MODELING LONG-TERM HUMAN POPULATION DYNAMICS USING KERNEL DENSITY ANALYSIS OF ^{14}C DATA IN THE ATACAMA DESERT (18º–21ºS)

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ABSTRACT. Food production is one of the most significant achievements in Andean history. The domestication of plants and animals presented an enormous challenge, relating to changing technologies, settlement patterns, and social organization. This paper aims to assess Atacama Desert population dynamics and their relationship to the domestication of plants and animals through chronological modeling using kernel density estimation on radiocarbon (^{14}C) dates, assuming that a higher ^{14}C probability density is related to more intense human occupation. The analysis is based on a ^{14}C dataset comprising 1003 ^{14}C dates (between 11,000 and 150 BP) from 243 archaeological sites in the Arica and Tarapacá regions of northern Chile, collected from published data. We observed two population-dynamics inflection points for these regions. First, starting at ca. 3000 BP, constant population growth occurred, which was related to horticulture in the Arica region and to agriculture in the Tarapacá region. Second, between ca. 1000 and 400 BP, a general population rise occurred due to the consolidation of intensive agriculture in the lowlands and *precordillera* altitudinal belts in both regions and the integration of the coast and the *altiplano* into macro-regional population dynamics.

KEYWORDS: Andes, farming, food production, population changes, radiocarbon data modeling.

INTRODUCTION

Synthesizing chronometric data on a regional scale for comparative and global studies is methodologically challenging. The adoption of an aggregation framework in chronological modeling has improved the knowledge of the Andean past (Contreras 2022), notably in regard to the relationship between humans and paleoecology (Williams et al. 2008; Marquet et al. 2012; Maldonado and Santoro 2016) and to chronologies referring to specific periods (Korpisaari et al. 2014; Barberena et al. 2017; Pestle et al. 2021) or large-scale processes (Gayó et al. 2015; Goldberg et al. 2016). These methods of chronological modeling have made it possible to analyze the changing population dynamics of local chronologies, previously described statically and homogeneously.

In archaeology, radiocarbon (^{14}C) dates have been used as an indirect proxy for assessing demographic patterns over time (Rick 1987; Williams 2012; Shennan et al. 2013; Crema 2022). This methodology is not without relevant criticism (Contreras and Meadows 2014; Attenbrow and Hiscock 2015; Freeman et al. 2018; Carleton 2021; Carleton and Groucutt 2021; Timpson et al. 2021), resulting in skepticism about its reliability. Criticism is based on methodological issues regarding the representativeness of data sampling, the potential "noise" or spurious tendencies generated by calibration curves, and the reliability of paleodemographic interpretations. Introduced in 2017 by Bronk Ramsey, kernel density estimation (KDE) of ^{14}C data is a mathematical, non-parametric method of data integration that, in part, overcomes some of the weaknesses of the more traditional summed probabilities (SPD) approach, specifically those linked to the calibration process (Bronk Ramsey 2017). This method limits the artifacts generated by the calibration irregularities and helps to distinguish artificial fluctuations by limiting the sharpest peaks

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and troughs through smoother oscillations, a process that is also not without criticism for its use of fairly aggressive moving averages (Capuzzo et al. 2020; Carleton and Groucutt 2021; Crema and Bevan 2021). Nevertheless, it is important to note that some sampling biases, such as overdated periods or geographic regions, are still present in KDE models.

Inferring past population trends and dynamics is more complex than analyzing a mere summary of a large ^{14}C dataset (Pardo-Gordó and Carvalho 2020; Crema and Bevan 2021). Such analyses may be biased by taphonomic factors (Surovell et al. 2009), archaeological research priorities, ^{14}C method uncertainties, and calibration curves, among others (Gayó et al. 2015; Williams 2012; Crema et al. 2017; Crema 2022). Chronological modeling is an excellent tool for comparative studies, since it can show general trends of human occupation according to different spatial units, such as sites, regions, or altitudinal belts.

