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Research article

2 Social adaptive responses to climatic degradation: insights from a pre-Hispanic Andean society

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18 **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.
20 analyzed the geographic and remote sensing data. All authors contributed to the interpretation of the
findings and the writing of the paper.

22

Data availability: Data are available upon request to the authors.

24 **Social adaptive responses to climatic degradation: insights from a pre-Hispanic Andean society**

Abstract

26 The scarcity or unpredictability of natural resources is a threat to the equitable distribution of wealth
and power within societies. Under these difficult conditions, economic defensibility theory predicts a
28 greater sustainability of large and mobile human groups, accompanied by an increase in inequality. Is
this increase in political and economic inequality inevitable? Our in-depth archaeological study of
30 the arid Andean highlands of Bolivia reveals the development of a complex agrarian society in a
harsh environment marked, moreover, by a prolonged climatic degradation from the 13th to the 15th
32 centuries. The 49 residential settlements studied were all structured around independent households
that managed their own economic resources. A detailed study of the granary and housing structures
34 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
36 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
38 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
40 social and wealth inequality, similar to other well-established horticultural and agricultural societies
around the world. Enriching the theory of economic defensibility, we propose a conceptual model of
42 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
44 natural resources. The sustainability of the society is then guaranteed by a balance between collective
action and family-based social organization.

46 **Keywords:** Andean highlands; archaeology; economic defensibility theory; Gini indices; social
inequality

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56

INTRODUCTION

58 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
60 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,
62 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
64 the regional society. At each scale, collective action generates different practices and institutions for
different purposes. These typically include food production and storage at the household level,
66 communal norms for access to natural resources at the territorial level, and trading routes or defense
against enemies at the regional or state level. At each scale, group size and decision making
68 procedures determine the ways that individuals and groups cooperate towards common interests
(Mattison et al. 2016, DeMarrais and Earle 2017). In ancient societies without writing, these essential
70 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
72 degree of social differentiation.

While current research brings many insights about the social and political drivers underlying
74 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. Many societies survived
76 and even flourished in deserts, high mountains, or through prolonged climate anomalies (Spielmann
et al. 2011, Balbo et al. 2016, Cruz et al. 2017, Gregorio de Souza et al. 2019), while others became
78 vulnerable and collapsed (Douglas et al. 2015, Kennett and Marwan 2015). The relative importance
of ecological and social drivers on the historical trajectory of past societies remains a subject of
80 debate (Calaway 2005, Butzer 2012). The theory of economic defensibility predicts the sustainability
or resilience of local populations in different environments, articulating the availability, density,
82 patchiness, or predictability of natural resources with the strategies developed by local populations to
use these resources (Mattison et al. 2016). Economic defensibility posits that localized, patchy or
84 predictable resources are worth controlling by small groups or individuals establishing territorial
exclusivity, while sparse or ephemeral resources are used at lower costs by large and mobile groups
86 exchanging information (Dyson-Hudson and Smith 1978). Yet, other theoretical studies identify
equitable access to natural resources and reduced social inequalities as prerequisites for sustainability
88 under environmental constraints (Ostrom 1990, Steffen and Smith 2013). These issues of social
equity in the context of environmental stressors highlight the importance of political economy and

90 collective action for the sustainability of human-nature relationships. Apart from the socioeconomic
aspects, human settlement strategies are also charged with symbolic values attached to geographical
92 spaces, especially in the mountains (Contreras 2010, Sarmiento et al. 2017). Though ecological
factors should not be used to ignore these social and cultural components of any livelihood strategy,
94 we argue that for premodern societies in harsh or rapidly changing environments the prevalence of
natural limitations and hazards in their daily life justifies a focus on environmental factors. Here
96 again, archaeological hindsight can help evaluate the social or technical solutions implemented by
resilient past societies.

98 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
100 15th centuries. Furthermore, after 1257 CE, this society thrived despite prolonged climate
degradation following large volcanic eruptions (Swingedouw et al. 2017). Despite insufficient annual
102 rainfall that does not cover the water requirements of a complete annual crop cycle, an agricultural
system excluding irrigation has been successfully implemented. This highly surprising fact was
104 based on the use of biennial fallowing which, thanks to the accumulation of water in the soil, allows
for a crop to be harvested every two years (Cruz et al 2017). This solution, not very common but
106 applied in other arid areas of the world (Passioura and Angus 2010, Schillinger 2016), contrasts with
the practice of irrigation usually adopted by societies facing similar environmental limitations
108 (Spielmann, et al. 2011). The high level of agricultural production in this context was thus achieved
through agricultural knowledge based on a thorough understanding of agro-ecological constraints,
110 without resorting to costly landscape modifications such as irrigation channels or terraces (Pouteau et
al. 2011, Cruz et al. 2017, Winkel et al. 2018). This resource use strategy was close to the
112 horticulturist and limited labor models of agrarian societies (Hillier and Hanson 1984, Kaplan et al.
2009, Barbaza 2018).

114 In this paper, based on new archaeological data, we expand our understanding of how this society
organized itself studying social adaptive responses to climate degradation. We analyze the settlement
116 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
118 capacity, two proxies of material wealth status in archaeological records (Bogaard et al. 2018, Kohler
and Smith 2018). Then, using the conceptual frameworks of economic defensibility (Dyson-Hudson
120 and Smith 1978) and eco-social interactions (Kaplan et al. 2009), we propose a new model of
resilience in small agrarian societies exposed to harsh and unstable environments enriching the

122 evolutionary model of persistent inequality in small-scale societies under climate stability elaborated
by Mattison et al. (2016).

124 **MATERIALS AND METHODS**

Study area, archaeological and field survey

126 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
128 arid climate with more than 260 nights of frost per year, a daily thermal amplitude that may exceeds
30 °C, and an annual precipitation limited between 150 and 300 mm. Furthermore, this region faces
130 large inter-annual and intra-annual rainfall variability and so a high level of unpredictability of
rainfall (Geerts et al. 2006). Paleoclimatic indices attest to a sustained aridity between 1100 and 1500
132 CE 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
134 1280 CE, induced climate degradation characterized by precipitation and temperature drops that
lasted several decades (Swingedouw et al. 2017).

136 We conducted archaeological research over this region between 2007 and 2017 in order to identify
and characterize 49 pre-Hispanic sites in a 1800 km² area. Aerial and field archaeology was
138 supplemented by geomorphological, agroecological, historical, sociological and ethnographic studies
of current populations (Winkel et al. 2016). Systematic studies, including field surveys, sampling,
140 excavations and analysis of material culture were carried out at 12 of these settlement sites. Based on
aerial photographs taken by a kite system and a fixed wing drone, high-resolution maps of the 12
142 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, chronology,
144 high resolution imagery processing and mapping).

Housing and storage structures statistical analysis

146 Analysis of distribution of 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-
148 parametric ANOVA using Kruskal-Wallis test. Dunn's multiple comparison tests were next
calculated to compare median values of each site against all sites median values.

150 **Gini coefficient calculation**

The use of a coefficient to compare levels of wealth inequality between populations, communities or
152 societies requires that several prerequisites be met (Deininger and Squire 1996). The observation

units must be comparable and of low aggregate level (household or individual), the quantitative
154 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
156 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
158 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
160 that have not been significantly altered since their abandonment at the end of the LRDP. This
exhaustive coverage allows us to characterize any household heterogeneity potentially present within
162 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
164 Ellyson 2018).

The variables under study were for each household unit the total housing space (THS), corresponding
166 to the sum of room surfaces and the total storage capacity (TSA), i.e. the sum of granaries surfaces
(see Appendix 3 for the choice of the variables). Lorenz curves and Gini coefficients for each site
168 were calculated on the basis of clearly identified home structures (see above) corresponding to
family units. These calculations were based on a proxy for per capita indices commonly used in
170 economics, which hypothesize that the number of rooms in each household is proportional to the
number of family members. Since storage units were always found outside houses, and rooms were
172 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 seek to aggregate them in order to
174 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
176 variable, the second following UNDP (2010) and Oka (2018) considers a composite index based on
the geometric mean of previous single-variable coefficients into a single coefficient (see Appendix 3
178 for the details of calculation).

