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Understanding foraging radius and mobility in a high desert

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ABSTRACT

We examine botanical and lithic assemblages from two rock-shelters in a high elevation desert in NW Argentina in order to understand the relationship between the size of foraging radii, territorial ranges and habitat quality during the Early and Middle Holocene (ca. 8300–6200 BP). We find an increase in foraging radii associated with declining habitat quality and propose a shift from complete radius leapfrog to a point-to-point mobility pattern. The use of nonlocal plants and obsidian suggest large territorial ranges, as well as wide interaction networks between the Puna and neighboring lowlands to the east.

1. Introduction

The aim of this paper is to examine the material traces of mobility in a high-elevation desert by considering static resources —plant macroremains and toolstone— as indicators of foraging radii, foraging ranges and interactions at a regional and macro-regional scale among prehistoric hunting societies in the Salt Puna (Fig. 1). Although archaeobotanical and lithic research often operate as independent research avenues, in this paper we integrate both in order to examine the effect that increased aridity had on the distribution of plant communities, and hence on firewood, plant gathering and toolstone procurement, as well as on the thresholds of human occupation in a high-elevation desert. First, we address land-use strategies at a local scale, within the Laguna de Antofagasta drainage basin, by focusing on the assemblages from Cueva Salamanca 1 site, a residential camp that contains evidence of human activity during the Middle Holocene (7600–6200 BP). Next we compare these finds to those from Quebrada Seca 3, which bears evidence of human occupation for the Early and Middle Holocene (Fig. 2). We propose an increase in the size of foraging radii around residential sites as the result of a decline in habitat quality during the Middle Holocene. Finally, the use of different obsidian sources suggests variation in territorial range sizes, and the intensification in the use of allochthonous plants suggests inter-regional interaction during periods of decreased habitat quality in the Puna.

1.1. Environment in the South Puna

Our research focuses in the Argentine Salt Puna —also known as the South Puna— where climate is cold, temperature averages less than 10° C annually, and vegetation is sparse. Solar radiation is high. Rainfall is estival (November to March) and averages less than 100 mm annually and potential evapotranspiration is 570 mm, resulting in a pronounced hydric deficit year round and arid environment (Morlans, 1995). Precipitation decreases in an east-west gradient, and a complete lack of rainfall over several consecutive years is common (Cabrera, 1976). Soils are immature, sandy and gravelly. The topography in the basin of Laguna de Antofagasta, where this study is centered, combines plateaus, or *pampas*, that rise rapidly from a base level of about 3400 masl. Mountain ranges and volcanoes to the east top 5500 masl. Wetlands (*vegas*), characterized by a dense plant cover of Poaceae and Juncaceae species, border rivers, streams, lakes and *salares* (saltpans).

Relief and altitude gradient have a pronounced effect on plant and animal communities, as well as on transportation and mobility costs to hunter-gatherers. From a phytogeographical standpoint, the vegetation of the Puna belongs to the Andean Dominion, which includes the Altoandean and Puneño provinces (Cabrera, 1957),

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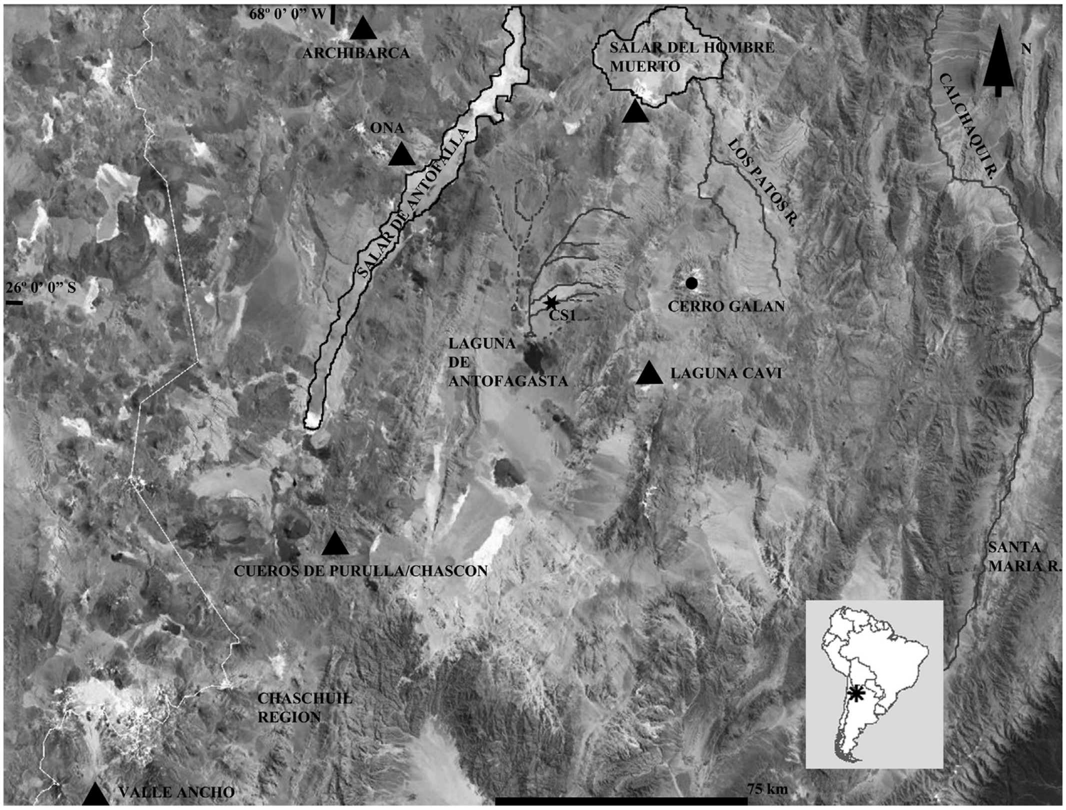

Fig. 1. The basin of Laguna de Antofagasta in the Salt Puna of NW Argentina. The following are shown: Cueva Salamanca 1 (CS1) and obsidian sources (▲).

better known as the *pajonal* and *tolar* respectively. The *tolar* plant community is characterized by shrub steppes dominated by *Fabiana densa*, *Acantholippia punensis*, *Adesmia horrida*, *Parastrephia* sp. and *Baccharis* sp. that occupy the lower elevations of the Puna in the basin floors between 3400 and 3900 masl. Ground cover is 20–30%. *Tolar* shrubs form heterogeneous associations dominated by one species. Shorter herbaceous plants grow in the shade of these shrubs. As elevation increases, shrubs become lower and are scattered.

The *pajonal* plant community, which covers mountain slopes at elevations between 3900 masl and 5600 masl, consists of grasslands where species of Poaceae (*Stipa* and *Festuca* genera) are predominant, although sub-shrub species of *A. horrida*, *Sysimbrium philippianum*, *Baccharis* and *Fabiana bryoides* are also present. *Pajonal* grasses grow in sandy soils, lack continuity given the topography, and form small islands. Ground cover ranges between 5 and 10%. Overall, primary productivity in the Puna is low, albeit with some variation (Morales, 2011), and pockets of resources result in a mosaic or patchy and heterogeneous environment (Yacobaccio, 1994). The local fauna includes vicuñas (*Vicugna vicugna*), which mainly graze in the *pajonal* grasslands, and llamas (*Lama glama*), which mostly feed off wetland grasses. Large rodents (Chinchillidae family) are found in *quebrada* rockeries, whereas birds (*Rhea pennata*, Phoenicopteridae family) are common around water sources. Foxes (*Pseudalopex culpaeus* and *Pseudalopex griseus*) and pumas (*Puma concolor*) are the main predators (Olivera and Elkin, 1994).

1.2. Paleoenvironment of Antofagasta de la Sierra (10,000–4500 BP)

Although today the climate is arid, paleoenvironmental studies show that it fluctuated during the Holocene. In the Puna region of northwest Argentina the Early Holocene had moist conditions (Alcalde and Kulemeyer, 1999; Fernandez et al., 1991; Kulemeyer et al., 1999; Markgraf, 1985; Morales, 2011; Olivera et al., 2004; Tchilinguirian et al., 2012; Yacobaccio and Morales, 2005). In the study region, sediment analyses in Laguna Colorada (Fig. 2) reveal a cold and wet climate that resulted in lake transgression, ca. 10,000–8700 BP, when the first human settlements in the study area occurred at Peñas de las Trampas 1.1 site ca. 10,200 BP, Quebrada Seca 3 site ca. 9400 BP and Punta de la Peña 4 ca. 8900 BP (Martínez, 2012; Urquiza, 2009) (Fig. 2). In general, an arid trend is observed in the Middle Holocene, ca. 8700–4500 BP. In our study region, this period coincided with the occupation of several rock shelters —Cueva Salamanca 1, Quebrada Seca 3 and Peñas de la Cruz 1— with brief humid events in the late Middle Holocene, ca. 6300–5800 BP, as shown by diatoms, organic materials and paleosoils in Laguna Colorada, Mirihuaca River and Las Pitas River (Fig. 2) (Tchilinguirian and Morales, 2013; Tchilinguirian and Olivera, 2014). This trend toward arid conditions is also observed in other regions of the South-Central Andes. Many Altiplano lakes, such as Lake Titicaca (Bolivia), Laguna Miscanti, Laguna del Negro Francisco (Chile), and Laguna El Peinado (Argentina) show low lake levels between 8500 and 4000 BP. An increase in grass pollen in Laguna Seca (Chile) and El Aguilar (northern Argentina) not only shows an increase in aridity, but also in temperature after 8000 BP (Baied and Wheeler, 1993; Grosjean et al., 2001, 2007; Markgraf, 1985; Valero Garcés et al., 1996, 2000). However, there is some disagreement regarding the extent of this aridity, given the presence of moist phases lasting several hundred years (Grosjean, 2001; Betancourt et al., 2000; Latorre et al., 2003, 2006, among others). It appears, therefore, that this climatic change did not have the same severity throughout the Puna, and that some locations retained moisture, such as rivers and lakes with large catchments as well as rivers that descend from the Puna into the Mesothermal