The introduction of plant and animal food production is one of the most important achievements in Andean history, and it profoundly impacted the mutual relationships among plants, animals, and humans (Zeder 2015). In the Atacama Desert, plants were domesticated starting in the Late Holocene, in stepwise fashion, following multilinear trajectories (Ugalde et al. 2021), and in the *circumpuna*, Andean camelids were domesticated synchronously (Cartajena et al. 2007). The transition from foragers to farmers/herders is characterized by complex and continuous interaction among humans, animals, and plants, with different degrees of intervention in plants' and animals' lifecycles, which can be evaluated through chronological models by analyzing population dynamics over time.

This paper describes population dynamics in the Atacama Desert and their relationship with the domestication of plants and animals through chronological modeling based on the ^{14}C record. First, we studied a large database of 1003 dates, from 11,000 to 150 BP, to analyze whether the introduction of food production economy in any way impacted on human survival or reproduction—and hence demography. Then we studied the same impact at a higher resolution on a subset of this long time-series, the interval from 4000 to 150 BP, when relationships between population dynamics and the economic transformation caused by the introduction of domesticated plants and animals in the different regions and through altitudinal gradient seem to be clearer.

SPATIO-TEMPORAL SCOPE

Regional Settings

The northern Atacama Desert (Latorre et al. 2005) encompasses 59,200 km^2 of the South Central Andes in northern Chile, including two ecologically and culturally differentiated regions. The northern of the two is the Arica region, formed by the valleys of five rivers that flow into the Pacific Ocean, and the southern of the two is the Tarapacá region, formed of a system of endorheic streams that do not reach the sea, between the Tana and Loa rivers (Figure 1). Within the Atacama Desert's contrasting landscapes, made up of hyper-arid desert plains, productive valleys, and fertile ravines, human settlements are usually close to water sources.

Forming part of the western slope of the Andes, the study area is composed of four altitudinal belts, each presenting a different ecology and human settlement pattern. The coast (<130 m asl)

Figure 1   Map showing the regional boundaries and altitudinal belts of the northern Atacama Desert and locations of the sites that yielded the dates included in our ^{14}C dataset.

constitutes a source of constantly available marine resources, which was crucial in favoring relatively stable pre-colonial human occupation. The lowlands (130–1700 m asl), including the Cordillera de la Costa, the Occidental Valleys, and the Pampa del Tamarugal, coincide with the hyper-arid desert core, but, at the same time, have variable agricultural potential depending on the availability of water, including very productive spaces in oases on valleys or ravines. Thanks to its rainy season, the *precordillera* (1700–3700 m asl) has agricultural and herding potential in highland locations. Finally, the *altiplano* (>3700 m asl) is a high-Andean grassland and shrubland, characterized by hunting and herding resources.

Chronology of the Northern Atacama Desert

The First Settlement and Archaic periods (covering the Late Pleistocene to Late Holocene, ~13,000–3000 BP) were characterized by the presence of hunter-gatherer groups. During the Late Archaic period (ca. 6000 BP), the first domestic plants (cotton, squash, and Andean tubers) were adopted within a system of low-level food production. Subsequently, quinoa, maize, beans, and chili pepper were introduced, in different intensities (Ugalde et al. 2021).

During the Formative period (3000–1000 BP), a gradual sedentarization of lifestyle, new social practices, and new economic structures emerged, along with horticultural production that combined a wide range of crops and wild plants (Núñez and Santoro 2011; Uribe et al. 2020), and with more consolidated agriculture (Rivera 2002), shaping a "Green Revolution" in the desert (Ugalde et al. 2021).

During the Middle period (1050–850 BP), in the Arica region, Late Tiwanaku groups settled in the Moquegua valleys, establishing interactions and influencing local Formative groups (Korpisaari et al. 2014; Muñoz 2019).

Late prehistory was a period of significant demographic growth (Santoro et al. 2017). During the Late Intermediate period (1000–500 BP), there was an expansion of the region used for settlements, especially in the lowlands and the *precordillera* (Muñoz et al. 2016), and a remarkable increase in agrohydraulic infrastructure. Then, during the Late period (500–400 BP), local groups were incorporated into the Inca Empire, which exerted differentiated control strategies between the lowlands and the highlands and between the Arica and Tarapacá regions (Santoro and Uribe 2018).