To test for a relation between settlement size and social inequality, Gini coefficients were correlated
180 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 concern 549 household units, 2767
182 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
184 housing (6%).

RESULTS

186 Settlement patterns, housing and storage structures

188 Systematic observation of an area of 1800 km² led to the identification of 49 settlements located on average only 2.5 km from their nearest neighbor (Fig. 1; Table A2.1). Twenty radiocarbon dates from 18 sites (Table A2.2), together with the settlement pattern and material culture, identify the 190 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 192 agricultural surfaces, the solidity of the stone houses and granaries, and the increasing number of these granaries in each housing unit (see below) clearly indicate that these settlements were 194 established for several generations. Only 4 sites show connections in architectural and ceramic styles to the southward expansion of the Inka and continued occupation during the Late Period (LP) (Fig. 196 A2.1).

We conducted in-depth studies in 12 settlements that combined field surveys and Unmanned Aerial 198 Vehicle (UAV) imagery of the entire sites (Fig. 2, A2.) and built precise detailed maps (Figs. 3 and A1.1). The internal structure of all sites is homogeneous, with no differentiation between sectors or 200 districts that would present a particular organization. Well-defined units with boundaries marked by low perimeter walls, housing and granaries structured all sites. Likewise, in all the sites, squares and 202 open collective spaces were identified, as well as multiple paths that allowed the circulation and communication between the units.

204 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. A2.2. top left), suggesting 206 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 208 cemented with mortar, they are square or rectangular with an average surface area of 15.4 m² (CV = 28%, n = 1317) (Fig. A2.2 top right). The size of the rooms reflects the limits of roof construction in 210 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 212 household unit is 3.9 (CV = 58%, n = 549) (Fig. A2.2 bottom left). Most granaries demarcate the limits of the household units (72%), while the remaining 28% are located inside the patios of the 214 households or scattered outside them.

The linear relationship between storage area TSA and living space THS per household unit 216 calculated over the 12 sites is highly significant ($TSA = 0.2383 * THS$, $r = 0.5755$, $P < 0.0001$, $n =$

455) (Fig. A2.3). This proportionality highlights the absence of a size effect that would ensure
218 greater storage accumulation for the largest units. This is consistent with the sequential attachment of
granaries—a pattern observed in most household units—that signals a progressive increase in
220 production and storage capacity. Taken together, these characteristics indicate a family ownership,
both in terms of housing and storage.

222 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, circulation within the sites
224 often required passing through the patios of other households (Fig. 4 right), which made these areas
of private household activities also common spaces of transit and meeting (Hillier and Hanson 1984).
226 As 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
228 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 large-scale buildings or outstanding
230 constructions (palaces, temples, or monuments) were identified in any of the sites. Funerary practices
were characterized by collective burial places on the periphery of settlement sites, with tombs located
232 inside rock shelters (Fig. A2.1 bottom left). 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,
234 33, 49, 51) do not show significant differences in the tomb architecture, offerings (mainly ceramic
vessels), and trousseaux (textiles, brooches, cactus thorn combs, etc.).

236 **Social inequality coefficients**

The Lorenz curves present similar patterns at all sites, showing no strong concentration of wealth in
238 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
240 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
242 (THS and TSA). Whatever the coefficient, simple or composite, the values converge towards
moderate regional averages between 0.22 for the composite variable CD05 and 0.26 for TSA (Table
244 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
246 inequalities in the storage capacity of the households do not translate into the size of the housing
space.

248 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
250 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 Jacha' Pucara (site 10)
252 with higher values (Table A3.1). Considering the specificities 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
254 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
256 with the populated settlements of Acalaya and Jacha' Pucara located next to the plains at *ca.* 3700 m.
Easy to access, both sites are the largest housing agglomerations in the region. For 8 other sites,
258 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
260 among the sites. Finally, the Gini coefficients obtained for Capillo (site 35, Fig. A2.1), the only case
showing Inka occupation, reveal values very close to the general averages suggesting that the mode
262 of settlement and social organization was maintained until the conquest and control of the region by
the Inkas.

264 **DISCUSSION**

Our quantitative study over an extended area allows us to argue that relative egalitarianism in social
266 status and wealth played a key role in the adaptation of Intersalar society to worsening climate
change in a high-altitude desert (Cruz et al. 2017). In such conditions in the past, many societies
268 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
270 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
272 Ancestral Puebloans, of Southwestern United States, who developed dry-farming and irrigation
without using draft animals (Spielmann et al. 2011, Bellorado and Anderson 2013, Bocinsky et al.
274 2016, Bocinsky and Varien 2017, Kohler and Ellyson 2018).

Settlement pattern and architecture features

276 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
278 due to the conflictual context supposed to prevail at that time (Arkush 2008, Arkush and Tung 2013).
Although some of the studied sites are located on promontories, none presents defensive structures.

280 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).
282 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
284 includes agricultural and sacred spaces (see Martínez (1983) and Cruz & Joffre (2020) for a
discussion of this polysemy).

286 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.
288 2011). These topoclimatic conditions would have been of critical importance when choosing where
to settle.

290 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),
292 all show a weak architectural differentiation. The presence of isolated granaries could correspond to
the collective food storage for cults and celebrations, a common practice in pre-Hispanic societies.
294 The accessibility of granaries indicates a low risk of theft or looting, whether from inside or outside
the settlements. All these features suggest low social differentiation. We cannot exclude the
296 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
298 hypothesis.

Lorenz Gini inequalities

300 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.
302 2017). They are in the range of the regional political scale (*sensu* Kohler *et al.* (Kohler et al. 2017))
(Fig. A3.2). Gini coefficients for storage units were generally higher than those for housing spaces
304 (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
306 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
308 may have occurred through practices of reciprocity common in Andean societies, or contributions to
collective storage for food security and religious festivities. In our case, the linear proportionality
310 between grain storage area and housing space at household unit level (Fig. A2.3) suggests that this

312 difference is related more to the productive capacities of households in terms of the number of active
persons than to the concentration of wealth.

Regional and historical context

314 The social processes since the beginning of the Regional Development Period (12th-15th centuries)
over south-central Andean highlands led to the formation of different territorial configurations
316 (Bouysse-Cassagne 1987) regionally integrated forming a confederation of nations (Platt et al. 2006).
Nevertheless, archaeological evidences combined with our results suggest that the Intersalar region
318 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
320 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
322 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
324 worth noting that, during the LRDP, none of the polities in the Andean highlands was powerful
enough to claim control over its neighbors. The success of the Intersalar society was not achieved by
326 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
328 model of sustainability and resilience of sedentary societies living in extreme and unstable
environments.

330 An evolutionary model of durable low inequality in agrarian societies living in extreme environments

332 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
334 understanding societies living in extreme environments, where natural resource scarcity strongly
conditions the daily life and survival of populations. Following Kaplan et al. (2009), three ecological
336 and economic dimensions guide our analysis: (i) skill and knowledge in resource production; (ii)
patterns of social leadership and labor cooperation; (iii) resource use strategies. Due to the lack of
338 available information in our data, we will deal only incidentally with the fourth dimension of male-
female relations hinted by Kaplan et al. (2009).

340 Skill 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 socio-ecological system (Gregorio de Souza et al. 2019). The seemingly slight though extended landscape modifications implemented by inhabitants of the Intersalar in the 13th-15th period 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, 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 individuals highly qualified 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 shared by all constituted an immaterial common, a form of "embodied wealth" (Borgerhoff-Mulder et al. 2009, Smith et al. 2010) used collectively. Once built, these landscape transformations also produced a "positive feedback loop" that contributed to stabilizing the social organization necessary to their realization (Langlie 2018). The persistence of the Intersalar agrosystem for more than two centuries demonstrates the adequacy and sustainability of these social and technical solutions to address the worsening climate change.