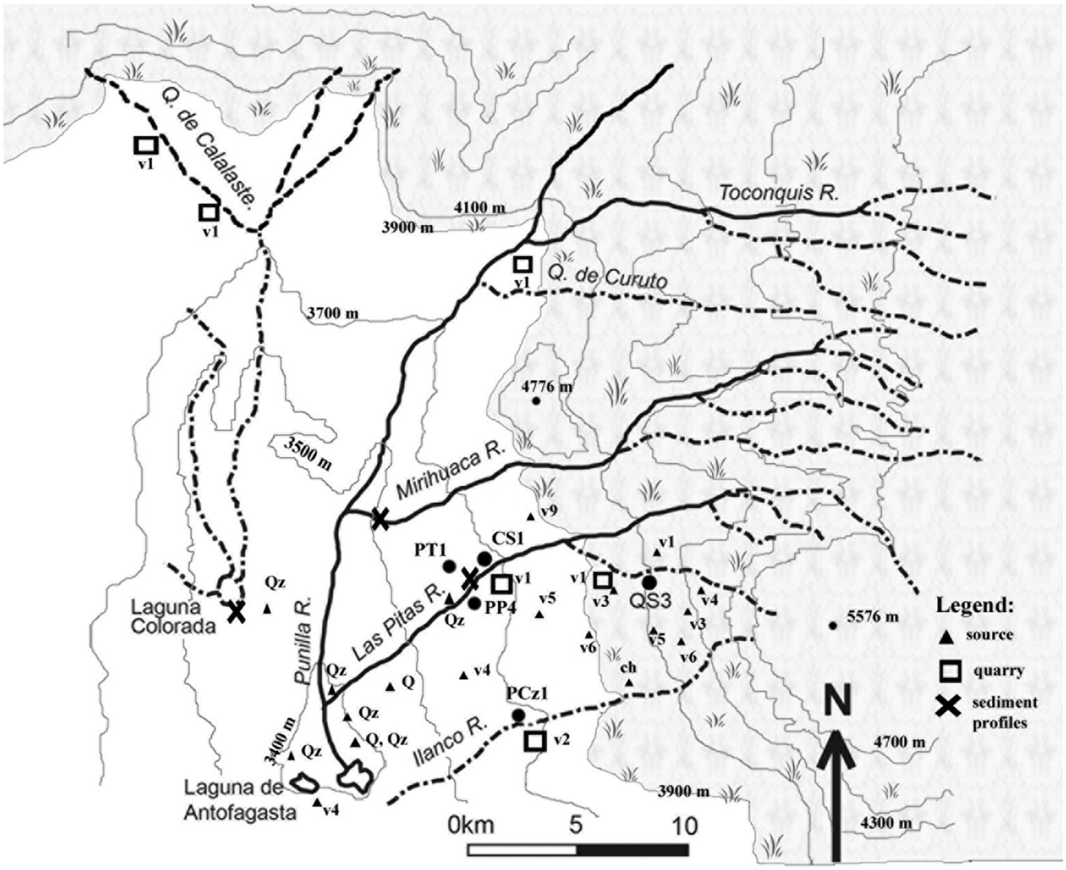

Fig. 2. Location of toolstone quarries in relation to elevation in the basin of Laguna de Antofagasta. The following are shown: Cueva Salamanca 1 (CS1), Quebrada Seca 3 (QS3), Peñas de la Cruz 1 (PCz1) and Peñas de las Trampas 1.1 (PT1) sites. V: vulcanite, Ch: chert, Q: quartz, Qz: quartzite.

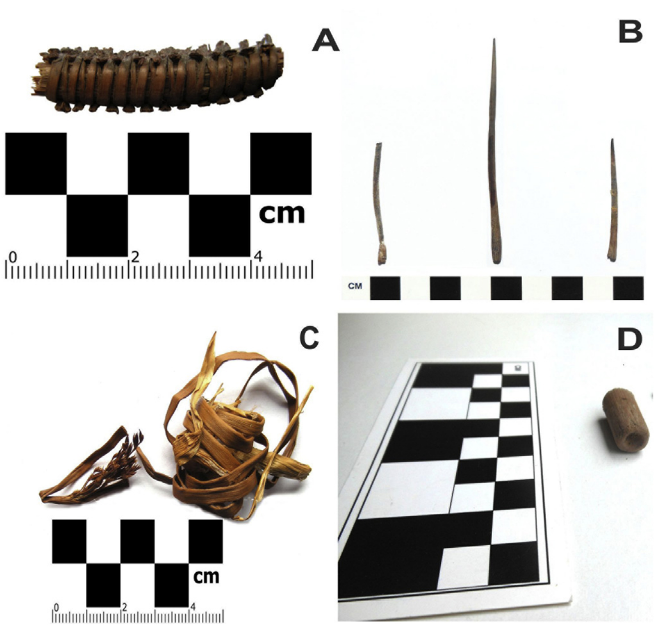

Fig. 3. Artifacts recovered at Cueva Salamanca 1. A: *Cortaderia speciosa* basket fragment (artifact 539); B: *Trichocereus pasacana* thorns (artifacts 254, 65, 70); C: *Juncus balticus* grass knot (artifact 538); D: *Chusquea lorentziana*, (artifact 531).

valleys, which were fed by glaciers (Tchilinguirian and Morales, 2013).

1.3. Modeling mobility in the Salt Puna

The movement of hunter-gatherers across the landscape is challenging to study archaeologically, since there are few, if any, material correlates that can answer questions such as how far, why and how often (Close, 2000, but see Ingbar, 1994). Among ethnographic hunter-gatherers, however, movement has been observed and quantified into number of residential moves per year, distance moved between camps and annually, as well as the distance of logistical trips. Further, these variables have been examined and modeled as they relate to technology, annual rainfall, latitude, effective temperature, storage, fertility, and social networks, among some variables (Binford, 1983, 2001; Grove, 2009; Kelly, 1988, 1992, 2013; Morgan, 2008; Surovell, 2009; Torrence, 1989; Whallon, 2006).

Mobility, as a "positioning strategy", allows foragers to exploit resources around residential camps on a daily basis—the foraging radius— and resources that are more than a day away —the logistical radius. The extent of overlap between foraging radii during an annual cycle depends in part on the biomass in the environments: in a *complete-radius leapfrog pattern* of movement in high-biomass environments, residential camps are relocated beyond the foraging radius of the previous residential location, thus avoiding the use of a previously depleted area. However, in lower-biomass settings, a *point-to-point* movement is common, where a residential camp is moved from one location with food, water and fuel to another in the region, without any overlap in foraging radii. The area used residentially and logistically during an annual cycle is the annual range, which is surrounded by a "no-man's land" in situations where there is no demographic packing. As firewood and local animal populations become depleted, groups shift their annual ranges. The sum of several annual ranges makes up the extended range or territory (Binford, 1982, 1983).

Some studies have focused on what factors affect the size of the radii, including the dependence on hunting (Kelly, 2013), habitat quality (measured by mean annual rainfall and effective temperature), occupation duration, and group size (Binford, 1980, 2001; Grove, 2009; Kelly, 1983, 2013; Surovell, 2000, among others). The analyses of Binford's (2001) ethnographic data suggest that habitat quality mostly affects foraging radii and thus the distance moved between camps, that is, foraging area increases with decreasing habitat quality (Grove, 2009). Likewise, that study suggests that a significant determinant of the size of the logistical radius is the dependence on hunting (Kelly, 2013). We should note that another factor —abrupt and mountainous terrain— also affects the size of foraging radii given the increase in mobility costs associated with mobility in high elevation settings, suggesting that radii in these environments are minimized and resource procurement is embedded in the annual round (Aldenderfer, 1998).

Central place foraging models are well suited to researching camp locations and foraging radii, given their principles of maximizing foraging returns relative to transport costs (Orians and Pearson, 1979; Zeanah, 2000; Morgan, 2008). We assume that hunter-gatherers choose central-place locations from where men and women set out to exploit resources and maximize foraging returns while minimizing transportation costs. We agree with the mobility expectations in mountainous terrain outlined by Aldenderfer (1998) for the foragers in the Peruvian South-Central Andes, so we expect foraging radii to be small, about 6–8 km, and residential camps should be sited in optimal locations, allowing minimization of travel time. Residential mobility should be low and logistical distances should be long (at Asana residential and logistical distances were estimated to be 20–25 km and 25–40 km respectively). Further, as habitat quality declined in the Middle Holocene, occupation duration, foraging radius and average moved distance between residential camps would have increased (Grove, 2009), as well as logistical mobility (Kelly, 1983, 2013; Grove, 2010). We expect that residential camp movements would follow the complete-radius leapfrog pattern in settings with higher biomass, and a point-to-point pattern (greater tethering) in lower biomass settings associated with a decline in habitat.

We assume a low population density during the first half of the Holocene given the characteristics of archaeological record for the South Puna: the earliest record for human habitation comes from the Laguna de Antofagasta basin beginning ca. 10,000 BP and remained uninterrupted throughout the Holocene, contrary to that of Antofalla (60 km to the NW) and of Chaschuil regions (180 km to the SW) (Fig. 2) where research suggests non-intensive and discontinuous occupations beginning ca. 8600 BP (Haber, 2009; Moreno, 2011; Ratto, 2006). Therefore, in the absence of population packing, we expect large annual and extended ranges that were not necessarily covered through residential mobility alone, but through long logistical forays that would have increased encounter rates with animals with large feeding territories as well as with conspecifics (Binford, 1990; Grove, 2010; Kelly, 2013).

Finally, we expect that the arid and unpredictable Mid-Holocene climate resulted in a high variance in return rates of resources (some good years, some disastrous years) living in the South Puna. We expect some degree of interaction with populations living in the eastern lowlands where moist conditions prevailed given the proximity to the Amazon and Atlantic moisture sources (Tchilinguirian and Morales, 2013). These interactions may have been in the form of non-subsistence tokens or gifts as well as assistance in during lean years.