MATERIALS AND METHODS

Dataset Structure

The Northern Atacama Radiocarbon Dataset was built based on archaeological ^{14}C dates published from 1963 until January 2021 (Supplementary Materials 1 and 2). It comprises 1003 dates, 80% more than the last dataset compiled for this study area (n=565) (Gayó et al. 2015). ^{14}C dates (published in journals, proceedings, theses, and some technical reports) were considered only when necessary data—^{14}C age, lab error, material, and provenance—were conveniently reported. Contextual information has also been taken into account, including the precise location of the sample within the site (archaeological spatial unit, subunit) and the predominant social function of the site (i.e., domestic, funerary, agricultural). The result is an open-access dataset available in the free domain (Mendez-Quiros 2023).

The collected ^{14}C dates relate to 243 archaeological sites, 137 in the Arica region and 106 in the Tarapacá region. More than 60% of these sites have multiple dates (n>1). The distribution of
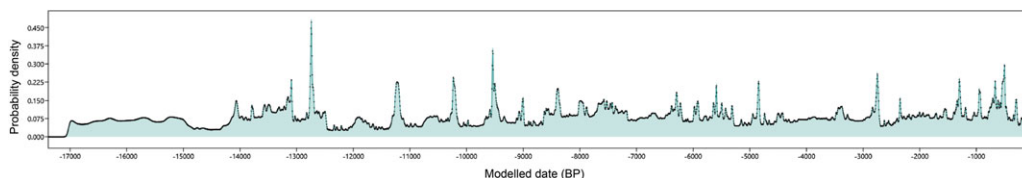
Figure 2 Aggregated probability distribution of simulated data (one date per 5-year interval) from 14,000 to 0 BP to test the effect of the calibration curve shape using the SHCal20 curve. Plotted using PAST (Hammer et al. 2001).

the dates is spatially uneven, with the highest frequency of dated archaeological contexts in the lowlands (54%) and the coast (27%). The analyzed samples come mainly from domestic (n_{dates}=582) and funerary contexts (n_{dates}=339), most of which are in the Azapa basin (n_{dates}=207). The most frequent material is vegetal (68%)—including wood/charcoal (44%) and wild plant (9%)—followed by human remains (15%), textile (9%), and animal bone (8%). Thanks to the high number of samples processed using AMS dating techniques, the majority of the estimates (n=594, 60%) have a low lab error (less than ±50). Lab errors between ±50 and ±100 uncorrected years are relatively frequent in the database (n=249, 25%), whereas high lab errors (more than ±100) are relatively scarce (n=158, 15%).

Chronometric Protocol and Bias Control

As not all chronometric data have the same reliability, a filtering protocol was applied to select the most reliable estimates (61% of the complete database). To avoid the potential of marine reservoir effect, only terrestrial samples were included (excepting gastropods), and marine fauna samples (n_{dates}=27; 3% of the complete database) were excluded. Although the percentage of marine foods in human diet is unknown, we have also excluded samples of coastal human remains (n_{dates}=74; 7% of the original total database) to prevent marine reservoir bias. We excluded another 158 samples (16%) because the material submitted for dating was unreported or the archaeological context was unreliable, as reported in the original publication. We also excluded samples with a large laboratory error (more than ±100) (n_{dates}=121; 12% of the total database), because such large errors are in most cases the consequence of poorly preserved analyzed samples, with a very small proportion of organic material.

Throughout, we have given priority to short-lived samples, which are generally abundant in the desert due to the excellent preservation. However, in our database, there are still a relatively large number of long-lived samples, and therefore the "old-wood" effect is still a concern, mainly among the conventional ^{14}C dates. We have considered this potential source of bias when interpreting observed peaks in the Summed and KDE probability distributions, by statistically weighting accumulated probability to the frequency of sampled material and the frequency of conventional dating in this part of the dataset.