362 *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 absence of any outstanding monument or urban division into productive, political or religious districts throughout the Intersalar indicates a high degree of political and cultural homogeneity. 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 at the scale of 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

374 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
376 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
378 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
380 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
382 (Kaplan et al. 2009), but it is also the basis for the equitable transfer of the right of access to common
land resources.

384 While 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
386 complexity of the chain of deliberation and decision-making and the relative autonomy of the
settlements might hamper their reactivity and regional coordination, for example in the event of
388 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
390 to size effects and becomes difficult to organize in large groups where internal divisions and conflicts
of interests easily multiply (DeMarrais and Earle 2017).

392 *Resource use strategies*

Land resources in the Intersalar can be considered in some way homogenous, with no patches of rich
394 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
396 watercourses) do not favor the concentration of water in space. However, local farmers found how to
concentrate it over time through biennial fallowing (Cruz et al. 2017), a practice that requires large
398 areas, unfavourable 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
400 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.
402 The absence of draft animals required labor cooperation to enable hand-cultivation of the large areas
needed to compensate for the low productivity of drylands. By making it easier to collectively defend
404 the land, commoning could also have been an adequate strategy against possible pressure of
neighboring groups.

406 Food storage is another essential aspect of resource use, as building up food stocks ensures food
security and avoids prolonged emigration. Many dry farming societies around the world continue to
408 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
410 known archaeological site in the dry Andes.

An evolutionary model of durable low inequality

412 Mattison's evolutionary model of inequality highlights the central role of resource defensibility and
wealth transmission enabled by climate stabilization (Mattison et al. 2016). Indeed, Mattison et al.
414 considered a 100 ky time scale to differentiate a "stable" Holocene from the previous Ice Age.
Keeping the centrality of the concept of defensibility, we propose a model of durable social cohesion
416 and low inequality in societies facing extreme or unstable environments on shorter time scales (Fig.
5). Our model examines instability *within* the Holocene, a 12 ky period marked by prolonged secular
418 climatic anomalies (e.g. the Medieval Warm Period *ca.* 950-1250 CE, or the Little Ice Age *ca.* 1300-
1850 CE) to which are superimposed shorter climatic oscillations (e.g. ENSO events).

420 What we add to Mattison's et al. model is evidence that, in unstable environments, undefensible
resources may be durably managed by egalitarian societies. In the absence of defensibility, the
422 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
424 cooperation did not mean full collectivization of the food production and daily life. Instead, they
suggest that the intergenerational family system described by Kaplan et al. (2009) remained the
426 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
428 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
430 resilience in a 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
432 varieties (D'Alpoim Guedes et al. 2015, Winkel et al. 2018), coupled to the development of
alternative cropping practices and social organization (Bellorado and Anderson 2013).

434 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
436 landesque capital, which involves agricultural landscape modifications aimed at long term risk
minimization rather than short term yield maximization. Although the causality between social

438 stratification and agricultural intensification is still debated (Sheehan et al. 2018), these studies, like
ours, suggest that autonomous rather than centralized social organization is key for the
440 socioecological resilience to climate disturbances.

A significant result of our study concerns the multiscale social cohesion of an agrarian population,
442 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
444 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
446 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
448 other. This non-hierarchical and self-regulating social model was not anecdotal, since it covered a
vast area and allowed for the development and coexistence of numerous settlements for more than
450 two centuries. Collective action principles and values combined with shared skill and knowledge
were thus put to the service of the resilience of the whole society, compensating for the lack of
452 material technology and draft animals, in order to cope with a harsh and unpredictable environment.

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Figures in the Main Text

Fig.1. Location map of 49 archaeological sites identified in the Intersalar region. Numbers refer to site identification in Table A2.1.

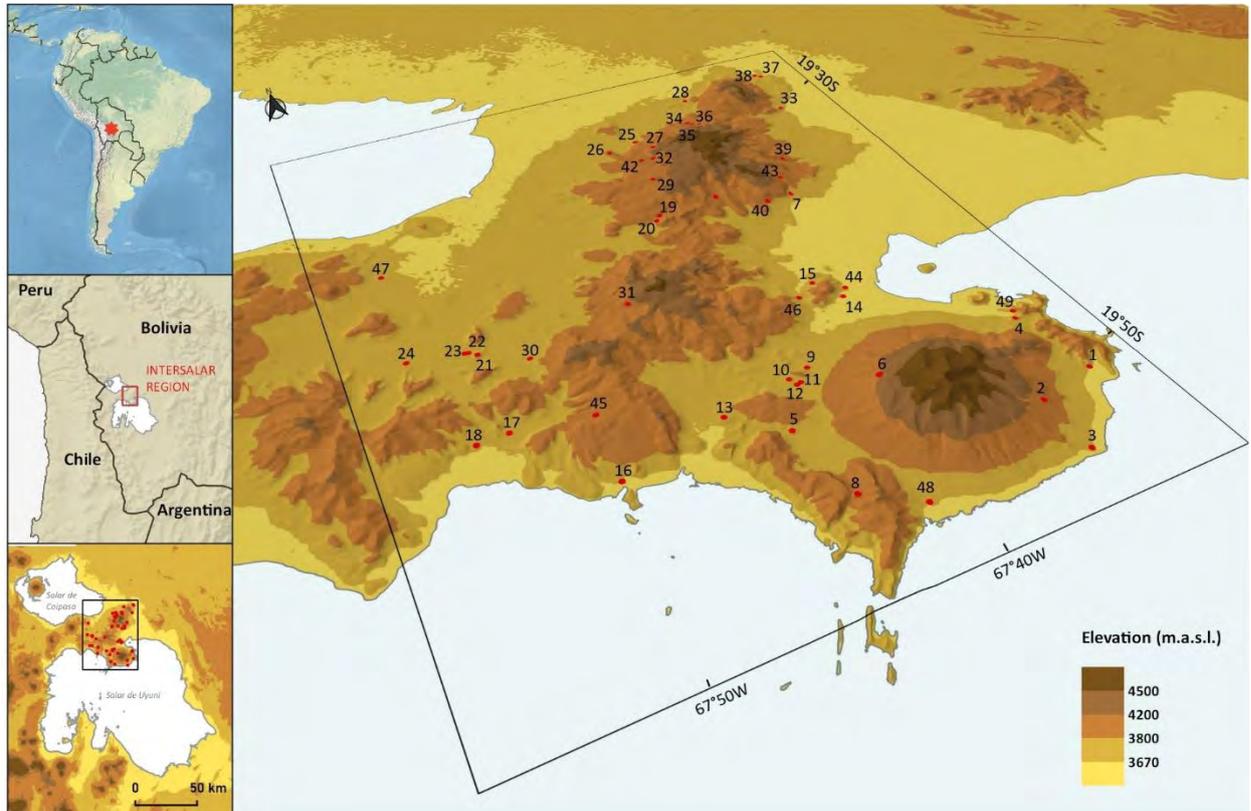


Fig. 2. High-resolution aerial photographs (left panel) and interpretative map (C) of the archaeological site of Acalaya, Intersalar Region. Aerial photographs with ground resolution of 15 mm/pixel were used to map household units individualized with different colors, based on the pattern of rooms around patios with granaries (Photo credits: Bruno Roux, L'Avion Jaune).

