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Radiocarbon dates and anthropogenic signal in the South-Central Andes (12,500–600 cal. years BP)

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ABSTRACT

This paper presents the analysis of the anthropogenic signal documented by four time-series in the highlands of the South-Central Andes (Puna of Argentina and North Chile) spanning the period between 12,500 and 600 cal years BP. Our goal is to extract demographic and occupational histories from temporal data. In this way, based upon the full radiocarbon dataset and the sites of provenance of the dates, we built the following time-series: the summed probability distribution of calibrated ages; the relative frequency of calibrated ages; the relative frequency of sites per unit of time; and the frequency of new sites per unit of time. For controlling the effects of site destruction on the anthropogenic signal, we used the exponential model as well as the volcanic empirical model of taphonomic bias. The four time-series coincide in showing a regional pattern with a phase of low and fluctuating demography of relative long term duration, followed by an growth phase well evident at 5000 cal BP in a context the economic intensification. The long-term demographic success of the hunter-gatherers in the highlands many millennia before the consolidation of food production exemplifies the flexibility of this mode of subsistence for achieving human adaptation to extreme selective environments as the Puna.

1. Introduction

The aim of this work is to study the anthropogenic signal documented by four time-series in the highlands of the South-Central Andes (Puna of Argentina and North Chile) spanning the period between 12,500 and 600 cal years BP, seeking to extract the demographic and occupational history of the area. Thus we pursue to document the anthropogenic signal on a broad spatial and temporal scale so as to discuss hypotheses related to past population dynamics. With this objective in mind we assessed possible sources of taphonomic bias as well as the resolution of the dates. In this way, by comparing different time series and taphonomic models our work seeks to contribute to the broader theoretical and methodological discussion that is currently taking place on the analysis of past demography (Surovell et al., 2009; Collard et al., 2010; Peros et al., 2010; Steele, 2010; Williams, 2012).

The space covered by this study comprises the so-called Puna of Argentina and the highlands of northern Chile, with an approximate area of 125,150 km^2 (Fig. 1). The Argentine side includes the Puna region, a high altitude environment over 3000 masl in the present-day provinces of Jujuy, Salta, and Catamarca. The Chilean side encompasses the Atacama basin and the upper and mid Loa regions, with spaces at over 2500 masl.

Consensus exists that the first human occupations of the study area were associated with a low demography and with a strategy of high residential mobility in an environment somewhat more humid than at present (Yacobaccio and Vilá, 2002; Yacobaccio and Morales, 2013). From the mid-Holocene on, large-scale aridization processes will have increased the ecological fragmentation of the south-Andean highlands, enlarging clearly localized patches with a greater supply of resources than the mean. In this way Núñez (1992) proposed that in the Atacama salt flat of north Chile an "archaeological silence" (absence of anthropogenic signal) is to be found during a part of the mid-Holocene, with human occupations restricted to "eco-refugia" (*sensu* Núñez, 1992). Towards the end of the mid-Holocene, in a patchy environment it has been suggested that the south-Andean hunter-gatherers reduced their residential mobility triggering processes of population aggregation (Aschero, 1994). In this way, it has been proposed that a context of high population density and larger local group sizes gave place to the

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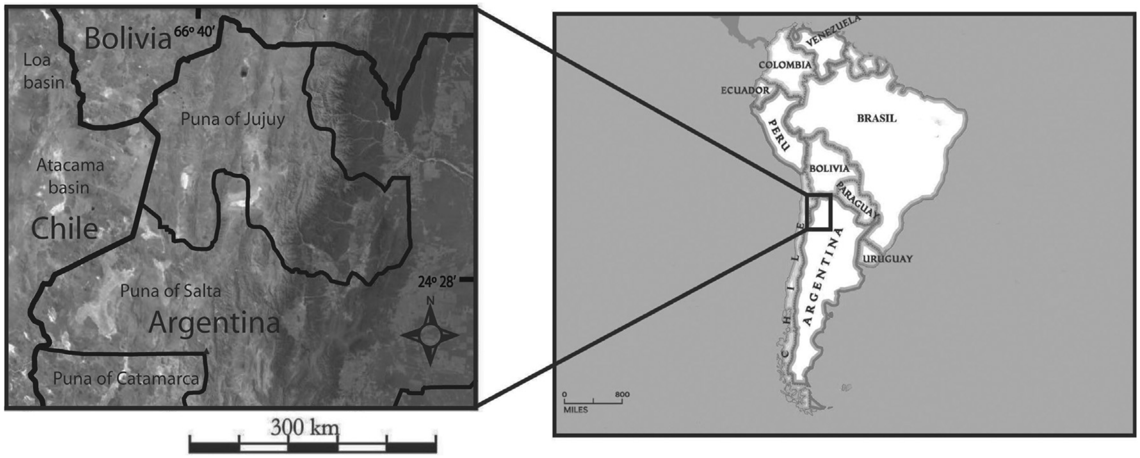

Fig. 1. Study area, the highlands of the Puna of Argentina (in the provinces of Catamarca, Salta and Jujuy) and North Chile (the Atacama basin and the Loa basin).

processes of camelid intensification and domestication, and to the increase of social complexity (Aschero, 1994; López and Restifo, 2012; Yacobaccio, 2001). In the same way it has been posited that the evolution of technological innovations was also related to population size increase (Muscio, 2012). Finally, the consolidation of productive economies during the late Holocene will also have been related to demographic growth (Albeck, 2001). Thus because the above mentioned questions are linked to demography the study of the anthropogenic signal on the scale undertaken here contributes to these issues. Indeed, Morales (2011) and Gayo et al. (2015) showed the utility of the analysis of radiocarbon dates series in order to document past demography in the Puna region.

2. Materials and methods

Currently, the study of archaeological time-series for discussing past demography and space use is a growing area of research (Rick, 1987; Shott, 1992; Collard et al., 2010; Steele, 2010). This demands to assess the possible sources of biases that affect the representation of a given sample of dates. Broadly, we can recognize natural and procedural sources of biases (Shott, 1992; Peros et al., 2010). The first includes those processes affecting the preservation of sites and which are technically named taphonomic biases (Surovell and Brantingham, 2007). The second source of biases comprehends a broad list of processes intervening in the recovering of the archaeological data. For instance the bias associated with the over-dating of particular periods or regions and the sampling biases resulted from differences in the visibility or in the probabilities of discovery of sites. In this paper our methodology will focus mainly on taphonomic biases, limiting the analysis of the procedural biases to the assessment of the uncertainty of the radiocarbon dates. This obeys to the current availability of a number of sophisticated mathematical models for controlling taphonomic biases and the lack of similar tools for assessing procedural biases. In this vein, in order to increase the reliability of the archaeological inference, our methodology is aimed to analyze the anthropogenic signal by means of time-series of different nature built to discuss the discrepancies between the patterns they document.