We have taken into account the bias introduced by the variations in the accuracy of calibration at different parts of the SHCal20 curve (Hogg et al. 2020). We have modeled a Sum of Probabilities of 3190 simulated ^{14}C estimates with the same lab error (20 years), from 14,000 to 0 BP, to build the accumulated probability distribution on the assumption of a single date every 5 years using OxCal (Figure 2). Given that the number of dates is uniform within each time interval, a straight line would be expected, and departures from this uniform expectation should be consequences of irregularities in the calibration curve

(Capuzzo et al. 2018). This simulation allows us to conclude that there are time intervals when rapid variations in atmospheric[14]C content may have biased date estimations and the accumulated probability. Particularly problematic sections seem to be 12,750 BP, 11,250 BP, 10,100 BP, 9600 BP, 8300 BP, 7500 BP, 6300 BP, 4900 BP, 2700 BP, 1200 BP, 800 BP, 550 BP, and 0 BP.

Another source of bias is sampling strategies overrepresenting data from sites or archaeological units that have been dated with more intensity (see Table 1 and Supplementary Material 3) or from areas with a denser archaeological record (Supplementary Material 4). We are aware that this potential bias is minimized by increasing the spatial scale and size of the global dataset (Barberena et al. 2017). But this strategy is not enough to avoid the risk of spurious peaks in the global time-series. We have followed a strict approach to minimize this overrepresentation. Date samples from the same site, archaeological unit, and temporal interval, were statistically checked for apparent contemporaneity (Ward and Wilson 1978; Ramsey 2009), and in positive cases, we have statistically combined dates with the same provenience and time (Combine) (Supplementary Material 5).

Only after checking all those conditions can we say that a higher frequency of ^{14}C events is related to more intense human occupation (Freeman et al. 2018). In the remainder of this paper, we discuss when this hypothesis may be at risk.

To evaluate the relationship between population dynamics and the introduction of farming economies, two timescales and different spatial units were analyzed in OxCal, using KDE_Model function and SHCal20 curve (Hogg et al. 2020) for calibrating (Table 1). First, were analyzed the entire time-series (11,000–150 BP) on a regional basis (northern Atacama Desert, Arica, and Tarapacá regions) to compare different regional historical trajectories. Second, we used a subset of the time-series (4000–150 BP) to compare demographic trends between differentiated altitudinal belts (coast, lowland, *precordillera*, and *altiplano*). This subset of the global time range has higher resolution (0.15 dates/year) than the complete one.

RESULTS

11,000–150 BP Regional Modeling

On a regional scale, the complete KDE-averaged chronological model (Figure 3) indicates a very low density of human occupation from the first human presence, in the Late Pleistocene (12,800 cal BP) until 3000 cal BP. The bumps and peaks in this initial part of the resulting distribution cannot be interpreted as population interruptions, because they cannot be differentiated from the irregularities in SHCal20 curve, which are mostly attributed to variations at the atmospheric level in the proportion of [14]C (Figure 2). Some earlier studies have suggested a possible population deflation around the mid-Holocene (Barberena et al. 2017), which locally manifested some centuries before, at 8500 cal BP. Although our results show some interruptions in the calibrated time-series, it is not possible to distinguish population trends from irregularities in the calibration curve, given the low estimated density of population at that time.

The accumulated ^{14}C signal does not show a significant change until 3000 cal BP, when a constant increase in the relative frequency of dated archaeological contexts begins. The growth from 3000 cal BP onwards clearly exceeds the irregularity of the calibration curve

Table 1   Spatial distribution of dates in the ^{14}C dataset analyzed: [14]C dates and ^{14}C events. Regions: northern Atacama Desert (NAD), Arica, and Tarapacá.