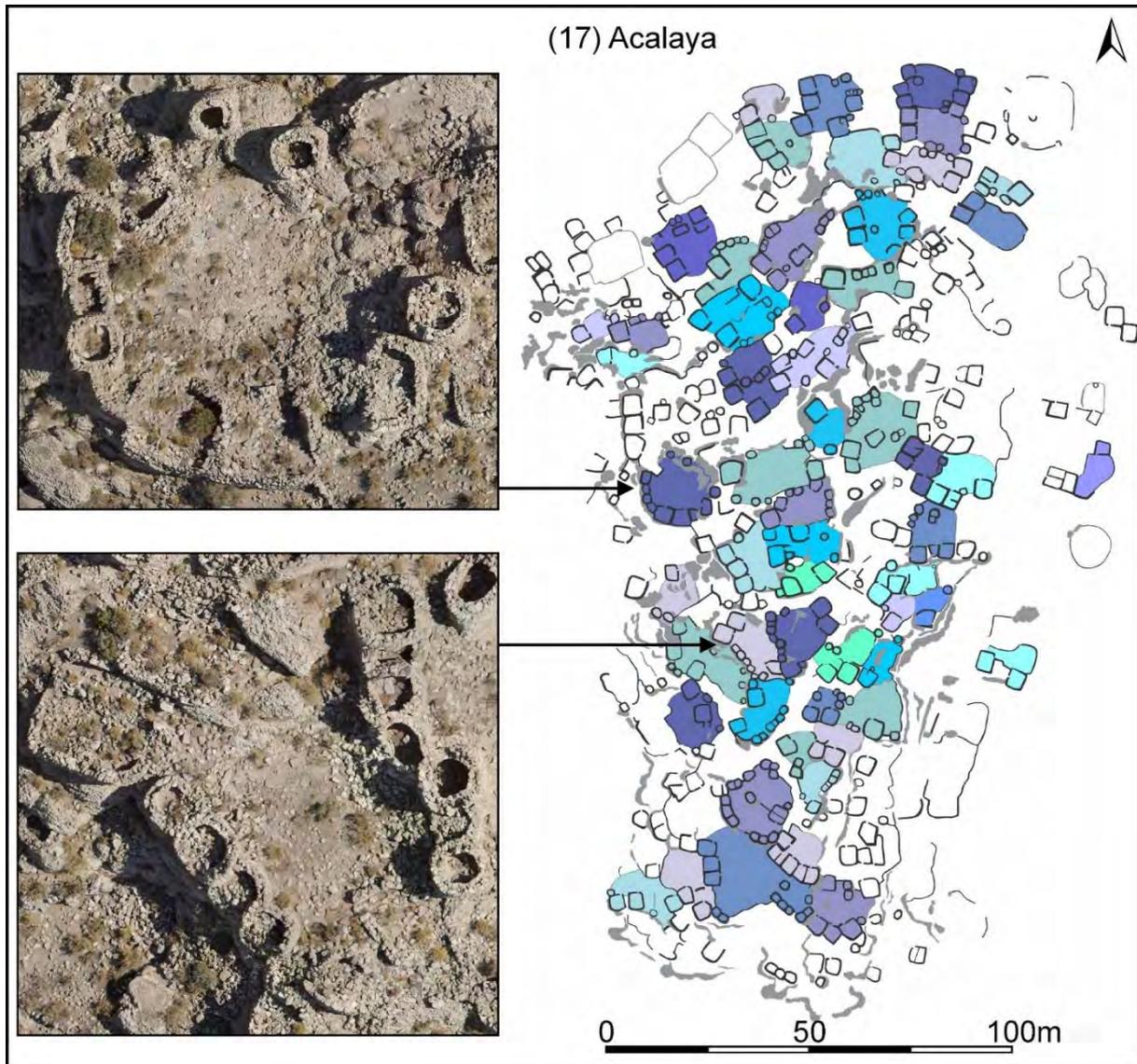


Fig. 3. Detailed maps of 4 study sites in the Intersalar region. Shaded areas show open collective spaces. Site numbers and names refer to identification in Fig. 1 and Table A3.1. (The maps of 8 other study sites are presented in Appendix 1 Fig. A1.1).

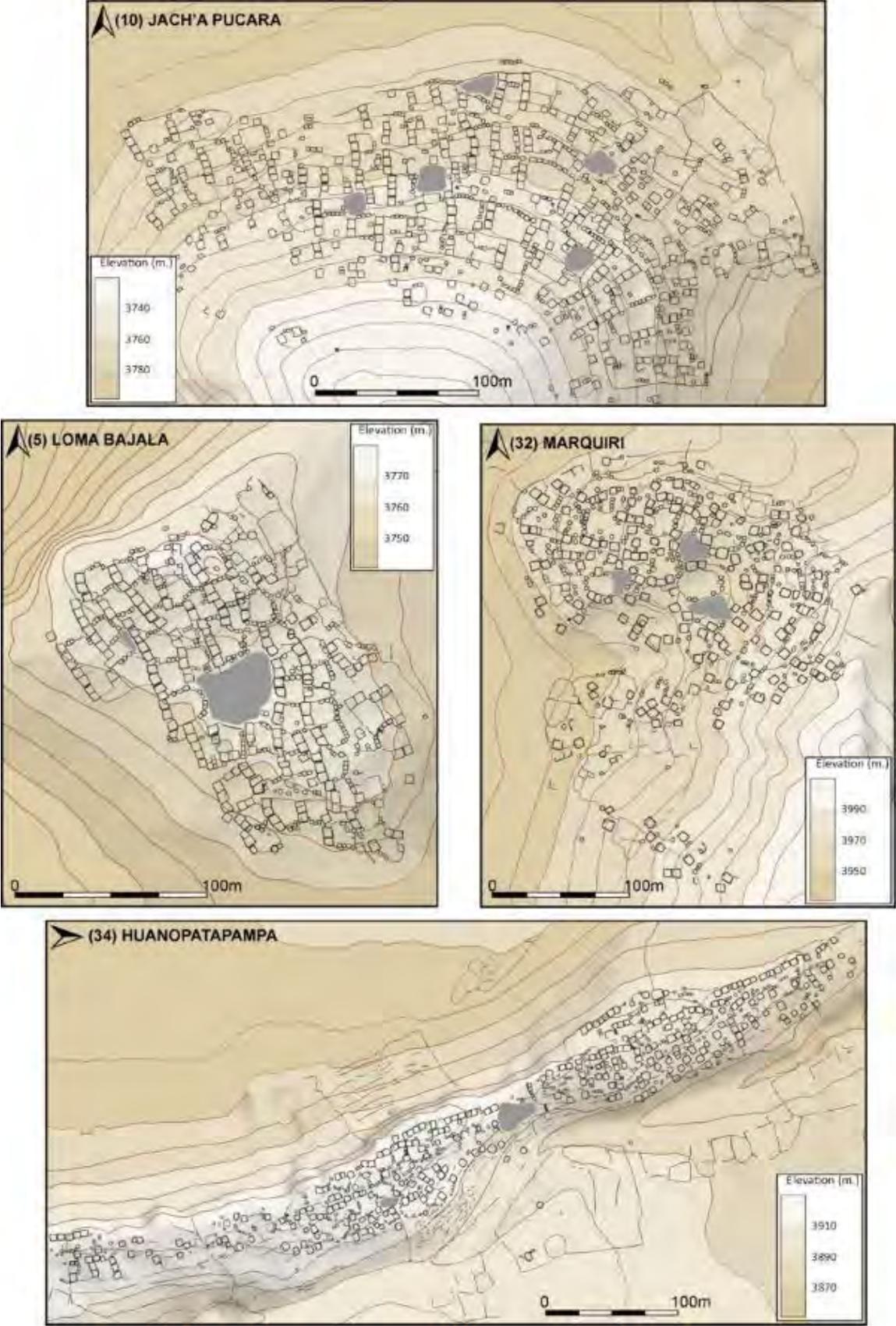


Fig. 4. Map of Loma Bajala (site 5) showing conglomerated structure (A) and circulation (B).

