



On optimal use of a patchy environment: archaeobotany in the Argentinean Andes (Argentina)



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ABSTRACT

In this paper, optimal foraging theory is used to interpret wild plant collecting behaviors using experimental data and remains recovered from eleven archaeological sites in the Argentine Andes. Using simple techniques believed to approximate those of traditional hunting and gathering societies, I collected and processed twelve plant species endemic to southern Mendoza Province to assess their utility as human food resources. Experimental collection and processing events were timed and total caloric yield weighed against post-encounter handling time to determine each resource's relative rank. In addition, I calculated maximum transport distances to better understand which resources are likely to be recovered in the archaeological record. The results suggest that the distance that must be traveled to reach each plant gathering site determines the whether particular plants will be collected since people should maximize caloric yield relative to both handling costs and transport distance. I conclude by cautioning that optimal foraging theory does not explain all of the variation in hunter-gatherer plant collection, but suggest that the value of the approach lies in its capacity to provide testable hypotheses of foraging behavior and behavioral changes likely to occur under different circumstances.

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1. Introduction

Cost-benefit models derived from optimal foraging theory provide a robust framework for the analysis of hunter-gatherer subsistence patterns (e.g. Bettinger, 2009; Kaplan and Hill, 1992; Pyke et al., 1977; Smith and Winterhalder, 1992). I argue that these models provide a new perspective on the assessment of human dietary breadth in the Argentine Andes, a patchy environment characterized by dramatic ecological changes in relatively short distances. This paper provides a synthesis of experimental and archaeobotanical research conducted over the course of the last five years in central western Argentina and northern Patagonia (Llano and Ugan, 2010; Llano, 2011; Llano et al., 2012; Llano and Barberena, 2013). I have produced data on the costs and nutritional benefits of obtaining and processing native plant resources, providing the basis for a quantitative application of foraging models at a macro-regional scale.

Evolutionary ecology is distinguished as a subfield of biology by the use of simple mathematical models to predict relationships

between features of the natural environment and variation in animal behavior that can be tested with quantitative observations (Winterhalder and Smith, 1992).

Ecological and evolutionary models facilitate pattern detection and offer testable predictions and are therefore well suited for the study of decision-making criteria related to natural resource and landscape use (Soldati and Albuquerque, 2012). Despite some early criticism (e.g. Begossi, 1993; Pierce and Ollason, 1987), optimal foraging theory is an increasingly common approach to the study of human behaviors (Borgerhoff Mulder and Schacht, 2012; Brown and Richerson, 2014; Figueroa and Dantas, 2012; Winterhalder and Smith, 2000).

Optimal foraging models generate hypotheses for the study of benefits and costs associated with various strategies of food procurement (Bettinger, 2009; Simms, 1984; Smith and Winterhalder, 1992; Stephens and Krebs, 1986). Two primary foraging models consider the costs and benefits of acquiring resources: prey and patch choice models (Charnov, 1976; MacArthur and Pianka, 1966). Prey choice models are designed to predict the food items foragers should attempt to exploit ("handle") and those they should ignore in favor of continued search for higher-ranked foods (Kaplan and Hill, 1992). The currency in the simplest model is energy. The

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model assumes that foragers' decisions are designed to maximize the long-term net rate at which energy is acquired during foraging, and that foragers have no impact on resource abundance and distribution (Kaplan and Hill, 1992). Because foragers spend energy and time in obtaining resources (MacArthur and Pianka, 1966), the distance that must be traveled to obtain them may determine which resource patches will be visited. Patch choice models consider that when a forager enters a patch and begins to exploit it, the rate at which he or she gains energy from the patch may change as a function of time spent there (Kaplan and Hill, 1992). The patch choice model assumes that resource return rates diminish exponentially as foraging time in a patch increases.

The data presented here represent handling costs, that is, the cost of collecting and processing a resource once it has been encountered. The accompanying nutritional data should be useful to those interested in the food value of wild plants, and may also prove useful in foraging models requiring the analysis of variables other than energy.

The cost/benefit data presented here are expressed as post-encounter return rates measured in units of energy acquired per unit of time invested. Post-encounter costs are termed "handling time" and can be used to construct a ranking of resources to assess dietary breadth (Simms, 1985). Resource ranking is a tool for making initial predictions about the order in which resources will be added to or excluded from a changing diet (e.g., Charnov and Orians, 1973; MacArthur and Pianka, 1966; O'Connell and Hawkes, 1984; Simms, 1984:30–35).

From this perspective, I utilize the ecological variables proposed by OFT to assess whether prehistoric people acquired wild resources according to a strategy designed to minimize energy expended in foraging. I develop a method of estimating the cost of resource transportation and use the results to illustrate how these

and similar data can be incorporated into existing diet breadth models to generate hypotheses concerning resource exploitation. This study is an important starting point because it is well matched to a level of data typically found in the archaeological record. Analyses of eleven archaeological sites, in different areas of southern Mendoza and northern Neuquén (Fig. 1) are presented here. The results form the basis of a novel paleodietary and spatial interpretation of past human behavior in patchy environments.

1.1. Environmental setting

The study area, from central Mendoza Province to northern Neuquén Province (between 33° and 40° S, 70° and 67° W) is characterized by marked environmental diversity (Fig. 1). In geomorphological terms it includes the Andes mountains to the west, a piedmont fringe extending along the mountain front, and a large eastern plain (Abraham, 2000; González Díaz and Fauqué, 1993). The Diamante, Atuel, Grande, and Colorado Rivers drain the area (Dessanti, 1956, 1978; González Díaz, 1972). In this part of Patagonia, there is a transition between two atmospheric circulation systems, the Subtropical and the Temperate (Páez et al., 2004), resulting in arid and semi-arid conditions, with annual precipitation ranging between 900 mm in the west and 250 mm in the east (Abraham, 2000). Based on the northern and southern weather patterns described by Páez et al. (2004), the study area is under the influence of the southern pattern reflecting variability in the seasonality of rainfall. Large seasonal variations are due to elevation and continental conditions (Capitanelli, 1972). Plant communities of several phytogeographic provinces (e.g., Monte, Patagonia, Altoandina) are distributed following altitudinal and latitudinal gradients (Cabrera, 1976; Mare et al., 1985; Morrone, 2001; Roig, 1972; Roig et al., 2000; Ruiz Leal, 1972). The