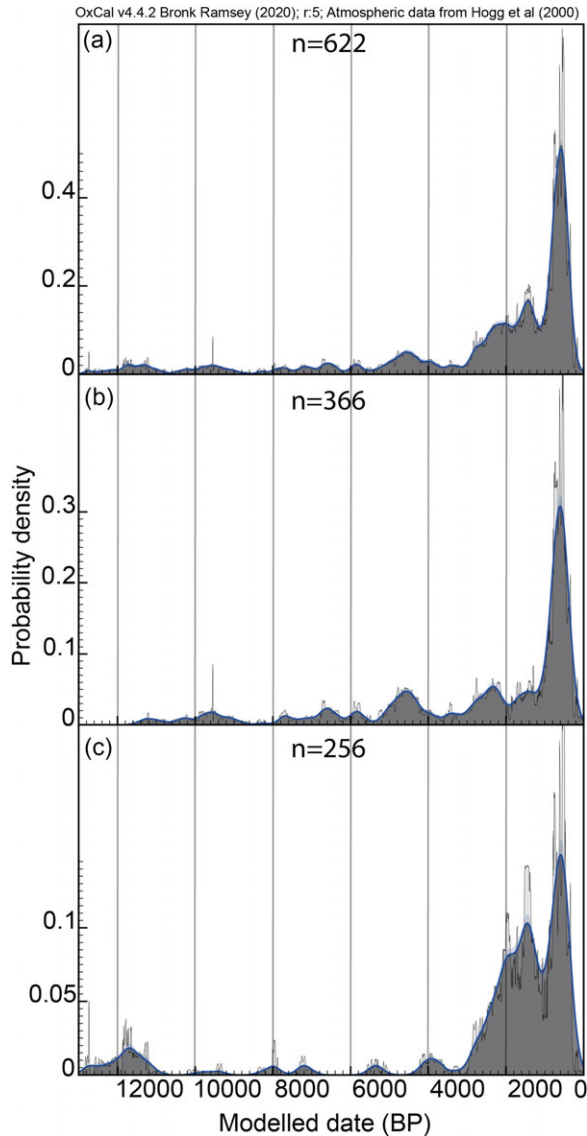| Time-series	Altitudinal belt	All ^{14}C dates			Analyzed ^{14}C dates			Analyzed ^{14}C events		
		NAD	Arica	Tarapaca	NAD	Arica	Tarapaca	NAD	Arica	Tarapaca
11,000 BP	All	1003	610	393	744	425	319	622	366	256
4000 BP	Coast	156	120	36	67	49	18	62	45	17
	Lowland	456	213	243	407	195	212	355	172	183
	Precordillera	75	57	18	69	53	16	68	53	15
	Altiplano	28	13	15	25	12	13	20	9	11

Figure 3   Kernel density estimation (KDE) models for 11,000 BP ^{14}C time-series in the northern Atacama Desert. (a) general dynamics, geographically undifferentiated; general dynamics, geographically differentiated: (b) Arica region, (c) Tarapacá region. Light gray: summed probability distribution; dark gray distribution: KDE.

(Figure 2) and can be considered unaffected by variations in atmospheric ^{14}C. This change suggests a notable turning point in population dynamics, a long period of constant growth, interrupted by an apparent fall-off between 1200 and 800 cal BP, which coincides with a period of rapid change in atmospheric ^{14}C. The highest density, here termed the Late Pre-Hispanic peak, was reached at 1000 and 400 cal BP.