2.1. Time–series

In this work we built time-series of calibrated years based on radiocarbon dates as well as sites-frequency and sites-occurrence data. These series are: 1) the summed probability distribution of calibrated ages; 2) relative frequency of calibrated ages; 3) relative frequency of sites per unit of time; and 4) frequency of new sites per unit of time. Each of these series provides singular information.

For series 1 and 2, the adopted analytical unit is the single radiocarbon dating of stratigraphic archaeological contexts. In this way we assume that the presence and frequency of radiocarbon events document the anthropogenic signal as well as its fluctuations in time and space (Rick, 1987). Other authors use other units, such as phases, components, or occupations, and averages of the calibrated dates (Prates et al., 2013; Shennan and Edinbourough, 2007; Buchanan et al., 2008; Steele and Politis, 2009; among others). By recognizing that instances of overlapping dates are always possible due to sampling biases, we used the other time-series (3 and 4) for which the unit of analysis is the dated site. These time-series alongside those built on the basis of the calibrated dates were used for comparison and control. Thus we seek to document the anthropogenic signal by alternative proxies in order to highlight potential discrepancies between them.

2.2. Radiocarbon distributions: summed probability and relative frequency of calibrated ages

As for the construction of time-based distributions, the first method we used is the summed probability of calibrated ages (Barrientos, 2009; Buchanan et al., 2008; Morales, 2011; Williams, 2012). To this end we employed the summed probability function with the calibration method of Oxcal 4.2 with the atmospheric curve of the southern hemisphere (ShCal13) (Bronk Ramsey and Lee, 2013). Because the number of sites or occupations throughout a period of time can be expected to co-vary positively with population size, changes in the distribution of the summed probability of calibrated dates from different sites or occupations serve as a proxy of population dynamics (Collard et al., 2010; Gamble et al., 2004; Shennan and Edinbourough, 2007).

In addition, we built the series of relative frequencies of calibrated dates (i.e. Steele, 2010). For this purpose we took the mid point of the two sigma calibrated range of each particular dating, so as to construct the distribution of dates along discrete time-intervals. The logic of this method is such that it relies on the frequency of calibrated dates. The temporal distributions were obtained working with 200 years intervals. The value of these intervals gives us a suitable scale to document anthropogenic signal patterns considering our sample size.

For discussing relevant archaeological patterns a critical issue is the assessment of the radiocarbon resolution of the uncalibrated dating (Steele, 2010), along others possible sources of variation (i.e. Shott, 1992). In order to establish a cut-off value for the dates to be included in the sample, we analysed the distribution of each standard deviation value (SD) for the uncalibrated dates so as to minimize the variability of errors, disregarding extreme values. In practice we took the SD value above 200 as our cut-off point. The coefficient of variation of the SD on the whole sample is 73% (mean SD = 81.14), while after excluding those dates with SD values higher than 200 gives a working sample with a coefficient of variation of 43% (mean SD = 73). By this procedure we eliminated 14 dates, giving a working sample of 466 dates with a more homogeneous distribution of errors (see Tables 1 and 2 in supplementary data).

A sample size of 200–500 has been suggested as the acceptable minimum for the analysis of the summed probability of calibrated ages for samples with mean standard deviations between 115 and 170 (Williams, 2012). As we can see, our sample satisfies these requirements since it produces a mean standard deviations of 73 for a sample of 466 dates. In turn, the reliability of the sample increases on considering the spatio-temporal scale. In this way, in our case the density is 290.85 dates/kyrs/km^2. Robust time-series have been constructed with spatio-temporal densities calculated by us of 5.81 dates/kyrs/km^2 in the case of the north of North America (Buchanan et al., 2008) and 10.99 dates/kyrs/km^2 in the case of Australia (Williams, 2012).

It has been pointed out the importance of the differential preservation of sites on archaeological time-scales conditioning the anthropogenic signal of a regional dataset (Surovell and Brantingham, 2007). Hence, for controlling the representation of our sample regarding the action of site destruction processes we assessed the role of taphonomic bias. It has been stressed that the destruction of sites by the passage of time leaves a pattern of distribution of temporal frequencies that could be of an exponential nature (Surovell and Brantingham, 2007). Following this line of thought, we corrected the data frequency with an exponential function with a rate of site destruction of 0.0001% (Surovell and Brantingham, 2007).

On the other hand, from volcanic and chronological information a model of site destruction was proposed that avers that the highest rate of destruction of sites takes place in the earliest moments after their abandonment, following a *power function* predicting the probability of site loss (Surovell et al., 2009). Under this model the destruction of sites is not taken as continuous but variable, and can be corrected by using Surovell et al. (2009:1717) Equation 1.

For comparative purposes, in this work we corrected the relative frequency of calibrated ages according to both models, in order to analyse the degree of discrepancy between them and their effects on the anthropogenic signal in our data set.

2.3. Time-series of relative frequency of sites and frequency of new sites

The relative frequency of sites per unit of time is the total of recorded sites in each time-interval of calibrated dates expressed as a fraction of its maximum value. For instance, if a site has 2 or 3 dates whose calibrated ages fall into a single interval, then they are counted as 1. Hence the time-frequency of sites is defined as the sum of sites per interval of time. In this way we evaluate the differences in the anthropogenic signal documented by the radiocarbon dates and by the archaeological sites. Just as importantly, this methodology enables us to assess the influence on the anthropogenic signal of sites with similar or recurrent dates into a single time interval. Also this allows the assessment of intra-site sampling biases (see Williams, 2012).

Another complementary but important indicator is the generation of new sites throughout time. We call this series frequency of new sites, and it is defined as the total number of new sites per interval of time. The originality of this series is that it documents the generation of sites per time unit in the region under study, which we assume to be a function of the demographic and settlement dynamics. Consequently the generation of new sites is one line of evidence, among others, for the study of population dynamics in time that additionally informs about the incorporation of new spaces for human use.