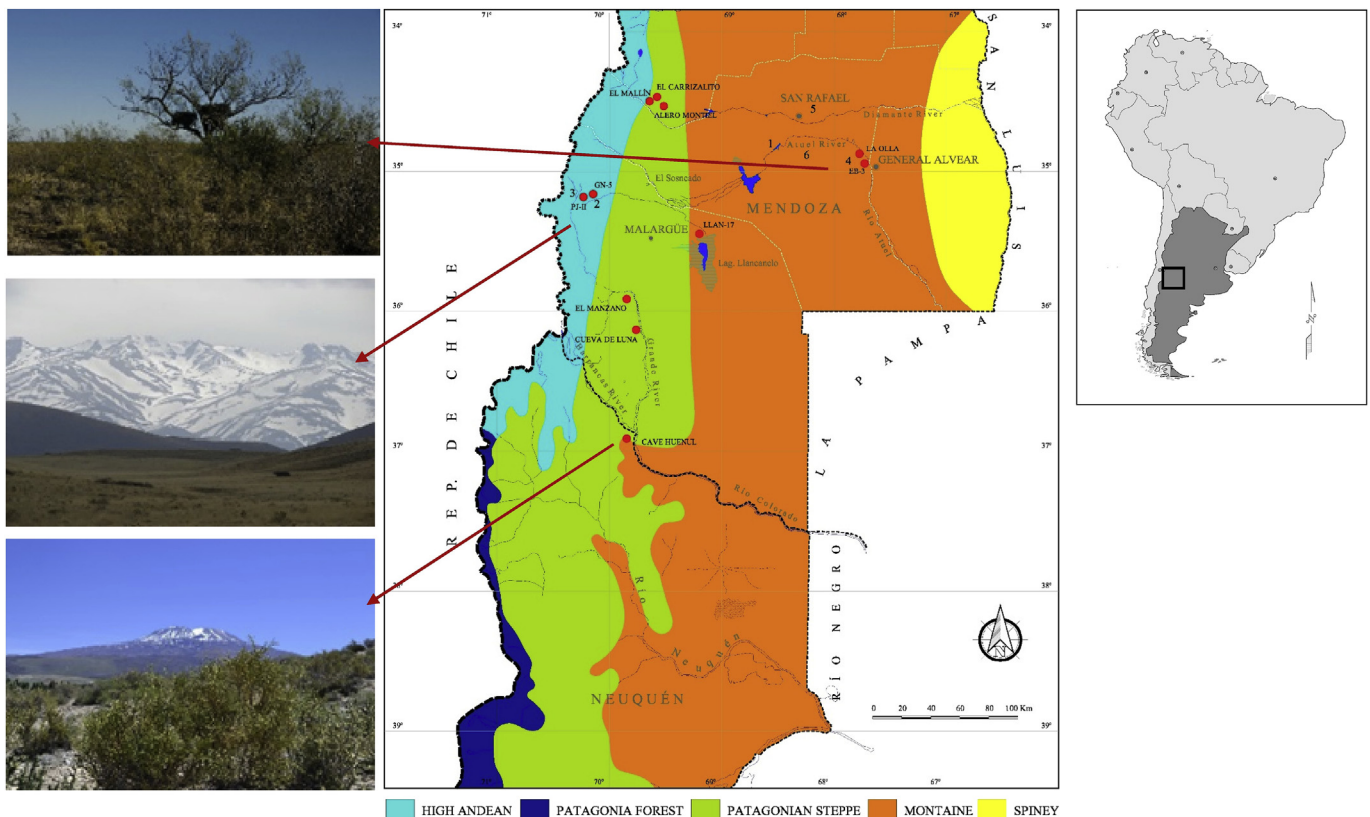


Fig. 1. Location of archaeological sites.

physiognomy is generally dominated by evergreen shrub steppes, since the Monte biogeographic province occupies the largest area. In the Andes, the distribution of plant species is limited by climatic factors and temperature is the strongest determinant of ascent and descent of vegetation belts. In this sector of the Province, grass-steppe predominates, including chamaephytes and some patches of shrubs.

1.2. Andean ethnobotany

Human ecology and ethnobotany provide tools that contribute to the interpretation of archaeological sites (Alcorn, 1995; Atchison et al., 2005; Cotton, 1996; Dimpleby, 1978; Ford, 1979; Ladio and Lozada, 2009), evaluating the human impact on biotic and abiotic factors, reconstructing social conditions and ideologies, and exploring the range of interactions between humans and plants. Since ca. 11,000 BP hunter-gatherers in different parts of this macro-region faced environmental conditions that limited certain subsistence practices, so the collection of wild plants was a necessary and effective complementary practice (Gragson, 1997). Clearly, the use of wild resources as a primary food source and for a wide variety of other purposes played a central role in local human subsistence. Here I focus on the analysis of wild plants used as food, and whose macro-remains are generally the most common in the archaeobotanical record.

Ethnohistoric information (Michieli, 1978, 1983) indicates that wild plants represent a significant component of the diet for many hunter-gatherer groups. As in other arid zones, human use of trees, shrubs, and underground storage organs is more frequent than the use of herbs (e.g., Almeida et al., 2005; Gragson, 1997). The ethnobotanic record of plant use among local communities in the study region indicates the use of xeric species as food, medicine, dye, animal fodder, building material and fuel (Ladio and Lozada, 2009). The most useful plant families are those that dominate this phytogeographical region, including Fabaceae, Asteraceae, Zygophyllaceae and Anacardiaceae. These resources functioned as dietary supplements and their abundance made them suitable buffer species in periods of seasonal scarcity (Ladio and Lozada, 2009).

