–156.

Barber, K.E., Charman, D.J., 2003. Holocene palaeoclimate records from peatlands. In: Mackay, A.W., Battarbee, R.W., Birks, H.J.B., Oldfield, F. (Eds.), Global Change in the Holocene. Hodder Arnold, London, UK, pp. 210–226.

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

Bobst, A.L., Lowenstein, T.K., Jordan, T.E., Godfrey, L.V., Ku, T.-L., Luo, S., 2001. 106 ka paleoclimate record from drill core of the Salar de Atacama, northern Chile. Palaeogeography, Palaeoclimatology, Palaeoecology 173, 21–42.

Bradbury, J.P., Grosjean, M., Stine, S., Sylvestre, F., 2001. Full- and late-glacial lake records along PEP-1 transect: their role in developing inter-hemispheric paleoclimate interactions. In: Markgraf, V. (Ed.), Interhemispheric Climate Linkages. Academic Press, San Diego, pp. 265–291.

Camacho, M., 2001. Dataciones radiocarbónicas de la fase tauca (Tardi – glacial) en la laguna de Los Pozuelos, Puna Jujeña, Argentina. Trabajo presentado en Actas I. Primer Congreso Argentino de cuaternario y geomorfología, La Pampa, Argentina, pp. 105–112.

De Souza, P., 2004. Cazadores recolectores del Arcaico temprano y Medio en la Cuenca superior del río Loa: Sitios, conjuntos líticos y sistemas de asentamiento. Estudios Atacameños 27, 7–43.

Fernández, J., Markgraf, V., Panarello, H., Albero, M., Angiolini, F., Valencia, S., Arriaga, M., 1991. Late Pleistocene-early Holocene environment and climates, fauna, and human occupation in the Argentine Altiplano. Geoarcheology 6, 251–272.

Garreaud, R.D., Vuille, M., Clement, A.C., 2003. The climate of the Altiplano: observed current conditions and mechanisms of past changes. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 5–22.

Grana, L., 2007. Diatomeas fósiles: un acercamiento a la relación entre Sociedad y el Ambiente durante el Holoceno en Antofagasta de la Sierra, Puna Meridional Argentina. Tesis de Licenciatura en Cs, Antropológicas, orientación Arqueología de la Facultad de Filosofía y Letras, UBA, Ms.

Grana, L., Morales, M., 2005. Primeros resultados paleoambientales del análisis de diatomeas fósiles del Holoceno Medio y Tardío de la cuenca del Rio Miriguaca, Antofagasta de la Sierra, Puna Catamarqueña. In: Entre Pasados y Presentes. Instituto Nacional de Antropología, Buenos Aires, Argentina, pp. 392–409.

Grosjean, M., 2001. Mid-Holocene climate in the south-central Andes: humid or dry? Science 292, 2391–2392.

Grosjean, M., Nuñez, L., 1994. Late glacial, early and middle Holocene environment, human occupation and resource use in the Atacama (Northern Chile). Geoarchaeology 9, 271–286.

Grosjean, M., Cartajena, I., Geyh, M.A., Núñez, L., 2003. From proxy data to paleoclimate interpretation: the mid-Holocene paradox of the Atacama Desert, northern Chile. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 247–258.

Grosjean, M., Nuñez, L., Cartagena, I., 2005. Palaeoindian occupation of the Atacama Desert, northern Chile. Journal of Quaternary Science 20, 643–653.

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

Grosjean, M., Nuñez, L., Cartajena, I., Messerli, B., 1997b. Mid-Holocene climate and culture change in the Atacama Desert, northern Chile. Quaternary Research 48, 239–246.

Grosjean, M., Van Leeuwen, J.N., Ammann, B., Geyh, M.A., Knaap, Van Der W.O., Tanner, W., 2001. A 22,000 year sediment and pollen record from Laguna Miscanti, Northern Chile, Central Andes 24°S. Global and Planetary Change 28, 35–51.

Grosjean, M., Santoro, C., Thompson, L.G., Núñez, L., Standen, V., 2007. Mid-Holocene climate and culture change in the south central Andes. In: Anderson, D.G., Maasch, K.A., Sandweiss, D.H. (Eds.), Climate and Cultural Dynamics: a Global Perspective on Mid-Holocene Transitions. Elsevier, Amsterdam, pp. 51–115.

Igarzabal, A.P., 1981. El sistema glaciolítico de la cuenca superior del río Juramento, provincia de Salta. VIII Congreso Geológico Argentino, San Luis, Argentina, pp. 167–183.

Kulemeyer, J.A., Lupo, L.C., Kulemeyer, J.J., Laguna, L.R., 1999. Desarrollo paleoecológico durante as ocupaciones humanas del precerámico del norte de la Puna Argentina. Beiträge zur quartären Landschftsentwicklung Sudamerikas. Festschrift zum 65, 233–255.