Similarly, this series documents the weight of each site on the anthropogenic signal along time. For instance, in a case of a multicomponent site with a long history of occupation, in the time-series of frequency of new sites it is counted only once and associated to its oldest age. Clearly this implies an important difference with the time-series of radiocarbon dates that would count such multicomponent sites several times.

3. Results

3.1. Series 1

The summed probability of the radiocarbon dataset from the highlands of northern Argentina and Chile show high fluctuations in the anthropogenic signal throughout the Holocene (Fig. 2). In any case, some of the fluctuations are more noticeable, such as the fall in *ca.* 7500–7900 cal BP and between *ca.* 6900–6300 cal BP, which are in fact associated to a decrease in dates, for which reason they would not be by-products of the heterogeneity of the calibration curve (see also Steele and Politis, 2009). In the same way, becomes evident a tendency towards an increase of the anthropogenic signal as from the end of the mid Holocene (*ca.* 5000 cal BP) and especially from ca. 1700 cal BP. Still, in this general pattern there are peaks that seem to reflect the over-representation of dates in a single site. For example, around *ca.* 9300–9100 cal BP there is a peak explained by 4 dates from the Peña de las Trampas site, while between *ca.* 2700 and 2500 BP there is another peak coming from the Tulán 54 site (9 dates). On the contrary, other earlier peaks such as those around 11,100 cal BP and 4700 cal BP indeed reflect an increase in the anthropogenic signal.

3.2. Series 2

Regarding series 2 from the Chilean and Argentine dataset, the

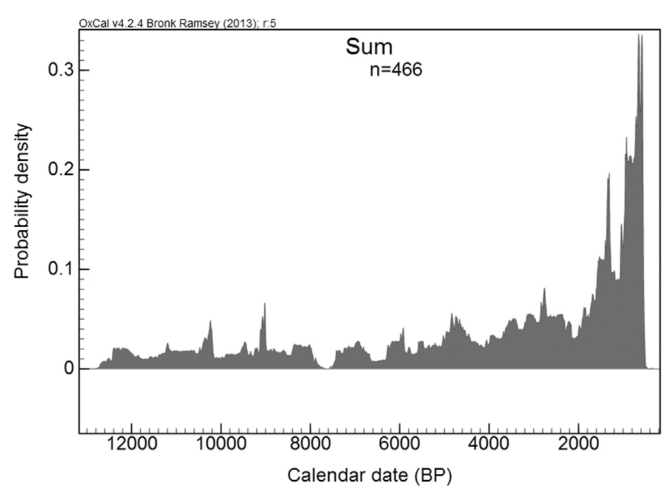

Fig. 2. Summed probability distribution of calibrated ages from the Puna of Argentina and the highlands of North Chile.

peaks and valleys are dispersed along different periods of the Holocene, although in some cases the fluctuation is wide (Fig. 3). Similarly to the summed probability series, in this case the most important valley in the anthropogenic signal occurs between 7500 and 7900 cal BP. In addition, a noticeable drop in dates from 6900 to 6300 cal BP can be observed, which is also evident in the summed probability series. Another significant drop takes place between 4500 and 4100 cal BP, which occurs after the peak of 4700 cal BP. Anyway, an increment, though fluctuating, of the anthropogenic signal is seen, with an inflection towards greater growth that starts at 6.3 kyrs cal BP becoming well evident at 5000 cal BP. Nonetheless, a pronounced drop is seen in the anthropogenic signal in 2500 cal BP, explainable in part by a previous peak due to the overrepresentation of the Tulán 54 site (Atacama basin).

Analysing the curves of both geographic areas separately there are important differences at some periods (Fig. 4). In North Chile, the anthropogenic signal becomes inexistent in the intervals *ca.* 8700–8100 and 7900–7300 BP, although it must be pointed out that if we consider a continuous block of 1400 years there is only one radiocarbon event from the upper Loa (7978 cal BP). In contrast in the Puna of Argentina this absence of dates is limited only to 7900–7500 BP cal., spanning 400 years (Fig. 5). The latter is one of the most important differences. The second difference appears during the mid Holocene in the period 6700–6500 cal BP, when there is a lack of dates in the Puna of Argentina, whereas for this same time interval in North Chile the anthropogenic signal is present, though at a low frequency. In summary, during this period there is a fall in the anthropogenic signal in both regions, although with differences.

Towards the end of the mid Holocene (*ca.* 4500 cal BP) the anthropogenic signal, with fluctuations, becomes stronger in both regions. From 900 cal BP significant variations between the two countries are evident, where the eastern side has the greater number of dates. In this sense it is worth noting that many dates for this chronology in Chile were carried out by the method of thermoluminescence and were therefore not included in this analysis.

Moreover, in the total dataset of dates from the highlands of Argentina and Chile we assessed the role of taphonomic bias over the anthropogenic signal. By using the exponential model of taphonomic loss, the pattern that emerges is fairly similar to that recorded without any correction analysis. The solely difference is the increase of the anthropogenic signal in the early Holocene and consequently the increasing contrast between peaks and valleys (Fig. 6). Regarding the use of the volcanic model of taphonomic loss for correcting our time-series, we followed Surovell et al. (2009) and Kelly et al. (2013) in the assumption that because caves and rockshelters act as sediment traps, they are largely insulated from taphonomic bias, particularly with respect to erosion. In this way we constructed the averaged distribution of the corrected dates from open-air sites, and the uncorrected time-series of dates from caves and rock-shelters (Fig. 7). The averaged corrected time-series depicts the similar pattern of peaks and valleys documented by the rest of the series, but showing a high amplitude peak at the beginnings of the early Holocene.

While the exponential model increases monotonically the anthropogenic signal of the dataset, describing a more regular frequency distribution, the volcanic correction increases unequally more the frequencies corresponding to the earliest times, and depicts a more realistic unevenly distribution of contrasted peaks and valleys. This is in line with the empirical finding that site loss does not occur at a constant rate, which is the foundation of the volcanic model (Surovell et al., 2009). And it is for this latter reason that the volcanic correction model tends to be very sensitive to the biases of temporal oversampling, from which spurious or exaggerated peaks emerge. This is the case of the peak at 12,300 cal BP which obeys to the multiple dating of a single open air site (Salar Punta Negra 1). For dealing with this issue in the next section we use the volcanic model for correcting site-based temporal series.