2. Materials and methods: plants and toolstone

Next, we examine the archaeobotanical and lithic assemblages from two sites: Cueva Salamanca 1 and Quebrada Seca 3 in order to reconstruct their foraging radii. Both rock shelters are located in the drainage basin of Las Pitas River (Fig. 2), are 8 km apart, and their elevation differential is 450 m.

Archaeobotanical research includes the identification of macrobotanical remains (artifacts and ecofacts). These analyses are not exhaustive (analysis is ongoing) but are used to propose general patterns in the archaeological record. The identification of archaeobotanical material was carried out by comparative anatomical and morphological analyses using present-day material, which is part of a reference collection (Rodríguez, 1998), and followed the procedures outlined in previous works (Rodríguez, 2005; Rodríguez and Aschero, 2005). All specimens were stored in the Herbarium of the Instituto de Botánica Darwinion in Buenos Aires (Holmgren et al., 1990).

Debitage analyses consisted in flake aggregate analysis (Aschero, 1983). Local toolstone, found within 25 km of our sites (Hocsman, 2007), includes vulcanite, quartzite, quartz and chert (Fig. 2) (Aschero et al., 1991, 2002–2004). Obsidian, however, is nonlocal to the study area. Six sources have been located in the South Puna, within a distance of 35–200 km from our sites (Laguna Cavi, Ona, Salar del Hombre Muerto, Cueros de Purulla/Chascón, Archibarca and Valle Ancho, listed from nearest to furthest) and have been identified by XRF analysis at the Archaeometry Lab in Missouri (Yacobaccio et al., 2002, 2004; Escola and Hocsman, 2007). Whereas one source is located near a high elevation lagoon (4500 masl, Laguna Cavi), all others are located in areas near wetlands with streams and/or lagoons (Fig. 1).

Table 1
Radiocarbon dates from Cueva Salamanca 1.

Level	Conventional dates (^{14}C yr BP)	Calibrated dates (p = 0.95) (Cal. BP)[a]	Period[b]	Site function	Material
2(2)	6250 ± 70	7262–6907	LMH	Residential camp	charcoal
2(3)	7410 ± 100	8371–7995; 7990–7981	EMH	Residential camp	charcoal
2(3)	7630 ± 40	8454–8306; 8239–8218	EMH	Residential camp	charcoal
2(4)	7500 ± 60	8391–8161; 8085–8066	EMH	Residential camp	charcoal
2(5)	7550 ± 60	8402–8185	EMH	Residential camp	charcoal
2(6)	7540 ± 50	8387–8188	EMH	Residential camp	charcoal
2(7)	7620 ± 60	8514–8495; 8478–8466; 8462–8276; 8268–8199	EMH	Residential camp	charcoal

[a] Calib 6.1.0 for the Southern Hemisphere.
[b] LHM: late Middle Holocene; EMH: early Middle Holocene.

2.1. Cueva Salamanca (CS1)

Cueva Salamanca 1 provides evidence for human habitation pertaining to the early Middle Holocene, ca. 8100–6250 BP, and late Middle Holocene, ca. 6200 BP (Table 1). CS1 is a large cave (77 m^2) with southern exposure located at 3650 masl, within the *tolar*. A series of excavations have uncovered 30 m^2 of the site. Three stratigraphic units have been identified. In the lower unit, a series of ten finely stratified levels correspond to the earliest occupations in the cave and date ca. 8100 BP–4500 BP. Lithic debitage, faunal and botanical remains (preservation conditions are exceptionally good) were distributed around one to three hearths per level. A hiatus of 1200 radiocarbon years (719 calendar years; Table 1) separates the last occupation pertaining to the early Middle Holocene (ca. 7400 BP) from that of the late Middle Holocene (ca. 6200 BP) and a second larger hiatus of ca. 1800 radiocarbon years (2000 calendar years) occurred until ca. 4500 BP (not included in this study). A layer of volcanic ash was deposited in the rock shelter after 4500 BP that is tentatively attributed to the eruption of Cerro Blanco ca. 4200 BP, a volcano located 95 km SW of the site (Ratto et al., 2013). The last occupation at CS1 corresponds to an agro-pastoral occupation estimated to be ca. 3500 BP. In this study we focus on five assemblages pertaining to the early Middle Holocene (spanning about 530 calendar years) and one late Middle Holocene assemblage (spanning 350 calendar years; analyses of older deposits is ongoing).

The abundant lithic, faunal and botanical assemblages suggest that CS1 mostly functioned as a residential camp where multiple activities were carried out: a) manufacture and maintenance of hunting weapons; b) hunting camelids, predominantly guanacos and vicuñas, although rodent, bird, fox and one cervid bone are also present (Mondini and Elkin, 2014; Mondini et al., 2013, in press); c) cooking and grinding food; d) hidework, basketry making, sewing and cord/rope making, and e) storage. Seasonal indicators (botanical and faunal) suggest spring-summer occupations, although autumn visits cannot be discarded (Pintar, 2014 a, b).

2.1.1. Botanical assemblages at CS1

Our analysis shows that fourteen species of plants pertaining to Puna plant communities were used for firewood, bedding and/or

Table 2
Local plant species recovered at Cueva Salamanca 1.

Level	Taxa; Vernacular name; Structure	Materials	Function	Reference material	Plant community and micro-environment (elevation range)
2(2)	*Parastrephia lucida* (Meyen) Cabrera, **Asteraceae;** Tola; stem	Charcoal	Firewood	*Rodríguez 11* (SI)	*Vega* (3400–4600 masl)
	Deyeuxia sp., **Poaceae;** Leaf, flowering culm	Tied grass bundle[a]	Artifact	*SI 28338, SI 28339, Rodríguez 10, 26* y *27* (SI)	
	Atriplex imbricata -(Moq.) D. Dietr., **Chenopodiaceae**; Cachiyuyo; stem	Stem	Forage	*Rodríguez s.n.* (SI 28.212)	*Tolar* (3400–3900 masl)
	Ephedra multiflora Phil. Ex Stapf, **Ephedraceae;** Tramontana; stem	Charcoal	Firewood	*Rodríguez 22* (SI)	
	Acantholippia sp., **Verbenaceae;** Rica–rica; stem	Charcoal	Firewood	*Rodríguez 1 in SI (Acantholippia deserticola* (Phil.) Moldenke) SI 28.218 (*Acantholippia salsoloides* Griseb. in Goett)	
	Artemisia copa Phil., **Asteraceae;** Copa–copa; flower	Flower remains	Medicinal	*Rodríguez s.n.* (SI 28.330)	Upper *tolar* and lower *pajonal* (3700–4000 masl)
	Adesmia horrida Gillies ex Hook. & Arn., **Fabaceae;** Añawa; stem	Charcoal	Firewood	*Rodríguez 13* (SI)	
2(3)	*Deyeuxia eminens* var. *fulva* (Griseb.) Rúgolo., **Poaceae;** Pasto de vega, Cebadilla de vicuña; leaf, flowering culm	Grass stems	Bedding feature	*Rodríguez s.n.* (SI)	*Vega* (3400–4600 masl)
	Cortaderia speciosa (Nees & Meyen) Stapf., **Poaceae;** Cortadera; leaf, lateral side, leaf, mid-nerve	Basket fragment, bundle and stitch[b]	Container/tray	*Rodríguez 5* (SI)	
	Juncus balticus subsp. mexicanus Willd. ex Roem. & Schult.) Kirschner, **Juncaceae;** Junco; stem	Grass knot[c]	Artifact	*Rodríguez 19, 24* (SI)	
	Hoffmanseggia eremophila (Phil.) Burkart ex Ulibarri., **Fabaceae;** Algarrobita; pod[(d)]	Pods	Edible plant	*Rodríguez s.n. (SI 28.221)*	*Tolar* (3400–3900 masl)
	Adesmia horrida Gillies ex Hook. & Arn., **Fabaceae;** Añawa; stem	Charcoal	Firewood	*Rodríguez 13* (SI)	Upper *tolar* and lower *pajonal* (3700 – 4000 masl)
	Baccharis tola Phil. **Asteraceae;** Lejía; stem	Charcoal	Firewood	*Rodríguez 18* (SI)	*Quebrada* slopes (>4000 masl)
	Festuca sp., **Poaceae;** Leaf	Grass stems	Feature	*Rodríguez 6, 7, 8, 9* (SI)	*Pajonal* grasslands (>3900 –4700 masl)
2(3) and 2(4)	*Fabiana bryoides* Phil., **Solanaceae;** Pata de perdiz; stem	Charcoal	Firewood	*Rodríguez s.n.* (SI 28.217, SI 28.331)	*Quebrada* slopes (>4000 masl)
2(5) and 2(6)	*Adesmia horrida* Gillies ex Hook. & Arn., **Fabaceae;** Añawa; stem	Charcoal	Firewood	*Rodríguez 13* (SI)	Upper *tolar* and lower *pajonal* (3700 – 4000 masl)
2(6) and 2(7)	*Baccharis salicifolia.* (Ruiz & Pav.) Pers, **Asteraceae;** Suncho; stem[d]	Cut stems	Unknown	*Rodríguez s.n.* (SI)	*Tolar* (3400–3900 masl)
2(7)	**Poaceae;** Leaf central vascular bundle	Grass knots[e]	Artifact		*Vega* (3400–4600 masl)
	C. speciosa, **Poaceae;** Cortadera; leaves	Leaves and bundles[f]	Artifact	*Rodríguez 5* (SI)	

Notes.
[a] Artifact b.181.
[b] Artifact 539.
[c] Artifact 538 (Fig. 5A).
[d] Plants with edible roots/tubers.
[e] Artifacts 590 and 596.
[f] Artifact 630.

