Research

Social adaptive responses to a harsh and unpredictable environment: insights from a pre-Hispanic andean society

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ABSTRACT. The scarcity or unpredictability of natural resources is a threat to cooperation within human societies. Exacerbated competition between individuals could affect social cohesion and collective action, generate conflicts over natural resources, and compromise their sustainable use. Yet, our in-depth archaeological study of the arid Andean highlands of Bolivia reveals the sustainable development of a complex agrarian society in a harsh environment marked, moreover, by a prolonged climatic degradation from the 13th to the 15th centuries. The 49 community settlements studied comprised independent family households that managed their own economic resources. A detailed study of the granary and housing structures of 549 of these households provided a strong quantitative data set for an analysis of Gini coefficients for grain storage capacity and housing area. This agro-pastoral society flourished with neither notable inequalities of wealth between villagers nor apparent long-lasting conflicts between villages. By sharing local knowledge, labor, and natural resources, this society succeeded both in limiting power and wealth concentration, and in sustainably producing food surpluses to be exchanged with neighboring populations. These results indicate a high degree of social cohesion and low levels of social and wealth inequality, similar to other well-established horticultural and agricultural societies around the world. We propose a conceptual model of low inequality in agrarian societies subject to extreme or unstable environments, where the sharing of knowledge, resources, and labor are the adaptive social responses to cope with the uncertainty in natural resources. The sustainability of the society is then guaranteed by a balance between collective action and family-based social organization.

Key Words: *Andean highlands; archaeology; food storage; Gini indices; settlement infrastructure; social inequality; sustainability*

INTRODUCTION

Models of collective action have received increased attention in studies of the political economic strategies of past societies as potential alternatives to hierarchical rule (Blanton 2010, DeMarrais and Earle 2017, Stanish 2017). The archaeology of everyday life provides ever more evidence of premodern polities that were structured by cooperative institutions, revealing the circumstances, cultural traits, and rationales that fostered processes of collective action. Of particular importance are the multiple scales at which collective agency develops, from the household and the community, to the regional society (Rockenbauch and Sakdapolrak 2017). At each scale, collective action generates different practices and institutions for different purposes. These typically include food production and storage at the household level, communal norms for access to natural resources at the territorial level, and trading routes or defense against enemies at the regional or state level. Group size and decision-making procedures within each scale determine the ways that individuals and groups cooperate toward common interests (Mattison et al. 2016, DeMarrais and Earle 2017). In ancient societies without written language, these essential characteristics of social organization can be revealed by an analysis of archaeological settlements and agricultural infrastructures, whose distribution and spatial dimensions make it possible to deduce the degree of social differentiation.

Although current research brings many insights into the social and political drivers underlying collective action in past societies, little is known about its relevance as an adaptive strategy for their sustainability when exposed to extreme or rapidly changing environments. These harsh conditions can threaten collective action and sustainability because they exacerbate competition for

resources, leading to more or less open conflicts that challenge social cooperation, reciprocity, and cohesion. In fact, some societies have become vulnerable and collapsed because of such environmental pressures (Douglas et al. 2015, Kennett and Marwan 2015), but many others have survived and even flourished durably in deserts, high mountains, or through periods of prolonged climate anomalies (Spielmann et al. 2011, Balbo et al. 2016, Cruz et al. 2017, Gregorio de Souza et al. 2019). For fairly stable environments, Mattison et al. (2016) elaborate on an evolutionary model predicting persistent wealth inequality in small-scale societies. Yet, for harsher environments, collective action and reduced social inequalities appear crucial for the equitable and sustainable access to natural resources in small-scale communities (Lyle and Smith 2014, Paul et al. 2016).

Apart from the socioeconomic aspects, human settlement strategies are also charged with symbolic and religious values attached to landscapes, especially those related to ancient mountain cults (Singh 2006, Contreras 2010, Sarmiento et al. 2017, Cruz and Joffre 2020). Though ecological factors should not be used to ignore these social and cultural components of any livelihood strategy, we argue that for premodern societies in harsh or rapidly changing environments, the prevalence of natural limitations and hazards in daily life justifies a focus on environmental factors. Here again, archaeological hindsight can help evaluate the social or technical solutions implemented by resilient past societies.

In the highlands of southern Bolivia, an extensive pre-Hispanic rain-fed agricultural system supporting dense human populations was established under arid climatic conditions during the 13th to 15th centuries. Furthermore, after 1257 CE, this society thrived

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Fig. 1. Location map of 49 archaeological sites identified in the Intersalar region of Bolivia. Numbers refer to site identification in Table A2.1.
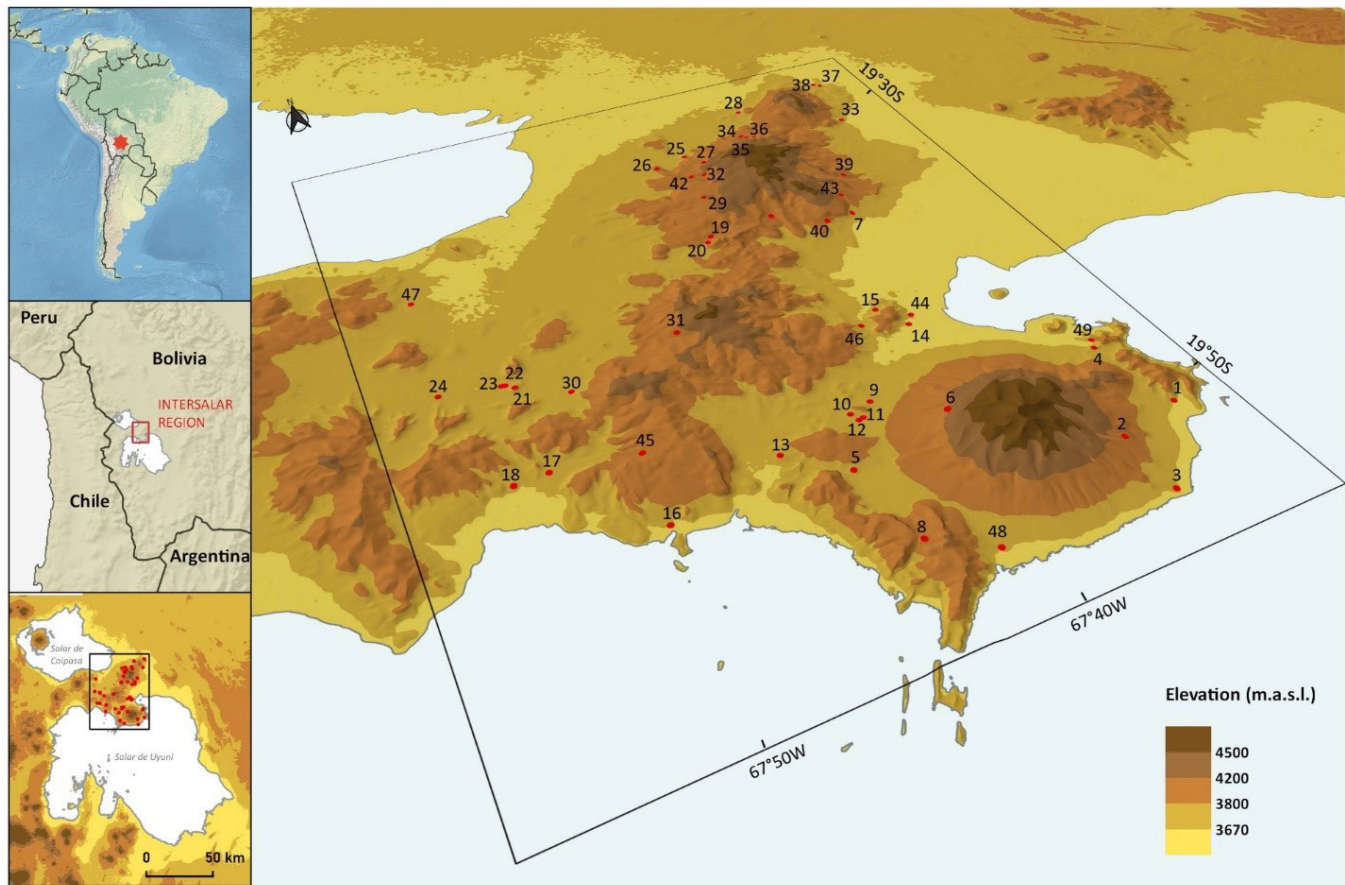
despite prolonged climate degradation following large volcanic eruptions (Swingedouw et al. 2017). Despite limited annual rainfall that does not cover the water requirements of a complete annual crop cycle, an agricultural system excluding irrigation has been successfully and sustainably implemented. Agriculture flourishing in this extreme environment was based on biennial fallowing which, thanks to the accumulation of water in the soil, allowed for a crop to be harvested every two years (Cruz et al. 2017). This solution, although not very common, has been applied in other arid areas of the world (Passioura and Angus 2010, Schillinger 2016), and contrasts with the practice of irrigation usually adopted by societies facing similar environmental limitations (Spielmann et al. 2011). The high-agricultural production in this context was thus achieved through agricultural knowledge based on a thorough understanding of agro-ecological constraints, combined with a collective work of landscape modifications covering vast areas to retain soil and runoff water, but without resorting to costly techniques such as irrigation channels or monumental terracing (Pouteau et al. 2011, Cruz et al. 2017, Winkel et al. 2018). This resource-use strategy was close to the horticulturist and limited labor models of agrarian societies (Hillier and Hanson 1984, Kaplan et al. 2009, Barbaza 2018).

Based on new archaeological data, we will expand our understanding of how an agrarian society organized itself to cope sustainably with prolonged climate degradation. We analyze the settlement patterns and spatial organization of sites, and examine inequalities in the concentration of wealth through the calculation of the Lorenz curves and Gini coefficients of housing space and grain storage capacity, two proxies of material wealth status in archaeological records (Bogaard et al. 2018, Kohler and Smith 2018). Then, using the conceptual frameworks of eco-social interactions (Kaplan et al. 2009, Gregorio de Souza et al. 2019), we propose a new model of resilience, sustainability, and low social inequality in small agrarian societies exposed to harsh and unstable environments.

MATERIALS AND METHODS

Study area, archaeological, and field survey
The Intersalar region is located between the salt flats (*salares*) of Uyuni and Coipasa, in the southern highlands of Bolivia, between 3650 and 5320 masl (Fig. 1). The region today has a cold and arid climate with more than 260 nights of frost per year, a daily thermal amplitude that may exceed 30 °C, and a limited annual precipitation rate between 150 and 300 mm. Furthermore, this

region faces large inter-annual and intra-annual rainfall variability, resulting in a high level of unpredictability of rainfall (Geerts et al. 2006). Paleoclimatic indices attest to a sustained aridity between 1100 and 1500 CE (Common Era) in the south central Andes (Chepstow-Lusty et al. 2009, Cruz et al. 2017). Moreover, catastrophic events like the eruptions of the Samalas in Indonesia in 1257 CE and of the Quilotoa in Ecuador in 1280 CE, induced climate degradation characterized by precipitation and temperature drops that lasted several decades (Swingedouw et al. 2017).