3.3. Series 3 and 4

Regarding the relative frequency of sites per unit of time (series 3) in the highlands of Argentina and Chile (Fig. 8), there are no significant variations with the anthropogenic signal documented by the other time-series. Also a similar pattern is found in both regions (Fig. 9).

As we mentioned this series eliminates the over-representation of dates overlapping each other in a given interval and from a given site. Because of this the obtained time-series flattens the spurious peaks shown in the distributions of relative frequency of calibrated ages and summed probability. Agreeing with the other series we find peaks and valleys throughout the Holocene. From 7900 to

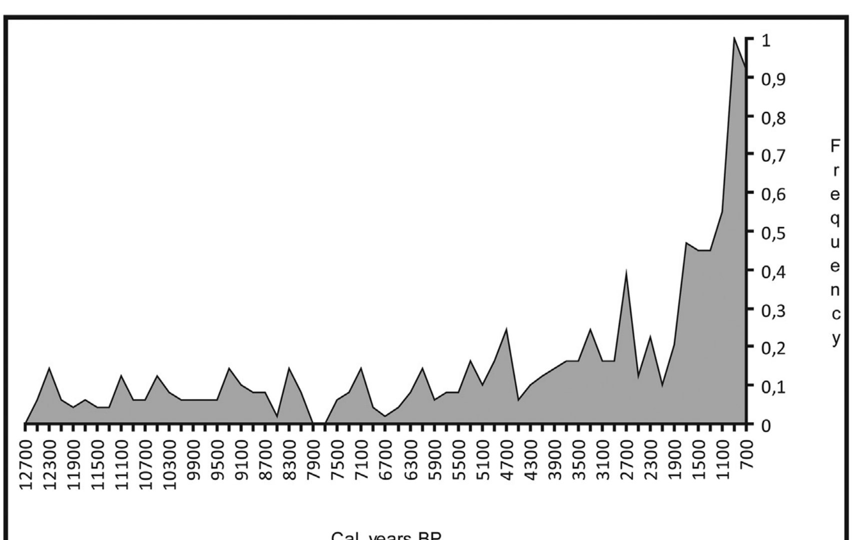

Fig. 3. Relative frequencies of the calibrated ages from the Puna of Argentina and North Chile.

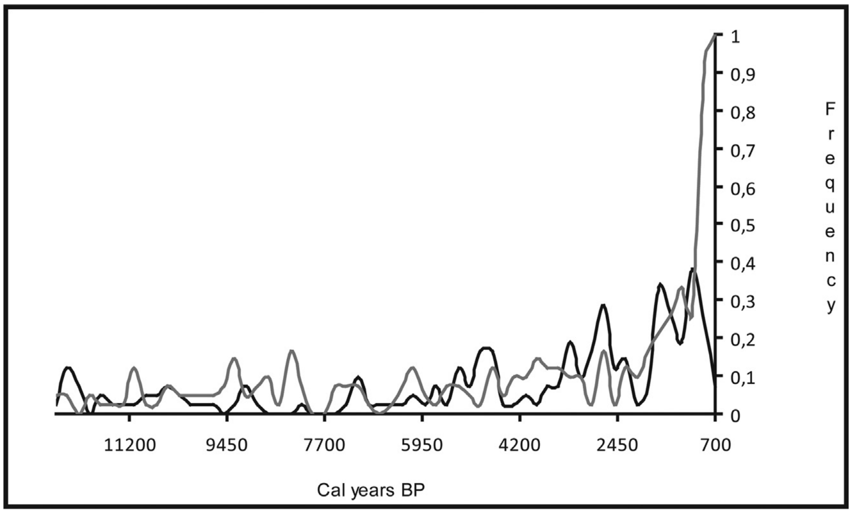

Fig. 4. Comparison between the relative frequencies of calibrated ages from the Puna of Argentina, grey line, and North Chile, black line.

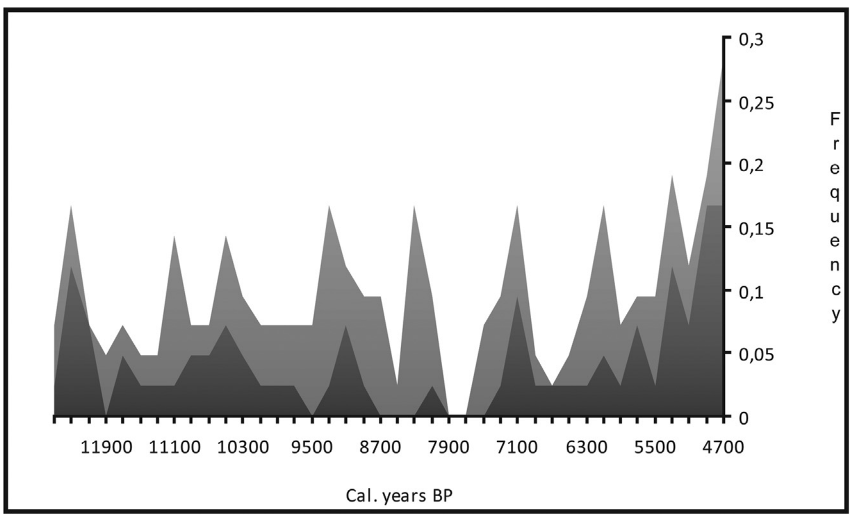

Fig. 5. Comparison between the relative frequencies of calibrated ages for the interval 12,500–4700 BP from the Puna of Argentina, grey area, and North Chile, black area.

7500 cal BP, this series documents the absence of the anthropogenic signal along a tendency towards a sustained increase, even with fluctuations, which is more noticeable as from *ca*. 5000 cal BP. On this time series we conducted the taphonomic correction using the volcanic model of site loss. Again we built the averaged distribution from uncorrected rockshelters and caves frequencies and the corrected distribution of open-air sites frequencies (Fig. 10). Whereas the resulted distribution preserves the main patterns of the rest of time series, it also exposes important differences with the corrected series of dates, particularly in the amplitude of peaks. Hence, the corrected frequency of sites flattens the early Holocene peaks as the one occurring at 12,300 cal BP. This results in a more even distribution of amplitudes of peaks and valleys during the early and mid Holocene. So, the main virtue of this time series is the reduction of oversampling biases in large datasets.