Latorre, C., Betancourt, J.L., Arroyo, T.K., 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.

Latorre, C., Betancourt, J.L., Rylander, K.A., Quade, J., Matthei, O., 2003. A vegetation history from the arid prepuna of northern Chile (22–23°S) over the last 13,500 years. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 223–246.

López, G., 2008. Arqueología de Cazadores y Pastores en Tierras Altas. Ocupaciones humanas a lo largo del Holoceno en Pastos Grandes, Puna de Salta, Argentina. In: British Archaeological Research International Series S 1854. Archaeopress, Oxford, UK.
Lupo, L., 1998. Estudio sobre la lluvia polínica actual y la evolución del paisaje a través de la vegetación durante el Holoceno en la cuenca del río Yavi. Borde Oriental de la Puna, Noroeste argentino, Ph.D. thesis, Universität Bamberg.
Markgraf, V., 1985. Paleoenvironmental history of the last 10000 years in northwestern Argentina. Zentralblatt für Geologie und Paläontologie Teil I 11/12, 1739–1749.
Morales, M.R., 2011. Arqueología ambiental del Holoceno Temprano y medio en la Puna Seca Argentina. Modelos paleoambientales multi-escalas y sus implicancias para la arqueología de cazadores-recolectores. In: British Archaeological Research 2295, South American Archaeology Series, vol. 15. Archaeopress, Oxford, UK.
Morales, M., Barberena, R., Belardi, J.B., Borrero, L., Cortegoso, V., Durán, V., Guerci, A., Goñi, R., Gil, A., Neme, G., Yacobaccio, H., Zárate, M., 2009. Reviewing human–environment interactions in arid regions of southern South America during the past 3000 years. Palaeogeography, Palaeoclimatology, Palaeoecology 281, 283–295.
Morales, M., Schittek, K., 2008. Primeros resultados paleoambientales del Holoceno medio en Alto Tocomar (Puna Salteña): interpretación local e implicancias regionales. In: Primeras jornadas del área puneña de los Andes Centro-Sur, Tucumán, Argentina, pp. 109–110.
Moreno, A., Giralt, S., Valero-Garcés, B., Sáez, A., Bao, R., Prego, R., Pueyo, J.J., González-Samériz, Taverner C., 2007. A 14 kyr record of tropical Andes: the Lago Chungará sequence (18° S, Northern Chilean Altiplano). Quaternary International 161, 4–21.
Nuñez, L., 2005. La naturaleza de la expansión aldeana durante el formativo tardío en la cuenca de Atacama. Chungará (Arica) 37 (2), 165–193.
Nuñez, L., Santoro, C., 1988. Cazadores de la puna seca y salada del área centro-sur Andina (Norte de Chile). Estudios Atacameños 9, 11–60.
Nuñez, L., Grosjean, M., Cartajena, I., 2002. Human occupations and climate change in the Puna de Atacama, Chile. Science 298, 821–824.
Olivera, D.E., Tchilinguirian, P., De Aguirre, M.J., 2006. Cultural and Environmental Evolution in the Meridional Sector of the Puna of Atacama During the Holocene. In: International Prehistoric Congress. En Change in the Andes: Origins of Social Complexity Pastoralism and Agriculture. Acts of the XIVth UISPP Congress. University of Liege, Belgium. 1–7.
Oxman, B., 2010. Una perspectiva paleoecológica de las primeras ocupaciones de la Puna Seca Argentina: análisis polínico de perfiles naturales holocénicos ubicados en el Dto. de Susques, Provincia de Jujuy, Argentina, Ph.D. thesis, Universidad de Buenos Aires University, Argentina.
Pintar, E., 2009. Un “ecorrefugio” en la cuenca de la Laguna de Antofagasta (Puna Salada) entre 7900 y 6200 años AP. Arqueología 15, 85–108.
Quade, J., Rech, J.A., Betancourt, J.L., Latorre, C., Quade, B., Rylander, K.A., Fisher, T., 2008. Paleowetlands and regional climate change in the central Atacama Desert, northern Chile. Quaternary Research 69, 343–360.
Ratto, N., Carolina, M., Hongn, F., Randall, M., 2008. Gente y volcanes: el registro arqueológico de ambientes inestables del oeste Tiñogasteño de Catamarca (ca. 5000–1500 AP). In: Primeras jornadas de arqueología del área Puneña de los Andes centro-sur, Tucumán, Argentina, pp. 113–112.
Rech, J.A., Quade, J., Betancourt, J., 2002. Late Quaternary paleohydrology of the Central Andes (22–24.1°S), Chile. Geological Society of America Bulletin 114, 334–348.