We conducted archaeological research over this region between 2007 and 2018 in order to identify and characterize 49 pre-Hispanic sites in a 1800 km² area. Aerial and field archaeology was supplemented by geomorphological, agroecological, historical, sociological, and ethnographic studies of current populations (Winkel et al. 2016). Systematic studies, including photogrammetric and topographic surveys, sampling, excavations, and analysis of archaeological materials were carried out at 12 of these settlement sites. These 12 sites were chosen for their excellent conditions of conservation, allowing the development of complete cartographies with a high degree of precision and for being representative of the diversity of locations and architecture. In order to have a greater statistical robustness of the analyses, we have also given priority to the sites with a significant number of housing and storage structures. Based on aerial photographs taken by a kite system and a fixed wing drone, high-resolution maps of the 12 settlement sites detailed the totality of the household units, and the housing and storage structures composing each of these units (see Appendix 1 for details on archaeological surveys and chronology, high-resolution imagery processing, and mapping).

Housing and storage structures statistical analysis
Analyses of the distribution of the number and area of rooms and granaries were performed to test their normality. The assumption of Gaussian distributions was not verified, so we next performed non-parametric ANOVA using the Kruskal-Wallis test. Dunn's multiple comparison tests were next calculated to compare median values of each site against all sites median values.

Gini coefficient calculation
The use of a coefficient to compare levels of wealth inequality between populations, communities, or societies requires that several prerequisites be met (Deininger and Squire 1996). These include that the observation units must be comparable and of low aggregate level (household or individual), the quantitative measurements used must be made on the whole population or on a sample whose representativeness has been validated, and finally, it must be ensured that the measurements represent the entire wealth of the observed units. For pre-modern societies, the most satisfactory level of analysis is generally that of households. The representativeness of the sampling is a difficult condition to meet when the data concerns large archaeological sites requiring complete excavations. In our case, field surveys and aerial photographs provide exhaustive coverage of individual household units over entire sites that have not been significantly altered since their abandonment at the end of the Late Regional Development Period (LRDP). This exhaustive coverage allows us to characterize any household heterogeneity potentially

present within the study sites, while the 12 sampled sites out of the 49 identified give us a representative picture of the Intersalar society, with a correct spatial and social scope for Gini calculations (Kohler and Ellyson 2018).

The variables under study for each household unit were the total housing space (THS), corresponding to the sum of room surfaces, and the total storage area (TSA), i.e., the sum of granary surfaces (see Appendix 3 for the choice of the variables). Lorenz curves and Gini coefficients for each site were calculated on the basis of clearly identified home structures corresponding to family units. These calculations were based on a proxy for per capita indices commonly used in economics, which hypothesizes that the number of rooms in each household is proportional to the number of family members. Because storage units were always found outside houses, and rooms were of medium and fairly uniform size, we considered that the rooms were only used to shelter people. Beyond the analysis of each of these two separate variables, we sought to aggregate them in order to give a synthetic account of household wealth. Two approaches were followed, the first following Bogaard et al. (2018) involves the Cobb-Douglas production function to calculate an aggregate variable, the second following UNDP (2010) and Oka et al. (2018) considers a composite index based on the geometric mean of previous single-variable coefficients into a single coefficient (see Appendix 3 for the details of calculation).

To test for a relation between settlement size and social inequality, Gini coefficients were correlated with site size, using the number of household units as a proxy for site size, with Pearson coefficients as criterion of significance at P < 0.05. In total, the analyses included 549 household units, 2767 granaries, and 1317 rooms in the 12 sites examined. This analysis does not take into account household units without granaries, a small minority (3.8%), nor granaries located in areas without housing (6%).

RESULTS

Settlement patterns, housing, and storage structures
Systematic observation of an area of 1800 km² led to the identification of 49 ancient settlements located on average only 2.5 km from their nearest neighbor (Fig. 1; Table A2.1). This density of past occupation by community settlements of various sizes is comparable to that of the 52 villages of the present period. The complete aerial coverage of the area means that this enumeration of 49 ancient settlements is exhaustive. None of these sites show any monumental remains such as palaces, temples, or large-scale buildings. Twenty radiocarbon dates from 18 sites (Table A2.2), together with the settlement pattern and material culture, identify the period of occupation as the Late Regional Development Period (LRDP 1200–1450 CE). Although unique dating cannot prove the temporal continuity of occupation at each site, the scale of the agricultural surfaces, the solidity of the stone houses and granaries, and the increasing number of these granaries in each housing unit clearly indicate that these settlements were established for several generations. Only four sites show connections in architectural and ceramic styles to the southward expansion of the Inka and continued occupation during the Late Period (LP); the other 45 sites appear to have been abandoned following the Inka invasion (Fig. A2.1).

Fig. 2. High-resolution aerial photographs (left panel) and interpretative map (right panel) of the archaeological site of Acalaya, Intersalar region, Bolivia. Aerial photographs with ground resolution of 15 mm/pixel were used to map household units individualized with different colors, based on the pattern of rooms around patios with granaries. (Photo credits: Bruno Roux, L'Avion Jaune).
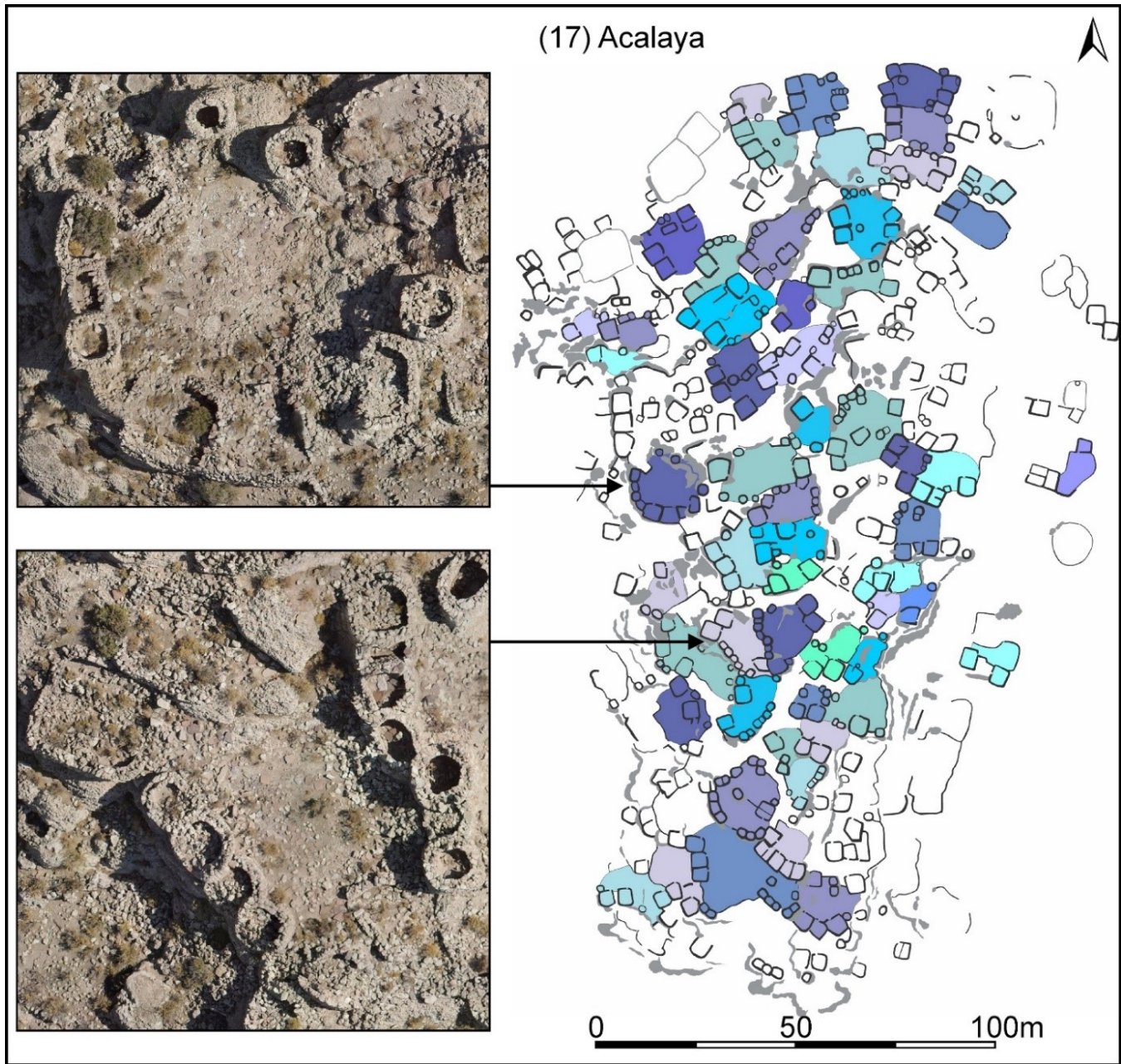
We conducted in-depth studies in 12 settlements that combined field surveys and Unmanned Aerial Vehicle (UAV) imagery of the entire sites (Fig. 2, Appendix 1) and built precise detailed maps (Figs. 3 and A1.1). The internal structure of all sites is homogeneous, with no differentiation between sectors or districts that would present a particular organization. Well-defined units with boundaries marked by low perimeter walls, housing, and granaries were found at all sites. Additionally, squares and open

collective spaces were identified, as well as multiple paths that allowed for movement and communication between the units.

The majority of the units are composed of a variable number of rooms and granaries, arranged around a patio. They were generally composed of 1 to 3 rooms (84%, Fig. A2.2A), suggesting that they were occupied by nuclei of direct relatives not exceeding three generations and, for this reason, are hereafter referred to as household units. Built with stone walls from 1 to 1.5 m high and