In order to obtain an estimation of the global trend for the whole dataset we smoothed the corrected distribution of series 3 by using the moving average algorithm of Past 2.17 c (Fig. 11). By this procedure the pattern that emerges can be described by a first phase of fluctuating and small growth of the anthropogenic signal, and a second phase beginning around 6300 cal BP of oscillating but sustained growth, more evident at 5000 cal BP. In the not smoothed distribution (Fig. 10), the anthropogenic signal along the first phase accumulates only the 36.64% of the data up to 6300 cal BP, showing a relatively low growth throughout the early and mid Holocene. The second phase from 6300 to 700 cal AP accumulates the 63,36% of the data. We highlight that in this second phase the 22% of the data corresponds to the period 4900–2900 cal BP showing the increase of number of sites during the transition from mid to late Holocene. This coincides with our interpretation of the growth of the anthropogenic signal observed in the other time-series.

Finally the frequency distribution of new sites (series 4) shows a similar pattern in the anthropogenic signal to those discussed so far. All the same, we mention once more that this series measures the generation of new sites in time, and for this reason is qualitatively different from the rest of the time-series. For instance the peaks of the distribution gain greater significance in that they document increases in the rate at which humans occupied new spaces. This is the case of the three peaks shared by Puna of Argentina and North Chile between 12,500–12100, 11,100–10900, and 9100–8700 cal BP documenting an early success in the dispersion of the humans in the highlands (Fig. 12). Similarly, the

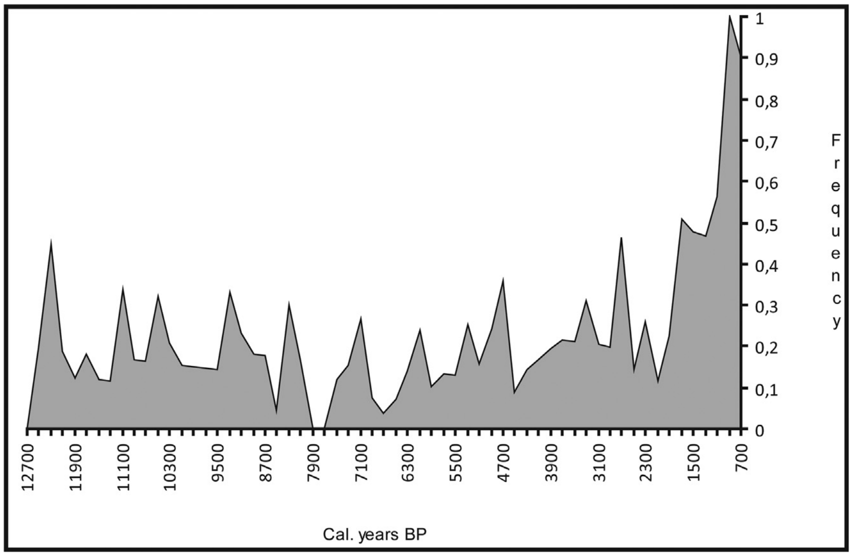

Fig. 6. Correction by the exponential site-loss model of the calibrated ages from the Puna of Argentina and North Chile.

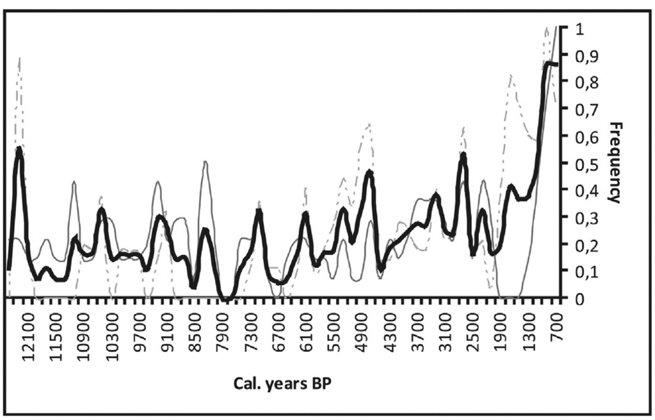

Fig. 7. Correction by the volcanic site-loss model of the calibrated ages from the Puna of Argentina and North Chile. Average (thick black line), open air sites (dotted grey line), rockshelters and caves (thin grey line).

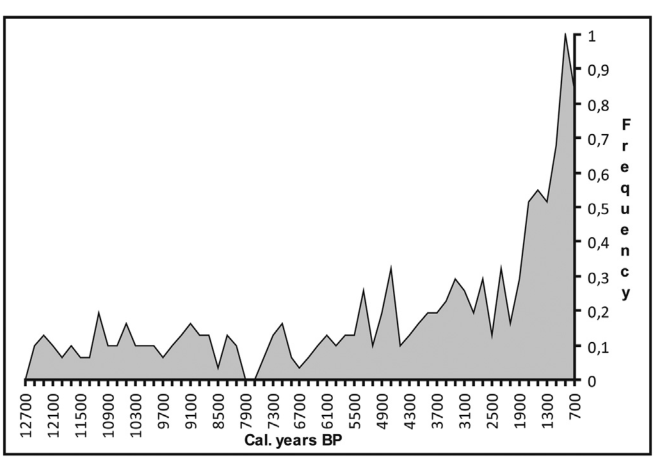

Fig. 8. Distribution of the relative frequencies of sites from the Puna of Argentina and North Chile.

valleys in this distribution record a fall in the generation of new sites and in the broadening of the occupied spaces. In other words, when these values approach zero this does not necessarily imply the abandonment of previously used sites, but that new sites are not added and because of this the rate of human occupation of new spaces remains constant or near constant. The most notable absence of new sites takes place in 8700–7300 cal BP, suggesting a declining or stagnant demography, and the absence of occupation of new spaces in the highlands. In any case differences are recorded on the broader scale throughout the Holocene. The first difference occurs during the early Holocene when from 10,900 to 9100 cal BP, no new sites appear in the Argentine Puna, whereas they do in North Chile (Fig. 13).

The second difference is associated with a greater increase in the generation of new sites in northern Chile as from 5000 cal BP, an increment that, with fluctuations, occurs simultaneously in both regions. This growth in the generation of new sites and the occupation of new spaces remains continuous until late periods, peaking towards *ca*. 1700 BP in North Chile and 900 BP in the Puna of Argentina.