From ethnobotany analyzed documentation shows that the populations of hunter-gatherers could prepare drinks and foods from diverse species such as *algarrobo* (*Prosopis flexuosa* DC.), *molle* (*Schinus polygamus* (Cav.) Cabrera), and *chañar* (*Geoffroea*

decorticans (Gillies ex Hook. and Arn.) Burkart (Michieli, 1978, 1983; Llano, 2011; Llano et al., 2012) (Fig. 2). The use of fleshy fruit was an important strategy in the Monte, where species include *yaoyin* (*Lycium chilense* Miers ex Bertero var. *chilense*), *piquillín* (*Condalia microphylla* Cav.) and *solupe* (*Ephedra ochreate* Miers). In addition, the use of roots, rhizomes and bulbs, such as *macachín* (*Arjona tuberosa* Cav.), and *chupasangre* (*Maihueiopsis darwinii* (Hensl.) J.F. Ritter var. *hickenii*), shows a profound learning process related to the use of subterranean organs (Ladio and Lozada, 2009; Martínez-Crovetto, 1983). Several authors have noted the cultural and nutritional importance of these plants (e.g., Ragonese and Martínez-Crovetto, 1947).

2. Materials and methods

The materials analyzed here were recovered from eleven archaeological sites representative of the environmental diversity in the macro-region. These are: La Olla, El Bosquecito, and Llan-17 (extra cordilleran fluvial valleys); Cueva de Luna, El Manzano and Cueva Huenul 1 (floodplain); Gruta El Carrizalito, El Mallín, Alero Montiel, Gendarmería Nacional-5 and Puesto Jaque-II (cordillera) (Fig. 1). Table 1 summarizes the characteristics and chronology of these sites.

Archaeological samples were recovered using a flotation machine, were screened through a 2 mm mesh. The fraction larger than 2 mm was sorted visually, while the fraction smaller than 2 mm was examined in full under the microscope (a Nikon SMZ800). For recovery during excavation of each site, following standard extraction protocols (Pearsall, 2000). Lastly, our diverse studies helped us reconstruct the complex formation of these archaeobotanical records, discriminating those generated by humans from those formed by natural causes (Llano, 2011).

2.1. Collection and processing experiments

Few tools were used to collect the plant resources during the experiments. One-kilogram bags (40 cm in diameter and 10–15 cm deep) served as receptacles. A slightly dished metate, measuring 50 by 25 cm, and a one-handed mano were used when grinding was necessary (e.g., in the case of *Prosopis*).

Nutritional data were provided by the Center for Technological Studies, Department of Applied and Industrial Sciences, University of Cuyo. Nutrient content assessments were taken for every 100 g of



Fig. 2. Edible fruits (A) *Prosopis flexuosa*, (B) *Schinus polygamus*, (C) *Geoffroea decorticans*, (D) *Condalia microphylla*, (E) *Ephedra chilensis* (F) *Maihueiopsis darwinii*.

Table 1
Characterization of archaeological sites studied.

Sites	Chronology	Descriptions	Type of site	Phytogeography unit
Cueva Huenul 1	ca. 10200–300 BP	Multi-activity site, with repeated short-term occupations. Artifacts indicate processing and consumption of plants and animals.	Cave	Monte
El Mallín	ca. 8900–1400 BP	Few data given the lack of specific analyses. Evidence indicates an important sequence of occupation, perhaps with stays of longer duration and higher frequency during the early Holocene. Production and disposal of stone tools, and processing and consumption of plant debris are evident. Human remains are present.	Cave	Altoandina
El Manzano	ca. 8100–1300 BP	Sequence of human occupation begins in the early and middle Holocene; site may have been abandoned during the middle Holocene; occupations are of lower intensity or redundancy during the late Holocene. Artifacts reflect an important diversity of activities including food preparation, leather processing, possibly basket-making and pottery use. A human burial is present.	Cave	Patagonia
Cueva de Luna	ca. 3800–200 BP	Multi-activity site that was frequently reoccupied, and where inhabitants engaged in the processing and consumption of food and skins. Grass litters also suggest use as a place of rest. Ceramic are present in upper levels and historical occupations.	Cave	Patagonia
El Carrizalito	ca. 2400–500 BP	The lack of analyses in this overhang hinders its characterization, but it seems to reflect a limited-activity, low redundancy occupational site.	cave	Patagonia
Alero Montiel	ca. 2200–400 BP	The lack of analyses in this overhang hinders its characterization, but it seems to reflect a limited-activity, low redundancy occupational site.	Cave	Altoandina
Llan-17	ca. 1000–700 BP	Multi-activity site with that was frequently reoccupied. Artifacts reflect plant and animal processing, clothing production and discard stone tools	Open air	Monte
El Bosquecito-3	ca. 900–200 BP	Limited activity site with, low frequency reoccupation and evidence of stone tool and ceramics production (analyses not yet complete)	Open air	Monte
GN-5	ca. 900–550 BP	Limited activity site, perhaps on a secondary basis. Stone tools appear to have been discarded during limited periods of time and occupational redundancy is low.	Open air	Patagonia
PJ-II	ca. 650–360 BP	Multi-activity base camp that was frequently reoccupied and where stone tools were produced and discarded; food processing (plant and animal) and the use of ceramics are also indicated.	Open air	Patagonia
La Olla	ca. 645 BP	Multi-activity site that was frequently reoccupied, and where inhabitants engaged in fishing and food processing (meat and plants), and stone tool and ceramics production. Human burials are also present.	Open air	Monte

each resource's edible portions. The samples were analyzed for moisture, ash, dietary fiber, protein, fat, carbohydrates, and energetic content following the methods proposed by the Association of Analytical Communities (AOAC 2005).