Fig. 3. Detailed maps of four study sites in the Intersalar region, Bolivia. Shaded areas show open collective spaces. Site numbers and names refer to identification in Fig. 1 and Table A3.1. (The maps of eight other study sites are presented in Appendix 1, Fig. A1.1).
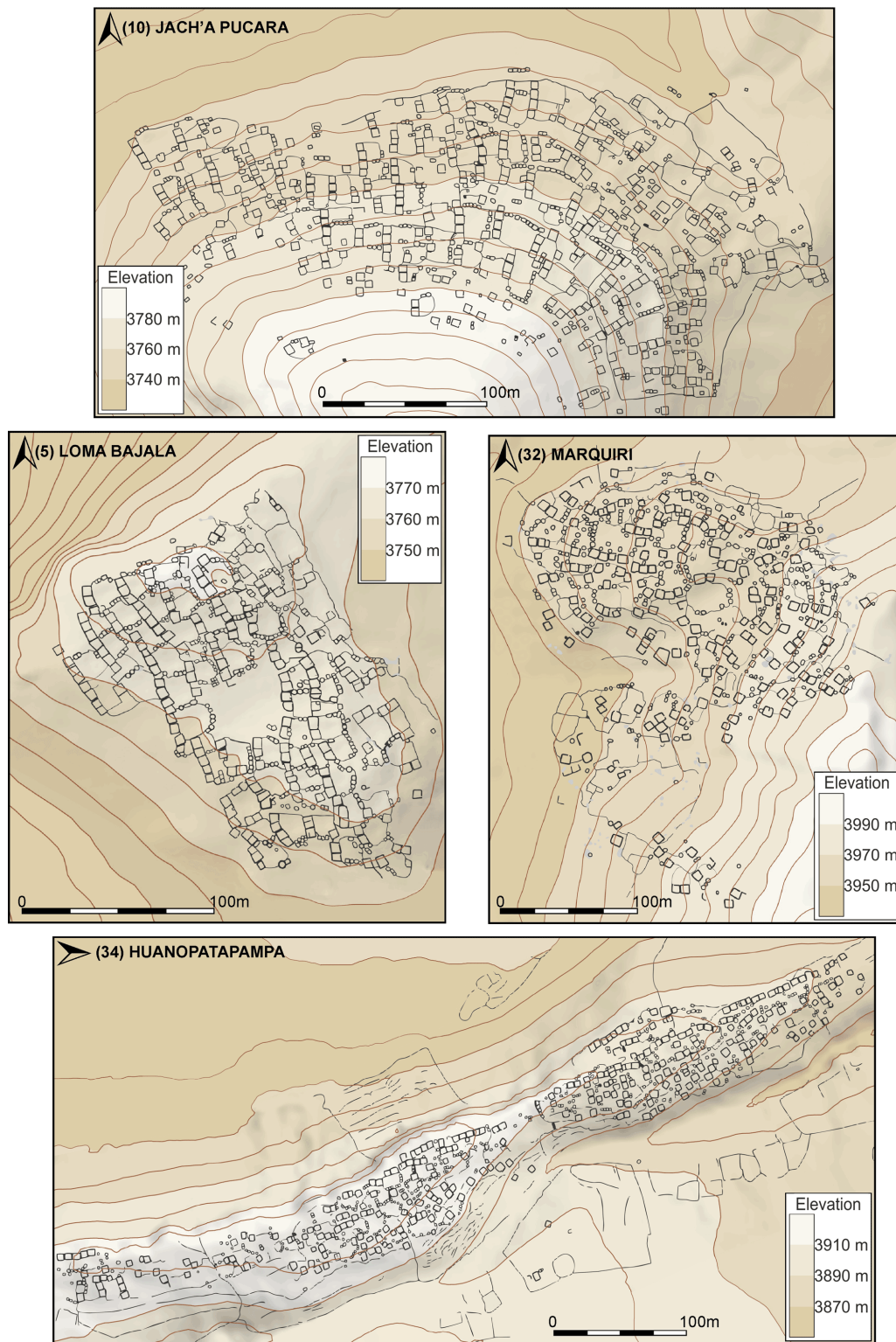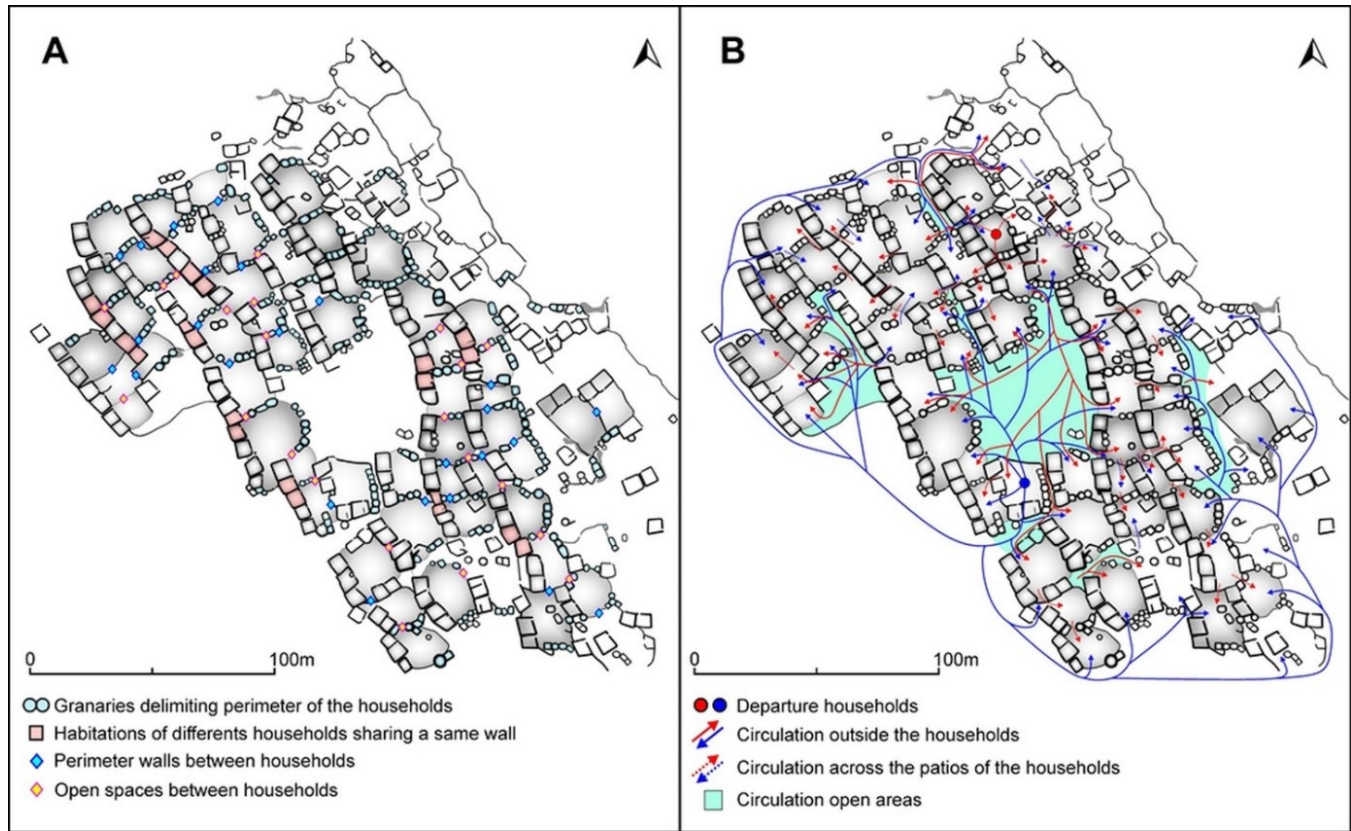
Fig. 4. Map of Loma Bajala (site 5) showing conglomerated structure (A) and circulation (B).

cemented with mortar, they are square or rectangular with an average surface area of 15.4 m² (CV = 28%, n = 1317; Fig. A2.2B). The size of the rooms reflects the limits of roof construction in this arid region where giant cacti (*Trichocereus pasacana*) and small *queñua* trees (*Polylepis* spp.) were the only source of wood materials for beam construction. The mean number of granaries per household unit is 3.9 (CV = 58%, n = 549; Fig. A2.2C). Most granaries demarcate the limits of the household units (72%), while the remaining 28% are located inside the patios of the households or scattered outside them.

The linear relationship between total storage area (TSA) and total housing space (THS) per household unit calculated over the 12 sites is highly significant (TSA = 0.2383*THS, r = 0.5755, P < 0.0001, n = 455; Fig. A2.3). This linear proportionality suggests that storage range is related more to the productive capacities of the households in terms of the number of active persons than to the concentration of wealth, which would have led to an exponential accumulation of storage in the larger household units. This is consistent with the sequential attachment of granaries, a pattern observed in most household units that signals a progressive increase in production and storage capacity. Taken together, these characteristics indicate a family ownership, both in terms of housing and storage.

Most household units (87%) were attached to one another in dense conglomerates, sharing perimeter and house walls (Fig. 4). Although each family's housing was delimited, movement within

the sites often required passing through the patios of other households (Fig. 4B), which made these areas of private household activities also common spaces for transit and meeting (Hillier and Hanson 1984). Because most granaries marked household perimeters in all sites, they were within sight and reach of immediate neighbors and anyone who circulated through the patios. A variable number of isolated granaries (6% on average in the 12 sites) located along walls delimiting non-housing spaces or the outer perimeters of settlements were found at all sites. No remarkable constructions were identified in any of the 49 sites exhaustively observed in the study area. Funerary practices were characterized by collective burial places on the periphery of settlement sites, with tombs located inside rock shelters (Fig. A2.1D). In the entire Intersalar zone, no above-ground mortuary structures categorized as *chullpa* exist. Observations made in funerary contexts (sites 1–3, 6, 10, 20, 33, 49, 51) do not show significant differences in the tomb architecture, offerings (mainly ceramic vessels), and trousseaux (textiles, brooches, cactus thorn combs, etc.).

Social inequality coefficients
The Lorenz curves present similar patterns at all sites, showing no strong concentration of wealth in the distribution of granaries and housing spaces among the different household units at any site (Fig. A3.1). Regardless of the calculation method used, variations in Gini coefficients between sites are comparable (Table A3.1). Composite Gini coefficients (CD02, CD05, and CAI-W)

show less variation between sites than Gini coefficients corresponding to the distribution of a single variable (THS and TSA). Whatever the coefficient, simple or composite, the values converge toward moderate regional averages between 0.22 for the composite variable CD05 and 0.26 for TSA (Table A3.1). With the exception of two cases with minimal differences, Incali (site 8) and Sivingani (site 7), the Gini coefficients for housing are lower than those for storage. This indicates that existing inequalities in the storage capacity of the households do not translate into the size of the housing space, which corroborates the archaeological record from across the Intersalar region.

We found no significant correlation between the Gini coefficients and the topographic or structural features of the sites except for a positive although weakly significant correlation between site surface and Gini TSA and Gini CD02 (Table A3.2). Beyond a fairly clear general pattern, three sites stand out: Incali (site 8) with systematically lower values, and Acalaya (site 17) and Jach'a Pucara (site 10) with higher values (Table A3.1). Considering the specifities of Incali, *viz*. small size, few household units, a ridge topographic position at an elevation of 4035 m with a high degree of intervisibility, and low inequality coefficients, we speculate that this site was a satellite productive settlement linked to the major sites located further downhill on the Intersalar plains. Higher Gini values were associated with the populated settlements of Acalaya and Jach'a Pucara located next to the plains at ~3700 m. Easy to access, both sites are the largest housing agglomerations in the region. For 8 other sites, substantial overlap on bootstrapped error ranges (Table A3.1) provides strong support that the level of differentiation within these sites was quite similar, something indicative of a close social structure among the sites. Finally, the Gini coefficients obtained for Capillo (site 35, Fig. A2.1), the only site showing Inka occupation, reveal values very close to the general averages suggesting that the mode of settlement and social organization was maintained until the conquest and control of the region by the Inkas.

DISCUSSION
Our quantitative study over an extended area demonstrates the flourishing of a non-centralized Andean highland society with low levels of social inequality during a period when already extreme environmental conditions had worsened considerably (Cruz et al. 2017). The persistence of the relative egalitarianism in status and wealth, and the social cohesion mechanisms in use suggest their efficacy in sustaining a functioning society. In such conditions in the past, many societies were nomadic as in the Sahara desert or the Mongolian steppes (Barbaza 2018, Burentogtokh et al. 2019), while others, as in the Arab oases or the Tibetan highlands, were sedentary but used irrigation or draft animals (D'Alpoim Guedes et al. 2015, Cremaschi et al. 2018), two resources absent from our study area. The agrarian societies most comparable to that of the Intersalar seem to be the Ancestral Puebloans, of the Southwestern United States, who developed dry-farming and irrigation without using draft animals (Spielmann et al. 2011, Bellorado and Anderson 2013, Bocinsky et al. 2016, Bocinsky and Varien 2017, Kohler and Ellyson 2018).

Settlement patterns and architectural features
The inhabitants today identify several sites in the Intersalar as *pucara*. This term is often associated with an elevated defensive structure, a pattern widespread during the LRDP over much of

the Andes due to prevailing conflict-oriented society during that time (Arkush 2008, Arkush and Tung 2013). Although some of the studied sites are located on promontories, none presents defensive structures. Generally located in easily accessible locations, the Intersalar sites differ substantially from the defensive *pucara* described around Lake Titicaca (Arkush 2008, Arkush and Ikehara 2019). Therefore, it can be assumed that conflicts were not a determining factor in the organization of the sites. In fact, the term *pucara* covers a semantic field that goes beyond mere military defense and includes agricultural and sacred spaces (Martínez [1983] and Cruz and Joffre [2020] discuss this polysemy).