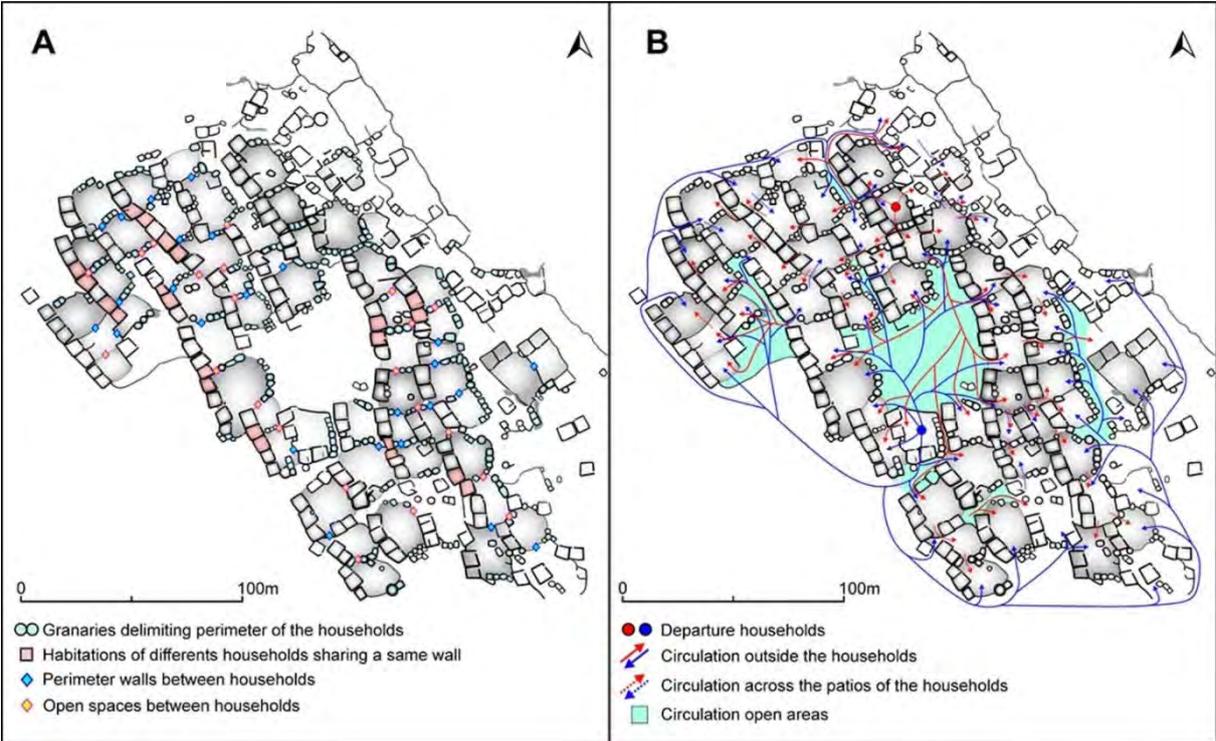
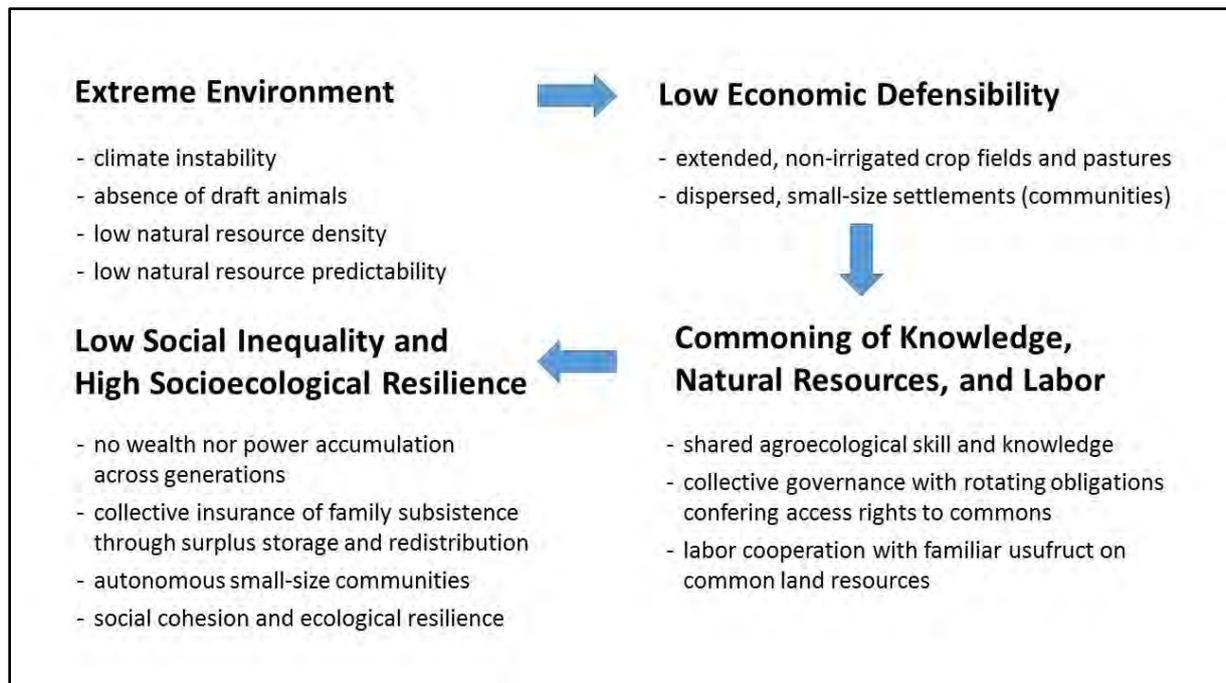


Fig. 5. An evolutionary model of durable low inequality in agrarian societies living in extreme environments. (Adapted from Mattison et al. 2016).



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.