Our analysis of the time-series within regional subsets shows that, although there is a common trend, there are also some differences. The Tarapacá region seems to have been populated
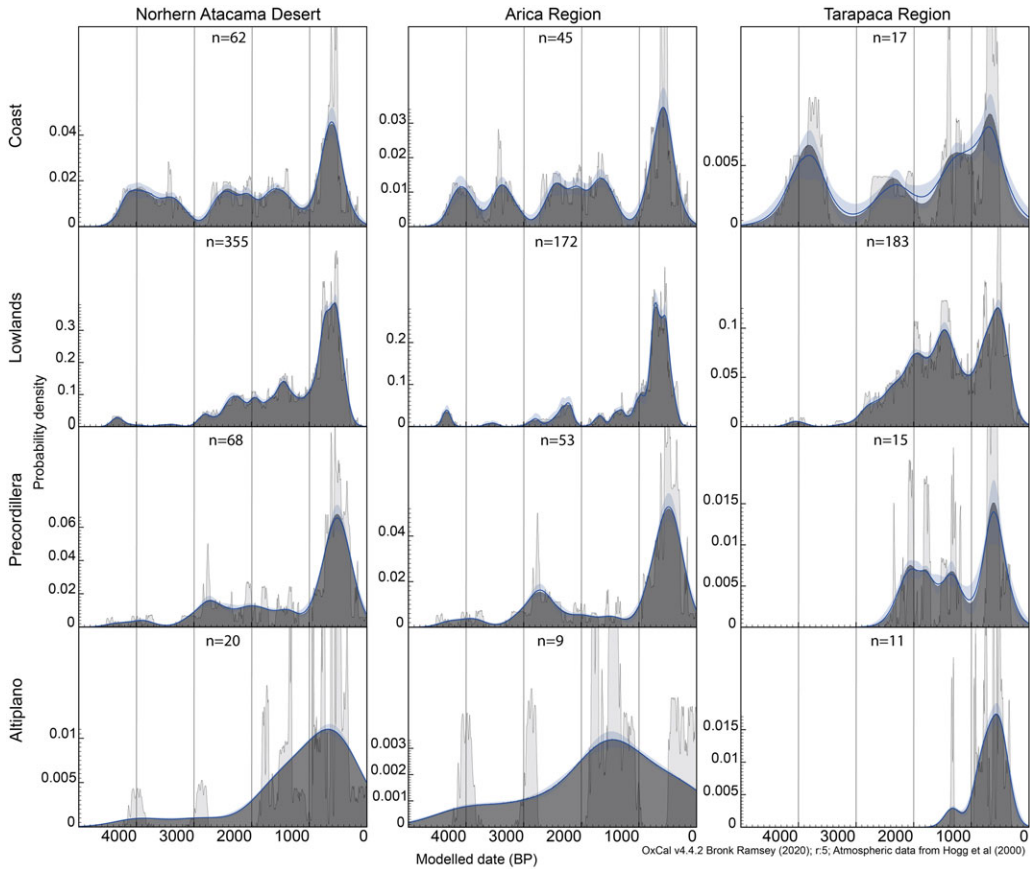
Figure 4   Kernel density estimation (KDE) models for the 4000 BP ^{14}C time-series subsets for different regions and altitudinal belts. Light gray distribution: SPD; dark gray distribution: KDE.

earliest, at 12,800–11,000 cal BP. The timing of the long period of sparse occupation by mobile human groups seems to be very similar in both regions (11,000–3000 cal BP). We cannot exclude the possibility of occasional moments of local deflation or even depopulation throughout the Archaic period, although these moments cannot be statistically tested because of their correlation at some points in the global distribution with the irregularities and biases caused by the calibration curve. In both regions, Arica and Tarapacá, the main concentration of dated archaeological contexts is observed after 3000 cal BP, suggesting the end of sparse occupation by mobile hunter-gatherers and the beginning of a more sedentary lifestyle, with a farming economy that still strongly relied on the local wild resources. The demographic success of this new economy would explain the increasing number of dated contexts between 3000 and 300 cal BP. The dated contexts reach their highest density between 800 and 500 cal BP, during the Late Pre-Hispanic peak.

4000–150 BP Altitudinal Belt Modeling

It should be taken into account that 3000 cal BP seems to be a turning point in the Southern Hemisphere Calibration Curve and that irregularities in the KDE distribution may have been

affected by the resulting shape of the calibration curve. However, from 2000 cal BP onwards, the increasing ^{14}C signal clearly exceeds possible effects of the calibration curve and the exponential increase in standard taphonomic loss (Surovell et al. 2009; Capuzzo et al. 2018). Moreover, the apparent fall-off around 1000 cal BP also coincides with irregularities in the calibration curve. We cannot exclude the possibility that the apparent climax after 900 cal BP is a consequence of the joint contribution of lesser degrees of taphonomic loss in more recent stratigraphic layers and rapid variations in atmospheric ^{14}C related to the Medieval Climate Anomaly (Hughes and Diaz 1994; Lüning et al. 2019).