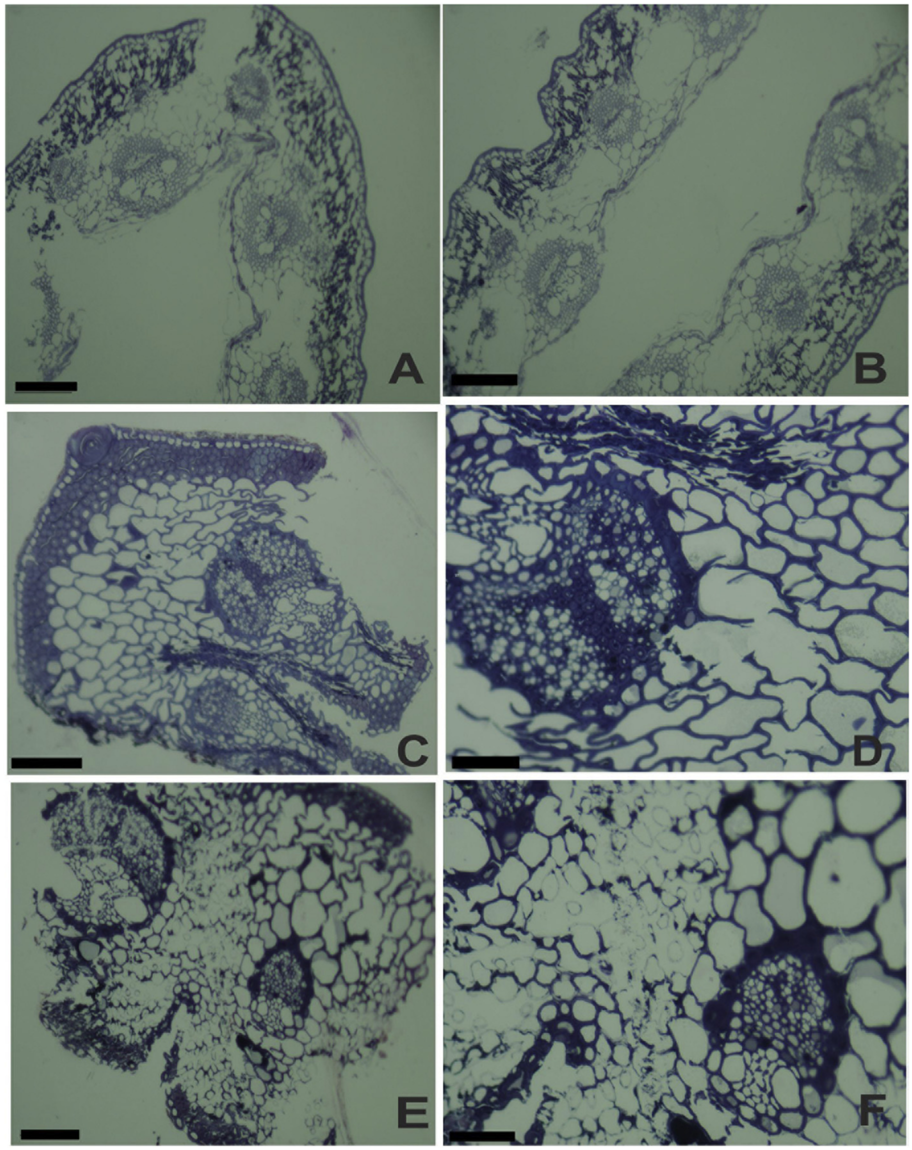

Fig. 4. Histological sections of some artifacts recovered at Cueva Salamanca 1. A–B: grass knot, *Juncus balticus* var. *mexicanus* (stem), artifact 538; C–F: Basket fragment, *Cortaderia speciosa*, artifact 539; C–D: Basket stitch (leaf, mid-nerve); E–F: Basket bundle (leaf, lateral portion). Scales: A–C and E = 100 μm; D and F = 50 μm.

flooring, basketry and making knots (Table 2; Figs. 4–7). We observe a mixed use of local plant communities and their associated microenvironments, including wetlands (*vegas*), sandy slopes of *quebradas* and gravelly *pampas* from 3400 to 3900 masl, as well as higher grasslands (*pajonal*). Nonlocal cane was also utilized for hafting projectile points (Table 3).

2.1.2. Lithic assemblages at CS1

Local vulcanite (<25 km) and non-local obsidian (>25 km) were utilized at CS1 during the early Mid-Holocene (ca. 7600–7400 BP) and late Mid-Holocene (ca. 6200 BP) (Pintar, 2009, 2014b). The results of flake aggregate analysis of 12 m^2 corresponding to 40% of the excavated area (over 10 kg of debitage, including approximately 9000 flakes) show the prevalent use of two vulcanites (Table 4).

Further, quarries reveal the presence of very large non-transportable nodules to very small sized ones (Fig. 2). Tested nodules, and nodules with one large flake removal are common. Flake scatters and very crude bifaces show that early stages of production occurred at these quarries. Large nodules were also chipped into smaller nodular flakes, which were more manageable for transportation.

Obsidian is allochthonous to the basin of Laguna de Antofagasta. Approximately 55% of projectile points from CS1 from the contexts analyzed were manufactured of obsidian (n = 11). Geochemical characterization of obsidian tools and flakes from the contexts being discussed in this paper (n = 66) by XRF analyses were carried out at the Archaeometry Laboratory at the University of Missouri Research Reactor (MURR). These tools were manufactured on obsidian from five different obsidian sources (Table 5) (Pintar and Pessarossi-Langlois, 2013; Pintar et al.submitted for publication). Laguna Cavi is the closest source to CS1 (35 km), whereas Archibarca (95 km) is the most distant. There is a lack of a sixth source —Valle Ancho (200 km)— also located in the South Puna (Fig. 1).

2.2. Quebrada Seca 3 (QS3)

This rock shelter has northeastern exposure and is located at 4100 masl (450 m higher than CS1, within the *pajonal*) in a *quebrada*, or gorge, with natural springs. Its dimensions are 9 m × 5 m deep with an excavated surface of approximately 25 m^2. Although this site bears evidence of human occupation spanning most of the Holocene (9400–2500 BP), in this paper we only include those Early and Middle Holocene assemblages for which both archaeobotanical and lithic analyses have been performed (or those that have statistically similar dates) (Table 6). Given that all stratigraphic levels have not been dated, we include the plants and the toolstone varieties identified in the studied assemblages in Tables 7 and 8. Lithic analyses suggest this site functioned as a residential camp during the Early Holocene and a logistical site during the Middle Holocene (Pintar, 1996). Camelids—predominantly vicuñas, chinchillids and birds were hunted, with a progressive focus on camelid hunting during the Middle Holocene that included intense exploitation of bone marrow (Elkin, 1996; Mondini and Elkin, 2014).

2.2.1. Botanical assemblages at QS3

These have been reported elsewhere. Here we summarize the results.

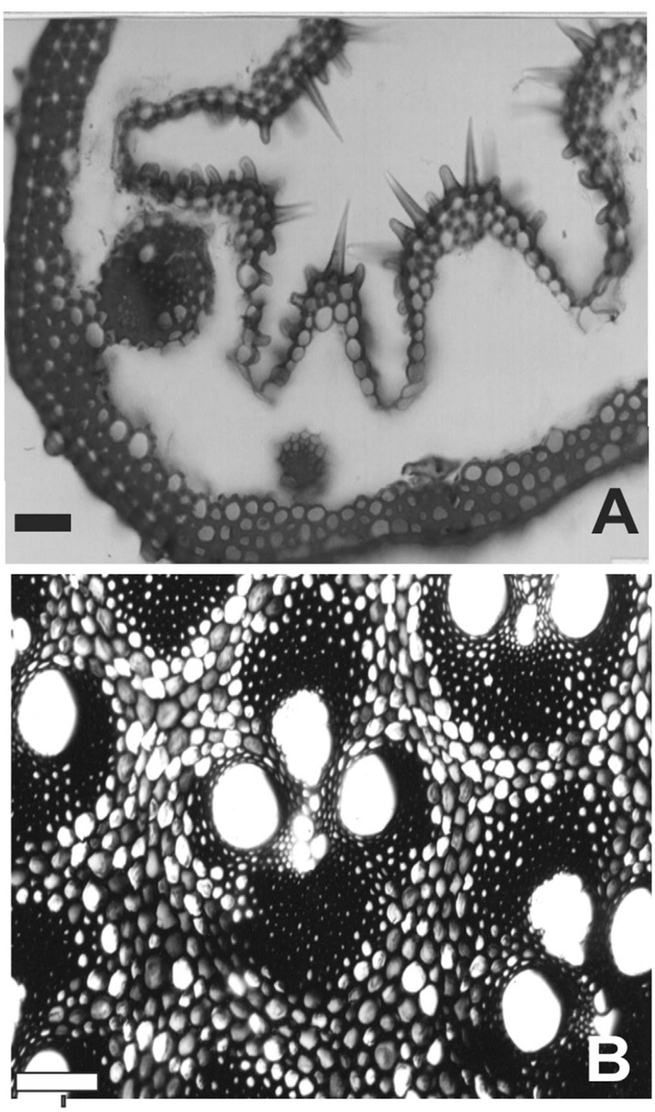

Fig. 5. Histological sections obtained with ultramicrotome of some artifacts recovered at Cueva Salamanca 1. A: *Juncus balticus* (leaf), level 2(3), artifact 538; B: *Chusquea lorentziana* (stem), artifact 531. Bars: A = 50 µm, B = 100 µm.

2.2.2. Lithic assemblages at QS3

Flake aggregate analyses were carried out on lithic assemblages from 90% of the excavated site (approximately 23 m^2). The debitage count and percentages of toolstone used are presented in Table 9. Geochemical analyses of projectile point samples (n = 7) from QS3 were carried out at the Archaeometry Laboratory at the University of Missouri Research Reactor (MURR). The XRF results reveal the utilization of three different sources during the Early and Middle Holocene (Table 10).

3. Results

We have calculated the geodesic distance to toolstone outcrops and quarries that were used at CS1 and QS3 and the minimum/maximum distances to the current upper and lower limit of plant microenvironments in the region. Given our model's assumption that transportation costs in mountainous terrain are minimized, we calculated distances to the nearest toolstone sources for each vulcanite variety in the area surrounding the sites (Tables 11 and 12).