2.2. Calculating the cost of resource transportation

The work of Jones and Madsen (1989) and Rhode (1990) was used as a model for calculating the cost of food transport. These authors consider a number of variables that are included in the present analysis: (i) *maximum transport quantity* (MTQ): the maximum amount of a resource that can be transported in a basket-load (here the caloric value of one kilogram of a particular resource); (ii) *net maximum transport quantity* (nMTQ): calculated by subtracting the cost in calories of collecting enough of the resource to fill the basket from the total caloric value of the basket-load (here estimated to be 300 Cal/hr for all resources); and (iii) *maximum transport distance* (MTD): the distance at which the energy used in gathering and transporting a given resource equals the amount of energy obtained (Jones and Madsen, 1989).

While a large number of variables influence caloric expenditure, including body weight, ambient temperature, terrain, grade, load and rate of travel, for the present analysis I assume (1) uneven terrain with an average grade of 5%, and (2) a walking rate of about 3 km/h (Jones and Madsen, 1989). With these assumptions, the MTD is obtained as follows:

$$MTD = nMTQ / (100\text{Cal} + [1.25\text{Cal} * x])$$

where 100 is the cost in calories of walking 1 km, 1.25 is the cost in calories of carrying 1 kg for 1 km, and *x* is the weight in kg of the

MTQ (values taken from the work of Jones and Madsen, 1989; Rhode, 1990).

3. Results

3.1. Experiments and nutritional composition

The post-encounter return rates and resource rankings presented in this paper were derived from direct field experiments or estimated on the basis of previous studies. Handling-times for plants were obtained through collecting experiments conducted during 2008 and 2010. Fig. 1 and Table 2 indicate the field experiment locations.

Table 3 presents nutritional data, and Table 4 provides return rate data and notes on resource characteristics. More detailed comments about the resources, strengths and weaknesses of the data, and archaeological issues relevant to specific aspects of the data are offered in Llano and Ugan (2010) and Llano (2011).

The quality of the nutrients provided by each plant species was evaluated in terms of proteins, lipids and carbohydrates, which indicate considerable variation between the different items. Among the fruits, all from the Monte province with the exception of *Schinus* (Patagonian and Altoandina provinces), carbohydrates and proteins are relatively high (Fig. 3). It is important to note the high lipid content in the fruits of *Ephedra*. This fruit is found in the mountains and foothills, and is one of the only edible fruits in this environment. The rhizomes and tubers are mainly sources of carbohydrates.

The return rates shown in Table 4 reflect the temporal costs of pursuit and processing. Pursuit time is defined as that spent gathering the resource into a receptacle while processing time refers to the winnowing and parching of seeds to prepare them for

Table 2
List of plant-gathering locations shown Fig. 1.

Reference number	Location	Vegetable collected resources
1	Valle Grande	<i>Pterocactus tuberosus</i>
2	Las Leñas	<i>Schinus polygamus</i>
3	Valle Hermoso	<i>Rhodophiala rodholirion</i> <i>Ephedra chilensis</i>
4	Jaime Prats	<i>Condalia microphylla</i> <i>Prosopis flexuosa</i>
5	NE de San Rafael	<i>Opuntia sulphurea</i> <i>Condalia microphylla</i>
6	Sur de Malvinas	<i>Geoffroea decorticans</i>

consumption. Root processing was limited to cleaning and removal of the epidermis (Llano, 2011).

The goal of acquiring the return rate data was to produce general figures suitable for ordinal level comparison between resources and between classes of resources (e.g., nuts vs. seeds vs. roots).

3.2. Archaeological results

The results of this analysis indicate variation in the use of wild plant resources through time and across space. Some vegetal resources were used for purposes beyond strictly subsistence. Spatially, there are changes in the diversity of the archaeobotanical samples relative to the altitude of the sites, as well as variations in the use of particular taxa as a function of the abundance of plants with high return rates (*S. polygamus*; *Prosopis* sp. and *G. decorticans*) (Llano, 2011; Llano and Barberena, 2013). The results of the archaeobotanical analysis of the sites studied are summarized in Table 5, organized by blocks of time.

Table 3
Caloric returns for edible wild species (per 100 g of sample).

Resource	Water (g)	Ash (g)	Fiber (g)	Protein (g)	Fat (g)	Carbohydrates (g)	Caloric values (Kcal/100 g)	Part of the plant analyzed
<i>Schinus polygamus</i>	11.1	3.2	34.2	<0.1	3.7	47.8	310	Fruits
<i>Opuntia sulphurea</i>	56.7	3.3	32.1	1.7	0.7	5.5	115	Fruits
<i>Ephedra chilensis</i>	73.6	1.1	4.8	2.1	11.5	6.9	152	Fruits
<i>Prosopis flexuosa</i>	6.4	3.7	10.8	5.9	3.9	69.3	360	Fruits
<i>Pterocactus tuberosus</i>	73.4	5.3	2.6	0.5	<0.1	18.2	81	Tuber
<i>Maihueiopsis darwinii</i>	75.9	7	2.4	0.5	<0.1	14.2	65	Tuber
<i>Condalia microphylla</i>	55.9	1.3	13.2	2.3	3.8	23.5	170	Fruits
<i>Rhodophiala rodholirion</i>	63.5	5.2	16.0	1.6	0.5	13.2	104	Bulb
<i>Geoffroea decorticans</i>	17.5	3.1	2.3	6.2	14.0	56.9	378	Fruits
<i>Geoffroea decorticans</i>	2.9	2.4	1.0	20.6	51.1	12.0	590	Seed
<i>Ximenea americana</i>	71.2	2.1	2.7	2.8	1.2	20	109	Fruits
<i>Ximenea americana</i>	11.8	3	13.3	0.9	35.4	35.6	498	Seed

Table 4
Return rates for southern Mendoza resources.