The coast seems to have had higher occupation density than any other altitudinal belt during the Late Archaic, between 4400 and 3000 cal BP (Figure 4). Despite having the smallest territorial extent, it holds a greater population of fisher-foragers along the coastline. Population growth beyond the uniform assumption is statistically relevant after 2800 cal BP. In any case, it is possible to argue for minor variation between the two regions, with an earlier start of the Late Pre-Hispanic peak in the Tarapacá region, where it is expressed more mildly than in the others altitudinal belts.

In the lowlands, hunter-gatherer occupation also seems to have been very low before 3000 cal BP. The transition to a trend of population growth occurs rather suddenly and very late in the Arica region, and more gradually and earlier in the Tarapacá region, where population would have begun to grow synchronously with that of the coast from 3000 cal BP.

The *precordillera* shows a similar pattern, apparently in sync with the lowlands, with a very small and sparse hunter-gatherer population before 3300 cal BP and a sudden growth from 1000 cal BP onwards. In the Arica region, the ^{14}C signal evidences a low, more constant, and more recent occupation. In contrast, the human occupation in the Tarapacá region starts in the Formative period, from 2300 cal BP onwards.

The number of dated archaeological contexts in the *altiplano* is not sufficient to come to relevant conclusions.

DISCUSSION

Human occupation in the northern Atacama Desert extends from 12,800 cal BP to the present, following a complex, non-linear, and non-monotonic sequence that includes some apparent discontinuities. Our analysis of chronological models of different time intervals and spatial units (regions and altitudinal belts) suggests variations in population dynamics at those scales.

The First Settlement and Archaic periods (Late Pleistocene and the Early and mid-Holocene) were characterized by a small population, mobile and unevenly distributed in space. The low estimated density of human occupation during those times prevents us from testing whether discontinuities in the time-series may be related to paleoenvironmental changes (Williams et al. 2008; Barberena et al. 2017; Riris and Arroyo-Kalin 2019). In any case, the irregularities in the calibration curve, resulting from rapid variations in atmospheric ^{14}C, suggest the impact of climatic change.

The Archaic period population reaches its highest density between 5300 and 3600 cal BP, which coincides with the first evidence for the domestication of plants among foragers reported for the coast and the valleys, although the addition of these plants did not majorly alter the consumption patterns of these populations (García et al. 2020). The gradual population

growth from 3000 cal BP onwards, during the forager–farmer transition (Late Archaic–Early Formative), is consistent with the hypothesis of locally based cultural change (Muñoz et al. 2016; Santoro et al. 2017). In that context, it can be suggested that the coast was home to a more stable population, which probably triggered food production, and which led the population to expand into the lowlands to find better conditions for cultivation (Muñoz and Chacama 2012).

The archaeological record indicates a remarkable increase in the number of domesticated plants and their ubiquity related to horticulture production in the Arica region (Núñez and Santoro 2011) and to agrohydraulic features in the Tarapacá region since the Early Formative period (3000–2000 cal BP), because of a Green Revolution (Ugalde et al. 2021). However, the intense use and consumption of wild species continued to be a fundamental component of the staple economy (García et al. 2014).

Population increases from 3000 cal BP onwards in the northern Atacama Desert have been previously pointed out (Williams et al. 2008; Gayó et al. 2015). Our investigation suggests that this process of population increase was neither regular nor evenly distributed in time and space. On the one hand, in the Arica region, the initial increase seems to be attenuated, slightly more intense in the lowlands, associated mainly with cemeteries and ceremonial sites in the Azapa valley, shell middens on the coast, and shelters in the *precordillera*. During the Late Formative period (2000–1100 cal BP), human occupation was noticeably concentrated in the Azapa lowlands. In contrast, in the Tarapacá region, the population density dramatically increased after a very sporadic occupation during most of the Archaic period. Starting in 3000 cal BP, during the Early Formative period, the development of bigger settlements, such as villages and cemeteries, in the lowlands resulted in the first peak of events, between 2100 and 1900 cal BP. This continuous growth persisted through the Late Formative period and led to a demographic peak between 1600 and 1200 cal BP. Our data do not support the supposed demographic collapse during the Formative period suggested by Gayó et al. (2015:12).