Rech, J., Pigati, J.S., Quade, J., Betancourt, J., 2003. Re-evaluation of mid-Holocene deposits at Quebrada Piripica, northern Chile. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 207–222.
Rigsby, C.A., Bradbury, J.P., Baker, P.A., Rollins, S.M., Warren, M.R., 2005. Late Quaternary palaeolakes, rivers, and wetlands on the Bolivian Altiplano and their palaeoclimatic implications. Journal of Quaternary Science 20, 671–691.
Sayago, J.M., 1999. El Cuaternario de la Región Pre-Puneña del Noroeste Argentino. In: Caminos, L. (Ed.), Geología Argentina, vol. 23. Servicio Geológico Minero Argentino, Buenos Aires, Capítulo, pp. 688–690.
Schwalb, A., Burns, S., Kelts, K., 1999. Holocene environments from stable isotope stratigraphy of ostracods and authigenic carbonate in Chilean Altiplano Lakes. Palaeogeography, Palaeoclimatology, Palaeoecology 148, 153–168.
Servant, M., Servant-Vildary, S., 2003. Holocene precipitation and atmospheric changes inferred from river paleowetlands in the Bolivian Andes. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 187–206.
Sylvestre, F., Servant, M., Servant-Vildary, S., Causse, C., Fournier, M., Ybert, J.P., 1999. Lake level chronology on the southern Bolivian Altiplano (18–23°S) during lateglacial time and the early Holocene. Quaternary Research 51, 54–66.
Tapia, P., Fritz, S., Baker, P., Seltzer, G., Dunbar, B., 2003. A Late Quaternary diatom record of tropical climate history from Lake Titicaca (Peru and Bolivia). Palaeogeography, Palaeoclimatology, Palaeoecology 194, 139–164.
Tchilinguirian, P., 2009. Paleoambientes Holocenos en la Puna Austral (27°S): implicancias geoarqueológicas, Argentina. Ph.D. thesis, Universidad de Buenos Aires University, Argentina.
Tchilinguirian, P., Morales, M.R., Oxman, B., Lupo, L.C., Olivera, D.E., Yacobaccio, H.D., 2012. Early to Middle Holocene transition in the Pastos Chicos record, Dry Puna of Argentina. Quaternary International. http://dx.doi.org/10.1016/j.quaint.2012.03.006.
Thompson, L., Mosley-Thompson, E., Davis, M., Lin, P.-N., Henderson, K., Cole-Dai, J., Liu, K., 1995. Late glacial stage and Holocene tropical ice core records from Huscarán, Peru. Science 269, 46–50.
Thompson, L., Davis, M., Mosley-Thompson, E., Sowers, T.A., Henderson, K., Zagorodnov, V.S., Lin, P.N., Mikhalenko, V.N., Campen, R.K., Bolzan, J.F., Cole-Dai, J., Francou, Y.B., 1998. A 25,000-year tropical climate history from Bolivian ice cores. Science 282, 1858–1864.
Thompson, L., Mosley-Thompson, E., Henderson, Y.K., 2000. Ice-core palaeoclimate records in tropical South America since the Last Glacial Maximum. Journal of Quaternary Science 15, 377–394.
Thompson, L., Mosley-Thompson, E., Davis, M.E., Lin, P.N., Henderson, K., Mashiotta, T.A., 2003. Tropical glacier and ice core evidence of climate Change on annual to millennial time scales. Climatic Change 59, 137–155.
Trauth, M.H., Bookhagen, B., Marwan, N., Strecker, M.R., 2003. Multiple landslide clusters record Quaternary climate changes in the NW Argentine Andes. Palaeogeography, Palaeoclimatology, Palaeoecology 194, 109–121.
Valero-Garcés, B., Grosjean, M., Schwalb, A., Geyh, M.A., Messerli, B., Kelts, K., 1996. Limnogeology of Laguna Miscanti: evidence for mid to late Holocene moisture changes in the Atacama Altiplano. Journal of Paleolimnology 16, 1–21.
Villagrán, C., 1993. Una interpretación climática del registro palinológico del último glacial-postglacial en Sudamérica. Bulletin de l'Institute Francaise des Etudes Andines 22 (1), 243–258.
Yacobaccio, H., Lazzari, M., Guráieb, A.G.Y., Ibañez, G., 2000. Los cazadores en el borde oriental de Atacama (Susques, Jujuy). Arqueología 10, 11–38.
Yacobaccio, H., Morales, M., 2005. Mid-Holocene environment and human occupation of the Puna (Susques, Argentina). Quaternary International 132, 5–14.
Zipprich, M., Reizener, B., Zech, W., Singl, H., Veit, H., 2000. Upper Quaternary landscape and climate evolution in the Sierra Santa Victoria, north-western Argentina, deduced from geomorphological and pedogenic evidence. Zentralblatt für Geologie und Paläontologie 7/8, 997–1012.