The reconstructed foraging radii for plant and toolstone procurement are presented in Table 13 and Fig. 7. The pattern of toolstone use is bimodal and decreases with distance from both sites (Figs. 8 and 9), although there is no significant correlation with distance from the sites, except during the late Middle Holocene (Table 14). The second mode is associated with a vulcanite quarry located 9–10 km from the sites (v2 in Fig. 1) that is 500 m from Peñas de la Cruz 1 site (Fig. 2), a logistical camp with Early and Middle Holocene dates (ca. 8900–7200 BP) (Martínez, 2005, 2007, pers. comm.; Funes Coronel and Martínez, 2013). We discuss the significance of these results in the next section.

3.1. Analysis

Our data indicate that foraging radii size varied according to site function and over time. In reconstructing the sizes of foraging ranges, we take into account distances to local plant microenvironments and toolstone sources. Paleoclimatic records (discussed earlier) show a wet Early Holocene and a dry Middle Holocene, which leads us to assume a vertical displacement of vegetation belts (Tchilinguirian and Morales, 2013; Tchilinguirian and Olivera, 2014), however, we lack specific records regarding the magnitude of these shifts in our study area. It is possible that the downstream radius during the Early Holocene could have been longer than we are proposing. Also, it is likely that the downstream radius during the Middle Holocene was shorter and the upstream radii longer than we are proposing due to an increase in aridity in the region during that period.

Our data however, show an agreement between distances to plant communities and toolstone sources (Table 13), so we will refer to: a maximum radius suggested by the greatest distance to plants, a minimum radius suggested by the shortest distance walked to reach all plant communities exploited, and a minimum toolstone radius. We propose an actual foraging radius that combines the minimum plant and toolstone radius, within which foragers took the majority of plant and toolstone resources. This radius could be the effective radius within which forager's daily return rates were maximized (Kelly, 2013). Finally, we propose a logistical radius based on the second and third modes in Figs. 8 and 9, which begins 8 km from residential sites.

The actual radius during the (a) Early Holocene, when QS3 functioned as a residential base, was 2–3 km (Rodríguez, 1997, 1999a, 2004). Six plant species and three local toolstone varieties were exploited within this radius during the Early Holocene (Tables 7 and 9), suggesting an environment with abundant plant resources where foragers had high encounter rates, low search

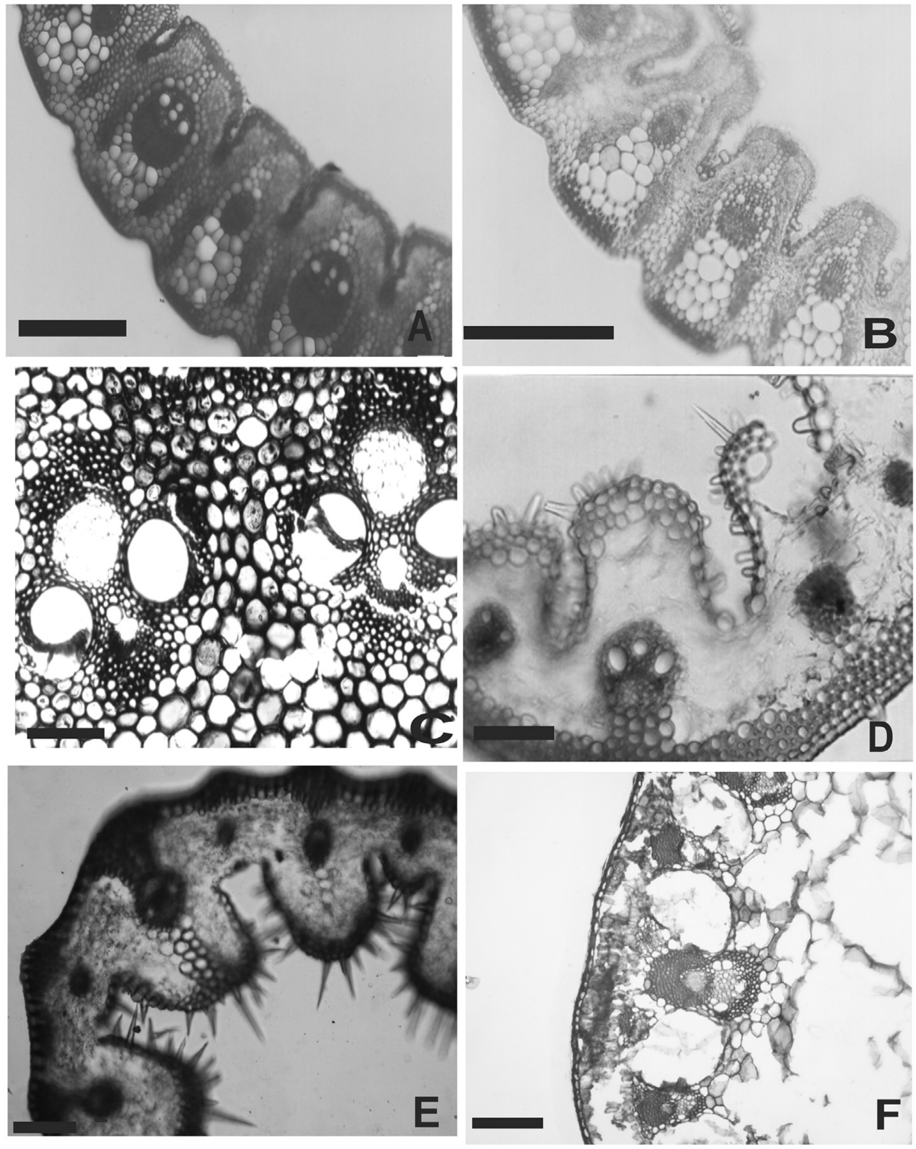

Fig. 6. Examined current reference material. Reference collection. A–B. *Cortaderia speciosa*: A: leaf, lateral portion; B: leaf, central nerve, *Rodríguez 5* (SI); C, *Chusquea lorentziana* (stem), *Schreiter 11508* (SI); D: *Deyeuxia eminens* var. eminens (leaf) *Cabrera 8944* (BAA); E: *Festuca weberbaueri* (leaf), *Rodríguez 6* (SI); F: *Juncus balticus* subsp. mexicanus (stem), *Rodríguez 19* (SI). Bars: A–B = 400 μm, C–F = 100 μm.

costs, and would have been able to carry large loads for short distances to the camp although prolonged occupation would have soon depleted resources (Bettinger, 1991). Plants from communities further from the site would have not been optimally procured and were thus bypassed.

Instead, the actual radius during the (b) early Middle Holocene when CS1 was a residential base was 6–7 km. Fourteen local plant species and 12 toolstone varieties from five microenvironments were exploited within this radius. Embedding toolstone procurement into subsistence tasks would offset higher daily foraging costs associated with a larger foraging radius (Binford, 1979), because the cost of embedded procurement is lower than direct procurement when resources are closer to camp (Surovell, 2009). It follows that resources within greater distances from camp would be cheaper to procure when they are embedded in other activities far from camp, such as logistical hunting. So, subsistence task groups would have procured raw materials for making stone tools and basketry (*Cortaderia speciosa*) while searching in the *tolar* plant community for edible roots and tubers such as *Hoffmanseggia eremophila* and while procuring material for making bedding features, such as *Deyeuxia eminens* var. *fulva*, in the *vega* plant community (Pintar, 2008a; Table 2). Moreover, we propose that embedded procurement of toolstone during other subsistence activities would have resulted in the use of small stone outcrops encountered during daily trips around camp (Fig. 2; Tables 2 and 4).

There is a gap in the stratigraphic sequences at CS1 and QS3—between the early and late Middle Holocene (Tables 1 and 6)— of about 720 calendar years and 510 years respectively. It is likely that an aridity threshold was reached in the study area that resulted in the temporary abandonment of this area. Aridity thresholds were also reached in the Atacama Desert of northern Chile, where some areas were abandoned in favor of newly formed ecological refuges like at Puripica (Núñez et al., 2013). Paleoenvironmental studies in the Las Pitas River (Fig. 2), about 1 km from CS1, suggest a brief period with humid conditions ca. 6000 BP (5963 ± 54 BP; 6890–6566 cal BP), after the late Middle Holocene occupation at