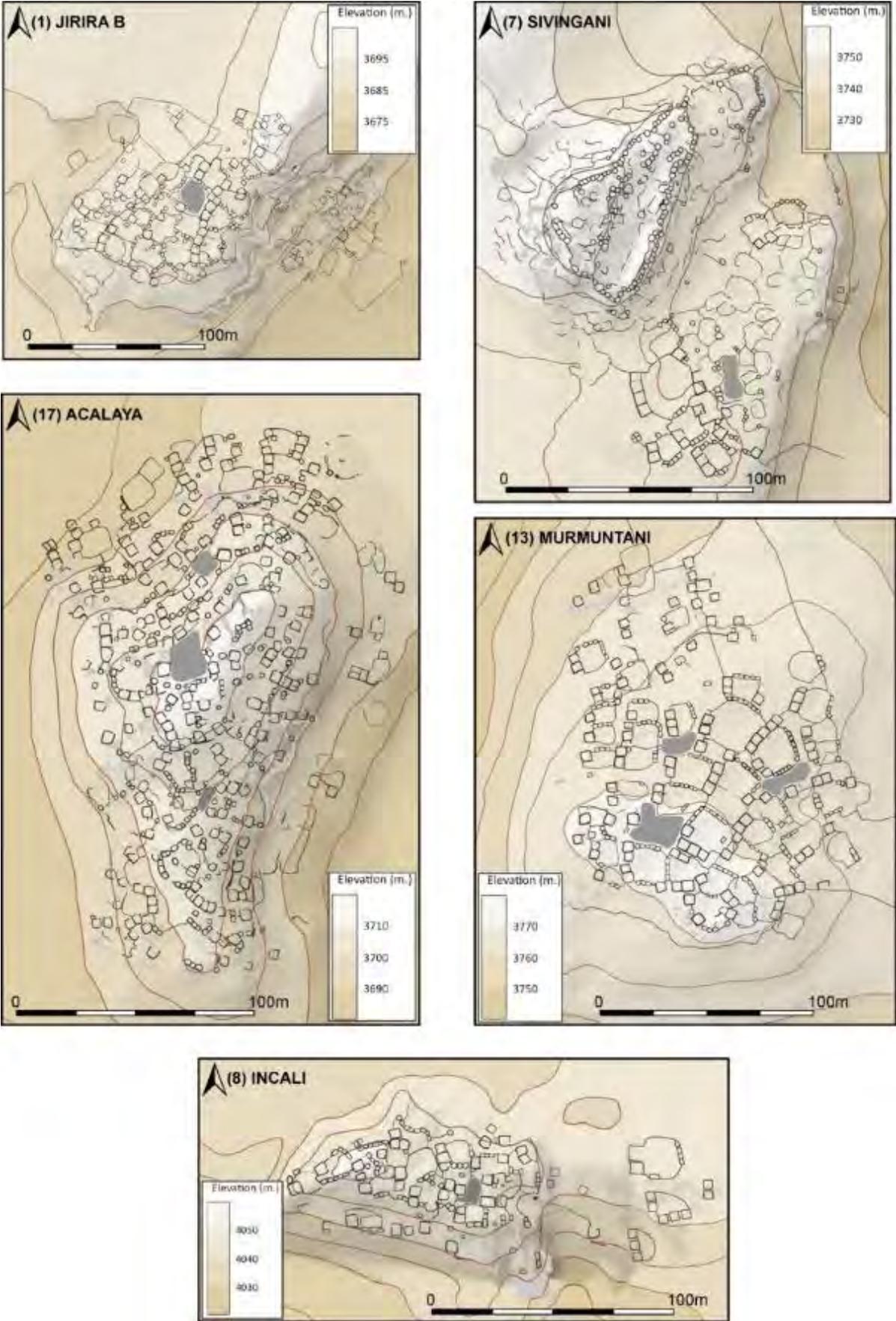
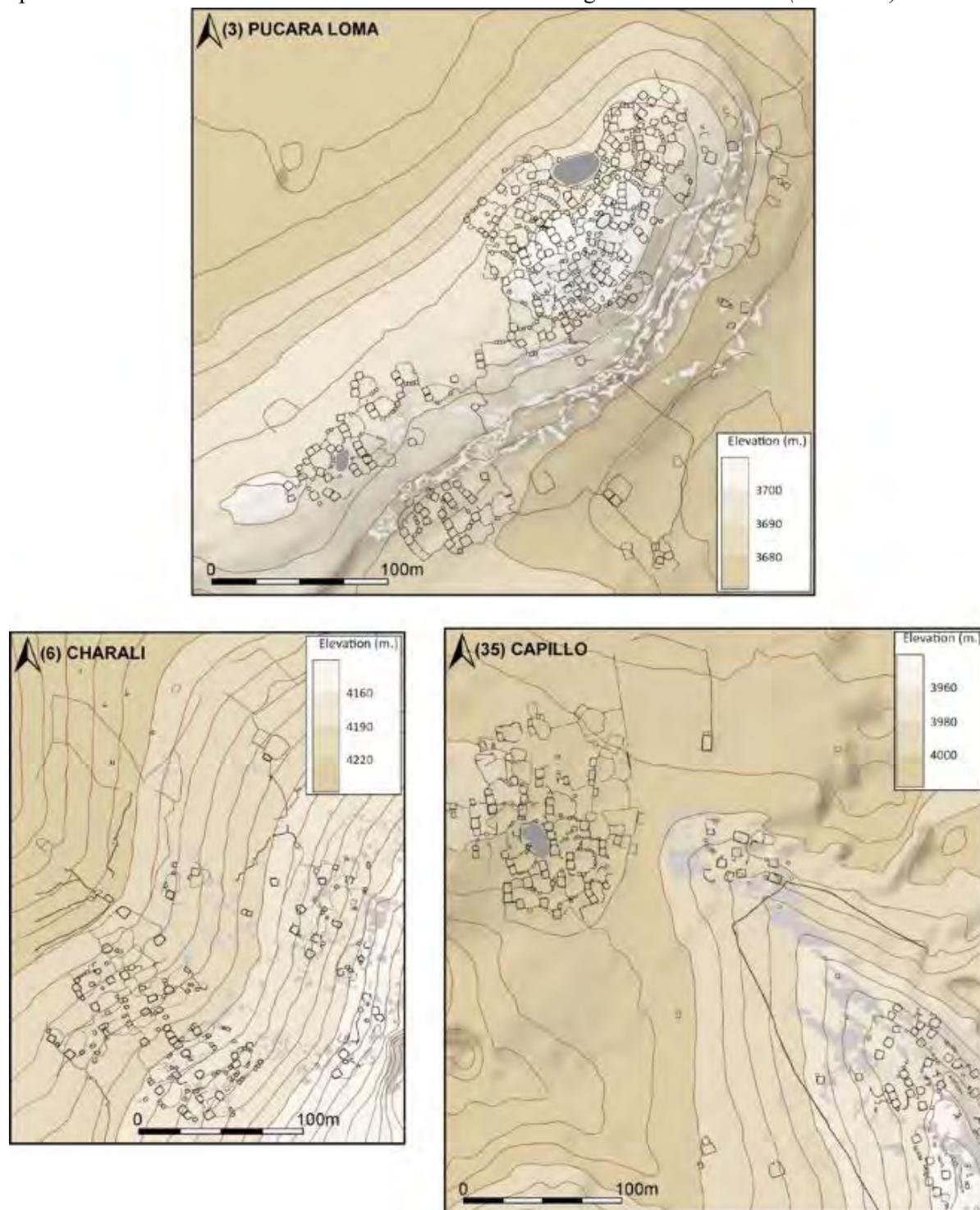


Fig. A1.1. Detailed maps of the study sites in the Intersalar region. Shaded areas show open collective spaces. Site numbers and names refer to identification in Fig. 1 and Table A3.1. (*continued*)



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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'	67° 33' 15.03"	3682
2	Cheka-Cheka	19° 51'	67° 36' 03.34"	4039
3	Pucara Loma	19° 53'	67° 35' 21.06"	3688
4	Chullpa Cuchu	19° 47'	67° 34' 13.60"	3694
5	Loma Bajala	19° 49'	67° 44' 11.46"	3777
6	Charali	19° 48'	67° 40' 33.06"	4208
7	Sivingani	19° 37'	67° 37' 28.80"	3743
8	Incali	19° 52'	67° 43' 46.62"	4035
9	Loma Pucara	19° 46'	67° 42' 11.16"	3767
10	Jach'a Pucara	19° 47'	67° 43' 04.58"	3767
11	Saitoco 3	19° 47'	67° 42' 48.40"	3734
12	Saitoco 4	19° 47'	67° 42' 58.80"	3729
13	Murmuntani	19° 48'	67° 44' 58.43"	3760
14	Cerro Puchucaya	19° 44'	67° 38' 55.60"	3677
15	Pucara Puchucaya	19° 42'	67° 39' 35.20"	3741
16	Loma Chiquini	19° 48'	67° 49' 56.60"	3696
17	Pucara Loma Acalaya	19° 45'	67° 52' 28.30"	3690
18	Loma Acalaya	19° 45'	67° 52' 29.00"	3709
19	Pucara Viantarani	19° 36'	67° 43' 09.50"	3888
20	Cerro Panturani	19° 37'	67° 43' 34.70"	3779
21	Cerro Pucara	19° 41'	67° 52' 17.70"	3764
22	Kothoña Pampa Loma	19° 41'	67° 52' 33.60"	3688
23	Pucara Kothoña 2	19° 41'	67° 52' 40.20"	3689
24	Uta Chuto	19° 40'	67° 54' 39.71"	3691
25	Cayo Palca 1	19° 30'	67° 41' 40.82"	3902
26	Cayo Palca 2	19° 31'	67° 43' 04.59"	3839
27	Cayo Palca 3	19° 31'	67° 41' 14.31"	4090
28	Cacota	19° 28'	67° 37' 56.43"	3790
29	Huerta Lakha	19° 34'	67° 42' 27.81"	4200
30	Loma Wila Pucara	19° 42'	67° 50' 42.78"	3738
31	Villa Pucara Faldas	19° 41'	67° 46' 39.82"	4100
32	Marquiri	19° 32'	67° 41' 42.01"	3980
33	Cerro Pucara	19° 30'	67° 34' 02.42"	3759
34	Huanopatapampa	19° 30'	67° 38' 49.49"	3950
35	Capillo	19° 30'	67° 38' 40.68"	3992
36	Quebrada Paicori 3	19° 31'	67° 38' 38.07"	4061
37	Pucara Chusquiri 1	19° 27'	67° 33' 21.61"	3706
38	Pucara Chusquiri 2	19° 27'	67° 33' 35.46"	3696
39	Pucara Rancho Pitca	19° 35'	67° 36' 27.10"	4019
40	Pucara Pisalague	19° 37'	67° 38' 40.54"	3836
41	Pucara Anchohoca	19° 36'	67° 40' 32.70"	3925
42	Marquiri 2	19° 32'	67° 42' 07.56"	3920
43	Quebrada Sivingani	19° 36'	67° 37' 26.92"	3969
44	Cerro Puchucaya 3	19° 43'	67° 38' 34.51"	3669
45	Cerro Yarıpunta	19° 46'	67° 49' 43.17"	3950
46	Ancoyo	19° 43'	67° 40' 21.96"	3693
47	Pucara Luca	19° 35'	67° 54' 21.88"	3721
48	Loma Iglesia	19° 53'	67° 41' 52.04"	3679
49	Illamalla	19° 47'	67° 33' 49.50"	3690