4. Discussion

From the analysis of the discussed series and by considering the exponential and the volcanic taphonomic models of site loss we find congruence in the following:

1) The anthropogenic signal is an oscillating one in the early Holocene, with peaks and valleys. For both areas there are peaks in the anthropogenic signal distribution that, according to the exponential and the volcanic taphonomic models, but especially to judge by the generation of new sites, are very significant. We posit that the peaks appearing simultaneously in both regions in 12,500–8700 cal BP interval document early events of achieved peopling and reproductive success. As we saw, 27% of the data accumulated during the early Holocene. This is equivalent to a 0.0069 annual growth rate which, though low, is enough for any successful population dispersal. This argument gains strength in considering that there are human occupations in the areas of greatest altitude for this period, as documented by the record of Alero Cuevas (4400 masl), Hornillos 2 (4100 masl), and Quebrada Seca 3 (4100 masl) in Puna of Argentina. In this regard our information supports the hypothesis that the peopling of the region co-

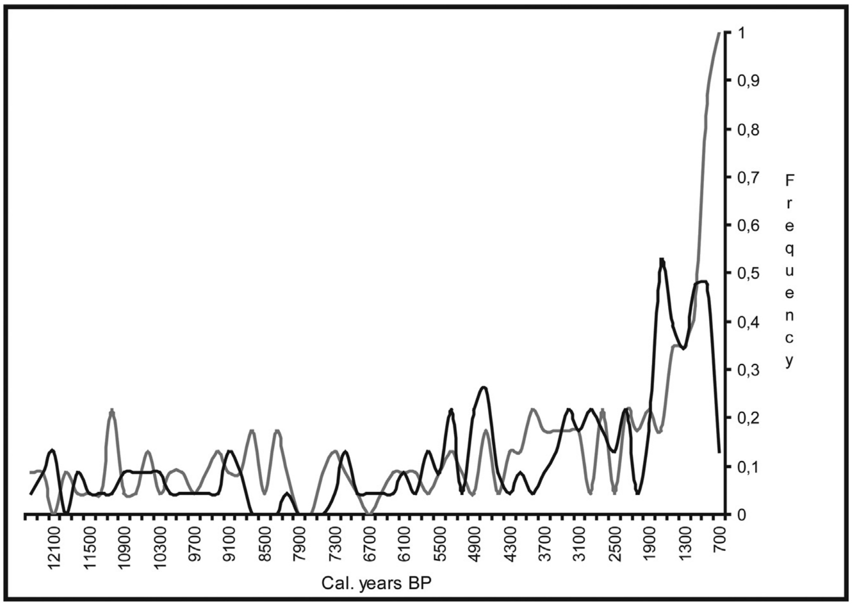

Fig. 9. Comparison of the relative frequencies of sites between the Puna of Argentina, grey line, and North Chile, black line.

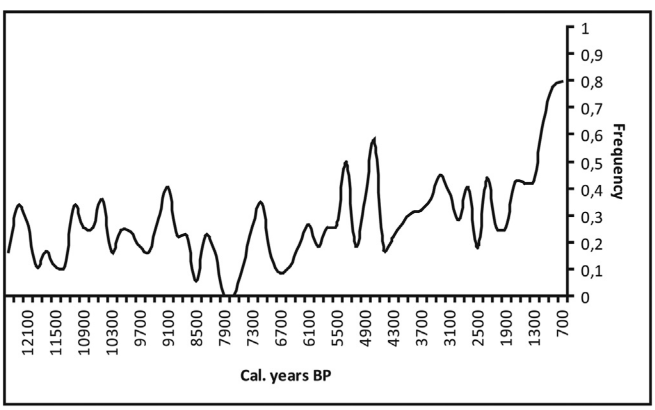

Fig. 10. Correction by the volcanic site-loss model of the relative frequencies of sites from the Puna of Argentina and North Chile (average of open air sites and rockshelters and caves).

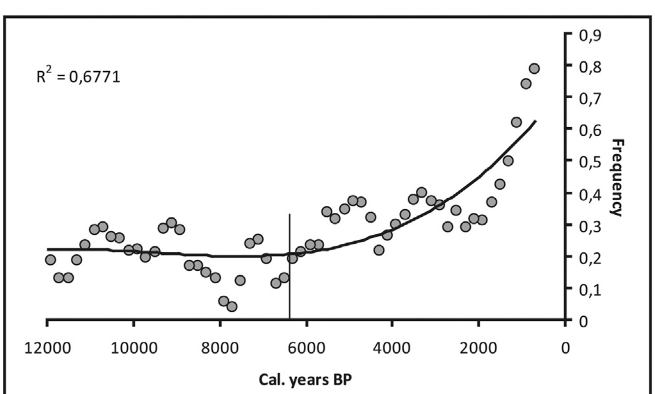

Fig. 11. Smoothed distribution and polynomial trendline of the corrected relative frequencies of sites from the Puna of Argentina and North Chile by the volcanic site-loss model. The vertical line marks the approximate start of the sustained growing.

occurred with the more humid, less fluctuating, and warmer conditions of the Coipasa palaeoclimatic event (12,615–10556 cal BP), which implied a more favourable scenario for the human adaptation to the highlands (Yacobaccio and Morales, 2013).

In contrast the valleys of the distributions document episodes of population retraction. This happens when the summed probabilities, site frequency, and especially the generation of new sites tend to diminish simultaneously. These retractions of the human range make sense in considering a fluctuating phase of a long-term peopling process by small populations. For instance, the absence of new sites in the 11,700–11100 cal BP interval in the Puna of Argentina, and 11,500–11,300 cal BP in the North Chile result explained by this model. Anyway as we have shown, since the early Holocene there is a trend towards the demographic and dispersive success by the first hunter gatherers in the Puna.

2) Towards the mid Holocene there are two events of anthropogenic signal loss. The first spans the *ca.* 7500–7900 cal BP interval for all the analysed series. However, in the Chilean highlands there is a 1400-year period between *ca.* 8700 and 7300 cal BP, in which there is only one dating from *ca.* 8000 cal BP, at the upper Loa, in a context where site generation is null. Instead in the Puna of Argentina the absence of anthropogenic signal spans a 400-year period, from 7500 to 7900 cal BP, with null site generation. In this way our analysis allows geographic disparity to be shown in the loss of anthropogenic signal during the beginning of the mid Holocene. Indeed the Chilean area is the one recording the longest duration of absence of radiocarbon events and generation of new sites. Núñez (1992) suggested an “archaeological silence” that involved the de-occupation of broad areas of the highlands as a response to increasingly desertification conditions during the mid Holocene. Our results suggest that indeed there is an absence of anthropogenic signal during the beginning of the mid Holocene, and a pause in the generation of new sites, which could indicate a demographic decline and de-population of spaces. This pattern, however, was not spatially homogeneous in Puna of Argentina and North Chile.