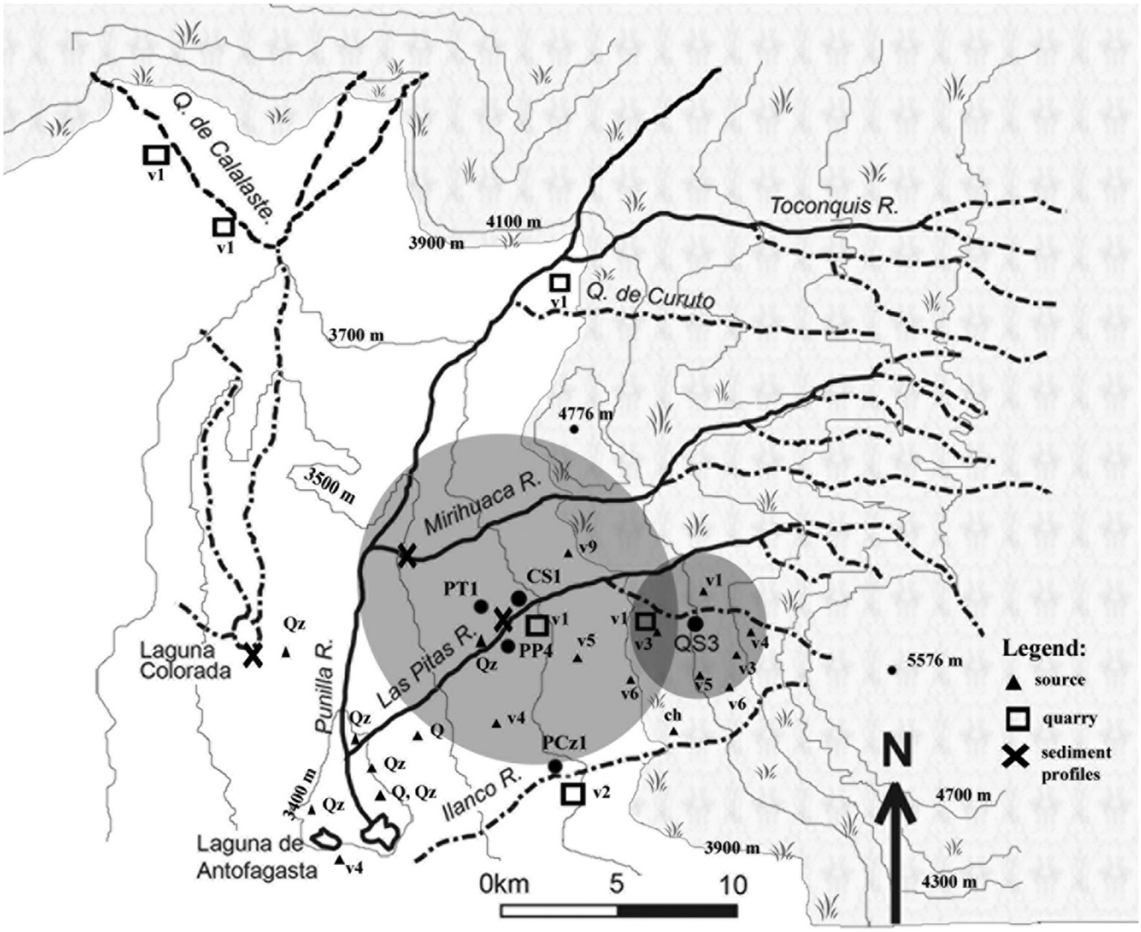

Fig. 7. Foraging radii around CS1 and QS3 sites during the Holocene.

CS1 (Table 1) (Tchilinguirian and Morales, 2013; Tchilinguirian and Olivera, 2014). Therefore, it is difficult to ascertain the level of aridity during the occupation at CS1. However, the actual foraging radius during the (c) late Middle Holocene was 1–7 km and encompassed three microenvironments and 10 toolstone varieties—a reduction compared to the early Middle Holocene. The use of *Acantholippia deserticola* —often accompanied by *Artemisia copa* (Cabrera, 1957), another species used in the late Middle Holocene (Table 4) which currently dominates the very dry soils of the basin bottom (*campo*) and *tolar*— points to an environmental change in the study area. The use of *A. deserticola* for firewood (it has low heat output and is smoky) suggests the presence of degraded plant communities surrounding CS1.

Logistical activities requiring overnight stays, such as those involving camelid hunting and exotic toolstone procurement, were carried out beyond the daily foraging radius. The evidence of logistical radii comes from the 8 km distance between CS1 and QS3 (which functioned as a logistical camp during the Middle Holocene), as well as from the second and third modes in toolstone source distribution at 9–10 km from residential camps (Figs. 8 and

Table 3
Artifacts made from plant species that grow in lowlands to the east of the Puna.

Level	Taxa -Vernacular name – Structure	Materials	Function	Reference material	Vegetation community; elevation; distance
2(2) 2(3) 2(5)	*Chusquea lorentziana* Griseb. **Poaceae** Caña brava; cane	Mid-shaft fragments[a] End-shaft with dimple[b] Fore-shafts, beveled[c]	Shafts	*Schreiter 11508* (SI); *Krapovickas & Cristóbal 20452* (BAA)	Lowlands to the east of the Puna; <2000 masl; 180 km
2(6)	*Trichocereus pasacana* (Web) Britton et Rose–**Cactaceae** Pasacana; spine	Cactus thorns[d]	Knitting/ sewing	*Burkart 7616* (SI)	Lowlands to the east of the Puna; 2500–3000 masl; 100 km
2(7)	*Chusquea lorentziana* Griseb. **Poaceae** Caña brava; cane	Mid-shaft fragments[b] End-shaft with dimple[c]	Shafts	*Schreiter 11508* (SI); *Krapovickas &Cristóbal 20452* (BAA)	Lowlands to the east of the Puna; <2000 masl; 180 km

[a] Artifacts 117, 124, 107, 33, 527, 552, 550, 304, 317, 242, 585, 612.
[b] Artifact 531 (Fig. 3D).
[c] Artifacts 701, 707.
[d] Artifacts 65, 70, 254, 651.

Table 4
Toolstone representation at Cueva Salamanca 1.

Toolstone	Early Middle Holocene (7600–7400 BP)	Late Middle Holocene (6200 BP)	Minimum distance to nearest quarry/outcrop
Obsidian	11%[a]	11%[b]	35 km
Vulcanite 1	69%	36%	1 km
Vulcanite 2	13%	47%	9 km
Vulcanite 3	1%	1%	7 km
Vulcanite 4	3%	2%	5 km
Vulcanite 5	2%	<1%	3 km
Vulcanite 6	<1%	<1%	6 km
Vulcanite 9	<1%	–	<1 km
Chert	<1%	–	8 km
Andesite	<1%	<1%	<1 km
Quartz	<1%	<1%	6 km
Quartzite	<1%	<1%	8 km
Debitage count[c]	Level 2(3): 765 Level 2(4): 888 Level 2(5): 1092 Level 2(6): 875 Level 2(7): 4660 **Total = 8280**	Level 2(2): 656 **Total = 656**	

[a] Five obsidian sources are represented (see Table 5).
[b] Two obsidian sources are represented (see Table 5).
[c] Only flakes with platforms were analyzed (minimal number of flakes or MNF).

Table 5
Sources of obsidian tools (T) and flakes (f) from Cueva Salamanca 1.

Level and date	Laguna Cavi (35 km, SE)	Ona (60 km, NW)	Salar del Hombre Muerto (65 km, N)	Cueros de Purulla- Chascón (90 km, SW)	Archibarca (95 km, NW)
2(2): *ca.* 6250 BP		f = 3	T = 1 f = 1		
2(3): *ca.* 7400 BP	T = 1	f = 1	T = 1		T = 1
2(4): *ca.* 7500 BP			T = 2		T = 1 f = 1
2(5): *ca.* 7550 BP			T = 2 f = 1		
2(6): *ca.* 7540 BP			T = 3 f = 1	T = 1	
2(7): *ca.* 7600 BP		T = 2 f = 4	T = 1 f = 4	f = 34	

9). Another Middle Holocene logistical site (not included in this study) is located 9 km from CS1, near a large quarry and hunting grounds (Peñas de la Cruz 1, Fig. 1; Martínez, 2005; Funes Coronel and Martínez, 2013). We propose that logistical activities began at 8 km from residential camps. The Tobler hiking function (Aldenderfer, 1998:12; Table 15), which allows calculating walking speed (km/hr) over an angled slope, including the return trip with a load (80% effectiveness in walking speed), predicts that logistical trips began beyond about 2 h (4 h round-trip) from residential camps (Table 15). The distance to the nearest obsidian source —Laguna Cavi, 35 km away— could have been reached within a two-day walk, and might signal the upper end of logistical mobility, although procurement could have been accomplished from a residential base positioned at a closer distance.

Finally, the reconstructed actual foraging radius of a logistical site —QS3, during the Middle Holocene— is 3 km. Three hunting

Table 6
Radiocarbon dates from Quebrada Seca 3.

Level	Conventional dates (^{14}C yr BP)	Calibrated dates (p = 0.95) (Cal. BP)[a]	Period[b]	Site function	Material
2b8	6160 ± 100	7247–6742	LMH	Logistical	charcoal
2b9	7220 ± 100	8188–7782; 7777–7759	EMH	Logistical	charcoal
2b10[c]	6080 ± 70	7156–7111; 7068–7055; 7028–6672	EMH	Logistical	charcoal
2b11	7130 ± 110	8156–8088; 8060–7678	EMH	Logistical	charcoal
2b15[d]	(No date)	–	EH	Residential camp	–
2b16	8330 ± 110	9489–9008	EH	Residential camp	charcoal
2b17	8660 ± 80	9887–9874; 9867–9846; 9819–9801; 9799–9461	EH	Residential camp	charcoal

[a] Calib 6.1.0 for the Southern Hemisphere.
[b] LHM: late Middle Holocene; EMH: early Middle Holocene; EH: Early Holocene.
[c] Given the incongruous date between this one and those above and below it, typological indicators were used to assign this level to the early Middle Holocene rather than the late Middle Holocene. Further, these dates are statistically similar.
[d] This level has no date. Typological indicators were used to assign this level to the Early Holocene.

Table 7
Plant taxons per vegetation community present at Quebrada Seca 3.[a]

Level	Taxa	Plant community and micro-environment (elevation range)
2b8	*Fabiana bryoides*	Upper *quebrada* slopes (4000–~4700 masl)
	Parastrephia quadrangularis	
	Baccharis tola	
	Adesmia horrida	Upper *tolar* and lower *pajonal* (3700–4000 masl)
2b10	*Festuca chrysophylla* Phil.	*Pajonal* (>3900–4700 masl)
	Fabiana bryoides	Upper *quebrada* slopes (4000–~4700 masl)
	F. punensis S.C. Arroyo	
	Parastrephia quadrangularis (Meyen) Cabrera	
	Baccharis tola	
	Adesmia horrida	Upper *tolar* and lower *pajonal* (3700–4000 masl)
	Deyeuxia eminens	*Vega (3400–4600 masl)*
2b15	*Fabiana bryoides*	Upper quebrada slopes (4000–~4700 masl)
	P. quadrangularis	
	Baccharis tola	
	Parastrephia lucida	*Vega (3400–4600 masl)*
	Adesmia horrida	Upper *tolar* and lower *pajonal* (3700–4000 masl)
2b17	*Fabiana bryoides*	Upper *quebrada* slopes (4000–~4700 masl)
	P. quadrangularis	
	Baccharis tola	
	Parastrephia lucida	*Vega* (3400–4600 masl)
	Adesmia horrida	Upper *tolar* and lower *pajonal* (3700–4000 masl)

[a] Data is taken from Rodríguez 1999b, 2000, 2004, 2005.

Table 8
Artifacts at Quebrada Seca 3 made from plant species that grow in lowlands to the east of the Puna.[a]

Period	Taxa	Function	Vegetal community; Distance
Late Middle Holocene	–	–	–
Early Middle Holocene	*Chusquea lorentziana*	Shaft	Mountain rainforest; 180 km
	Acrocomia aculeata (Jacq.) Lodd. Ex Mart.	Knitted bags	Chaqueño forest; 450 km
Early Holocene	*Prosopis torquata* (Cav. ex Leg.) DC	Wood	Pre-Puna valleys; 120–150 km
	Salix humboldtiana Willd.	Shaft	Valleys, jungle and Chaqueño plains; 450 km
	Rhipidocladum neumannii Sulekic, Rúgolo & L. Clark	Hollow canes	Mountain rainforest; 180 km

[a] Data published by Rodríguez 2004.

Table 9
Toolstone representation at Quebrada Seca 3.

Toolstone	Early Holocene (8700–8300 BP)	Early Middle Holocene (7200 BP)	Late Middle Holocene (6200 BP)	Minimum distance to nearest quarry/outcrop
Obsidian	28%[a]	1%[b]	–	30 km
Vulcanite 1	44%	82%	70%	1 km
Vulcanite 2	8%	8%	18%	10 km
Vulcanite 3	17%	3%	7%	2 km
Vulcanite 4	3%	1%	1%	2 km
Vulcanite 5	<0.1%	4%	2%	3 km
Vulcanite 6	<0.1%	1%	1%	2 km
Debitage count[c]	Level 2b15: 476 Level 2b16: 797 Level 2b17 505 **Total = 1778**	Level 2b9: 3145 Level 2b10: 3451 **Total = 6596**	Level 2b8: 91 **Total = 91**	

[a] Two different obsidian sources are represented (See Table 10).
[b] Three obsidian sources are represented (see Table).
[c] Only flakes with platforms were analyzed (minimal number of flakes).

Table 10
Sources for obsidian tools (T) from Quebrada Seca 3.

Level	Laguna Cavi (35 km, SE)	Ona (60 km, NW)	Salar del Hombre Muerto (65 km, N)
2b9 (*ca.* 7220 BP)	T = 1	T = 1	T = 1
2b10: (*est.* 7100–7200 BP)			T = 1
2b15: (*est.* 7400–8300 BP)	T = 1		
2b16: (*ca.* 8300 BP)	T = 1	T = 1	

Table 11
Plant taxons per vegetation community at Cueva Salamanca 1.

Cueva Salamanca 1 (3650 masl)			
Current elevation range	Early Middle Holocene 7600–7400 BP	Late Middle Holocene 6250 BP	Distance
Pajonal (>3900–4700 masl)	*Festuca* sp.	–	5 km (lower limit) 13 km (upper limit)
Upper *quebrada* slopes (4000–~4700 masl)	*Fabiana bryoides*, *Baccharis tola*	–	6 km (lower limit) 13 km (upper limit)
Upper *tolar* and lower *pajonal* (3700–4000 masl)	*Adesmia horrida*	*Adesmia horrida*, *Artemisia copa*	1 km (lower limit) 6 km (upper limit)
Tolar (3400–3900 masl)	*Baccharis salicifolia*, *Hoffmanseggia eremophila*	*Atriplex imbricata*, *Ephedra multiflora*, *Acantholippia* sp.	8 km (lower limit) 5 km (upper limit)
Vega (3400–4600 masl)	*Parastrephia lucida*, *Deyeuxia eminens*, *Cortaderia speciosa*, *Juncus balticus*	*Parastrephia lucida*	9 km (lower limit) 13 km (upper limit)

Table 12
Plant taxons per vegetation community at Quebrada Seca 3.

Quebrada Seca 3 (4100 masl)				
Current elevation range	Early Holocene 8700–8300 BP	Early Middle Holocene 7400–7200 BP	Late Middle Holocene 6200 BP	Distance (minimum)
Pajonal (>3900–4700 masl)	–	*Festuca chrysophylla*,	–	4 km (lower limit) 5 km (upper limit)
Upper *quebrada* slopes (4000–~4700 masl)	*Fabiana bryoides*, *F. punensis*, *Parastrephia quadrangularis*, *Baccharis tola*	*Fabiana bryoides*, *F. punensis*, *Parastrephia quadrangularis*, *Baccharis tola*	*Fabiana bryoides* *Parastrephia quadrangularis* *Baccharis tola*	3 km (lower limit) 5 km (upper limit)
Upper *tolar* and lower *pajonal* (3700–4000 masl)	*Adesmia horrida*	*Adesmia horrida*	*Adesmia horrida*	3 km (upper limit) 7 km (lower limit)
Vega (3400–4600 masl)	*Parastrephia lucida*	*Deyeuxia eminens*	–	6 km (upper limit) 14 km (lower limit)

Table 13
Minimum foraging radii based on distance to plant microenvironments and toolstone sources.

Period, site	Downstream plant radius[a]		Upstream plant radius[a]		Local toolstone radius		Nonlocal toolstone (obsidian)		Plant communities	Actual foraging radius
	Max.	**Min.**[b]	**Min.**[b]	Max.	Min.[c]	Max.[d]	Min.	Max.	Total	
EH – QS3	7 km	**3 km**	0 km	5 km	**2 km**	10 km	30 km	60 km	3	2–3 km
EMH – CS1	8 km	0 km	**6 km**	13 km	**7 km**	9 km	35 km	95 km	5	6–7 km
EMH – QS3	7 km	**4 km**	0 km	5 km	**3 km**	10 km	30 km	65 km	4	3–4 km
LMH – CS1	8 km	0 km	**1 km**	6 km	**7 km**	9 km	35 km	65 km	3	1–7 km
LMH – QS3	7 km	**3 km**	0 km	5 km	**3 km**	10 km	–	–	2	3 km

[a] The lower and upper limits may have moved upslope during the arid Middle Holocene.
[b] These values indicate a **minimum** foraging radius for procuring plants in all microenvironments exploited.
[c] This radius equates to the fall-off in toolstone (Figs. 8 and 9).
[d] This radius is given by the second mode in Figs. 8 and 9.

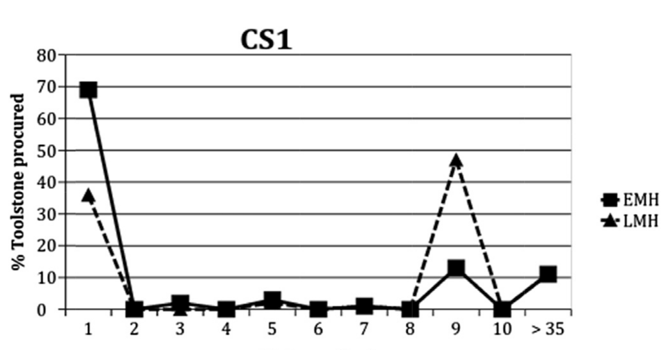

Fig. 8. Toolstone by distance from Cueva Salamanca 1.

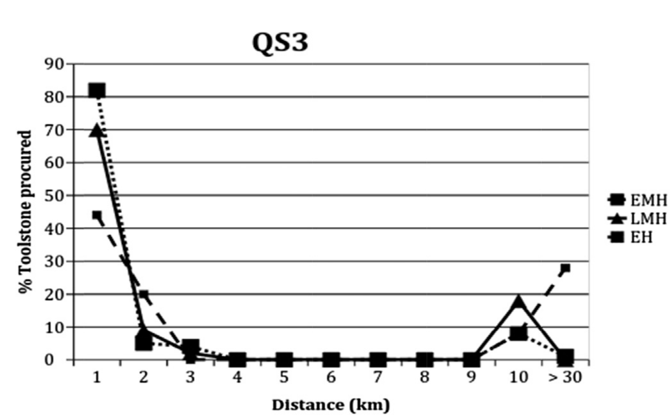

Fig. 9. Toolstone by distance from Quebrada Seca 3.

Table 14
Distance to toolstone sources.[a]

Distance from site (km)	1 km	2 km	3 km	5 km	7 km	9 km	10 km	r[b]	p
QS3– EH	61%	28%	–	–	–	–	11%	−0.818	>0.01
CS1– EMH	78%	–	2%	3%	1%	15%	–	−0.663	>0.01
QS3– EMH	83%	5%	4%	–	–	–	8%	−0.453	>0.01
CS1– LMH	42%	–	–	2%	1%	55%	–	−0.102	<0.01
QS3– LMH	71%	9%	2%	–	–	–	18%	−0.322	>0.01

[a] Data reflects proportion of local toolstone present at sites.
[b] Pearson's correlation between distance and local toolstone use.

Table 15
Round-trip travel time to logistical sites, returning with a load.[a]

Tobler formula: WV = 6exp[−3.5*abs(s + 0.05)]	QS3 (8.3 km)	PCz1 (8.7 km)	Laguna Cavi Obsidian (35 km)
CS1	3.7 h	3.9 h	13.9 h

[a] Distances are geodesic.

Table 16
Size of annual ranges based on Kelly's (2013) coverage index.

Coverage index for groups dependent on hunting	CI = Distance moved residentially per year/Total area exploited annually 0.05 = 16 km × 14 ± 5 moves a year/Total area
Estimated size of annual range	4480 km^2 ± 1600

techniques including different weapons, number of hunters, natural topographic features and stone parapets have been modeled for the area within 2.5 km of QS3 (Aschero and Martínez, 2001), supporting the role of high *quebradas* above 4000 masl, like this one, in camelid hunting activities.

4. Discussion

4.1. Territorial ranges

Our model predicted expanded radii during periods of habitat decline related to increased aridity in the Middle Holocene. The reconstructed foraging radii during the Middle Holocene at CS1 are larger than during the Early Holocene, probably as a response to habitat quality, although the smaller radius at QS3 might also result from the rugged terrain surrounding QS3 —in contrast to a gentler slope at CS1— and from minimizing mobility costs. However, it is also possible that brief occupations at QS3 would not require a large foraging radius. In support of this statement, we note the greater proportion of obsidian debitage in Early Holocene assemblages (Table 9) that suggests short-term occupations during which nonlocal toolstone dominated transported toolkits, contrary to long-term occupations that would have high proportions of local toolstone (Surovell, 2009).