The headland location leads us to consider a strategy of climate adaptation. Cold air drainage at night makes lowlands prone to frost while slopes, peaks, and ridges remain less exposed (Pouteau et al. 2011). These topoclimatic conditions would have been of critical importance when choosing where to settle.

A clear and unique pattern of room, patio, and granaries for all residential units, the homogeneity of building techniques, the absence of remarkable monuments, and of particular sectors (Moore 1996), all show a weak architectural differentiation. Furthermore, the contiguity of the constructions with common movement spaces between the household units strongly suggests a coordination in their construction, or even a collective work (*minka*) or reciprocal exchange of labor (*ayni*), two practices still frequently observed in the Andean region (Lyle 2017). The presence of some isolated granaries could correspond to the collective food storage for cults and celebrations, a common practice in pre-Hispanic societies. The accessibility of granaries indicates a low risk of theft or looting, whether from inside or outside the settlements (indeed, in Andean societies, theft itself has been considered a practice of positive reciprocity that reinforces egalitarian values; Johnsson [1986], and Bathurst [2009]). All these features suggest low social differentiation. We cannot exclude the possibility of economic differentiation resulting in the possession of symbolic goods that did not require large storage spaces. However, the lack of differentiation of funerary contexts counters this hypothesis.

Lorenz Gini inequalities
Gini coefficients calculated here are closer to the values characterizing horticultural societies (0.27) than those characterizing agricultural societies (0.35) worldwide (Smith et al. 2010, Kohler et al. 2017). They are in the range of the local and regional political scales (sensu Kohler et al. 2017; Fig. A3.2). Gini coefficients for storage units were generally higher than those for housing spaces (Blanton 2010, Barbaza 2018). If storage capacity is considered an indicator of annual harvest income and housing space an indicator of multi-year accumulated wealth and social status (Kohler and Higgins 2016), our results suggest a limitation of wealth concentration in the long term despite income disparities in the short term. In the study area, such social levelling of wealth inequalities may have occurred through practices of reciprocity common in Andean societies (Walsh-Dilley 2012, Lyle 2017), or contributions to collective storage for food security and religious festivities (Stanish 2017). In our case, the linear proportionality between grain storage area and housing space at household unit level (Fig. A2.3) suggests that storage difference is related more to the productive capacities of households in terms

of the number of active persons than to the concentration of wealth. The Gini indices thus corroborate the complete absence of architectural signs of wealth or social inequality in the archaeological record of the Intersalar society during the LRDP.

Regional and historical context
The social processes since the beginning of the Regional Development Period (RDP) (12th–15th centuries) over south-central Andean highlands led to the formation of different territorial configurations (Bouysse-Cassagne 1987) regionally integrated forming a confederation of nations (Platt et al. 2006). Nevertheless, archaeological evidence combined with our results suggest that the Intersalar region constitutes a unique socio-territorial entity. Major characteristics of the Intersalar region like high food surpluses stored in thousands of visible granaries, low wealth inequality, absence of defensive sites, burial towers, or collective granaries, underline the specificity of this society. Agricultural prosperity and long-lasting peaceful cohesion both within and among communities were maintained despite the worsening climate. The systematic presence of ceramic styles from nearby regions in the Intersalar settlement sites indicates a significant degree of regional interaction during this period. It is worth noting that, during the LRDP, none of the polities in the Andean highlands was powerful enough to claim control over its neighbors and extract wealth or labor from them (Cruz et al. 2017). The success of the Intersalar society was not achieved by all societies in the south-central Andean highlands and may have depended on the social structure and functioning that underpinned local adaptation strategies. Expanding our focus, we propose a new model of sustainability and resilience of sedentary societies living in extreme and unstable environments.

An evolutionary model of durable low inequality in agrarian societies living in extreme environments
Aware of the criticisms of a too narrow determinism between climate and social processes (Brumfiel 1992, Calaway 2005, Butzer 2012), we nevertheless consider that environmental factors are key to understanding societies living in extreme environments, where natural resource scarcity strongly conditions the daily life and survival of populations. Following Kaplan et al. (2009) and Rockenbauch and Sakdapolrak (2017), three ecological and economic dimensions guide our analysis: (i) skill and knowledge in resource production; (ii) patterns of social leadership and labor cooperation; and (iii) resource use strategies. Because of the lack of available information in our data, we will deal only incidentally with the fourth dimension of male-female relations hinted by Kaplan et al. (2009).

Skills and knowledge

Skills and knowledge result from co-evolutionary interactions between ecological and social processes, achieving a form of cumulative change necessary for the long-term persistence of any social-ecological system (Macfarlan and Lyle 2015, Gregorio de Souza et al. 2019). The seemingly slight, though extended, landscape modifications implemented by inhabitants of the Intersalar in the 13th–15th centuries testify to an intimate knowledge of local topoclimatic risks and soil limitations. To cope with them, the local populations developed various solutions: biennial fallowing, rudimentary, though extensive, terracing to retain soil and water resources, preferential exposure of crops to the northwest to limit the frost risks, and seeding in widely spaced

clumps (Cruz et al. 2017). These agroecological adaptations are similar to those developed by Puebloan societies to avoid cold-air drainage areas and store water in the soil several months before the crop cycle (Dominguez and Kolm 2005, Bellorado and Anderson 2013, Bocinsky and Varien 2017), yet with one notable difference: this knowledge appears shared by all and not monopolized by ritual-political leaders as among the Puebloans (Bellorado and Anderson 2013, Kohler and Ellyson 2018). In the Intersalar, landscape transformation techniques were too simple to be the preserve of a few highly qualified people who had mastered sophisticated knowledge in agricultural hydraulics or masonry. The same ecological knowledge about the local climate could explain the preferential location of the villages on headlands. These skills held by all constituted an immaterial common, a form of "embodied wealth" (Borgerhoff-Mulder et al. 2009, Smith et al. 2010) implemented collectively and dependent on a shared memory (Sousa et al. 2020). Once built, these landscape transformations also produced a positive feedback loop that contributed to stabilizing the collective organization necessary to their realization and maintenance (Langlie 2018). The persistence of the Intersalar agrosystem for more than two centuries demonstrates the adequacy and sustainability of these social and technical solutions based on collective action to address the worsening climate change.

Social organization, leadership, and cooperation

The Intersalar settlements shared a similar architectural pattern with the repetition of household units suitable for three-generation families. The accessibility of the granaries visible to all made them easier to control. In the absence of an identified leadership, this control would have been collective and an indicator of mutual trust and social cohesion. Similarity, in housing architecture and the absence of any remarkable monuments or urban division into productive, political, or religious districts throughout the study area indicates a high degree of political and cultural homogeneity in the Intersalar region. Even though political centralization may have no archaeological signature (Blanton et al. 1996), the lack of material signs of wealth accumulation in housing, storage capacity, and even in sepultures, either within villages or the whole Intersalar region, strongly suggests the lack of power concentration and hereditary transmission within elites. In the Intersalar, social leadership could have taken a more participatory form, as is still the case today in this region where communal functions are non-elective obligations assumed by each community household in turn on an annual basis (Winkel et al. 2016, 2020). This current participation in local governance is the necessary condition for the families to enjoy the usufruct of a specific part of the communal land. This right is transmitted within the families as long as they maintain their participation in local governance. In addition to ensuring access to land resources in exchange for temporary communal functions, this system hinders the emergence of too-large inequalities of wealth and status among families, notably by disallowing the creation of a land market or the hereditary transfer of leadership. Thus, the intergenerational family structure favors not only the transmission of skills for resource production (Kaplan et al. 2009), but it is also the basis for the equitable transfer of the right of access to common land resources.

Although land commoning and participative governance strengthen social cohesion at the local scale, they may also represent factors of collective vulnerability at a higher regional scale. Indeed, the complexity of the chain of deliberation and decision making, and the relative autonomy of the settlements, might hamper their reactivity and regional coordination, such as in the event of external aggression. This may have precipitated the downfall of the Intersalar society against the highly centralized and hierarchical Inka conquerors. The sharing of land and power is also vulnerable to size effects and becomes difficult to organize in large groups where internal divisions and conflicts of interests easily multiply (DeMarrais and Earle 2017).

Resource use strategies

Land resources in the Intersalar can be considered in some way homogenous, with no patches of rich soil or water resources, except for some extremely rare wetlands (*bofedales*) or water springs. In this region, soils and geomorphology (deep and well-drained sandy soils, lack of permanent watercourses) do not favor the concentration of water in particular sites. However, local farmers found how to concentrate it over time through biennial fallowing (Cruz et al. 2017), a practice that requires large areas, unfavorable to the creation of defensible resources. Consequently, the land lacked economic defensibility and, as is still the rule today in the region, was probably held in common with no individual right of disposal, preventing the emergence of differential property wealth (Kaplan et al. 2009). More than land area, labor represented the limiting factor for food production in this region. The absence of draft animals required intensive labor cooperation and reciprocity to enable hand-cultivation of the large areas needed to compensate for the low productivity of drylands. By making it easier to collectively defend the land, commoning could also have been an adequate strategy against possible pressure of neighboring groups.

Food storage is another essential aspect of resource use, because building up food stocks ensures food security and avoids prolonged emigration. Many dry farming societies around the world continue to use this strategy today (Tow et al. 2011, Balbo et al. 2016), and this seems to have already been the case of the Intersalar society, whose settlement patterns show more granaries than in any other known archaeological site in the dry Andes.

An evolutionary model of durable low inequality

We propose a model of durable social cohesion and low inequality in societies facing extreme or unstable environments on a decade or century scale (Fig. 5). This time scale corresponds to the climatic anomalies (e.g., the Medieval Warm Period ~ 950–1250 CE, or the Little Ice Age ~1300–1850 CE) to which are superimposed shorter climatic oscillations (e.g., ENSO events) that affected agrarian societies worldwide during the late Holocene. This differs from the 100 ky time scale used by Mattison et al. (2016) to delineate a stable Holocene from the previous Ice Age, leading them to infer the central role of resource defensibility and wealth transmission in the persistence of social inequality in stable environments. As a complement to the analysis of Mattison et al., we found that in extreme or unpredictable environments, scarce and undefensible natural resources may be durably managed by egalitarian societies. In the absence of defensibility, the commoning of knowledge, resources, and labor constitutes

the adaptive social responses that enable the sustainability of the society. Yet, the housing and food storage patterns in the Intersalar show that cooperation did not mean full collectivization of the food production and daily life. Instead, these patterns suggest that the intergenerational family system described by Kaplan et al. (2009) remained the foundation of social organization, and the frame for the transmission of wealth, skills, and, probably, land usufruct. The trade-off between collective action and family-based social organization was maintained for more than two centuries without a proprietary or dominant class emerging. The longevity of this social system is evidence of its sustainability, and even of its social and ecological resilience in the context of significant global climate degradation during the same period. Indeed, climate adversity can stimulate agricultural innovation through the adoption of new crop species or varieties (D'Alpoim Guedes et al. 2015, Winkel et al. 2018), coupled with the development of alternative cropping practices and social organization (Bellorado and Anderson 2013).

Fig. 5. An evolutionary model of low social inequality in agrarian small-scale societies living in extreme environments.
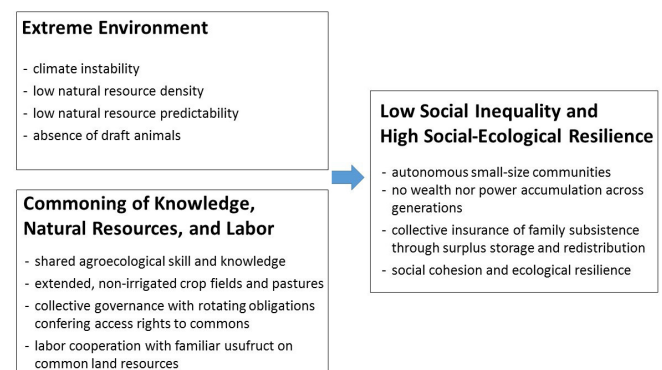
In their model of land use in Pre-Columbian societies of Amazonia, Gregorio de Souza et al. (2019) relate the lower climate change vulnerability of some of these societies to their investment in landesque capital, which involves agricultural landscape modifications aimed at long-term risk minimization rather than short-term yield maximization. Although the causality between social stratification and agricultural intensification is still debated (Sheehan et al. 2018), these studies, like ours, suggest that the land use system implemented by the autonomous communities is a determining factor for their social-ecological resilience to climate disturbances (Gregorio de Souza et al. 2019).

A significant result of our study concerns the multiscalar social cohesion of an agrarian population, from the household to the village and the region. At the regional scale, the apparent lack of hierarchy and defensive structures among the 49 settlements, combined with common sociocultural practices providing agricultural prosperity, suggests the development of a model of regional cohesion and peaceful coexistence of the settlement sites within a single political system. Our results show the existence of a balance between the control of agricultural production by family households on the one hand, and the collective action within villages to manage their common land resources on the other. This non-hierarchical and self-regulating social model was

not anecdotal, because it covered a vast area and allowed for the development and coexistence of numerous settlements for more than two centuries. Collective action principles and values combined with shared skill and knowledge served the resilience of the whole society, compensating for the lack of material technology and draft animals, in order to cope with a harsh and unpredictable environment.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.
php/13207

Author Contributions:

P.C., R.J., and T.W. designed the study. P.C., R.J., and B.R. realized archaeological field surveys. N.E. realized historical survey and edition. C.B., P.C., and R.J. analyzed the geographic and remote sensing data. All authors contributed to the interpretation of the findings and the writing of the paper.

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Data Availability:

The data that support the findings of this study are available on request from the corresponding authors (PC, TW).

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APPENDIX 1. Archaeological surveys, additional field campaigns and image processing

Archaeological survey and chronology
Identification of household units was based on the pattern of housing rooms (typically 2-3) around a courtyard (patio) with storage structures and low perimeter walls. A series of 20 AMS radiocarbon dates from 18 sites was drawn from samples of charcoal, seeds, and straw recovered mostly inside archaeological storage structures, and to a lesser extent from buildings and funerary contexts (table S2). All dates were calibrated and updated using OxCal v 4.3.2 with ShCal13 atmospheric curve (Bronk Ramsey and Lee 2013, Hogg et al. 2013). Analysis of ceramic material made it possible to define the different styles present in the sites and their chronological ascription. Radiocarbon datation consistent with ceramic ascription, place the occupation of these sites between the 13th and 15th centuries, in the LRDP (Late Regional Development Period).

Remote sensing, high-resolution imagery and mapping
Archaeological prospecting, surveys and excavations were complemented with two field campaigns in 2016 and 2017. For the identification of archaeological sites and agriculture surfaces by remote sensing, different high-resolution satellite coverages were used (GeoEye, DigitalGlobe, CNES/Astrium and CNES/Airbus). All records were subsequently corroborated, corrected, and complemented by fieldwork. For the elaboration of topographies and the Digital Elevation Model (DEM), we used the coverage of the Shuttle Radar Topography Mission (SRTM) v2 with a resolution of 1 arc second (~30 m), downloaded from the online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, (https://lpdaac.usgs.gov/data_access/data_pool). The data were entered into the WGS84/UTM19S coordinate system, with bilinear interpolation at a resolution of 30 m. All records were converted to raster files with the same resolution as DEM, using QGIS software.

Twelve settlement sites were surveyed by aerial photogrammetry (n° 1, 3, 5, 6, 7, 8, 10, 13, 17, 32, 34 and 35). A kite system and a fixed wing drone took the aerial photographs. They were later processed with PhotoScan photogrammetry software, then georeferenced and orthorectified, obtaining high-resolution orthomosaics of the entire sites with a resolution of 15 mm/pixel. Based on these, a detailed cartography of the sites was made, and then corroborated with field observations and structural surveys. Both aerial photographs and site cartographies were integrated into the QGIS cartographic base, which made it possible to obtain exhaustive statistical data on the surface areas of the sites and on 549 household units and the housing and storage structures composing each of these units (household units ranged from 10 to 86 per site).

Fig. A1.1. Detailed maps of the study sites in the Intersalar region. Shaded areas show open collective spaces. Site numbers and names refer to identification in Fig. 1 and Table A3.1.
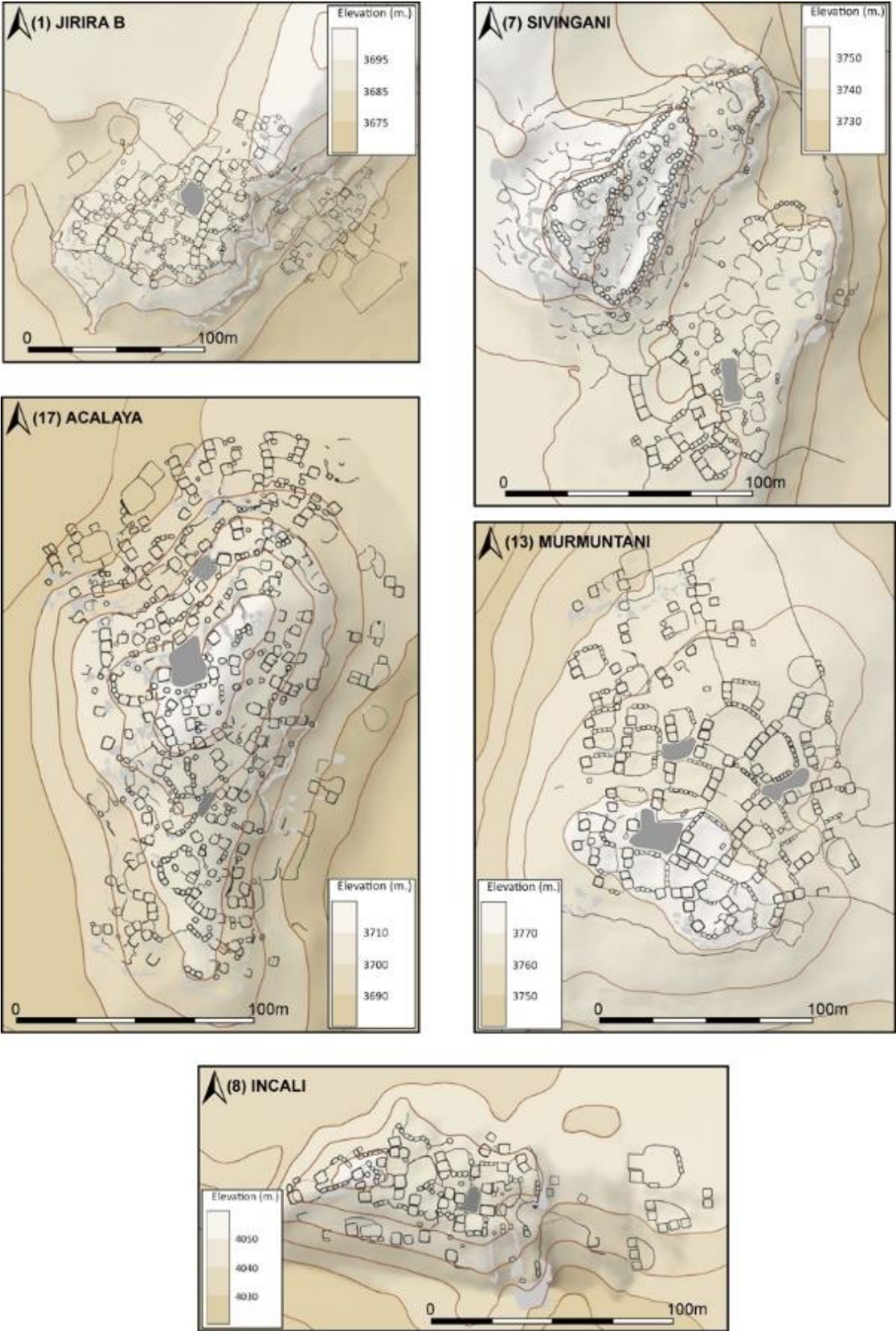
Fig. A1.1. Detailed maps of the study sites in the Intersalar region. Shaded areas show open collective spaces. Site numbers and names refer to identification in Fig. 1 and Table A3.1. *(continued)*
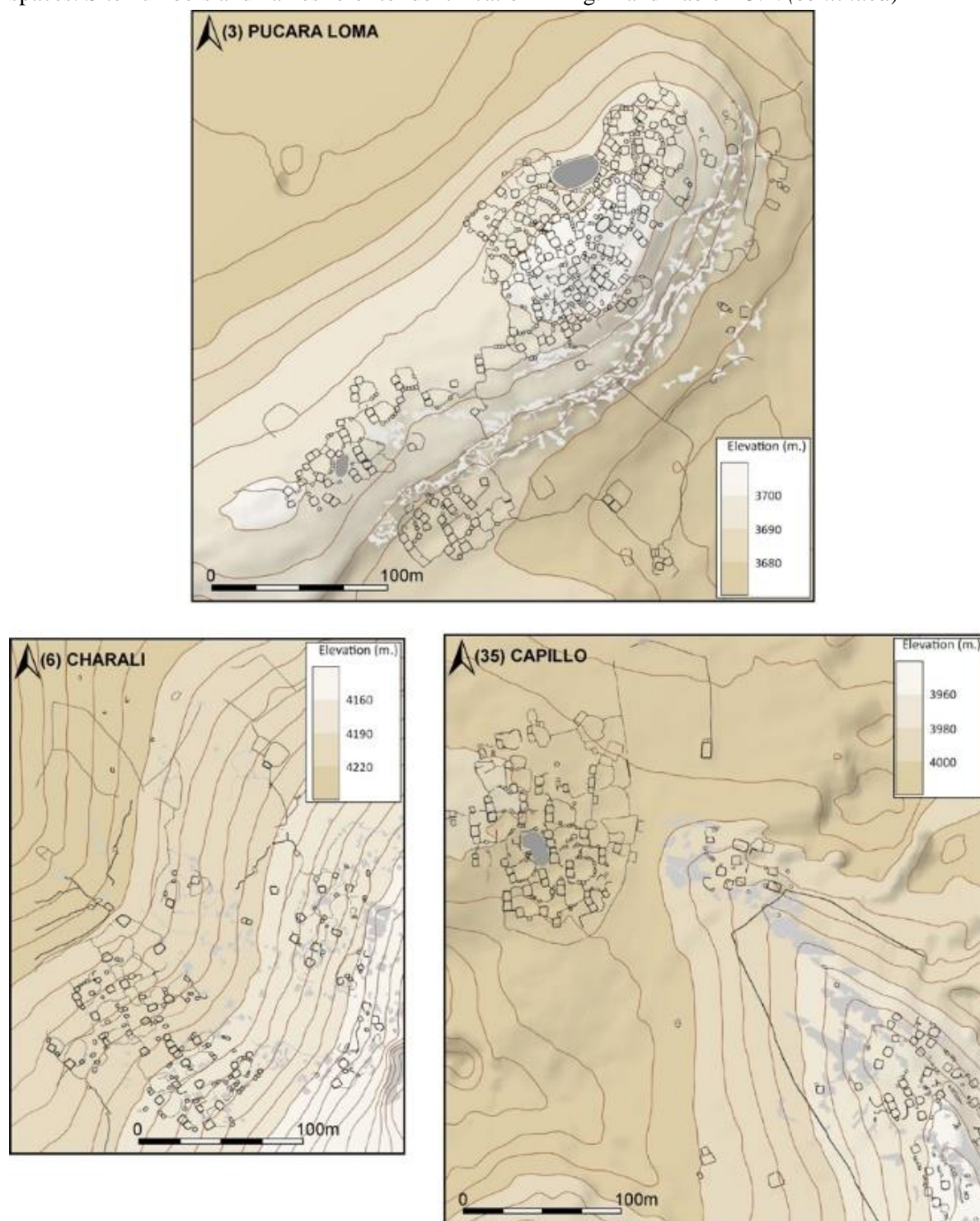
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APPENDIX 2. Settlement patterns, housing and storage structures

Table A2.1. Location data of 49 archaeological sites identified in the Intersalar region.

ID	Site name	Latitude South	Longitude West	Elevation (masl)
1	Jirira Vinto	19° 50' 58.32"	67° 33' 15.03"	3682
2	Cheka-Cheka	19° 51' 52.99"	67° 36' 03.34"	4039
3	Pucara Loma	19° 53' 33.81"	67° 35' 21.06"	3688
4	Chullpa Cuchu	19° 47' 54.80"	67° 34' 13.60"	3694
5	Loma Bajala	19° 49' 24.60"	67° 44' 11.46"	3777
6	Charali	19° 48' 49.24"	67° 40' 33.06"	4208
7	Sivingani	19° 37' 39.70"	67° 37' 28.80"	3743
8	Incali	19° 52' 32.89"	67° 43' 46.62"	4035
9	Loma Pucara	19° 46' 58.25"	67° 42' 11.16"	3767
10	Jach'a Pucara	19° 47' 11.72"	67° 43' 04.58"	3767
11	Saitoco 3	19° 47' 33.40"	67° 42' 48.40"	3734
12	Saitoco 4	19° 47' 36.20"	67° 42' 58.80"	3729
13	Murmuntani	19° 48' 34.18"	67° 44' 58.43"	3760
14	Cerro Puchucaya	19° 44' 07.30"	67° 38' 55.60"	3677
15	Pucara Puchucaya	19° 42' 53.90"	67° 39' 35.20"	3741
16	Loma Chiquini	19° 48' 51.70"	67° 49' 56.60"	3696
17	Pucara Loma Acalaya	19° 45' 30.50"	67° 52' 28.30"	3690
18	Loma Acalaya	19° 45' 42.10"	67° 52' 29.00"	3709
19	Pucara Viantarani	19° 36' 47.10"	67° 43' 09.50"	3888
20	Cerro Panturani	19° 37' 19.20"	67° 43' 34.70"	3779
21	Cerro Pucara	19° 41' 24.40"	67° 52' 17.70"	3764
22	Kothoña Pampa Loma	19° 41' 11.90"	67° 52' 33.60"	3688
23	Pucara Kothoña 2	19° 41' 09.30"	67° 52' 40.20"	3689
24	Uta Chuto	19° 40' 42.60"	67° 54' 39.71"	3691
25	Cayo Palca 1	19° 30' 46.26"	67° 41' 40.82"	3902
26	Cayo Palca 2	19° 31' 07.88"	67° 43' 04.59"	3839
27	Cayo Palca 3	19° 31' 47.00"	67° 41' 14.31"	4090
28	Cacota	19° 28' 13.52"	67° 37' 56.43"	3790
29	Huerta Lakha	19° 34' 29.10"	67° 42' 27.81"	4200
30	Loma Wila Pucara	19° 42' 31.70"	67° 50' 42.78"	3738
31	Villa Pucara Faldas	19° 41' 41.90"	67° 46' 39.82"	4100
32	Marquiri	19° 32' 55.92"	67° 41' 42.01"	3980
33	Cerro Pucara	19° 30' 43.78"	67° 34' 02.42"	3759
34	Huanopatapampa	19° 30' 53.50"	67° 38' 49.49"	3950
35	Capillo	19° 30' 59.37"	67° 38' 40.68"	3992
36	Quebrada Paicori 3	19° 31' 16.61"	67° 38' 38.07"	4061
37	Pucara Chusquiri 1	19° 27' 30.06"	67° 33' 21.61"	3706
38	Pucara Chusquiri 2	19° 27' 18.82"	67° 33' 35.46"	3696
39	Pucara Rancho Pitca	19° 35' 07.14"	67° 36' 27.10"	4019
40	Pucara Pisalaque	19° 37' 48.72"	67° 38' 40.54"	3836
41	Pucara Anchohoca	19° 36' 41.19"	67° 40' 32.70"	3925
42	Marquiri 2	19° 32' 37.19"	67° 42' 07.56"	3920
43	Quebrada Sivingani	19° 36' 42.92"	67° 37' 26.92"	3969
44	Cerro Puchucaya 3	19° 43' 42.80"	67° 38' 34.51"	3669
45	Cerro Yaripunta	19° 46' 13.30"	67° 49' 43.17"	3950
46	Ancoyo	19° 43' 34.26"	67° 40' 21.96"	3693
47	Pucara Luca	19° 35' 35.06"	67° 54' 21.88"	3721
48	Loma Iglesia	19° 53' 34.29"	67° 41' 52.04"	3679
49	Illamalla	19° 47' 50.30"	67° 33' 49.50"	3690

Table A2.2. Calibrated radiocarbon dates of archaeological samples from sites in the Intersalar region.

Si te	Name	Lab N°	Material	Cal 1σ (yr BP)	Calibration with SHCal13 and OxCal v. 4.2.4 - v. 4.3	
					Result 68.2% (yr CE)	Result 95.4% (yr CE)
1	Jirira Vinto	Poz-39415	quinoa seed	580±30	1396-1426 (68.2%)	1324-1343 (8.0%) 1389-1440 (87.4%)
3	Pucara Loma	Sac-A33899	wood	625±30	1320-1350 (40.4%) 1386-1406 (27.8%)	1307-1361 (54.6%) 1377-1419 (40.8%)
3	Pucara Loma*	Gif-7822	charcoal ashes	660±50	1306-1361 (52.3%) 1378-1395 (15.9%)	1286-1410 (95.4%)
3	Pucara Loma*	Gif-7823	charcoal ashes	640±50	1310-1360 (45.2%) 1378-1405 (23.0%)	1292-1421 (95.4%)
5	Loma Bajala	Poz-80817	charcoal	865±30	1190-1233 (48.9%) 1245-1264 (19.3%)	1162-1170 (2.1%) 1175-1274 (93.3%)
6	Charali	Poz-80818	charcoal	640±30	1319-1351 (49.0%) 1385-1398 (19.2%)	1300-1366 (64.6%) 1374-1410 (30.8%)
7	Sivingani	Poz-80826	charcoal	535±30	1415-1441 (68.2%)	1402-1450 (95.4%)
8	Incali	Sac-A33900	charcoal	690±30	1298-1320 (26.8%) 1350-1386 (41.4%)	1290-1392 (95.4%)
9	Loma Pucara	Poz-80825	charcoal	685±30	1300-1321 (26.0%) 1348-1386 (42.2%)	1292-1392 (95.4%)
10	Jach'a Pucara	Poz-80824	charcoal	675±30	1302-1326 (26.1%) 1340-1365 (26.3%) 1375-1390 (15.8%)	1294-1394 (95.4%)
13	Murmuntani	Poz-80822	charcoal	645±30	1318-1353 (50.0%) 1384-1398 (18.2%)	1300-1366 (66.9%) 1374-1406 (28.5%)
14	Cerro Puchucaya	Poz-80816	charcoal	570±30	1400-1429 (68.2%)	1326-1340 (3.3%) 1390-1445 (92.1%)
15	Pucara Puchucaya	Poz-80823	charcoal	635±30	1320-1350 (47.2%) 1386-1400 (21.0%)	1301-1365 (61.9%) 1375-1414 (33.5%)
17	Acalaya*	GIF 7825	plant	610±70	1314-1357 (31.0%) 1380-1430 (37.2%)	1290-1448 (95.4%)
32	Marquiri	Poz-80819	charcoal	745±30	1275-1304 (51.1%) 1362-1377 (17.1%)	1236-1242 (0.8%) 1266-1320 (66.7%) 1350-1386 (27.9%)
34	Huanopata-pampa	Poz-101045	charcoal ashes	785±30	1230-1248 (19.4%) 1262-1290 (48.8%)	1220-1300 (95.4%)
35	Capillo	Poz-101046	charcoal ashes	350±30	1508-1584 (59.8%) 1620-1630 (8.4%)	1492-1646 (95.4%)
35	Capillo Chullpa	Poz-101213	plant	360±30	1504-1590 (60.2%) 1616-1627 (8%)	1482-1642 (95.4%)
48	Loma Iglesia*	Gif-7824	charcoal ashes	825±50	1215-1280 (68.2%)	1156-1300 (95.4%)
49	Illamalla	Poz-101044	charcoal ashes	585±30	1394-1495 (68.2%)	1322-1346 (12.1%) 1388-1438 (83.3%)

Fig. A2.1. Comparative photographs of Capillo (site 35), one of the few pre-Hispanic sites in the Intersalar region that was continuously occupied during the LRDP (A, B) and the Late Inka Period (C, D). The pictures show the increase of social inequality and centralization of power after the arrival of the Inkas in the region. (A): View of the LRDP settlement; (B): Collective tombs (looted) under the rocky eaves of the LRDP; (C): Inka building; (D): Inka tomb. (Photo credits: P.Cruz, CONICET).
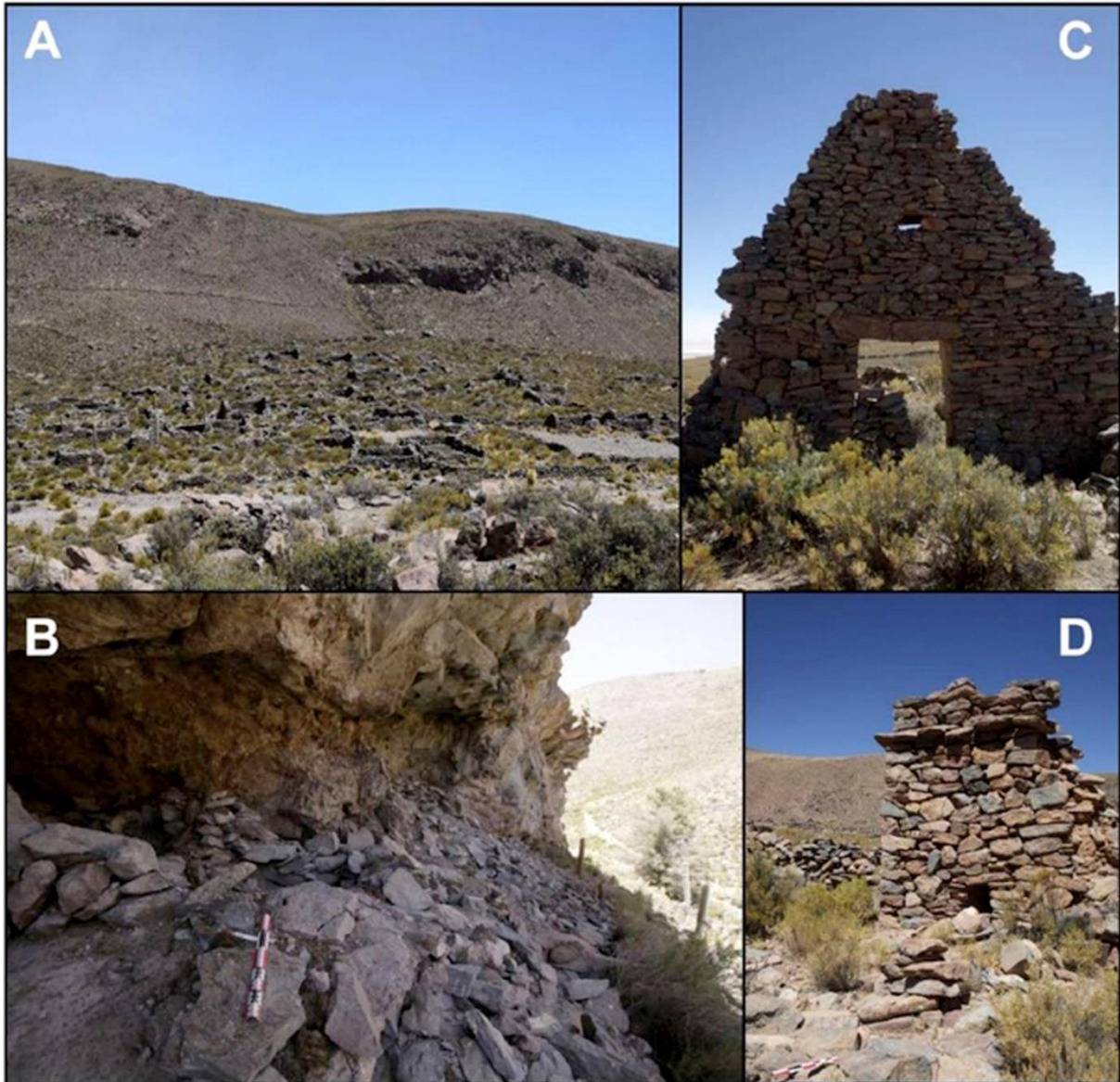
Fig. A2.2. Frequency distribution of housing and grain storage units. (A): Number of rooms per household unit (n = 549), (B): Individual room area (n = 1317), (C): Number of granaries per household unit (n = 549), (D): Individual granary area (n = 2767).
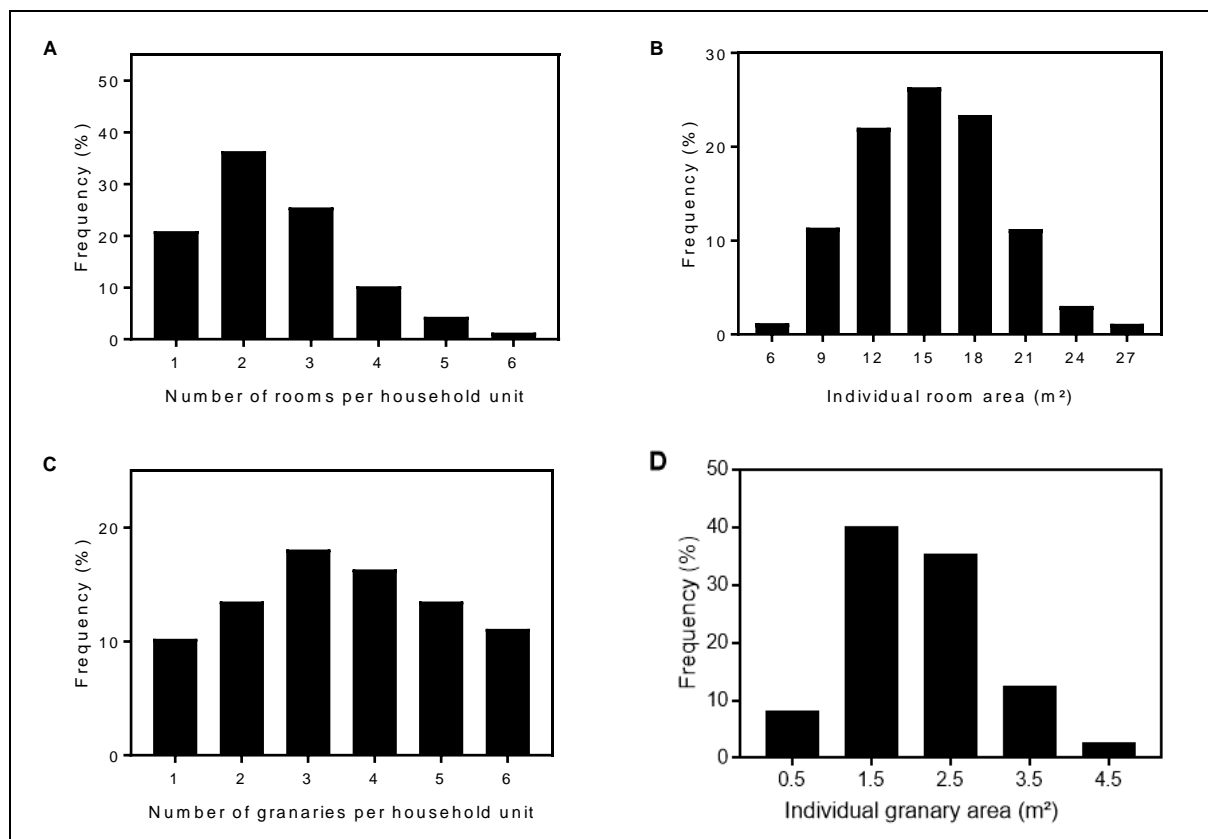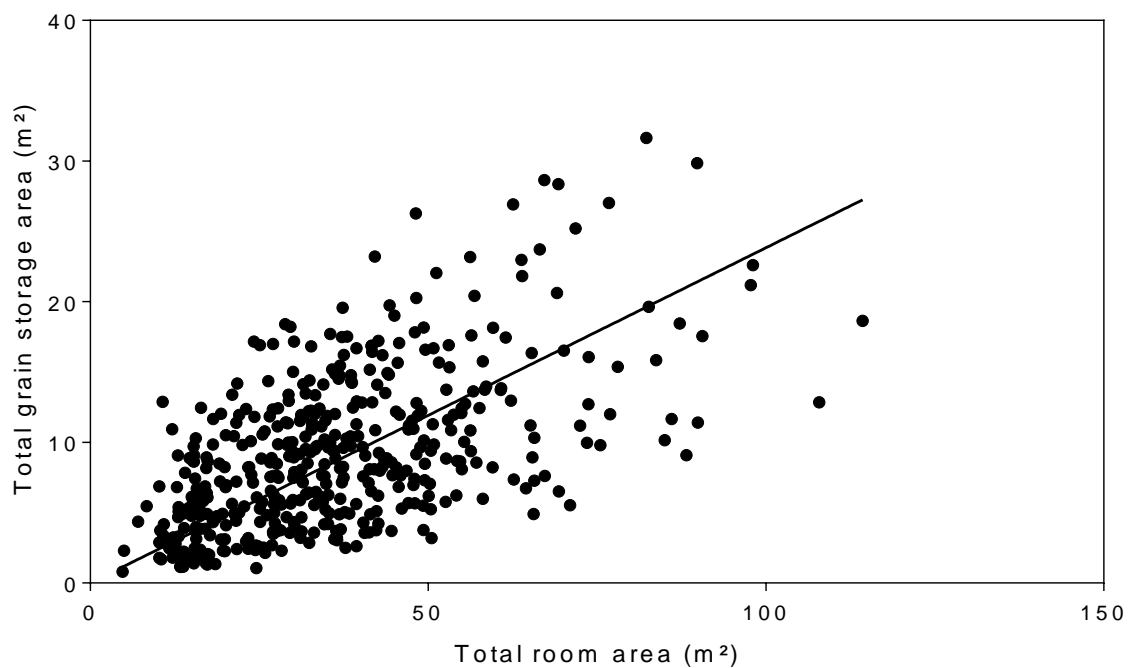

Fig. A2.3. Relationship between total grain storage area (m²) and total room area (m²) per household unit (r = 0.576, P < 0.0001, n = 455).

APPENDIX 3. Quantitative study of inequalities using Lorenz curves and Gini coefficients

The choice of variables

The level of wealth distribution between individuals, social groups, or entire societies can be represented by Lorenz curves from which Gini coefficients are derived (Kohler and Smith 2018). Many types of inequalities within community can be considered: wealth, prestige, health or access to resources (Peterson and Drennan 2018). Access to resources, mainly access to arable land, was not limited in the rainfed agricultural system we studied, since it did not rely on specific labor-costly landscape modifications related to water concentration or irrigation practices. Some indicators of social status (funeral ornaments, architectural features) do not necessarily constitute valid measures of wealth inequality but rather reflect differentiations of prestige (Peterson and Drennan 2018). Our observations do not reveal differences in architectural features or funeral assemblages within or among the settlements of the study area, thus ruling out notable inequalities in prestige.

Housing and storage unit areas are common indicators in studies of economic wealth in past societies. This choice can, however, be debated: some consider that the housing space reflects the size of the family more than its wealth (Cutting 2006) and that the size of the storage units is relevant if and only if, no part of the agricultural production is directly exported without the need for immediate storage. A direct export of agricultural products without storage seems unlikely in the Intersalar given the ease of grain conservation and the great isolation of the study sites within this pre-desert region. We therefore considered an analysis of the major inequalities within this society based on data on housing space and storage capacity to be justified.

Gini coefficient calculation

Beyond the analysis of the total housing space (THS) and the total storage capacity (TSA) per household unit, we seek to aggregate these variables m in order to give a synthetic account of household wealth. Two approaches were followed.

On the one hand, following Bogaard et al. (2018), we calculated a variable W for each household using a function similar to the Cobb-Douglas production function from economics. The aggregate variable calculated for each household unit is W_i:

$$W_i = THS_i^{\alpha}.TSA_i^{(1-\alpha)}$$

where THS_i is the housing space of the i-th household and TSA_i the storage area of the same household with α being the relative importance of housing compared to farming wealth as a determinant of one's living standard ($0 \leq \alpha \leq 1$). As proposed by Bogaard et al. (2018), we used two plausible values for α, 0.25 and 0.5, leading to the two Gini coefficients CD02 and CD05. All coefficient calculations used bootstrap resampling techniques with a number of resamples equal to 1000 (Dixon et al. 1987, Peterson and Drennan 2018).

On the other hand, we used a composite coefficient that considered, for each site, the geometric mean of the two previous coefficients into a single coefficient based on the calculation of the Human Development Index (HDI) as an alternative to single-variable Gini coefficient (UNDP 2010). This calculation assumes that increasing the number of variables increases the accuracy and precision of the coefficient aggregated. Applied to archaeology, Oka et al. (27) call such a coefficient the composite archaeological index (CAI) whose main advantages lie in the analysis of its temporal evolution within the societies studied and in the facilitation of comparative studies. We thus calculate a composite Gini as:

$$CAI\text{-}W = (Gini\_THS)^{0.5}.(Gini\_TSA)^{0.5}$$

Fig. A3.1. Lorenz curves for CD02 (—), CD05 (—), total housing space (THS - - -), and total storage area (TSA - - -) on a household basis at the 12 sites.
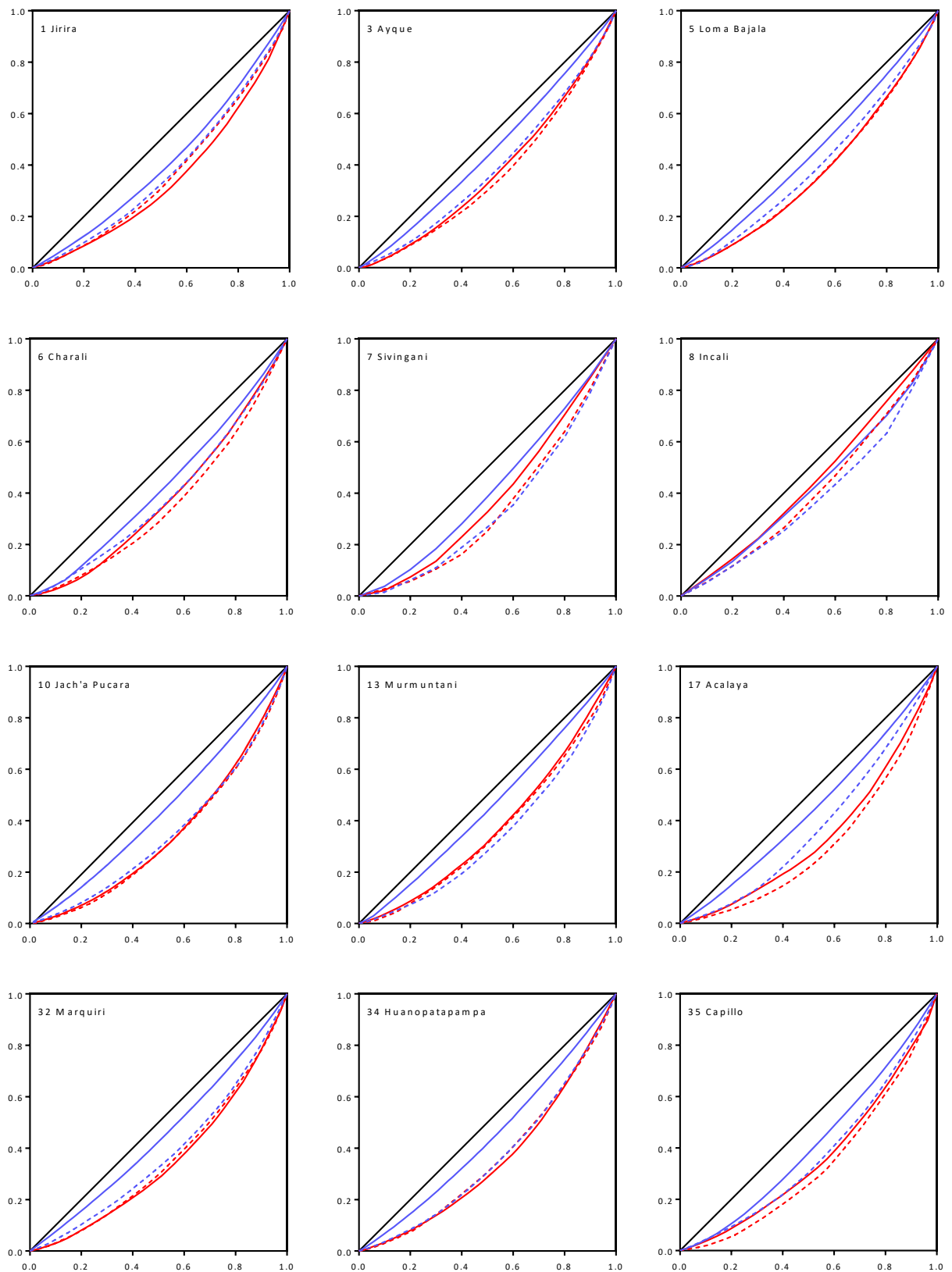
Fig. A3.2. Gini coefficients for the Intersalar region during the 13th-15th centuries (data points A and B) compared to 369 different sites across the world and different types of adaptation and 370 political scales. (After Figs. 2 and 3 in Kohler et al. 2017).
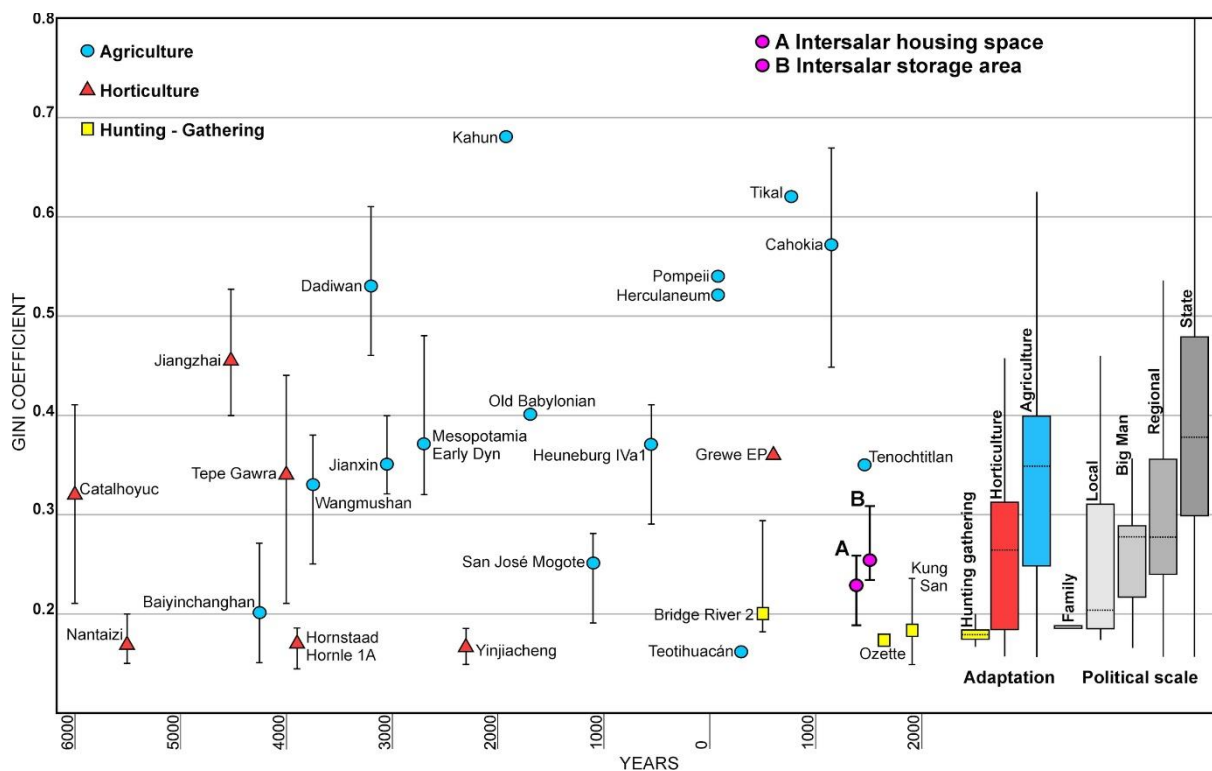
Table A3.1. Mean values for the Gini coefficients and their bootstrapped error ranges for 10-90 percent confidence based on 1000 resamples. THS: Gini coefficient for total housing space; TSA: Gini coefficient for total storage area; CD02 and CD05: Gini coefficients using the Cobb-Douglas production function for α = 0.25 and 0.5 respectively; CAI-W: composite archaeological index. (see Appendix 3 for complete definitions).

	Site n°	Household number	THS			TSA		
			Mean	10%	90%	Mean	10%	90%
Jirira	1	37	0.216	0.190	0.241	0.228	0.197	0.260
Ayque	3	40	0.192	0.168	0.215	0.251	0.221	0.281
Loma Bajala	5	56	0.183	0.158	0.210	0.236	0.211	0.262
Charali	6	22	0.211	0.175	0.249	0.271	0.228	0.314
Sivingani	7	10	0.248	0.175	0.325	0.254	0.186	0.319
Incali	8	10	0.152	0.089	0.205	0.130	0.098	0.159
Jach'a Pucara	10	86	0.286	0.262	0.309	0.315	0.284	0.345
Murmuntani	13	35	0.275	0.238	0.311	0.244	0.203	0.285
Acalaya	17	42	0.235	0.202	0.269	0.364	0.326	0.400
Marquiri	32	41	0.227	0.201	0.254	0.261	0.225	0.298
Huanopatapampa	34	52	0.250	0.225	0.275	0.255	0.222	0.289
Capillo	35	28	0.231	0.203	0.258	0.305	0.256	0.353
		Mean	0.226			0.259		
		CV (%)	16.92			21.70		

	Site n°	Household number	CD 02			CD05		
			Mean	10%	90%	Mean	10%	90%
Jirira	1	37	0.210	0.182	0.240	0.200	0.174	0.228
Ayque	3	40	0.219	0.192	0.245	0.205	0.177	0.231
Loma Bajala	5	56	0.211	0.189	0.232	0.189	0.165	0.213
Charali	6	22	0.231	0.193	0.274	0.211	0.173	0.251
Sivingani	7	10	0.242	0.173	0.303	0.243	0.177	0.308
Incali	8	10	0.100	0.063	0.133	0.097	0.059	0.132
Jach'a Pucara	10	86	0.291	0.266	0.315	0.277	0.255	0.299
Murmuntani	13	35	0.234	0.192	0.277	0.238	0.193	0.282
Acalaya	17	42	0.317	0.2842	0.351	0.276	0.245	0.305
Marquiri	32	41	0.233	0.198	0.270	0.217	0.184	0.250
Huanopatapampa	34	52	0.228	0.199	0.256	0.216	0.190	0.241
Capillo	35	28	0.272	0.223	0.319	0.251	0.210	0.290
		Mean	0.232			0.218		
		CV (%)	22.84			21.81		

(continued)

	Site n°	Household number	CAI-W		
			Mean	10%	90%
Jirira	1	37	0.222	0.201	0.242
Ayque	3	40	0.219	0.199	0.239
Loma Bajala	5	56	0.207	0.188	0.226
Charali	6	22	0.238	0.210	0.267
Sivingani	7	10	0.248	0.195	0.298
Incali	8	10	0.138	0.104	0.170
Jach'a Pucara	10	86	0.300	0.279	0.318
Murmuntani	13	35	0.258	0.230	0.285
Acalaya	17	42	0.292	0.2669	0.317
Marquiri	32	41	0.243	0.222	0.265
Huanopatapampa	34	52	0.252	0.231	0.273
Capillo	35	28	0.265	0.239	0.292
		Mean	0.240		
		CV (%)	17.62		

Table A3.2. Pearson correlation coefficients (r) between site features and Gini coefficients in the 12 study sites. THS: Gini coefficient for total housing space; TSA: Gini coefficient for total storage area; CD02 and CD05: Gini coefficients using the Cobb-Douglas production function with α = 0.25 and 0.5 respectively; CAI-W: composite archaeological index. (see Appendix 3 for complete definitions). For n = 12 (df = 10), the critical value of Pearson correlation coefficient (r) at P = 0.05 is 0.576.

Gini index	TSA	THS	CD02	CD05	CAI-W
Site surface	0.61 *	0.31 ns	0.59 *	0.51 ns	0.55 ns
Site elevation	-0.23 ns	-0.26 ns	-0.32 ns	-0.36 ns	-0.27 ns
Number of household	0.45 ns	0.45 ns	0.47 ns	0.45 ns	0.52 ns
Mean strorage area per household	-0.12 ns	0.11 ns	-0.071 ns	-0.025 ns	-0.023 ns
Mean housing space per household	0.12 ns	0.11 ns	0.17 ns	0.19 ns	0.15 ns

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