The second drop documented along the mid Holocene spans the 6900–6300 cal BP interval, when the generation of new sites is drastically reduced. In this interval of 600 years there are three

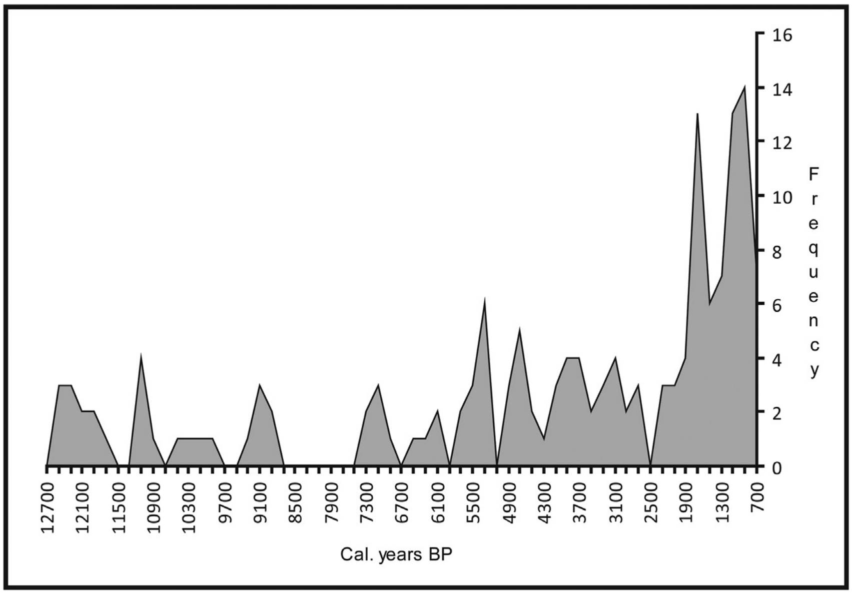

Fig. 12. Frequencies of new sites in the Puna of Argentina and North Chile.

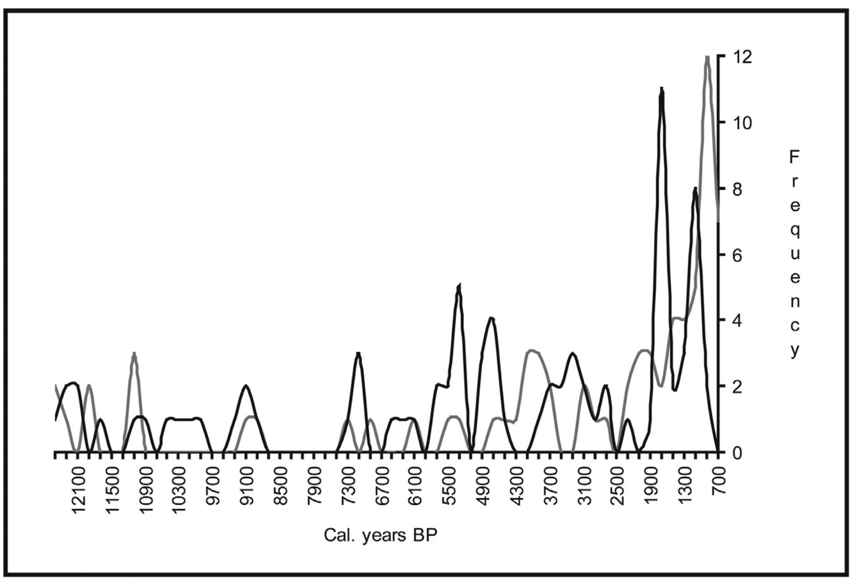

Fig. 13. Comparison of frequencies of new sites between the Puna of Argentina, grey line, and North Chile, black line.

dates in the highlands of Chile, while in the Puna of Argentina there are only two radiocarbon dates. One of them comes from an occupation below 3700 masl located in a present salt-flat environment (Abrigo Pozo Cavado, Puna of Salta). This suggests that the spaces below 4000 masl were also attractive for human use in a context of regional desertification.

In summary, the first part of the mid-Holocene shows the most noticeable fluctuations of the anthropogenic signal and the longest-lasting drops. This supports the hypothesis of the negative impact of desertification on human adaptation. In this regard it can be put forth as a hypothesis that the more arid conditions of the mid Holocene carried out to a decrease in the human occupation of local spaces due to the loss of suitable habitats, especially in the Atacama salt-flat. This is in agreement with the de-occupations of spaces mentioned by Núñez (1992) in this particular area. In the Puna of Argentina, more specifically in the Antofagasta de la Sierra basin (Puna of Catamarca), it was posited that during the events of greater aridity (after 7900 cal BP), processes of reorganization in the use of space and mobility will have been implemented, with the preferential occupation of the less vulnerable environments above 4000 masl (Pintar, 2014). However, instead of reorganization, the abandonment of habitats and the de-population of spaces might have been an adaptive response to aridization. In either case a more intensive control of sampling bias is needed to approach this issue.

3) Towards the end of the mid Holocene the increase of the anthropogenic signal shows a course of sustained though fluctuating growth, which results apparent in *ca*. 5000 cal BP. In fact, the 6300 cal BP–4500 cal BP interval (after the second significant loss of anthropogenic signal) contains just the 17,6% of the data, indicating that the growth rate increased (0,0097) in comparison with the early Holocene (0,0069) and the initial part of the mid Holocene (0.004). This trend to an increase of the anthropogenic signal

coincides in North Chile with sites of clustered architectonic structures (Tulán 52, Puripica 1) and in Argentina with broad surface artifacts distributions and the proliferation of blade technologies (Núñez, 1992; López and Restifo, 2012; Muscio, 2012). There is consensus that in this chronology several important processes took place. For instance the development of the intensification and domestication of camelids, the reduction of residential mobility, and the aggregation of human populations in localized spaces (Yacobaccio, 2001). We suggest that these processes occurred in a scenery of a sustained and fluctuating demographic growth that resulted from the successful human adaptation to the highlands environment, particularly at the ends of the mid Holocene.