The larger size of foraging radii during the Middle Holocene (6–7 km) along with a logistical radius of 8–35 km meets the model's expectations. In fact, the decision to select CS1 as a residential camp could have been related to the group's division of labor, its location near women's patches —reducing their mobility costs— and further from hunting patches which were reached logistically, thus increasing the spatial distance between men and women's activities (Elston and Zeanah, 2002; Zeanah, 2004). Although toolkits seldom include tools made of the full extent of annual ranges (Ingbar, 1994), larger foraging radii also can be associated with longer occupations which have relatively high frequencies of local toolstone, since transported toolkits are replaced with locally made tools (Surovell, 2009).

The reconstructed logistical radii of 8–35 km during the Mid-Holocene —assuming that obsidian from Laguna Cavi was procured logistically from CS1— suggest the existence of long logistical forays associated with a great dependence on hunting in hunter-gatherer societies (Binford, 2001; Grove, 2010; Kelly, 2013). If the positioning of residential bases followed the complete leapfrog pattern, then distances moved between residential sites would have been minimally at a distance twice the foraging radius and the lower end of the logistical radius, that is, greater than 14–16 km and less than 70 km, since logistical radii may have overlapped (Binford, 1980). Therefore, the area exploited logistically would have allowed for monitoring of water, game, firewood and maintaining information regarding neighbors, kin and networks over an area several times the size of a foraging radius (Whallon, 2006). Further, the higher mobility costs of logistical forays would have been offset by lower residential mobility: fewer residential moves annually although possibly over long distances, especially in an environment where unpredictable rainfall resulted in a high temporal and spatial variance in resource returns.

Exotic toolstone has often been used as a proxy for mobility, although translating its use into territorial ranges is a contentious issue (Ellis, 2011). Nonlocal toolstone —cores, preforms or tools— can enter a site in multiple ways: direct procurement (by a task force or the whole residential group) and indirect procurement (exchanges, gifts, visits, caching) (Meltzer, 1989, 2006; Bamforth, 2009; among others). People move for a variety of reasons, such as finding mates, visiting kin, gaining access to resources during bad years, monitoring resources (Wiessner, 1982; Cashdan, 1983; Kelly, 2013), so estimating annual range sizes is not simple, and it is further complicated by the fact that patterns of mobility and exchange are difficult to discern in the archaeological record (Meltzer, 1989).

Archaeologically it is difficult to discuss the extent of annual ranges without knowing group size and fission/fusion and aggregation dynamics, and this is further compounded by the coarse grained nature of the archaeological record which at best allows us to discuss mobility at a centennial scale. Archaeological sites and levels could equate to one big event, or the sum of several occupation events over the course of several seasons or even years. The archaeological deposits at CS1 and QS3 are stratigraphically discrete occupations (Tables 1 and 6) although we cannot state without a doubt that these are in fact single events, or whether groups inhabited the sites during the most dispersed or most aggregated phase of the year. Given the succession of re-occupations of CS1 during the early Middle Holocene —five over 530 calendar years— and one during the late Middle Holocene (Table 1)— we believe each occupation can tell part of the story of procurement movements within an annual range.

In order to obtain a very rough approximation of the size of these prehistoric ranges, we make three assumptions: 1) Puna hunter-gatherers behaved like ethnographic foragers studied by R. Kelly (Kelly, 2013, Table 4.1); 2) Puna hunters relied heavily on hunting and covered much of their ranges through logistical mobility; 3) the number of times moved per year is the average proposed by L. Binford for logistical terrestrial hunters (2001: 278, Table 8.06), which is 14 ± 5. Next, we use Kelly's coverage index for ethnographic hunters (Kelly, 2013: 96) to estimate territory size. The minimum distance moved between residential camps is 16 km (Table 16).

Although sites do not contain a complete inventory of toolstone sources utilized within an annual cycle (Ingbar, 1994), the sources used for making tools can yield a general measure of territorial ranges or "conveyance zones" (Jones et al., 2003; Smith, 2010). The obsidian source attributions from CS1 reveal the use of different sources (Table 5), suggesting that different territorial ranges are represented over the course of 530 calendar years represented by the stratigraphic sequences at this site. Further, the greater number of sources utilized in Middle than the Early Holocene (Table 10) suggest a greater knowledge of the environment that resulted from the process of exploring, colonizing and occupying a region which began in the Pleistocene/Holocene boundary (Borrero, 1999; Borrero and Franco, 1997; Civalero and Franco, 2003; Neme and Gil, 2008). It follows that we can calculate the area the obsidian sources encompass to see how they measure up to the range size estimated with Kelly's (2013) coverage index. Our calculations only involve the Middle Holocene because the dataset is larger for this period (Table 17).

The estimated annual ranges for three of the cases are outside the range of 2880–6080 km^2 proposed in Table 16, suggesting considerably fewer residential moves per year than those we used in Table 16. We propose that during periods of increased aridity complete radius leapfrog movements were less common than point-to-point mobility. Ranges would have shifted as lagoons and wetlands dried up, lower biomass levels led to increased efforts at hunting, and flies, vermin and scavengers were attracted to the sites, signaling it was time to move camp. That is, ranges were shifted as they became depleted of resources and reached aridity thresholds, and some foraging areas were temporarily abandoned and possibly monitored from a distance. This probably resulted in an occupation hiatus in Las Pitas river basin between the early and late Middle Holocene, and possibly to point-to point movements between areas with reliable water, thus resulting in differing patterns of obsidian source use throughout the period studied (Tables 5 and 10). Moreover, it is likely that during the late Middle Holocene a certain reliance on protected camelid herds in addition to hunting, increased sedentism by providing a reliable subsistence base to Puna foragers and setting the stage for a greater level of cultural and economic complexity (Yacobaccio et al., 2013; Babot, 2014; Hocsman, 2014; Reigadas, 2014). The complete lack of obsidian from sources located in the southern end of the North Puna, such as Quirón at 170 km (Yacobaccio et al., 2002, 2004, 2013), and from Valle Ancho source in the extreme southern South Puna 200 km away suggests little interaction with foragers living in those zones, and is a topic that merits further investigation (Pintar et al.,submitted for publication).

Table 17
Estimated annual ranges for the Middle Holocene.[a]

CS1 stratigraphic levels	Estimated territorial ranges (km^2)
2(2) ca. 6250 BP	2000 km^2
2(3) ca. 7400 BP	4500 km^2
2(4) ca. 7500 BP	2800 km^2
2(5) ca. 7550 BP[b]	–
2(6) ca. 7540 BP	1100 km^2
2(7) ca. 7620 BP	3100 km^2

[a] Calculation of the area within a geometric figure drawn from source to source.
[b] Level 2(5) has only one obsidian source.

4.2. Interaction with eastern lowlands

The majority of nonlocal materials found at CS1 and QS3 —as early as 9000 BP—consist of non-subsistence plants native to the eastern lowlands, up to 450 km from the study area (Tables 3 and 8), and suggest a deeply rooted interaction mechanism between Puna and the eastern valleys —including the Calchaquí, Santa María rivers, and beyond (Fig. 1). The plants include cactus thorns and shaft fragments (Table 7) native to the *yunga* forests (Boelcke, 1986; Judziewicz et al., 2000; Rodríguez, 2004, 2005), palm cordage of *Acrocomia aculeata* (synonymous to *Acrocomia chunta* Covas & Ragonese, *A. totai* Mart.) and wood fragments of *Salix humboldtiana*, *Prosopis torquata* and *Rhipidocladum neumannii* (Rodríguez, 1998, 1999a). Palm starch residue of aff. *Acrocomia* sp. was also found on a grinding stone at CS1 in level 2(3) (Table 1) (Babot, 2011). A cervid bone at CS1 ca. 7500 BP also hints at contact with ecological zones to the east of the Puna (Mondini and Elkin, 2014). Finally, a shell bead at CS1 ca. 7600 BP (of marine origin) suggests contact with the Pacific to the west.

As resources in the Puna became increasingly unpredictable and as annual ranges shifted, perimeter defense would have been uneconomical especially if population density was low. Inter-regional contacts between Puna and lowland foragers would have increased as long as there was low correlation of return rates between both regions, as suggested in the Kelly-Winterhalder model (Case B: Kelly, 2013: 162–163). So by establishing and maintaining social relations with their lowland neighbors —in the form of kinship ties, trade partnerships, alliances, and inter-regional reciprocal gift giving of tokens and non-subsistence raw materials— Puna foragers would have been able to call on those neighbors and eventually been granted access to resources in times of need (Cashdan, 1983; Whallon, 2006, 2011; Kelly, 2013; Aschero, 2014). A recent discovery of a projectile point (ca. 8500 BP) made of Puna vulcanite at Taller Puesto Viejo 1 site, east of the Santa María river about 170 km east of our study area (Martínez et al., 2013), suggests the existence of such mechanisms, although it is yet premature to draw any definitive conclusions. Further, *Chusquea lorentziana* canes used as dart and spear shafts in the Puna (Table 3) could have been obtained through this kind of inter-regional contact (perhaps in exchange for obsidian tools), however, it is also possible that logistical parties could have made long trips to the lowlands, especially if these trips were made from other residential camps located north of the study area from where distances would have been shortened (Pintar, 2008b).

5. Conclusions

Our study shows that by combining lithic and botanical analyses we were able to reconstruct the foraging radii within which plants and toolstone were procured, and infer the distance at which logistical hunting was carried out. Our results show that foraging radii were 2–3 km during the Early Holocene, whereas during the Middle Holocene these radii were 6–7 km and logistical radii were 8–35 km. Mobility probably followed a complete leapfrog pattern, and most of the territorial range was probably exploited and monitored by logistical activities. A point-to-point movement between areas was probably the pattern utilized during extremely arid periods of the Middle Holocene when territorial ranges contracted to areas with reliable critical resources. Simultaneously, interaction was intensified with other ecological areas, and the flow of items and probably people increased between neighboring regions showing that Puna societies were flexible and had fluid boundaries with their neighbors.

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