Rank	Resource	Caloric values (Kcal/100 g)	Collecting (min)	Weight (g)	Processing (min)	Weight (g)	Return rate (Kcal/Hr)	Processing technique
1°	<i>Prosopis flexuosa</i>	360	2.07	100	–	–	1045	Unprocessed
2°	<i>Geoffroea decorticans</i>	378	2.4	100	–	–	945	Unprocessed
3°	<i>Schinus polygamus</i>	310	5.79	100	–	–	321	Unprocessed
4°	<i>Opuntia sulphurea</i>	115	3.32	100	–	–	208	Unprocessed
5°	<i>Geoffroea decorticans</i> (seed)	590	2.4	100	7.3	37.3	136	Mortar-processed
6°	<i>Ephedra chilensis</i>	152	7.12	100	–	–	128	Unprocessed
7°	<i>Ximenea americana</i> (pulp)	109	5.38	100	–	–	122	Unprocessed
8°	<i>Maihueiopsis darwinii</i>	65	3.42	100	–	–	114	Unprocessed
9°	<i>Prosopis flexuosa</i>	360	2.07	100	7.9	45	97	Mortar-processed
10°	<i>Pterocactus tuberosus</i>	81	5.8	100	–	–	84	Unprocessed
11°	<i>Condalia microphylla</i>	170	14.64	100	–	–	70	Unprocessed
12°	<i>Rhodophiala rodholirion</i>	104	10.48	100	–	–	60	Unprocessed
13°	<i>Prosopis flexuosa</i>	360	2.07	100	16.7	51	59	Mill-processed
14°	<i>Ximenea americana</i> (seed)	498	5.38	100	90.3	36.6	11	Mortar-processed

The most frequently encountered remains at archaeological sites correspond to the plants/plant parts with the greatest nutritional content: seeds of *Prosopis* sp., *S. polygamus* and *G. decorticans* (Fig. 4).

To understand the prehistoric selection of resource areas I used the spatial stratification of the landscape and distances of resources patches from archaeological sites (see Fig. 1): (i) Andes: highland area corresponding to the Andean valleys which include small stands of *Schinus* (molle), more than 30 km from the closest archaeological site. (ii) "Travesía": lowland area located in an arid environment comprising the phytogeographic provinces of the Patagonian steppe and Monte located between 5 and 30 km from the nearest archaeological site; and (iii) archaeological site surroundings (within 5 km of sites): anthropic environments that include small patches of wild plants, trails, and roads, where weeds and xeric vegetation are present.

The practice of collecting in different environments shows that, in general, environments immediately around each archaeological site are the most exploited (see Rhode, 1990), as indicated by the near-universal dominance of vegetal remains that could be gathered within a short distance of each site. Interestingly, and despite this general pattern, high-altitude sites also indicate the exploitation of species from the lowlands, implying travel and transport across a greater distance. I suggest that this is due to the lower local diversity of species in the high-altitude Patagonian province (Fig. 5).

3.3. Cost of resource transportation

The return rates, nMTQ, and MTD values for the resources included in this study (Table 6) indicate that for short travel

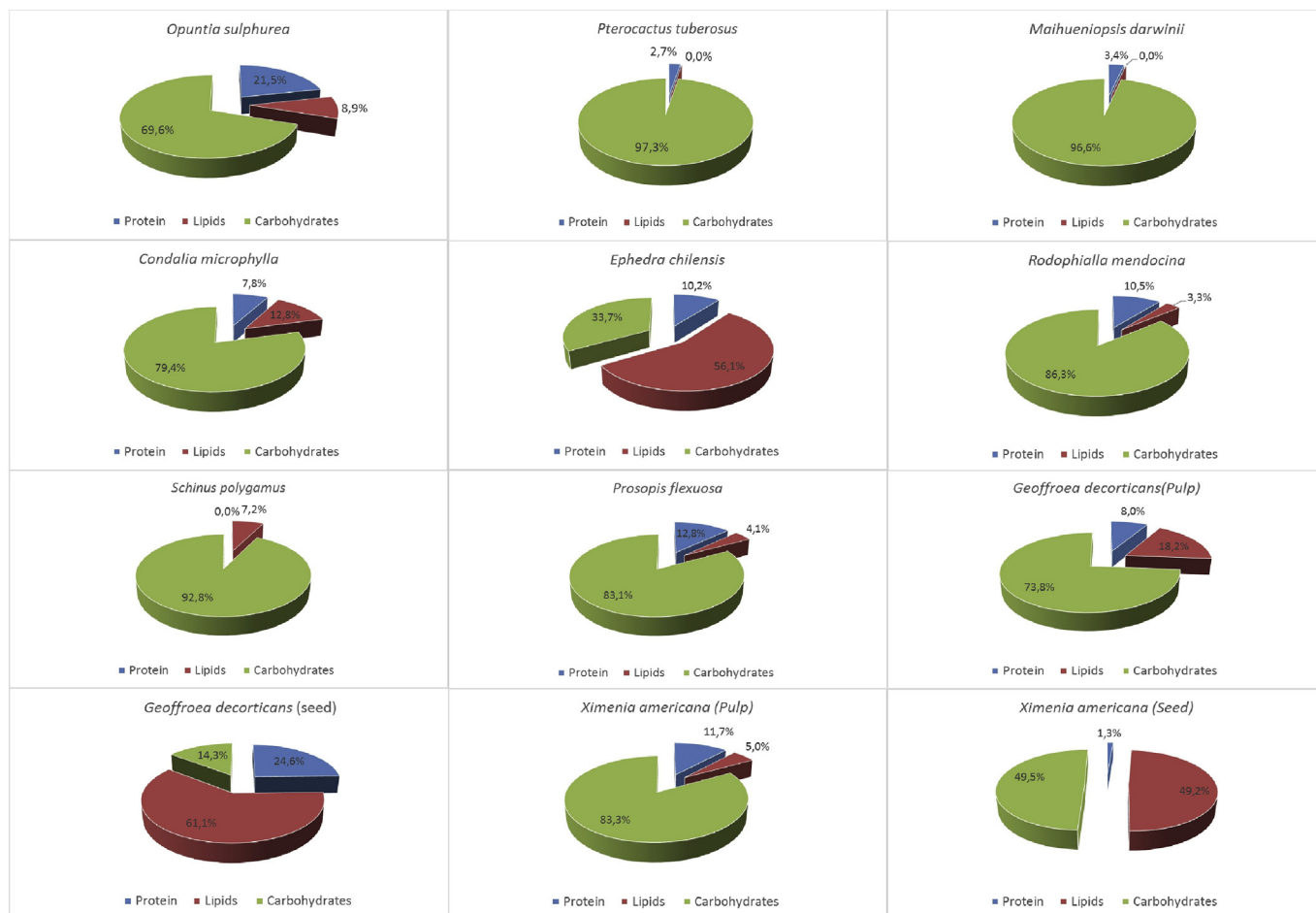


Fig. 3. Nutritional composition of wild plants.

distances algarrobo, chañar and molle, outrank all other resources by virtue of their high return rate (Table 6). Some resources, however, maintain a relatively high net caloric value, even at substantial travel distances, due to their high return rates and relatively high caloric value per basket.

