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**Research Article: GeoPACHA**

# A new view of hillforts in the Andes: expanding coverage with systematic imagery survey

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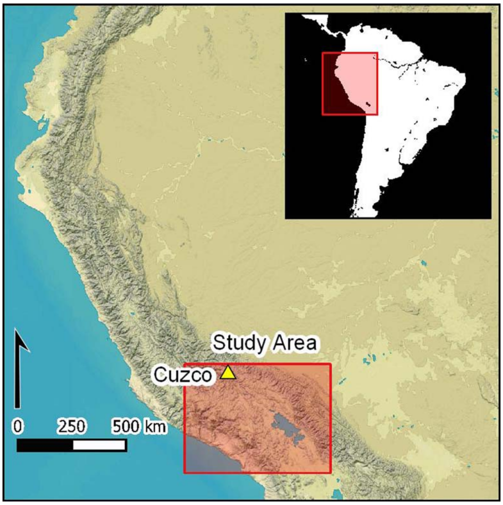


In the Andean highlands, hilltop fortifications known as *pukaras* are common. Dating predominantly to the Late Intermediate Period (AD 1000–1450), pukaras are important to archaeological characterisations of a political landscape shaped by conflict but the distribution of these key sites is not well understood. Here, the authors employ systematic satellite imagery survey to provide a contiguous picture of pukara distribution on an inter-regional scale covering 151 103km$^2$ in the south-central highlands of Peru. They highlight the effectiveness of such survey at identifying pukaras and capturing regional variability in size and residential occupation, and the results demonstrate that satellite surveys of high-visibility sites can tackle research questions at larger scales of analysis than have previously been possible.

Keywords: South America, Andes, Late Intermediate Period, satellite imagery survey, fortification, conflict

## Introduction

In the Andes, the term *pukara*, meaning fortress in both Quechua and Aymara, refers to a wide range of defensive sites that are strategically positioned on hills and ridges and protected by built defences (walls, ditches) and natural barriers (cliffs, steep slopes). This is a common and widespread category of site, especially in the Andean sierra. Pukaras are highly visible in archaeological landscapes, and often have good architectural preservation (Figure 1). The

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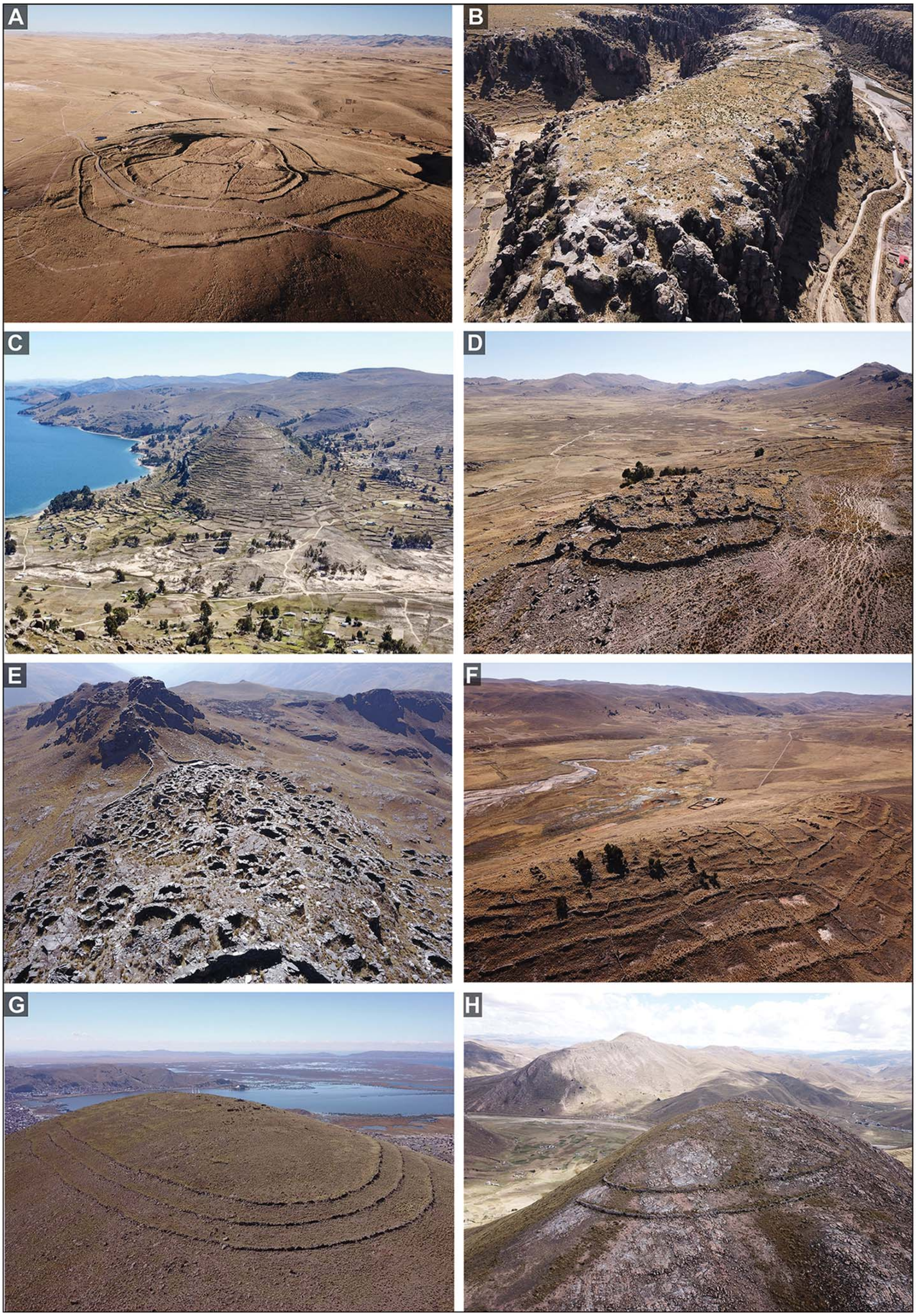


*Figure 1. Pukaras in the survey area. Sites occupy hilltops (A, C, D, F, G, H), ridgelines (E), and high plateaus (B) with significant natural defences that include steep slopes, cliffs (B), and rock outcrops (D & E). Built defences, such as perimeter walls and ditches (A) are highly visible in satellite imagery. Built defences are often well-preserved due to both their monumentality and the remoteness of the sites. Both residential (A–F) and non-residential (G & H) sites are found throughout the survey area (figure by authors with drone photographs by Ryan Smith and Christophe Delaere/ALTI-plano).*





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largest sites have been the subject of substantial research (Hyslop 1976; Lavallée & Julien 1983; Hastorf 1993; Tarragó 2000; Nielsen 2002; Kellett 2010; Arkush 2011; Kohut 2016; Álvarez Larrain & Greco 2018; Connell *et al.* 2019). For the south-central highlands, ceramic chronologies and radiocarbon dates place these sites overwhelmingly in the Late Intermediate Period (hereafter LIP; AD 1000–1450), especially after AD 1300 (Arkush *et al.* in press); with a few examples of pukaras having additional earlier, