

# Late Quaternary vegetation and climate history of a perennial river canyon in the Río Salado basin (22°S) of Northern Chile

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## Abstract

Plant macrofossils from 33 rodent middens sampled at three sites between 2910 and 3150 m elevation in the main canyon of the Río Salado, northern Chile, yield a unique record of vegetation and climate over the past 22,000 cal yr BP. Presence of low-elevation Prepuna taxa throughout the record suggests that mean annual temperature never cooled by more than 5°C and may have been near-modern at 16,270 cal yr BP. Displacements in the lower limits of Andean steppe and Puna taxa indicate that mean annual rainfall was twice modern at 17,520–16,270 cal yr BP. This pluvial event coincides with infilling of paleolake Tauca on the Bolivian Altiplano, increased ENSO activity inferred from a marine core near Lima, abrupt deglaciation in southern Chile, and Heinrich Event 1. Moderate to large increases in precipitation also occurred at 11,770–9550 (Central Atacama Pluvial Event), 7330–6720, 3490–2320 and at 800 cal yr BP. Desiccation occurred at 14,180, 8910–8640, and 4865 cal yr BP. Compared to other midden sites in the region, early Holocene desiccation seems to have happened progressively earlier farther south. Emerging trends from the cumulative midden record in the central Atacama agree at millennial timescales with improved paleolake chronologies for the Bolivian Altiplano, implying common forcing through changes in equatorial Pacific sea-surface temperature gradients.

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## Introduction

Large-scale controls on summer precipitation variability in the central Andes are being studied over a wide range of timescales. These studies include statistical analyses of instrumental weather data (Garreaud et al., 2003; Vuille and Keimig, 2004), general circulation model experiments (Lenters and Cook, 1997; Zhou and Lau, 1998), and a wide array of paleorecords (Clapperton et al., 1997; Mourguiart et al., 1998; Thompson et al., 1998; Geyh et al., 1999; Sylvestre et al., 1999; Abbott et al., 2000; Betancourt et al., 2000; Seltzer et al., 2000; Baker et al., 2001; Bobst et al., 2001; Wolfe et al., 2001; Mourguiart and Ledru, 2003; Paduano et al., 2003; Fritz et al., 2004). Some emerging issues include the influence and

independence of different moisture sources (e.g., Amazon Basin vs. Gran Chaco), controls on the strength of moisture transport from the lowlands westward across the Altiplano (i.e., the tropical easterlies), and the role of seasonal insolation forcing over land vs. sea on millennial timescales.

A new source of information about past summer rainfall variability in the central Andes is an ongoing survey of fossil rodent middens that span the entire length of the Atacama Desert from 16 to 26°S, essentially at the distal, waning end of the South American Summer Monsoon (Betancourt et al., 2000; Holmgren et al., 2001; Latorre et al., 2002, 2003, 2005; Maldonado et al., 2005). A singular advantage of plant assemblages from Atacama middens is the ability to separate precipitation from temperature effects. Heat loads at lower limits of most species are negligible in the Atacama, so that precipitation changes are wholly responsible for displacements of lower limits. Furthermore, the season of the precipitation anomaly can be identified from the seasonality of annual species preserved in the middens.

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We report on a 22,000-yr-long midden series from the Río Salado Basin (22°S) near Calama, northern Chile. This midden record is unique for the Americas in that it developed along what is now a perennial river, and it incorporates both hillslope and riparian vegetation. We use available information on modern regional and local plant distributions to estimate temperature at the upper limits of low-elevation species and precipitation at the lower limits of high-elevation ones. This allows us to place maximum and minimum constraints on the degree of cooling and wetting, respectively, that can be inferred from midden assemblages. We compare the Río Salado record to other Atacama midden series and evaluate the degree of synchronicity with other regional paleorecords to assess theories of climatic variability and change in the central Andes.

### Environmental setting

Occupying ~2430 km<sup>2</sup> in a conspicuous embayment along the Andean front (Fig. 1), the Río Salado basin is the major source of surface and ground water for the city of Calama and is the main perennial tributary of the Río Loa, the only river in northern Chile to start in the Andes and actually reach the coast. A large portion of the basin is covered by late Tertiary and early Quaternary ignimbrites, underlain by Paleozoic marine sediments and Mesozoic breccias that outcrop at Cerros de Aiquina (Fig. 1). Many conspicuous, parallel canyons form in these ignimbrites above 3100 m. The Andean Cordillera is mostly composed of Quaternary volcanic rocks, with extinct Tertiary rhyolite volcanoes dotting the eastern horizon. The region is tectonically active and several NW–SE normal faults control aspects of local hydrology.

Mean annual temperature (MAT) and rainfall (MAR) vary with elevation in the region (Fig. 2). The Río Salado Basin has six currently active weather stations at different altitudes,

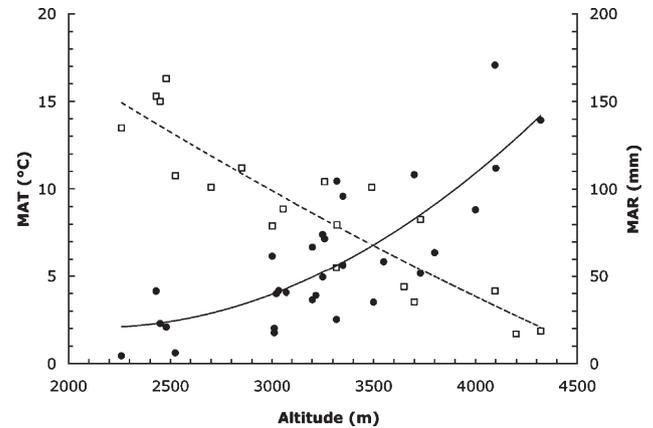


Figure 2. Plot of mean annual temperature (MAT—open squares) and mean annual rainfall (MAR—closed circles) with elevation in Region II (22–25°S) of northern Chile. The polynomial regression equation for MAT (dashed line) is  $y = 4.23 \cdot 10^{-7}x^2 - 0.009x + 33.17$ ,  $r^2 = 0.81$  ( $P < 0.0001$ ), and the standard error is 2.02°C. The equation for MAR (solid line) is  $y = 2.53 \cdot 10^{-5}x^2 - 0.10812x + 135.94$ ,  $r^2 = 0.65$  ( $P < 0.0001$ ) and the standard error is 23.8 mm.

providing unusually good coverage for the Atacama (see Houston and Hartley (2003) for station locations). MAT is 11°C at Aiquina (3031 m), the station nearest the midden sites, and declines with increasing altitude at the rate of  $-0.7^\circ\text{C}/100$  m. Although stations in the area do not measure snowfall (Vuille and Ammann, 1997), monthly data show that almost 90% of the annual rainfall occurs in summer and is highly variable from year to year. MAR is 6.1 mm at Chiu-Chiu (2524 m) and increases to 140 mm at El Tatio (4320 m) near the head of the basin. From December to March, the Río Salado can experience multi-peak seasonal floods from precipitation high in the Andes, particularly during La Niña events. At El Sifón, which has a stream gauging station maintained since 1978 less than 100 m from one of our midden sites, the highest annual flood

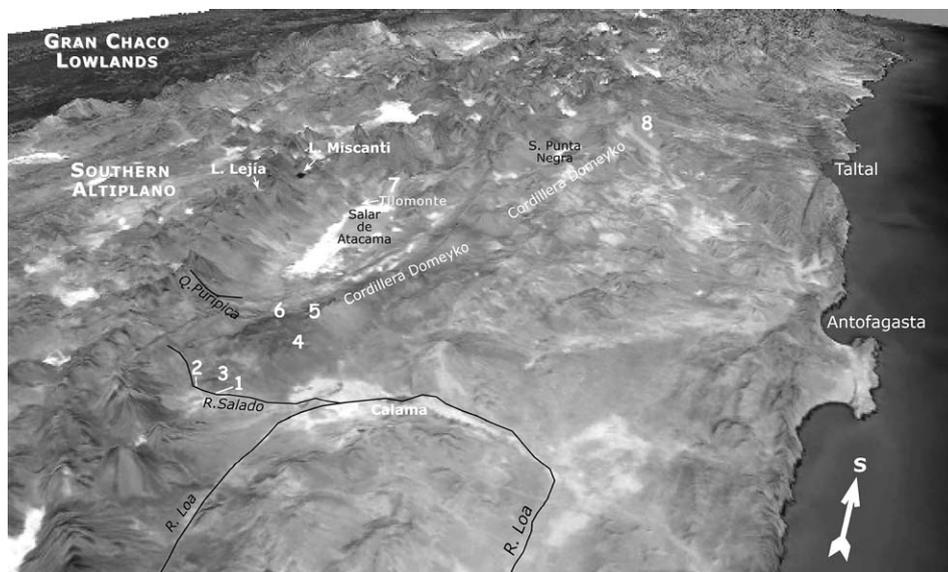


Figure 1. Oblique aerial view of northern Chile looking to the south along the Pacific slope of the Andes showing location of published rodent midden localities (1. El Sifón and Quebrada Aiquina; 2. Las Juntas; 3. Cerros de Aiquina and Cerros de Minta; 4. Cordon de Tuina; 5. El Hotel; 6. Pampa Vizcachilla; 7. Lomas del Quilvar/Tilocalar; 8. Quebrada del Chaco), and other relevant paleoclimate study sites discussed in the text. Image credit: NASA/JPL.

peak ( $310 \text{ m}^3 \text{ s}^{-1}$ ) occurred in February 2001, exceeding the previous record of  $25 \text{ m}^3 \text{ s}^{-1}$  in 1999 (Houston, in press).

Four major vegetation belts, *Prepuna*, *Puna*, *Andean Steppe* and *Subnival* (a high Alpine formation) have been described for this region (Villagrán et al., 1981, 1983; Arroyo et al., 1988). Near the upper margin of absolute desert, the Prepuna is a sparse xerophytic shrub formation spanning 2800–3100 m. Common plants include *Ambrosia artemisioides* (Asteraceae), *Atriplex imbricata* (Chenopodiaceae), and *Opuntia camachoii* (Cactaceae), *Cistanthe* spp. (Portulacaceae), *Cryptantha* spp. (Boraginaceae) and *Acantholippia deserticola* (Verbenaceae). The Puna (or Tolar) formation (3150–3900 m) is a diverse shrubland dominated by Asteraceae (*Baccharis* spp., *Chuquiraga*, *Senecio* spp.) and Solanaceae (*Fabiana* spp.). Columnar cacti *Echinopsis atacamensis* and *Oreocereus lanosus* also appear on slopes above 3100 m. *Baccharis tola*, *Parastrephia quadrangularis* (Asteraceae) and *Adesmia horrida* (Fabaceae) become important above 3700 m. The high Andean steppe (3900–4400 m) is dominated by tussock grasses (*Festuca*, *Stipa* and *Anatherostipa*). Large cushion plants (*Azorella*, *Pycnophyllum*) and small rosettes (*Chaetanthera*, *Mulinum*, *Senecio*, *Lenzia*, *Valeriana*) characterize the diverse Subnival formation, which extends to the vegetation limit at ~4800 m. Overall, total percent cover and species richness increases with altitude, peaking at 3900–4200 m (Villagrán et al., 1981; Arroyo et al., 1988; Latorre, 2002).

Riparian vegetation is common along the entire course of the perennial Río Salado. Below 3100 m, both the Río Salado and Río Loa floodplains are disturbed by land use and dominated by weeds (Gutiérrez et al., 1998). At 2985 m (El Sifón; Figs. 3 and 4), floodplain vegetation is dominated by *Tessaria absinthioides* (Asteraceae), *Distichlis spicata* (Poaceae) and *Cortaderia atacamensis*. The vegetation changes abruptly at ~3100 m with the appearance of several Puna species, including the shrubs *Fabiana denudata*, *F. ramulosa*, *Baccharis boliviensis*, *Chuquiraga atacamensis*, and the columnar cactus *Echinopsis atacamensis*. Independent of elevation, the warmer, drier north-facing cliffs have consistently higher species richness than the



Figure 3. Downstream view of Río Salado canyon at El Sifón in March 1997, after summer floods associated with 1996 La Niña destroyed the concrete bridge. Main midden sites are along north-facing side of the canyon on the left side of the photograph.



Figure 4. An upstream view of the Río Salado canyon at El Sifón, March 1997.

cooler, wetter south-facing cliffs, which are dominated by a few large shrubs (Table 1). A recent survey of riparian habitats along an elevational gradient from the coast to the high Andes pinpointed maximum plant diversity at intermediate elevations (3108 m; Gutiérrez et al., 1998), near our Las Juntas midden site (see below).

## Methods

Thirty-three rodent middens were dated and analyzed from north- and northeast-facing ignimbrite cliffs at three sites: (1) 21 middens from El Sifón (2985–3081 m), where most of the older middens came from one rock shelter in a narrow stretch of canyon; (2) eight from Las Juntas (3100–3137 m), 15 km upstream; and (3) four from Quebrada Aiquina, (2986 m) a dry tributary ~1 km downstream of El Sifón. Radiocarbon dates were obtained from rodent fecal pellets, or in a few cases from plants of interest. All middens were calibrated to calendar years BP using CALIB 5.1 (with the Intcal04 curve). Except in a few cases, there was no stratigraphic continuity between middens, and each midden series contains many temporal gaps.

Middens were wet-sieved and dried, and macrofossils (plants, vertebrate bone and insects) were separated according to standard techniques (Betancourt et al., 1990; Latorre et al., 2002). Plant macrofossils including seeds, leaves, flowers, and fruits were then identified by comparison to a modern reference collection. Relative abundance (0 = absent, 1 = very rare, 2 = rare, 3 = common, 4 = abundant, 5 = dominant) was plotted for select taxa in order of appearance. The total number of species was also plotted along with occurrence of macroscopic charcoal. Plant species nomenclature follows a published flora of the II Region of Chile (Marticorena et al., 1998).

For paleoclimatic inferences, we relied on the upper limits of Prepuna taxa and summer annuals, which are controlled by cold temperatures, and the lower limits of steppe grasses and Puna shrubs, which are controlled by precipitation. We caution that modern plant distributional data are sparse in the Atacama (Marticorena et al., 1998) and only a few weather stations are available to determine climatic envelopes.

The uppermost elevation for Prepuna or summer annual species and the lowermost elevation for Andean steppe and

Puna species between 22 and 25°S was established based on our own observations, herbarium data, or published floras. Polynomial regressions of temperature and rainfall changes with elevation and associated errors (Fig. 2) were used to estimate the MAT and MAR at midden sites, the MAT for the highest elevation or Prepuna/summer annual species, and MAR for the lowest elevation for Andean steppe/Puna species. For particular midden assemblages, we calculated the climatic differences between the equivalent elevation of the midden assemblages and the midden sites. The MAT difference indicates the maximum cooling possible given the presence of warm indicator species. Conversely, the difference in MAR indicates our estimate of minimum rainfall increase represented by the presence of a given wet indicator species. For example, *Tiquilia atacamensis*, a species found today at the margin of absolute desert, has never been collected above 3025 m, implying that MAT cannot fall below the equivalent altitude or  $9.8 \pm 2^\circ\text{C}$  when this species is present. By contrast, the presence of *Nassella arcuata*, a steppe grass which today no longer occurs south of 20°S latitude and does not grow below 3600 m, implies that MAR was  $\geq 122$  mm ( $\pm 23.8$  mm).

## Results

### Radiocarbon dates

Table 2 indicates midden provenance, material dated,  $\delta^{13}\text{C}$  values,  $^{14}\text{C}$  ages, and calibrated ages (at  $2\sigma$ ) for all middens. El Sifón midden ages range from 21,940 to 530 cal yr BP. Significant clusters of dates occur at 17,520–16,270, 10,740–9550 and 3490–2320 cal yr BP. Middens from Las Juntas date between 9840 and 7840 cal yr BP and between 1691 cal yr BP to modern. At Quebrada Aiquina, four middens date between 11,770 and 10,250 cal yr BP and at 748 cal yr BP. At El Sifón,  $\delta^{13}\text{C}$  values from dated fecal pellets (Table 2) are more negative (lighter:  $-22.0$  to  $-22.9\text{‰}$ ) before 10,740 cal yr BP than after ( $-16.6$  to  $-21.1\text{‰}$ ). This probably reflects greater importance of  $\text{C}_4$  and CAM plants in rodent diets at El Sifón after  $\sim 10,740$  cal yr BP. The Quebrada Aiquina series contains only one Holocene midden and the Las Juntas series lacks any sample older than 9840 cal yr BP, so these midden series are not directly comparable.

### Plant macrofossil series

We identified a total of 55 plant macrofossil taxa, 51 at El Sifón, 45 at Las Juntas, and 31 at Quebrada Aiquina (see Appendix A). A total of 39 taxa were identified to species, the rest to genus or family (e.g., Cyperaceae).

### El Sifón (Fig. 5)

The oldest midden (21,940 cal yr BP) has the fewest taxa (11) and is dominated by *Opuntia* spp. and *Baccharis tola*, with traces of *Atriplex imbricata* and *Cistanthe* sp. (Fig. 5). Three middens dated to 17,520–16,270 cal yr BP contain abundant Andean steppe grasses (*Nassella arcuata*, *Nassella nardioides*, *Anatherostipa* cf. *venusta*, *Anatherostipa* cf. *bomanii*), summer

annuals (*Aristida adsencionis*, *Munroa decumbens*, *Tagetes multiflora*), Puna shrubs (*Baccharis tola*, *B. boliviensis*, *Junellia seriphoides*, and *Fabiana* spp.), a few Prepuna taxa (*Exodeconus integrifolius* and *Atriplex imbricata*) and several unknown taxa. A 14,180 cal yr BP midden lacks Andean steppe and Puna elements, and is the first midden where riparian taxa become dominant with an increase in Cyperaceae and first appearance of *Cortaderia*. Andean steppe/Puna elements and summer annuals become dominant again in six middens between 10,740 and 9550 cal yr BP, concomitant with increasing dominance of Prepuna taxa (*Ambrosia artemisioides*, *Ephedra* sp., *Tarasa aperculata*, *Lycopersicon chilense*, *Krameria lappacea*, and *Hoffmannseggia* sp.) and columnar cacti (*Echinopsis* sp. and *Oreocereus* sp.). The Andean bog grass *Puccinellia frigida* appears in two of these middens. Macroscopic charcoal appears for the first time at 10,740 cal yr BP. There is a 2220-yr gap from 9550 to 7330 cal yr BP. Four middens between 7330 and 6720 cal yr BP have the greatest number of species in the El Sifón series, especially summer annuals and Prepuna taxa. *Fabiana* sp., a dominant Puna shrub absent at El Sifón today, was common in a 7190 cal yr BP midden, and *Nassella arcuata*, an Andean steppe grass, occurs at 6720 cal yr BP. Summer annuals, Puna and Andean steppe species are absent in a 4920 cal yr BP midden, which is dominated by Prepuna and riparian taxa. *Echinopsis* sp. reappears briefly in three middens between 3490 and 2320 cal yr BP, but is missing in younger middens. This species is not present at the site today but occurs farther up the canyon at  $\sim 3100$  m of elevation (Table 1). The youngest two middens (700 and 530 cal yr BP) are dominated by modern, local taxa (*Ambrosia artemisioides*, *Atriplex imbricata* and *Lycopersicon chilense*), and mark the reappearance of summer annuals. The 700 cal yr BP assemblage is the only midden that contains *Prosopis* sp. (*algarrobo* or mesquite), which does not occur at the site today.

### Quebrada Aiquina (Fig. 6)

Three of the four middens dated between 11,770 and 10,250 cal yr BP, and contain the steppe grasses *Nassella arcuata* and *Jarava atacamensis*, the Puna shrub *Junellia seriphoides*, columnar cacti *Oreocereus* sp. and several summer annuals. None of these species were found there growing today (Table 2). In contrast, a single midden dated to 748 cal yr BP contains only a few annuals and is dominated by *Opuntia camachoi* and *Atriplex imbricata*.

### Las Juntas (Fig. 7)

The three oldest middens dated to 9840–8910 cal yr BP and contain Andean steppe grasses, including *Anatherostipa* cf. *venusta* and *Jarava atacamensis*. *A. venusta* is especially abundant in the 9840 cal yr BP midden. Despite the site's high elevation (3100–3150 m), *Junellia seriphoides* is the only Puna taxa found in these older middens (Gutierrez et al., 1998). Other taxa include summer annuals, several cacti, and Prepuna perennials (*Ambrosia ambrosioides*, *Krameria lappacea*, *Tarasa operculata*). Again, the bog grass *Puccinellia frigida* appears in two middens dated at 9030 and 8640 cal yr BP



Table 1 (continued)

North facing slopes															
Altitude	<i>Ephedra breana</i>	<i>Tarasa operculata</i>	<i>Helogyne macrogyne</i>	<i>Echinopsis atacamensis</i>	<i>Opuntia camachoi</i>	<i>Opuntia cf. sphaerica</i>	<i>Fabiana denudata</i>	<i>Oreocereus</i>	<i>Stipa chrysophylla</i>	<i>Adesmia rahmeri</i>	<i>Sisymbrium</i>	<i>Haplopappus rigidus</i>	<i>Fabiana ramulosa</i>	<i>Junellia seriphioides</i>	Total
3185	1	0	1	1	1	0	1	0	0	0	0	1	1	1	12
3165	1	1	1	1	0	0	0	1	1	1	1	0	0	0	11
3116	1	1	1	1	1	1	0	0	0	0	0	0	0	0	15
3096	1	1	1	1	0	1	1	0	0	0	0	0	0	0	13
2957	1	0	0	0	0	0	0	0	0	0	0	0	0	0	12
South facing slopes															
Altitude	<i>Polyachyrus</i> sp.	Total													
3185	1	7													
3165	1	9													
3116	0	12													
3096	0	4													
2957	0	1													
Riparian vegetation															
Altitude	<i>Stipa</i> sp.	<i>Caiophora</i>	Total												
3185	1	1	7												
3165	0	0	8												
3116	0	0	9												
3096	0	0	7												
2957	0	0	5												

Table 2  
Radiocarbon chronology and collection data for 33 middens used in this study

Midden No	<sup>14</sup> C Lab No.	Altitude (m)	<sup>14</sup> C Age	Std Dev	δ <sup>13</sup> C (per mil)	Calendar yr B.P.	Range (2σ)	Material dated
<i>El Sifón</i>								
353	GX-26571	2913	540	50	-21.1	530	470–620	<i>Phyllotis</i> fecal pellets
356A	GX-26752	3031	800	100	-20.7	700	550–900	<i>Phyllotis</i> fecal pellets
362A	GX-26756	2985	2360	50	-19.3	2320	2150–2450	<i>Phyllotis</i> fecal pellets
358D1	GX-25662	2985	3080	210	-20.5	3200	2740–3700	<i>Phyllotis</i> fecal pellets
371A	GX-23855	3081	3310	155	-20.1	3490	3075–3870	<i>Phyllotis</i> fecal pellets
360B	AA-59510	2985	4355	34	-18.0	4865	4820–4970	<i>Phyllotis</i> fecal pellets
358C	GX-26753	2985	5930	280	-18.3	6720	6120–7395	<i>Phyllotis</i> fecal pellets
371B	AA-59511	3081	6220	41	-20.0	7070	6930–7190	<i>Phyllotis</i> fecal pellets
368C	AA-53958	2946	6325	73	-16.6	7190	6970–7390	<i>Phyllotis</i> fecal pellets
368A	AA-55392	2946	6448	47	-17.3	7330	7230–7430	<i>Phyllotis</i> fecal pellets
365	AA-59513	2950	8628	61	-20.0	9550	9460–9680	<i>Phyllotis</i> fecal pellets
357	GX-23854	2970	9120	350	-18.8	10,170	9510–10,970	<i>Phyllotis</i> fecal pellets
371C	AA-59512	3081	9166	46	-21.3	10,260	10,190–10,410	<i>Phyllotis</i> fecal pellets
364B	GX-26755	2950	9170	240	-20.1	10,260	9570–10,790	<i>Phyllotis</i> fecal pellets
370	AA-59514	2897	9545	47	-17.7	10,730	10,580–10,970	<i>Phyllotis</i> fecal pellets
355	GX-25660	3000	9560	130	-22.4	10,740	10,450–10,970	<i>Abrocoma</i> fecal pellets
366	AA-59516	2945	12,292	57	-22.9	14,180	13,990–14,580	<i>Abrocoma</i> fecal pellets
358E	GX-26754	2985	13,670	120	-22.0	16,270	15,820–16,760	<i>Phyllotis</i> fecal pellets
363B	GX-26757	2985	14,230	390	-22.7	17,110	15,990–18,480	<i>Phyllotis</i> fecal pellets
358B	GX-25661	2985	14,540	530	-22.4	17,520	16,110–18,820	<i>Phyllotis</i> fecal pellets
358D2	GX-25663	2985	18,490	690	-22.3	21,940	20,280–23,770	<i>Phyllotis</i> fecal pellets
<i>Las Juntas</i>								
308	Modern	3100	0	0	–	0	0	modern active midden
314-2	AA-54669	3112	938	36	-24.2	801	735–907	Individual grass flowers
314-2	GX-23850	3112	1145	175	-24.0	1020	700–1310	<i>Phyllotis</i> fecal pellets
367	AA-53961	3102	1828	48	-22.6	1691	1560–1820	<i>Phyllotis</i> fecal pellets
393A	GX-24212	3150	7050	290	-22.0	7840	7330–8390	<i>Phyllotis</i> fecal pellets
369	AA-59515	3102	7897	58	-19.3	8640	8465–8960	<i>Phyllotis</i> fecal pellets
318	GX-26750	3137	8080	200	-22.2	8910	8450–9420	<i>Phyllotis</i> fecal pellets
393B	AA-53957	3150	8151	68	-16.3	9030	8750–9270	<i>Phyllotis</i> fecal pellets
394Ph	GX-24108	3100	8820	230	-23.1	9840	9300–10,410	<i>Phyllotis</i> fecal pellets
<i>Quebrada Aiquina</i>								
348	AA-35150	2986	885	40	-19.9	748	676–872	<i>Phyllotis</i> fecal pellets
349	GX-23853	2986	9140	130	-22.4	10,250	9800–10,580	<i>Phyllotis</i> fecal pellets
350	AA-35151	2986	9430	75	-20.7	10,590	10,310–10,780	<i>Phyllotis</i> fecal pellets
352	GX-25659	2986	10,110	380	-20.9	11,770	10,700–12,820	<i>Phyllotis</i> fecal pellets

Andean steppe grasses and Puna shrubs are missing in two middens dated at 8640 and 7840 cal yr BP that include several summer annuals. *Pappophorum caespitosum*, a C<sub>4</sub> grass that has never been collected in Chile yet appears in many Atacama middens (Latorre et al., 2002, 2003), occurs for the first and last time in the Río Salado record. There is a prolonged gap in the Las Juntas midden record from 7840 to 1691 cal yr BP. At 1691 cal yr BP, there is a dry assemblage with no Andean steppe or Puna taxa, no summer annuals, and only one species of cactus (*Opuntia camachoi*). This assemblage is dominated by a few Prepuna perennials (*Tarasa operculata*, *Lycopersicon chilense*, and *Atriplex imbricata*). Andean steppe grasses (*Nassella arcuata*, *Stipa chrysophylla* and *Jarava atacamensis*) reappear at 801 cal yr BP, along with the Puna shrubs *Baccharis boliviensis* and *B. tola* which appear for the first time at Las Juntas. Summer annuals are mostly missing from this midden. A modern active midden closely reflects present-day community composition, with 15 taxa in both the midden and our 2003 census of the modern plant community (Table 1). *Chuquiraga*

*atacamensis* is prominent in both the modern midden and the present vegetation, but it does not appear anywhere else in the Río Salado midden record.

#### Paleoclimate estimates (Figs. 8 and 9)

The presence of *Cistanthe* spp. in the 21,940 cal yr BP El Sifón midden indicates that MAT could not have fallen <4.9°C (compared to 10°C at the site today) (Fig. 8A), whereas the presence of *Baccharis tola* suggests that MAR could have increased by 10 mm (Figs. 8B, 9). The abundance of *Nassella nardioides* and *N. arcuata* in 17,520–16,270 cal yr BP middens indicate an increase in MAR by at least 60 mm. Presence of summer annuals indicates that MAT must have increased with respect to the older midden. Appearance of *Tiquilia atacamensis* at 16,270 cal yr BP indicates that MAT was ≥9.8°C. At 14,180 cal yr BP, the lack of Andean steppe elements and summer annuals suggest that MAR declined to values similar to those at El Sifón today. The presence of *Helogyne macrogyne*

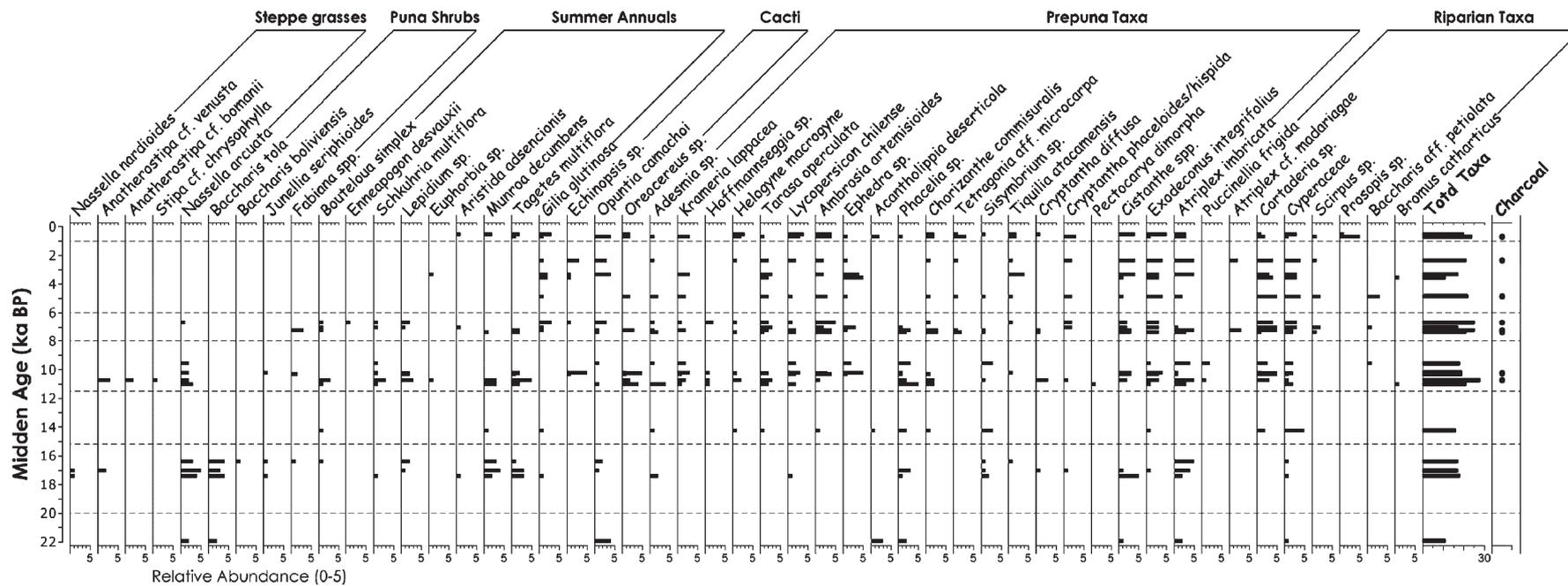


Figure 5. Plant macrofossil diagram for El Sifón midden series (2985 m) ( $n = 21$ ). Dotted lines denote major changes in midden assemblages. For charcoal: blank = absence, dot = presence.

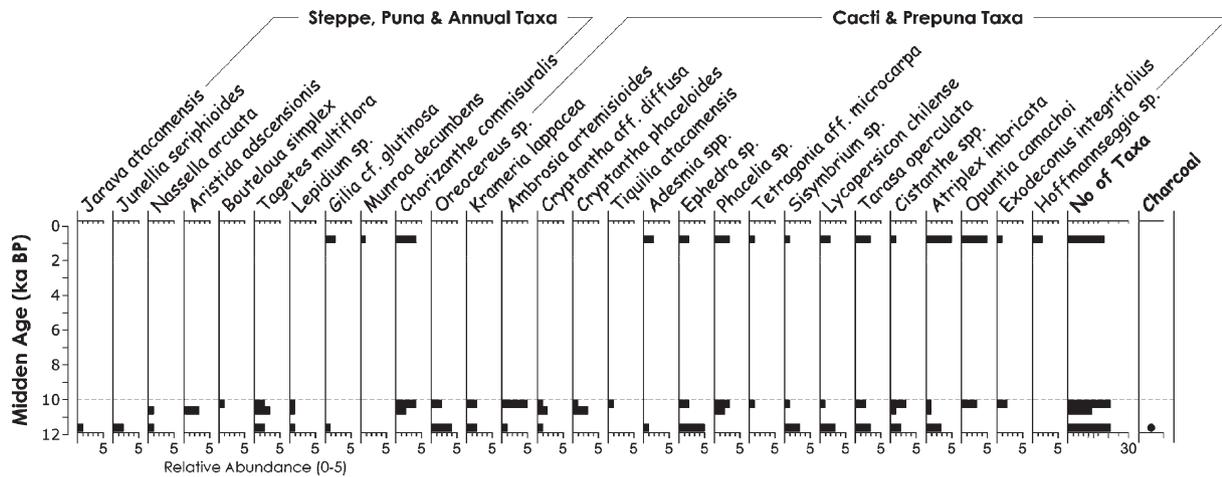


Figure 6. Plant macrofossil diagram for Quebrada Aiquina midden series (2986 m) ( $n = 4$ ). For charcoal: blank = absence, dot = presence.

indicates that MAT was at most  $2.1^{\circ}\text{C}$  cooler than today. Multiple species of Andean steppe grasses from midden assemblages between 11,770 and 9550 cal yr BP suggests MAR between 75 and 100 mm (Fig. 10). Middens from Las Juntas between 8640 and 7840 cal yr BP lack wet indicator species including Puna shrubs (common at this site today) and imply that MAR may have been much lower than today. Numerous summer annuals and *Nassella arcuata* at El Sifón indicate that MAR increased between 7330 and 6720 cal yr BP. The presence of *Fabiana* sp., in a midden dated to 7330 cal yr BP, indicates an increase in MAR by  $\sim 10$  mm. The presence of *Nassella arcuata* at 6720 cal yr BP indicates an increase of at least 60 mm (although see below). *Tiquilia atacamensis* is present in all El Sifón middens younger than 6720 yr BP, except at 3490 cal yr BP, indicating that MAT has not dropped below modern temperatures during formation of these middens. The appearance of *Echinopsis* sp. at El Sifón between 3490 and 2320 cal yr BP indicates a slightly higher MAR than today. Finally, the presence of Andean steppe and Puna species at Las Juntas at 801 cal yr BP suggests that MAR increased by at least 44 mm, which then decreased to modern values by possibly 700 cal yr BP as indicated by assemblages at El Sifón.

## Discussion

### General vegetation trends in the Río Salado midden record

Conspicuous trends from Pleistocene to Holocene include the reduction in importance of Andean steppe grasses and Puna shrubs, general increase in riparian taxa, and lack of summer annuals at 22,170 cal yr BP at El Sifón (Fig. 5). Poor coverage in the Las Juntas series (Fig. 7) limits comparisons to the increase in Puna shrubs from the early to late Holocene. In both the El Sifón and Las Juntas series, Prepuna taxa are surprisingly stable. This constrains the amount of cooling that could have occurred over the past 22,000 yr, at least while the middens were being deposited. The return of Andean steppe grasses at Las Juntas at 801 cal yr BP suggests a relatively fast response

time to wet multiyear episodes. Arrival of *Chuquiraga atacamensis* at Las Juntas less than 800 yr ago suggests that floristic turnovers are ongoing (Fig. 7). Macroscopic charcoal occurs in a Quebrada Aiquina midden at 11,770 cal yr BP (Fig. 6) and most El Sifón middens beginning  $\sim 10,740$  cal yr BP (Fig. 5). This charcoal is probably anthropogenic and could indicate human use of this perennial river canyon since 11,700 cal yr BP. The oldest occupation in the canyon dates to 8900 cal yr BP at Alero Toconce ( $22^{\circ}16'S$ ;  $68^{\circ}10'W$ ) (Aldunate et al., 1986). The lack of any charcoal from the oldest middens (358B, 358D, 358D2, 358E; Table 1) in the El Sifón series, which came from a habitable and deep rock shelter, suggests absence of human occupation before 11,770 cal yr BP.

### Paleoclimatic interpretation of the Río Salado midden record

Midden assemblages between 17,520 and 16,270 cal yr BP indicate twice the modern precipitation at El Sifón. Likewise, the Prepuna species *Tiquilia atacamensis* at 16,270 cal yr BP indicates that MAT may have been equal or greater than today. At 14,180 cal yr BP, MAR declined to values similar those present at El Sifón today, with MAT  $\sim 2.1^{\circ}\text{C}$  cooler than today. MAR increased again between 11,770 and 9550 cal yr BP with estimates ranging from 75 to 100 mm/yr, based on the presence of several Andean steppe grasses. The onset of aridity at the beginning of the Holocene, as indicated by the lack of Puna shrubs (presently common at this site) occurred at Las Juntas between 8730 and 7840 cal yr BP. The presence of numerous summer annuals, *Fabiana* sp., and *Nassella arcuata* at El Sifón implies that MAR increased significantly between 7330 and 6720 cal yr BP (Fig. 9). The presence *N. arcuata*, which does not occur in the region today, at 6720 cal yr BP could mean an increase in MAR by at least 60 mm. All middens at El Sifón younger than 6720 cal yr BP (save one at 3490 cal yr BP) contain *Tiquilia atacamensis*, a prepuna perennial. This implies that MAT has not dropped below modern temperatures at any time during midden deposition. The return of *Echinopsis* sp. to El Sifón between 3490 and 2320 cal yr BP indicates that MAR may have been slightly higher than today. The species

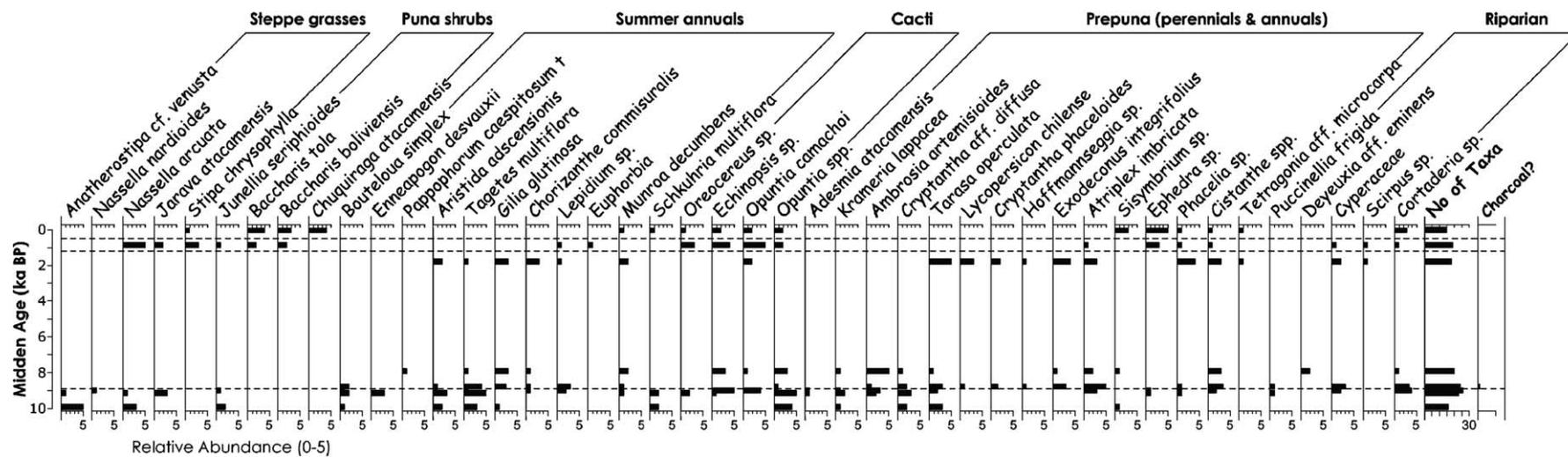


Figure 7. Plant macrofossil diagram for Las Juntas midden series (3100 m) ( $n = 8$ ). Dotted lines denote major changes in midden assemblages. The C<sub>4</sub> grass *Pappophorum caespitosum* has never been collected in Chile and may be locally extinct (see also Latorre et al., 2002).

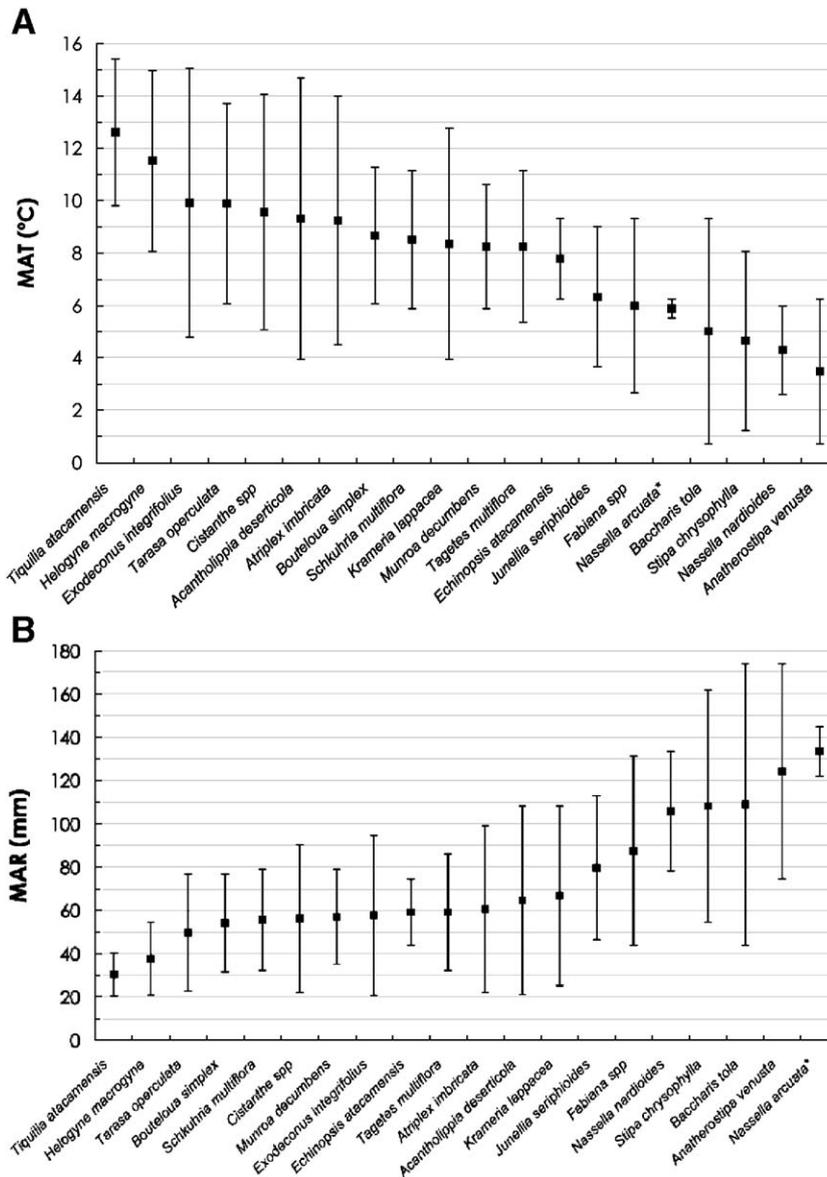


Figure 8. Mean Annual Temperature (MAT) and Mean Annual Rainfall (MAR) estimates inferred for several key indicator plant species present in the midden record based on elevational distribution (see Fig. 2). (\*) *Nassella arcuata* no longer grows south of 20°S and values calculated here should be considered as minimum estimates.

*Echinopsis atacamensis* is found starting at 3100 m along the north-facing slopes of the canyon, some 100 m above the El Sifón site. A brief but large precipitation increase is implied by the presence of Andean steppe and Puna species at Las Juntas at 801 cal yr BP, which then reversed to reach modern values possibly by 748 cal yr BP at Quebrada Aiquina and El Sifón.

#### Comparison with other midden records in the central and Southern Atacama

The Río Salado midden record complements a battery of Atacama paleostudies published over the last few years. These record include published midden series from the west and east slopes of the Cordillera de Domeyko in the Calama Basin (Sites 3–6 in Fig. 1; Latorre et al., 2003), the southern end of Salar de

Atacama (Site 7 in Fig. 1; Betancourt et al., 2000; Latorre et al., 2002), and Quebrada del Chaco in the southern Atacama (Site 8 in Fig. 1; Maldonado et al., 2005).

Our first midden study in the central Atacama focused on the transition from Prepuna to absolute desert between 2400 and 3050 m at Lomas de Tilocalar and Quilvar near the southern end of Salar de Atacama (Betancourt et al., 2000; Latorre et al., 2002). We earlier speculated, perhaps prematurely, that the lack of full glacial (24,000–16,000 cal yr BP) middens in the Quilvar/Tilocalar series might be linked to less precipitation and lower productivity than during the late glacial–early Holocene (Betancourt et al., 2000). Among the major findings at Quilvar/Tilocalar was the displacement of Puna and Andean steppe species 400–1000 m downslope from 16,200 to 10,500 cal yr BP, requiring a three- to five-fold increase in



Rech et al., 2003), Tilomonte and the lower Río Salado (Rech et al., 2002), sediment cores and shoreline deposits from small lakes (Lagunas Lejía and Miscanti) on the Chilean Altiplano (Geyh et al., 1999; Grosjean, 1994; Grosjean et al., 2001), a 100-m (100,000-yr) salt core record from Salar de Atacama (Bobst et al., 2001), and geoarcheological investigations throughout the central Atacama (Núñez et al., 2002) (see Fig. 1 for locations). The greatest discrepancy among these records in the central Atacama is the core evidence for a large salt lake between 54,000 and 15,200 yr in Salar de Atacama (Bobst et al., 2001). This salt lake, however, was mostly coeval with wet phases recorded in areas to the south that are now dominated by winter precipitation such as Quebrada del Chaco (Maldonado et al., 2005), saline lake (57,000–55,000, 45,000 yr) and saline pan (49,000, 44,000–38,000, and 24,000–20,000 yr) wet phases at Salar del Hombre Muerto (25°20'S, 67°W), a marine sedimentary record (27°30'S) for greater sedimentary contribution from the Andes to the Pacific Coast centered on 50,000 cal yr BP and 22,000 cal yr BP (Lamy et al., 1998), and the northward and downward expansion of southern beech forest between 30,000 and 17,500 cal yr BP and >36,000 cal yr BP at Laguna Tagua Tagua (34°30'S) (Heusser, 1983, 1990).

In contrast to Salar de Atacama, a freshwater lake present at Laguna Miscanti ~24,000 cal yr BP had disappeared by 20,000 cal yr BP, though exact timing of these events is somewhat compromised by large carbon reservoir effects on radiocarbon dates (Grosjean et al., 2001). For the most part, there is a close match between the midden and paleohydrological evidence for a late glacial–early Holocene pluvial event in the central Atacama. Both small lake (Lagunas Lejía and Miscanti) and groundwater levels, the latter inferred from spring deposits (Betancourt et al., 2000; Rech et al., 2002), were at their highest from 15,400 to 9000 cal yr BP. It is evident from the Quebrada del Chaco midden record that this pluvial increased summer precipitation as far south as 25°30'S (Maldonado et al., 2005). Kull and Grosjean (1998) concluded that precipitation must have doubled to account for lake levels some 25 m higher than today at Laguna Lejía. This pluvial episode was interrupted by a brief dry phase around 11,600 cal yr BP at L. Lejía and L. Miscanti (Grosjean et al., 2001). Given the uncertainties in the lake dates, this temporary decrease in lake levels may match the dry midden assemblages at ~12,000 cal yr BP in Quilvar/Tilocalar and the west slope of the Cordillera Domeyko. Increases in lake levels from 14,000 to 9000 cal yr BP were accompanied by increases in grass pollen between 11,000 and 9000 cal yr BP at Laguna Miscanti (Grosjean et al., 2001), confirming midden evidence for greatly expanded grasslands on the Pacific slope, high ground water tables (Rech et al., 2002) and numerous Paleindian and early Archaic sites between 13,000 and 9000 cal yr BP throughout the central Atacama (Núñez et al., 2002). Other evidence for a late glacial–early Holocene wet phase, though minor compared to one between 54,000 and 15,200 cal yr BP, comes from a U-series dated interval between 11,400 and 10,200 yr in the salt core at Salar de Atacama (Bobst et al., 2001).

The nature of mid-Holocene (9000–4000 cal yr BP) paleohydrology in the central Atacama remains a matter of

debate (e.g., Quade et al., 2001; Rech et al., 2002, 2003 vs. Grosjean, 2001; Grosjean et al., 1997, 2003). The controversy is muddled by dating uncertainties, contrasting temporal resolution for different proxies, and different interpretations of the same field evidence. As one example, rapid onset of aridity is recorded at ~9500 cal yr BP at Laguna Miscanti, followed by a drop in the regional groundwater table at 9000 cal yr BP as indicated by paleowetland stratigraphy (Rech et al., 2002, 2003). Groundwater levels rebounded between 7000 and 3000 cal yr BP while Laguna Miscanti only records decadal-scale (?) fluctuations until ~4500 cal yr BP, when the lake starts to rise again (Grosjean et al., 2003). The latter date has large uncertainties due to large carbon reservoir effects, so the lake conceivably could have started rising much earlier. The midden evidence shows a mix of wet and dry assemblages through the middle Holocene in each of the series, some of them synchronous, some of them not. At this stage in the Atacama work, we agree with Grosjean et al. (2003) that midden coverage to date may be too sparse and poorly replicated to capture more subtle trends in century to millennial-scale climate variability during the Holocene.

Finally, our new minimum rainfall estimates for the Río Salado record are in good agreement with a new record of past variations in paleolake surface area at Salar de Uyuni as established by 140 <sup>14</sup>C and U/Th dates on shoreline features (Placzek et al., in press) (Fig. 10). These can be summarized as follows: (1) the presence of a shallow lake at Salar de Uyuni (the Sajsi cycle) during the last glacial maximum (LGM) agrees with our estimates for only slightly increased precipitation (ca. +10 mm/yr with respect to modern), (2) the earliest midden evidence for a summer pluvial in the central Atacama, beginning at 17,520 cal yr BP slightly precedes abrupt infilling of paleolake Tauca at ~17,000 cal yr BP; (3) the 14,120 cal yr BP drop in MAR visible in the Salado record is coeval with a dramatic fall in lake surface area that marks the end of the Tauca phase; and (4) increased MAR at Río Salado between 11,770 and ~9000 cal yr BP overlaps to some degree with the Coipasa cycle, between 13,000 and 11,000 cal yr BP. In general, increased precipitation at Río Salado and higher lake levels at Salar de Uyuni are coeval with depleted  $\delta^{18}\text{O}$  values in the Sajama ice core (Thompson et al., 1998) (Fig. 10). Droughts at both Río Salado and Salar de Uyuni coincide with enriched  $\delta^{18}\text{O}$  values at Sajama, in particular the abrupt ~7‰ increase in  $\delta^{18}\text{O}$  at 14 ka.

At the continental scale, the early onset of a wet phase beginning at 17,500 cal yr BP coincides with an abrupt increase in SSTs to modern values along with heightened ENSO activity, as evinced by marine sediments of the coast of Lima, Peru (Rein et al., 2005) and with onset of deglaciation in southern Chile, as marked by the expansion of north Patagonian rainforests into the southern Lakes District (Denton et al., 1999; Moreno et al., 1999; Moreno and León, 2003). All of these features are contemporaneous with the collapse of the Laurentide ice sheet marked by Heinrich Event 1 in the North Atlantic (Bond et al., 1997) and argues for a major role of the tropical hydrosphere in bringing about global deglaciation, either through abrupt

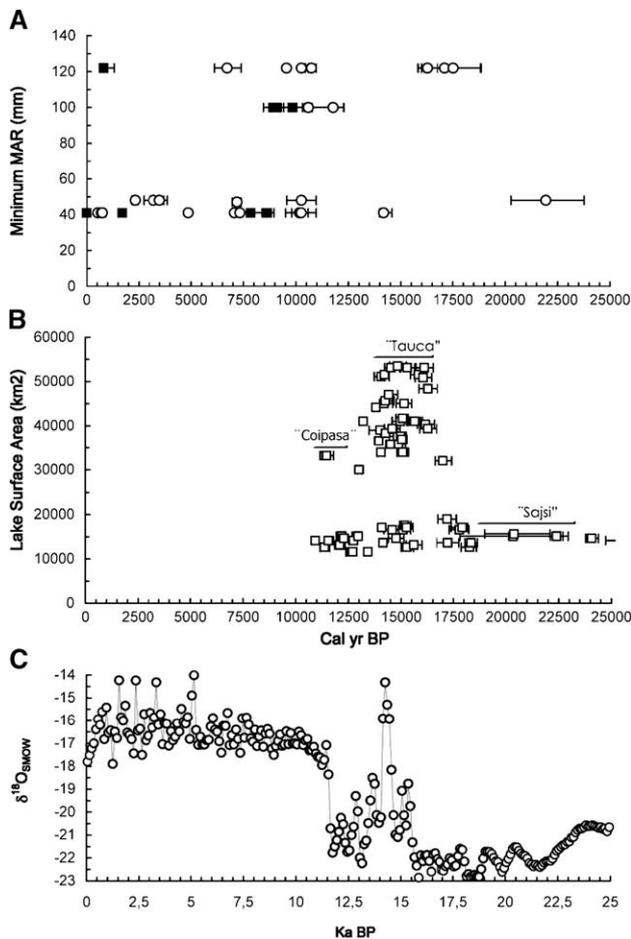


Figure 10. A regional comparison of paleoclimate records across the region. (A) minimum MAR estimates at Río Salado, as indicated in Figure 9 (vertical error bars removed for clarity); (B) palaeolake surface area obtained from radiocarbon dates along terraced outcrops at Salar de Uyuni (Placzek et al., in press); (C) the Sajama ice core record (Thompson et al., 1998).

increase of global water vapor, intensified Walker and Hadley cell circulation, or both (Pierrehumbert, 1999).

So, what are the actual mechanisms that contribute to wet and dry phases in the central Atacama? The answer could vary with timescale (Garreaud et al., 2003) and is further complicated by the roles of two regional moisture sources, the Amazon Basin to the northeast and the Gran Chaco lowlands (20–29°S) to the east (Vuille and Keimig, 2004). On interannual time scales, summer rainfall variability over the Altiplano is controlled by equatorial Pacific SST gradients and the strength of the tropical easterlies, independent of moisture availability in the western Amazon Basin (Vuille et al., 2000; Garreaud et al., 2003). Farther south, however, moisture availability in the Gran Chaco lowlands can modulate precipitation variability in the southern Altiplano and by extension the central Atacama to the west (Vuille and Keimig, 2004).

On glacial–interglacial timescales, there may be counteracting effects. During glacial periods the contrast in heating between northern and southern hemispheres yields stronger easterlies (a stronger Hadley cell in the austral summer) but the colder mean climate would tend to reduce low-level moisture available from both the Amazon Basin and the Gran Chaco

(Garreaud et al., 2003). At millennial timescales, precessional forcing would affect the land-sea contrast and continental-scale circulation, specifically the strength of the Bolivian High. Hypothetically, maximum (minimum) austral summer insolation would tend to strengthen (weaken) the equatorward portion of the upper-level anticyclone, yielding anomalous easterly (westerly) flow and wetting (drying) over the Altiplano.

At 20°S, January insolation reaches its maximum at ~20,000 cal yr BP and its minimum at ~10,000 cal yr BP. The importance of insolation forcing in modulating the strength of the Bolivian High finds support in inferences of maximum wetting during LGM from lake-core evidence in Salar de Uyuni (Baker et al., 2001) and Salar de Atacama (Bobst et al., 2001). The lake core evidence is contradicted, however, by inferences of maximum wetting during the late glacial and early Holocene from shoreline evidence in the Uyuni Basin and rodent midden and other evidence in the central Atacama. An explanation for maximum wetting during the late glacial–early Holocene could involve solar, nonlinear forcing of tropical Pacific SST gradients into prolonged La Niña-like phases and stronger tropical easterlies along the lines described by Clement et al. (2001).

## Conclusions

Midden records from the Río Salado Basin add to fast-developing knowledge about the timing and duration of past wet and dry phases in the central Atacama Desert over the last 22,000 yr. Given the earliest dates for the onset of the late glacial–early Holocene summer pluvial, the midden sequence is now in close agreement with new paleolake shoreline chronologies from the Bolivian Altiplano, including the rapid rise of Paleolake Tauca ~17,000 cal yr BP, the rapid drop around 14,100 cal yr BP, and a secondary “Coipasa” lake phase ~13,000–11,000 cal yr BP (Fig. 10) (Sylvestre et al., 1999; Placzek et al., in press). A late glacial–early Holocene timing for maximum wetting in the subtropical Andes may implicate changes in equatorial Pacific SST gradients, perhaps a dynamical oceanic response to radiative forcing over the sea (Clement et al., 2001). This could have had a greater impact in modulating the strength of the tropical easterlies and precipitation variations in the central Andes than linear responses to seasonal insolation variations over land.

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**Appendix A. Lifeform and vegetation belt affinity of plant taxa identified from macrofossils of Río Salado middens (QA = Quebrada Aiquina; ES = El Sifón; LJ = Las Juntas)**

Taxa	Family	Lifeform	Belt	QA	ES	LJ
<i>Gymnospermeae</i>						
<i>Ephedra</i> sp.	Ephedraceae	Shrub	Prepuna-Puna	1	1	1
<i>Dicotyledoneae</i>						
<i>Tetragonia</i> aff. <i>microcarpa</i>	Aizoaceae	Perennial herb	Prepuna	1	1	1
<i>Ambrosia artemisioides</i>	Asteraceae	Shrub	Prepuna	1	1	1
<i>Baccharis</i> aff. <i>petiolata</i>	Asteraceae	Shrub	Riparian	0	1	0
<i>Baccharis boliviensis</i>	Asteraceae	Shrub	Puna	0	1	1
<i>Baccharis tola</i>	Asteraceae	Shrub	Puna	0	1	1
<i>Chuquiraga atacamensis</i>	Asteraceae	Shrub	Puna	0	0	1
<i>Helogyne macrogyne</i>	Asteraceae	Shrub	Prepuna-Puna	0	1	0
<i>Schkuhria multiflora</i>	Asteraceae	Summer annual	Puna	0	1	1
<i>Tagetes multiflora</i>	Asteraceae	Summer annual	Puna	0	1	1
<i>Cryptantha diffusa</i>	Boraginaceae	Prepuna annual	Prepuna	1	1	1
<i>Cryptantha phaceloides/hispida</i>	Boraginaceae	Prepuna annual	Prepuna	1	1	1
<i>Pectocarya dimorpha</i>	Boraginaceae	Perennial herb	Coastal desert	0	1	0
<i>Tiquilia atacamensis</i>	Boraginaceae	Perennial	Prepuna	1	1	0
<i>Lepidium</i> sp.	Brassicaceae	Annual	Prepuna-Puna	1	1	1
<i>Sisymbrium</i> sp.	Brassicaceae	Annuals	Prepuna	1	1	1
<i>Echinopsis</i> sp.	Cactaceae	Columnnar cacti	Lim. Prepuna/Puna	0	1	1
<i>Oreocereus</i> sp.	Cactaceae	Columnnar cacti	Lim. Prepuna/Puna	1	1	1
<i>Opuntia camachoii</i>	Cactaceae	Cushion cacti	Prepuna-Puna	1	1	1
<i>Opuntia</i> spp.	Cactaceae	Cushion cacti	Prepuna-Puna	1	1	1
<i>Atriplex</i> cf. <i>madariagae</i>	Chenopodiaceae	Shrub	Riparian	0	1	0
<i>Atriplex imbricata</i>	Chenopodiaceae	Shrub	Prepuna	1	1	1
<i>Euphorbia</i> cf. <i>amandi</i>	Euphorbiaceae	Annual	Prepuna-Puna	0	0	0
<i>Phacelia</i> sp.	Hydrophyllaceae	Perennial	Prepuna	1	1	1
<i>Krameria lappacea</i>	Krameriaceae	Shrub	Prepuna-Puna	1	1	1
<i>Adesmia</i> spp.	Fabaceae	Shrubs	Prepuna-Puna	1	1	0

**Appendix A (continued)**

Taxa	Family	Lifeform	Belt	QA	ES	LJ
<i>Dicotyledoneae atacamensis</i>						
<i>Adesmia</i>	Fabaceae	Shrub	Prepuna	0	0	1
<i>Hoffmannseggia</i> sp.	Fabaceae	Annual	Prepuna	1	1	1
<i>Cristaria</i> sp1	Malvaceae	Annual	Prepuna	1	1	1
<i>Cristaria</i> sp2	Malvaceae	Annual	Prepuna	1	1	1
<i>Tarasa operculata</i>	Malvaceae	Perennial herb	Prepuna	1	1	1
<i>Prosopis</i> sp.	Mimosaceae	Tree	Riparian	0	1	0
<i>Gilia glutinosa</i>	Polemoniaceae	Annual	Prepuna	1	1	1
<i>Chorizanthe commisuralis</i>	Polygonaceae	Annual	Prepuna	1	1	1
<i>Cistanthe</i> spp.	Portulacaceae	Annuals	Prepuna	1	1	1
<i>Exodeconus integrifolius</i>	Solanaceae	Annual	Prepuna	1	1	1
<i>Fabiana</i> spp.	Solanaceae		Puna shrubs	0	1	0
<i>Lycopersicon chilense</i>	Solanaceae	Perennial herb	Prepuna	1	1	1
<i>Acantholippia deserticola</i>	Verbenaceae	Shrub	Prepuna-Puna	0	1	0
<i>Junellia seriphoides</i>	Verbenaceae	Shrub	Puna	1	1	1
<i>Monocotyledoneae</i>						
<i>Scirpus</i> sp.	Cyperaceae	Perennials	Riparian	0	1	0
<i>Anatherostipa</i> cf. <i>bomanii</i>	Poaceae	Perennial grass	Andean Steppe	0	1	1
<i>Anatherostipa</i> cf. <i>venusta</i>	Poaceae	Perennial grass	Andean Steppe	0	1	1
<i>Aristida adsencionis</i>	Poaceae	Summer annual C <sub>4</sub> grass	Prepuna-Puna	1	1	1
<i>Bouteloua simplex</i>	Poaceae	Summer annual C <sub>4</sub> grass	Prepuna-Puna	1	1	1
<i>Bromus catharticus</i>	Poaceae	Perennial grass	Riparian	0	1	0
<i>Cortaderia</i> sp.	Poaceae	Perennial grass	Riparian	0	1	1
<i>Deyuexia</i> sp.	Poaceae	Perennial grass	Riparian? Bog?	0	0	1
<i>Enneapogon desvauxii</i>	Poaceae	Summer annual C <sub>4</sub> grass	Prepuna-Puna	0	1	1
<i>Jarava atacamensis</i>	Poaceae	Perennial grass	Andean Steppe	1	1	1
<i>Munroa decumbens</i>	Poaceae	Summer annual C <sub>4</sub> grass	Prepuna-Puna	1	1	1
<i>Nassella arcuata</i>	Poaceae	Perennial grass	Andean Steppe	1	1	1
<i>Nassella nardioides</i>	Poaceae	Perennial grass	Andean Steppe	1	1	1
<i>Pappophorum caespitosum</i>	Poaceae	Summer annual C <sub>4</sub> grass	Extinct in Chile?	0	0	1
<i>Piptochaetium</i> cf. <i>panicoides</i>	Poaceae	Perennial grass	Andean steppe?	0	0	1
<i>Puccinellia frigida</i>	Poaceae	Perennial grass	High altitude bogs	0	1	1
<i>Stipa</i> cf. <i>chrysophylla</i>	Poaceae	Perennial grass	Andean Steppe	0	1	1
<b>Totals</b>				<b>31</b>	<b>51</b>	<b>45</b>

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