Geoffroea, *Prosopis* and *Schinus* all have maximum transport distances for all archaeological sites calculated above 25 km, indicating that they are likely candidates for transportation and probably storage by mobile societies (Fig. 6). I expect, therefore, that when extra-local resources are encountered in archaeological sites in this macro-region, these three are the most likely candidates. For shorter distances, I would expect to find several other resources added to the list. *Condalia* and *Ephedra* (Table 6), for example, yield lower but still significant caloric values at moderate transport distances.

4. Discussion and conclusions

The archaeological records of southern Mendoza and northern Neuquén provide strong evidence of systematic consumption of the wild species included in our experiments. All of the archaeological sites studied here indicate that the high-return wild resources were important sources of energy pre-Hispanic. Integrating ethnobotanical, ethnohistorical and archaeobotanical records, it can be shown that twelve edible plant species endemic to the macro-region were collected and processed using simple techniques such as those traditionally used by hunter-gatherer

societies. Archaeobotanical results show greater ubiquity of species such as *Schinus*, *Prosopis* and *Geoffroea*, the higher-ranked taxa providing the greatest energy returns. In addition, these species are located in the vicinity of most of the sites. According to the calculation of the maximum transport distance, hunter-gatherers would travel up to 30 km to collect them. This suggests that taxonomic variations in the macro-remains recovered from archaeological sites can be explained by differences in processing costs and nutritional benefits, as well as by the spatial and seasonal distributions of resources.

In this paper, I analyzed the foraging behaviors represented by a set of archaeological sites and concluded that pre-Hispanic hunter-gatherers behaved in a manner consistent with predictions derived from optimal foraging models. On this basis, I suggest that these general models will continue to prove useful in explaining variation in hunter-gatherer subsistence patterns throughout time and space.

The question raised initially was why hunter-gatherers choose the set of resources they do from among the available array. Our answer, formally tested by means of optimal foraging models, is that such choices are largely determined by cost/benefit considerations described in optimal foraging theory. This inference supports previous studies from other locations around the world (e.g., Hawkes et al., 1982).

My goal has been to keep the calculations and variables used as simple as possible. The results represent a simple measure of the number of calories available, discounted by those expended

Table 5
Macro-remains recovered from archaeological sites. From 4000 to 8000, there is no record of plant species. See discussion of this hiatus in Barberena (2013). Note: *Direct date on *Retanilla patagonica* (9261 ± 66 – AA99107). “N” represents the value of all the macro-remains were recorded, including fragments and whole remains.