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

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

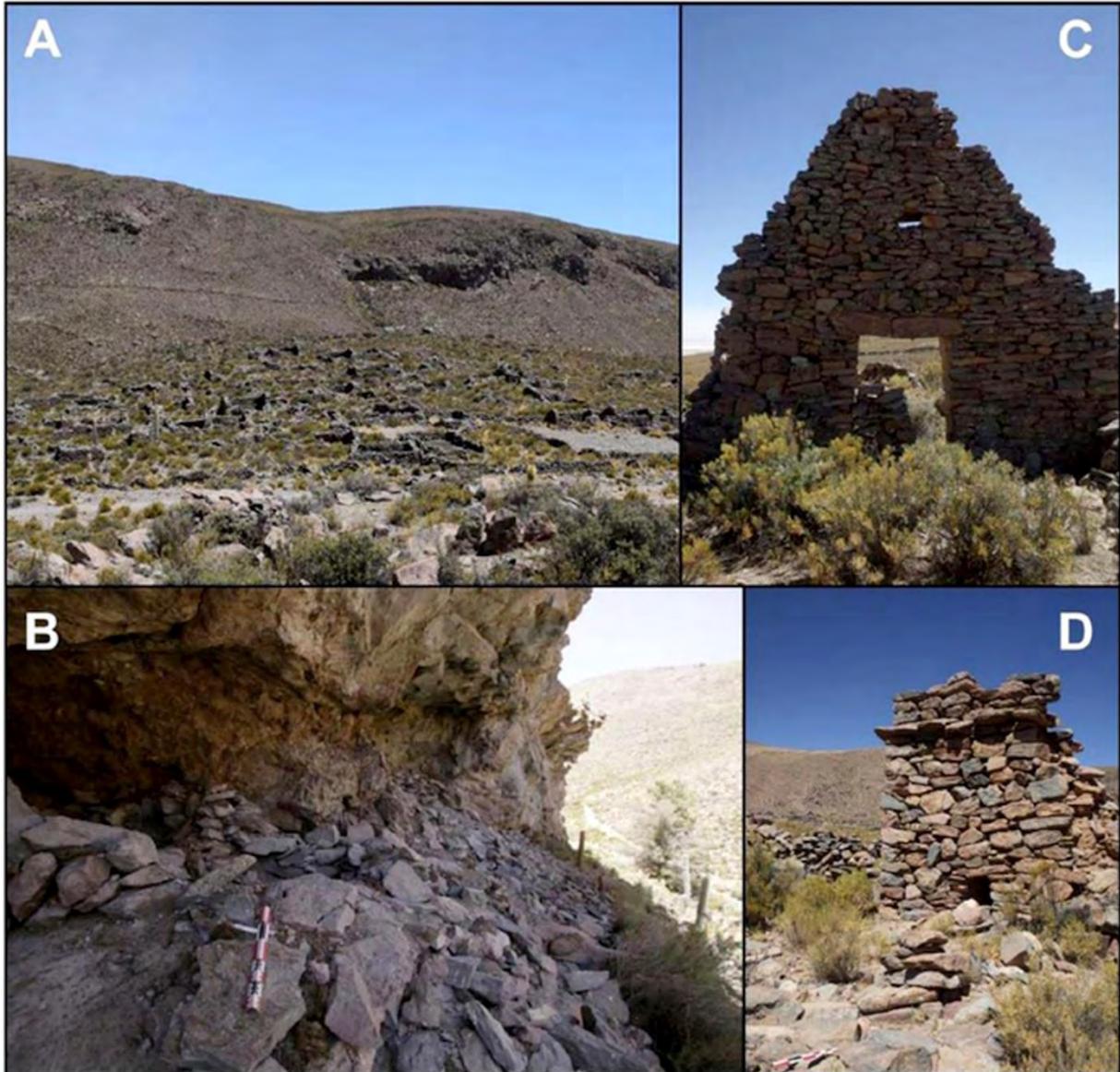


Fig. A2.2. Frequency distribution of housing and grain storage units. (A): Number of rooms per household unit (n = 549), (B): Individual room area (n = 1317), (C): Number of granaries per household unit (n = 549), (D): Individual granary area (n = 2767).