During the Middle period (1100–900 cal BP), the Arica region presents the start of a striking population increase, especially in the lowlands, coinciding with the start of the Late Pre-Hispanic peak, which contrasts with the apparent fall-off that is observed on the coast and in the *precordillera,* which may suggest an eventual population displacement toward the valleys.

In both regions, population estimates reach their maximum size between 800 and 500 cal BP, during the Late Pre-Hispanic peak, which appears to be a macro-regional process of population growth during the Late Intermediate period. However, the beginning of this process of population growth (ca. 1000 cal BP), as well as its rate of growth, may have varied among altitudinal belts and regions. Again, our data do not support a hypothesized deflation of the pre-colonial population (cf. Gayó et al. 2015; Figure 2). This peak of population is most probably the consequence of agricultural development after the introduction of fertilizers (Santana-Sagredo et al. 2021), in addition to the displacement of *altiplano* populations toward the *precordillera* and the lowlands during this period. This phenomenon acted as a catalyst for change among farming and herding groups because of its positive effect on food production, as described in colonial documents (Cieza [1553] 1932; Vazquez [1630] 1948). Additionally, herding activities took place in the *altiplano*,

precordillera, and lowlands, usually in conjunction with farming activities, which played an important role as a source of fodder.

The Late period dynamics are very difficult to understand using our data, because the extreme of the time-series is affected by a lack of samples from the early and later colonial periods. However, based on our data, we can suggest that the demographic trend that reached its peak during this period subsequently stabilized at that peak level. The minor increase in the population estimate for the *precordillera* of the Arica region during that time may be related to the arrival of the Inca and their agropastoral state control.

CONCLUSION

The compilation of the Northern Atacama Desert Radiocarbon Dataset is a substantive contribution to the evaluation of pre-Hispanic population dynamics in the South Central Andes. In this work we evaluate the general trends of population dynamics in relation to food production, seeking to open future interpretative lines.

Our study suggests two relevant inflections in the accumulated probability distribution of dated archaeological contexts in the northern Atacama Desert. The first begins at 3000 cal BP, coinciding with the adoption of food production (Santoro et al. 2017). The relatively lower intensity of human occupation in the Arica region and the region's later population growth could relate to horticultural social groups, who begin to continuously occupy the region thanks to the vegetal resources of the valley springs (Muñoz et al. 2016). Our data suggest a more intense occupation of the Tarapacá region, related to earlier agricultural development, linked with irrigation and crop field features mainly in the lowlands (Segura et al. 2021). There is a delay of approximately 2000 years in the change in estimated demographic trends in the Arica region, probably due to the difference in food production strategies, which involved an earlier and more intensive agricultural development in the Tarapacá region and a later and less intensive horticultural production in the Arica region. Beyond trivial geographical adaptations, we consider that the difference should be explained in terms of the different economic strategies and different organization of production leading to diverse local experiences, rather than in terms of a totalizing and uniform change, especially during the Formative period.

Our data also show that a generalized, abrupt population peak occurred after 1000 cal BP, here termed the Late Pre-Hispanic peak, when the different historical-demographic trends in the two regions converged. This convergence, characterized by high-intensity occupation, seems to be related to a new political and economic context, when farming agriculture became consolidated and economic strategies evolved toward agricultural and livestock intensification, especially in the lowlands and *precordillera*. Archaeological and historical evidence for population migration from the *altiplano* during the second half of the Late Intermediate period is also relevant to understanding our population estimates. Despite the absence of the development of agriculture, the coast and the *altiplano* also reached maximum population dynamics during the Late Pre-Hispanic peak, due to the establishment of very fluid relationships between the different altitudinal belts. Populational growth in areas unsuitable for agriculture can be explained as the consequence of extensive and intense interaction networks that articulated social space. Unfortunately, our data from the *altiplano* do not allow us to go further in testing such hypotheses.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2023.27

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