Species	Site	10000–9000 BP	4000–3000 BP	3000–2000 BP	2000–1000 BP	1000 BP–Present	Structure of the plant	State of preservation of the plant
<i>Astragalus pehuenches</i>	GN-5					n = 17	Seed	Uncharred
<i>Atriplex lampa</i>	Llan-17					n = 5	Bract	Uncharred
	Cueva Huenul	n = 1					Bract	Uncharred
<i>Berberis empetrifolia</i>	PJ-II					n = 6	Seed	Charred
Boraginaceae	GN-5					n = 2	Seed	Uncharred
Caryophyllales	PJ-II					n = 982	Seed	Uncharred
	GN-5					n = 92	Seed	Uncharred
<i>Cereus aethiops</i>	EB-3					n = 4	Seed	Uncharred
<i>Condalia micropylla</i>	La Olla					n = 3	Seed	Charred, uncharred
<i>Chenopodium</i> spp.	La Olla					n = 4	Seed	Uncharred
	GN-5					n = 4	Seed	Uncharred
<i>Chenopodium papulosum</i>	EB-3					n = 58	Seed	Uncharred
	PJ-II					n = 66	Seed	Uncharred
<i>Chuquiraga erinacea</i>	Cueva Huenul				n = 1		Inflorescence	Uncharred
<i>Chusquea culeou</i>	El Manzano				n = 19		Stem	Uncharred
	El Mallín				n = 5		Cane	Uncharred
	El Carrizalito			n = 1			Cane	Uncharred
<i>Diplolepis hieronymi</i>	El Mallín				n = 6		Seed	Uncharred
<i>Echinopsis</i> aff. <i>leucantha</i>	EB-3					n = 5	Seed	Uncharred
<i>Ephedra</i> sp.	Cueva de Luna				n = 1	n = 13	Seed	Uncharred
<i>Erodium cicutarium</i>	PJ-II					n = 4	Fruit	Uncharred
	GN-5					n = 6	Fruit	Uncharred
<i>Eruca vesicaria</i>	Cueva Huenul				n = 1		Fruit	Uncharred
<i>Geoffroea decorticans</i>	La Olla					n = 333	Endocarp	Charred
	EB-3					n = 1	Endocarp	Charred
<i>Hoffmannseggia erecta</i>	El Manzano				n = 1		Pod	Uncharred
<i>Juglans regia</i>	Cueva de Luna					n = 1	Endocarp	Uncharred
<i>Lagenaria</i> sp.	El Mallín				n = 1		Pumpkin	Uncharred
	Cueva Huenul				n = 3		Pumpkin	Uncharred
<i>Larrea cuneifolia</i>	EB-3					n = 38	Fruit	Uncharred
<i>Larrea nitida</i>	El Manzano				n = 3		Stem	Charred, uncharred
	Cueva de Luna				n = 4	n = 43	Mericaip	Uncharred
<i>Larrea divaricata</i>	Cueva Huenul				n = 8		Mericaip	Uncharred
<i>Maihuenia poepiggii</i>	Cueva de Luna				n = 2		Seed	Uncharred
<i>Maihueniopsis darwinii</i>	El Carrizalito			n = 1			Knuckle	Uncharred
	Cueva Huenul				n = 10		Knuckle	Uncharred
<i>Oxalis</i> sp.	PJ-II					n = 1	Seed	Uncharred
<i>Passiflora</i> sp.	EB-3					n = 6	Seed	Uncharred
<i>Phragmites australis</i>	El Manzano				n = 3		Stem	Uncharred
	El Carrizalito			n = 1			Inflorescence	Uncharred
<i>Phaseolus vulgaris</i>	Cueva de Luna					n = 2	Seed	Uncharred
Poaceae	PJ-II					n = 2	–	Uncharred
<i>Prosopanche americana?</i>	La Olla					n = 1	Perigonium	Uncharred
<i>Prosopis alpataco</i>	El Manzano				n = 4		Spine	Uncharred
<i>Prosopis</i> sp.	La Olla					n = 749	Endocarp, seeds	Charred, uncharred
	EB-3					n = 5	Pod, seeds	Charred
	El Manzano				n = 9		Endocarp	Uncharred
	Cueva de Luna		n = 16		n = 58	n = 77	Endocarp, seeds	Uncharred
	Alero Montiel					n = 1	Endocarp	Uncharred
	El Carrizalito			n = 24			Endocarp	Uncharred
	Cueva Huenul	n = 144			n = 130		Endocarp	Uncharred
<i>Prosopis strombulifera</i>	El Manzano				n = 8		Pod	Uncharred
<i>Retanilla patagonica*</i>	Cueva Huenul	n = 1					Fruit	Uncharred
<i>Schinus polygamus</i>	La Olla					n = 3	Endocarp	Charred, uncharred
	Llan-17					n = 1	Endocarp	Uncharred
	Cueva de Luna		n = 1		n = 4	n = 39	Endocarp	Uncharred
	Alero Montiel					n = 1	Endocarp	Uncharred
	El Carrizalito			n = 649			Endocarp	Uncharred
	PJ-II					n = 511	Endocarp	Charred
	Cueva Huenul				n = 16		Endocarp	Uncharred
<i>Schoenoplectus californicus</i>	El Manzano				n = 2		Stem	Uncharred
<i>Solanum elaeagnifolium</i>	El Carrizalito			n = 2			Fruit	Charred, uncharred
<i>Suaeda divaricata</i>	Llan-17					n = 8	Seed	Uncharred
<i>Tessaria dodonaefolia</i>	El Manzano				n = 1		Stem	Uncharred
<i>Trichocereus candicans</i>	La Olla					n = 2	Seed	Uncharred
<i>Triticum aestivum/durum</i>	Cueva de Luna					n = 136	Seed	Uncharred
<i>Zea mays</i>	Alero Montiel				n = 4		Corncob	Uncharred
	El Carrizalito					n = 45	Seed	Charred, uncharred

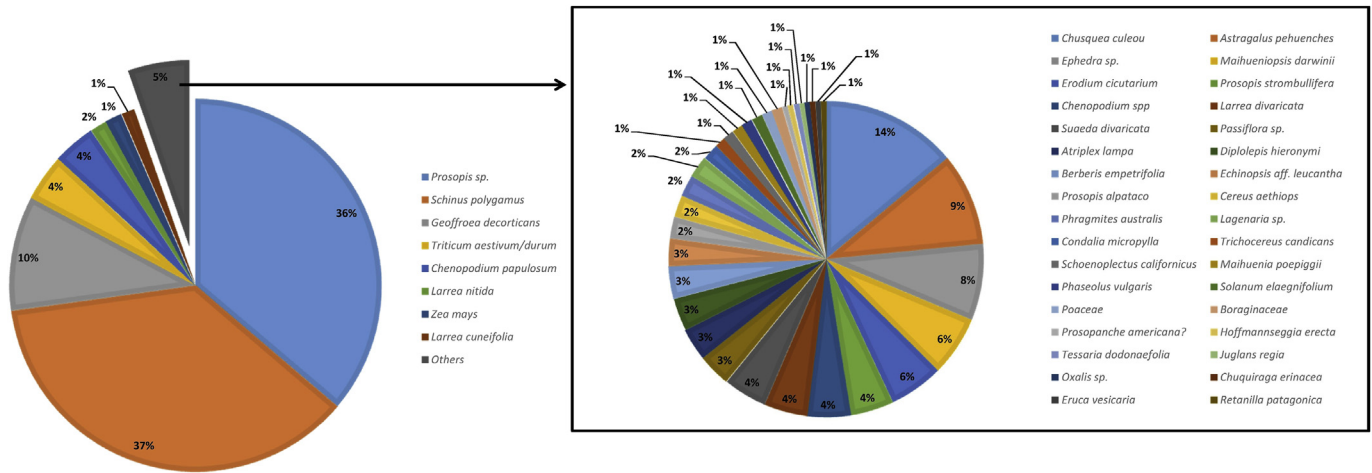


Fig. 4. Resources recovered from archaeological sites.

collecting and transporting the resources. Additional variables can be added to the calculations to increase their applicability to particular circumstances as needed.

Even though the techniques employed to collect and process the resources described here may not replicate aboriginal techniques exactly (Jones and Madsen, 1989), the values obtained by this method illustrate that return rate, caloric value per unit volume, and the cost of transport alone are insufficient to predict whether a resource is a good candidate for this kind of exploitation. An important additional limiting variable is the cost of processing to decrease weight and/or volume (Jones and Madsen, 1989). Barlow and Metcalfe (1996) have developed a model of the expected relationship between processing cost and transportable quantity, and Bettinger et al. (1997) describe a useful application.