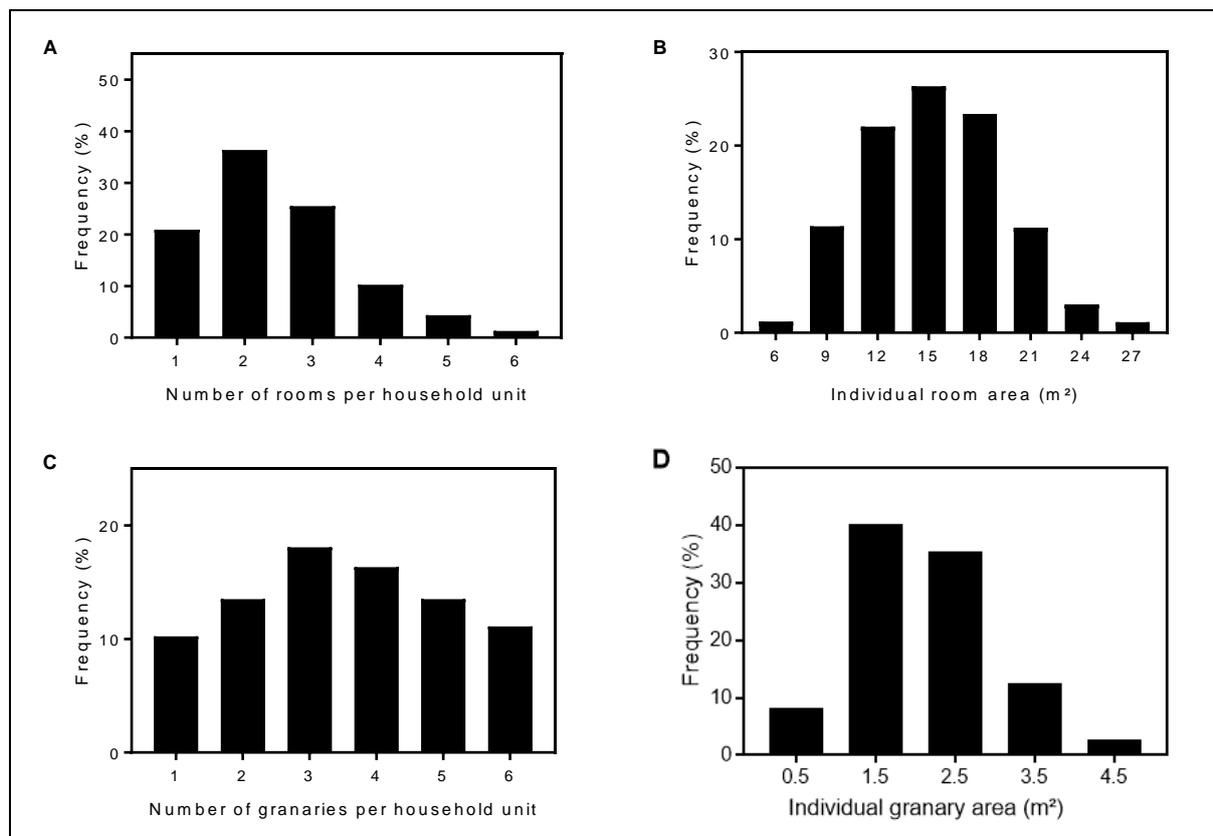
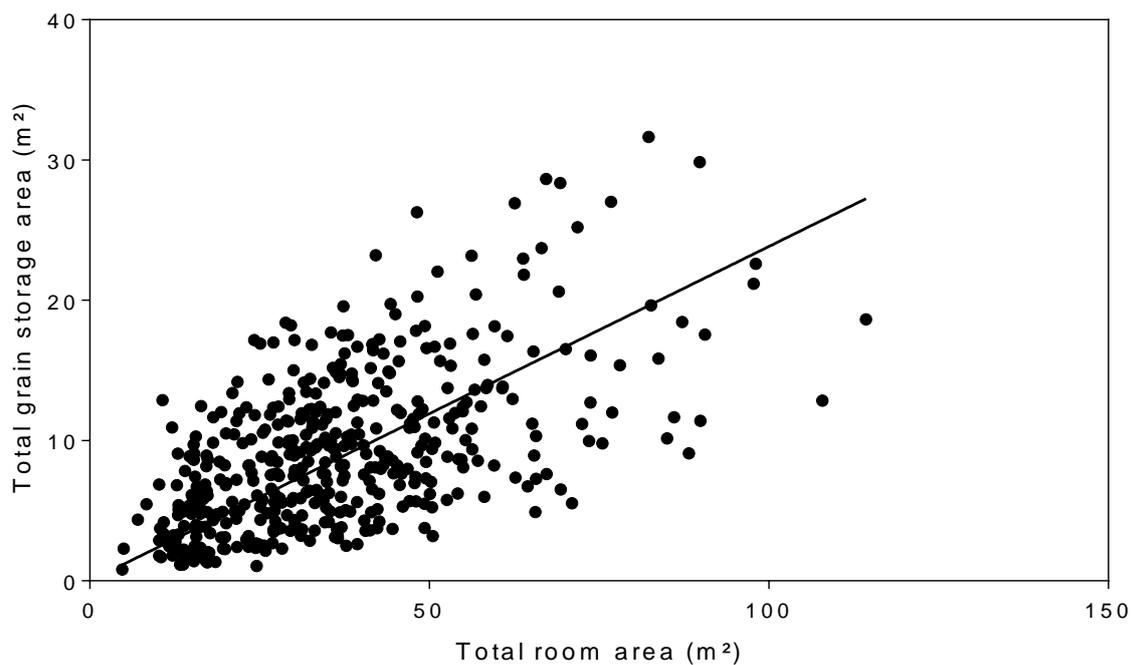


Fig. A2.3. Relationship between total grain storage area (m²) and total room area (m²) per household unit ($r = 0.576$, $P < 0.0001$, $n = 455$).



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 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 :

$$W_i = \text{THS}_i^\alpha \cdot \text{TSA}_i^{(1-\alpha)}$$

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:

$$\text{CAI-W} = (\text{Gini_THS})^{0.5} \cdot (\text{Gini_TSA})^{0.5}$$

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.

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 $\alpha = 0.25$ 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
Jacha 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
Huanopata pampa	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		

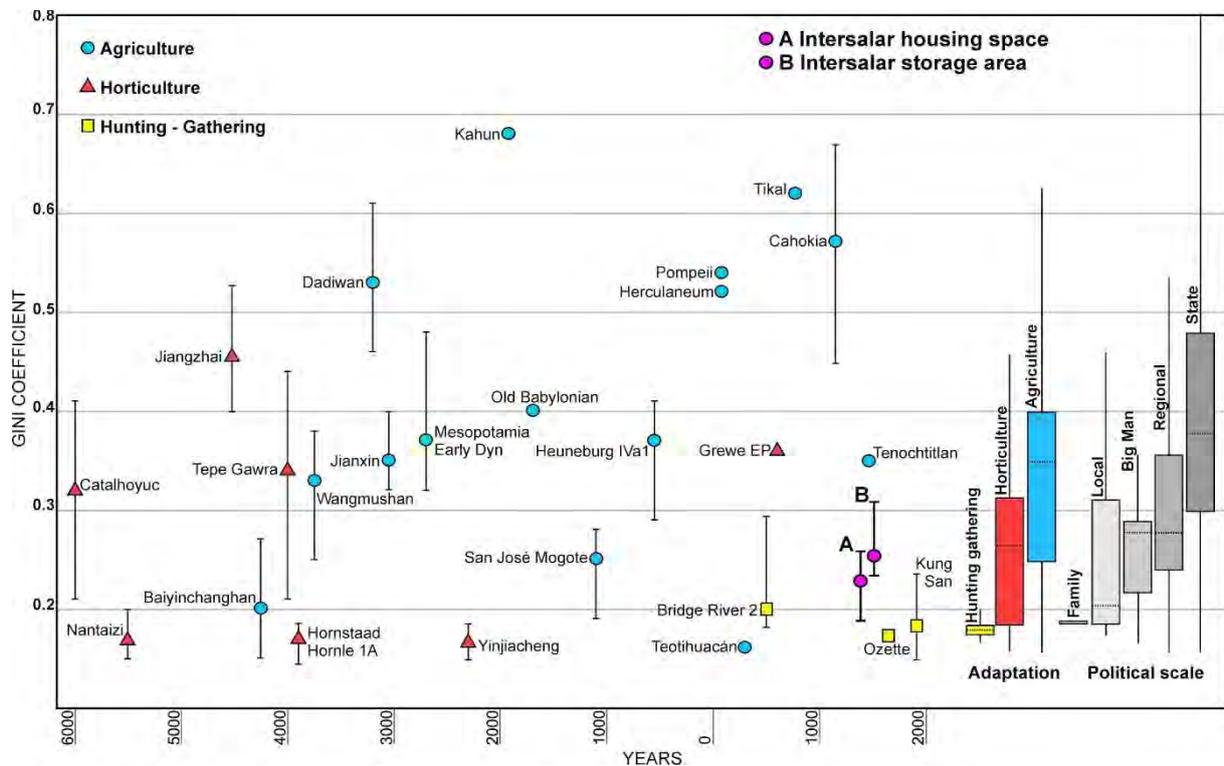
	Site n°	Household number	CD 02			CD05		
			Mean	10%	90%	Mean	10%	90%
Jirira	1	37	0.210	0.182	0.240	0.200	0.174	0.228
Ayque	3	40	0.219	0.192	0.245	0.205	0.177	0.231
Loma Bajala	5	56	0.211	0.189	0.232	0.189	0.165	0.213
Charali	6	22	0.231	0.193	0.274	0.211	0.173	0.251
Sivingani	7	10	0.242	0.173	0.303	0.243	0.177	0.308
Incali	8	10	0.100	0.063	0.133	0.097	0.059	0.132
Jacha 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
Huanopata pampa	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		

	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
Jacha 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 $\alpha = 0.25$ 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 storage 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

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).



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