As we have shown, an increasing and fluctuating demography is signalled by the growth trend of the dating for both regions, starting around 6300 cal BP and well evident at 5000 cal BP. This pattern does not seem to be explained by the taphonomic loss of the anthropogenic signal. On this basis, we argue that the trend towards a sustained increase of the anthropogenic signal is the signature of the demographic success of hunter-gatherers adaptations to the highlands. Indeed this trend begins early in the Holocene showing the potential of the hunter-gatherer way of life to disperse successfully into extreme environments. Moreover this tendency to a growing demography increases near three millennia before the consolidation of food production in the human economic niche. In this regard, the general pattern suggests a lengthy period of low demography with an acceleration of growth towards the end of the mid Holocene. In particular, the trend towards greater population growth co-occurs with the process of intensification of the use of camelids and space. Besides, the rate of occupations of both regions measured by the generation of new sites suggest a sustained increment towards 5000 cal BP with fluctuations. Anyway we must remark that all time-series show a drop of anthropogenic signal immediately following the first evidence of agricultural practices and more permanent settlements (*ca.* 2500–1700 cal BP).

4) Finally we highlight the greater rhythm of growth of the anthropogenic signal that occurs in the later phases of the archaeological history in both regions, which is more evident as from ca. 1700 cal BP. As we said earlier, this growth of the anthropogenic signal persists even after controlling by the exponential and the volcanic taphonomic models. In this later trend, which starts at 900 cal BP, occurs the 80% of increase in dates compared with the previous 200 years interval. This agrees with the archaeological knowledge which indicates that this period was one of high demography and spatial expansion of human occupations, associated with predominantly herding economies. Still, in later phases of the Holocene the more contrasting variations between the Puna of Argentina and North Chile may be attributed to a lesser number of radiocarbon dates in the Chilean area, with a large number of thermoluminescence dates not included in this analysis.

5. Conclusions

Finally, we highlight two broader issues of current debate in archaeology to which our work contributes. The first is the methodological strategy of using different analytical tools for documenting patterns in the anthropogenic signal of broader regions and for building reliable inferences about past demography.

We emphasize the congruence of the above mentioned patterns resulted of the comparative analysis among the four time-series approached when the unit of analysis are single radiocarbon dates and single sites. However, we conclude that the frequency of sites series is best suited to this end because it strongly ameliorates the biases associated with the over-representation of dates. In this line we found the frequency of new sites series as an important tool for discussing trends in the peopling of a region and for documenting temporal patterns in the use of the space.

In this sense, we think that these two time series can be used in the study the anthropogenic signal of different regions along the world allowing for the comparative analysis at highly inclusive spatial scales. As we have shown when applied to a distribution of sites along time the taphonomic model of Surovell et al. (2009), is the best tool for controlling the biases derived of site loss. While this model is an enormous contribution for controlling taphonomic bias we draw attention to the necessity of building regional models of site loss considering the singularities of the morphogenetic processes of particular geological regions, especially for the arid spaces of the Andean highlands where the action of the erosive agents are intense and dominant.

In another vein, our results contribute to the discussion of important theoretical issues in current global archaeology. From a more general point of view the long-term demographic success of the hunter-gatherers in the highlands exemplifies the flexibility of this mode of subsistence for achieving human adaptation to a wide range of selective environments, including the most extreme ones such as the Andean high-altitude steppes of the puna. Also, the rapid recovering of the anthropogenic signal after the ending of the mid Holocene hyper-arid event shows the resilience of the foraging strategy when confronting severe environmental perturbations. Resilience is a critical aspect of adaptive plasticity that by allowing the demographic recovering after adverse events decreases the risk of extinction. Furthermore, our work shows that the mid to late Holocene transition was a phase of particularly growing demography achieved by high-quality terrestrial resource dependent foragers. This growing demography was the basis for the macro-regional processes of intensification in the use of the space associated to the domestication of the wild camelids in the southern Andes and with other important processes of technological innovation and social evolution (Muscio, 2012). For example, the proliferation of blade technology that started in some regions of the south central Andes during the mid Holocene. In this regard it has been argued that in the processes of intensification and domestication, blade technology allowed a greater efficiency in order to maximize resource yield, in a context of increasing energetic demand (López and Restifo, 2012). This trend towards a greater use of blades in line with demographic increase has been noted in other parts of the world as in the Pre-Pottery Neolithic of the southern Levant, where highly standardized blades made from prepared cores (Naviform cores) are seen as a response to the intensification of food production and to the aggregation of a growing population (Quintero and Wilke, 1995). Also, it was proposed the occurrence of changes towards a greater social complexity among the hunter-gatherers of the puna, explained as part of the more general processes of intensification and domestication in the Andes (Yacobaccio, 2001). The same was documented in other regions of the world. Examples of this include the Chinchorro populations along the northern coast of Chile (Arriaza, 1995), the Natufians in the Levantine corridor of the Near East (Bar-Yosef, 1986), the Jomon of Japan (Imamura, 1996) and the Ertebølle of circum-Baltic Europe (Zvelebil, 1996). In this way, at the global scale there are many well documented examples of domestication processes preceded by economic intensification and population growth. Our findings adds to the more general claim that population growth is the prime mover of these processes. At this point we must remark that population growth is always the selective result of a successful economic niche in a particular environment.

On the other hand, the long term success of the hunter gatherers and herders in the puna contrasts with the demographic volatility associated with the earliest evidences of small-scale agriculture. In fact, the anthropogenic signal rises and falls immediately after the first evidences of agricultural practices in the region, around

2500 cal years BP. We have to wait until the 1700 cal years BP for a rebound towards a sustained trend of population growth associated with the development of new productive technologies and with a predominant pastoral economy. A similar phenomenon was documented during the first adoption of agriculture across Europe (Shennan et al., 2013). While the causes of these cycles of rise and fall remain speculative, we propose that boom and bust demographic cycles might result from Malthusian catastrophes occurring in high-cost economic niches, or alternatively from changing environmental conditions affecting small-scale agriculture in poor quality habitats. Anyway the discussion of this issue demands to be careful with the effects of sampling bias.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2015.11.007.

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