Jones and Madsen (1989) determined the caloric cost of carrying a specific volume of a resource as a function of distance. In their paper, MTD values are modeled on the assumption that a quantity of a particular resource is gathered and transported intact to a second location. I expect, however, that small quantities of a given resource may be routinely carried beyond the

maximum transport distance depending on whether it is being consumed in route. This expectation is based on the assumption that the cost of transporting a small quantity of a resource is negligible and a small amount might be carried for a great distance at no expense. This may result in the archaeological recovery of scant amounts of resources available only at considerable distances from the sites where they are found, but we do not expect to find substantial quantities of a resource much beyond the MTD calculated for that resource. Excavations at several Owens Valley archaeological sites (Bettinger, 1989) revealed abundant vegetal remains, all of which could be gathered within a short distance of the sites, coincident with the results presented here and the proposal of Rhode (1990).

These results have important implications. Plants with high nutritional content will potentially be recorded in the archaeological record. Plants that require extensive processing (e.g., roasting, grinding, or leaching) will often be relatively low-ranked. Indeed, they may be added to or dropped from local diets depending on the abundance of higher-ranked foods relative to the number of potential consumers but regardless of their own abundance or nutritional quality (Winterhalder and Smith, 1981). These data suggest that the distance of resource patches from sites determines the choice of places to be visited during foraging, with nearby zones visited most. In this sense, expended energy and time are minimized in collection events.

Radio and Lozada (2000) studied the use of food plants by a community in Patagonia and tested different hypotheses related to the optimal use of these resources. Despite evaluating the full range of plants recognized as food, the authors found a similar situation, in which the community extracted a higher percentage of food resources in the vicinity of residences. The authors justify this pattern by noting that two more distant resource areas demanded a greater investment of time and energy and have a lower abundance of resources. Furthermore, the results indicate that not all resources are likely candidates for logistical exploitation and that by analyzing the suite of resources available in a given area hypotheses can be formulated about whether “collecting” or “foraging” is the expected strategy for a particular resource from a particular place (see Binford, 1980).

I conclude with the obvious caution that optimal foraging theory does not necessarily explain all the variation in hunter-gatherer subsistence. Nevertheless, its value lies in the capacity to provide testable hypotheses about foraging behavior and about the likely

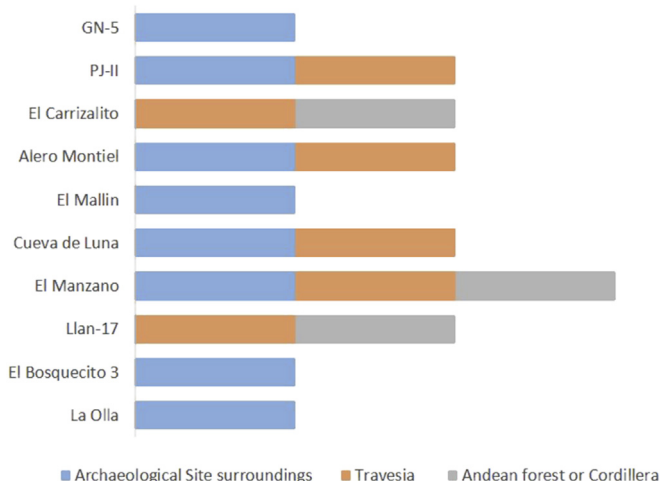


Fig. 5. Collection environments.

Table 6
Maximum transport distance (km).

Prosopis aff. flexuosa

amount collected:	1.00 Kg	MTQ	3600 Kcal	
Collection rate:	2.41 Kg/Hr			
Collection cost:	300 Kcal/Hr			
Calories:	3600 Kcal/Kg	MTD=	$\frac{2877}{101.25}$	= 28.4 Km
Harvest time:	2,41 Hr			

Schinus polygamus

amount collected:	1.00 Kg	MTQ	3100 Kcal	
Collection rate:	1.09 Kg/Hr			
Collection cost:	300 Kcal/Hr			
Calories:	3100 Kcal/Kg	MTD=	$\frac{2773}{101.5}$	= 27.4 Km
Harvest time:	1.09 Hr			

Condalia microphylla

amount collected:	1.00 Kg	MTQ	1700 Kcal	
Collection rate:	0.30 Kg/Hr			
Collection cost:	300 Kcal/Hr			
Calories:	1700 Kcal/Kg	MTD=	$\frac{1610}{101.25}$	= 15.9 Km
Harvest time:	0,30 Hr			

Geoffroea decorticans

amount collected:	1.00 Kg	MTQ	3780 Kcal	
Collection rate:	2.47 Kg/Hr			
Collection cost:	300 Kcal/Hr			
Calories:	3780 Kcal/Kg	MTD=	$\frac{3039}{101,25}$	= 30.0 Km
Harvest time:	2.47 Hr			

Ephedra chilensis

amount collected:	1.00 Kg	MTQ	1520 Kcal	
Collection rate:	0.84 Kg/Hr			
Collection cost:	300 Kcal/Hr			
Calories:	1520 Kcal/Kg	MTD=	$\frac{1268}{101.25}$	= 12.5 Km
Harvest time:	0.84 Hr			

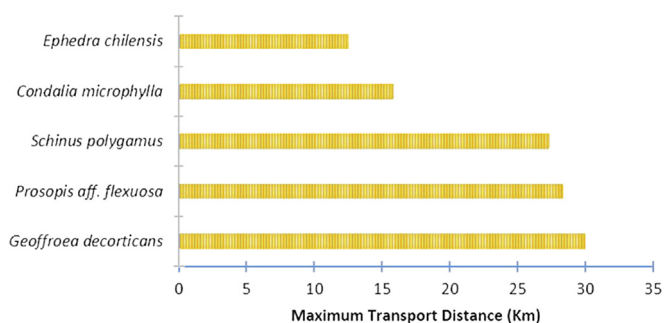


Fig. 6. Maximum transport distance (km) for each resource.

changes in behavior under changed circumstances. Whatever the outcome of any particular test, our knowledge of hunter-gatherer subsistence will have been enhanced by the use of such theory.

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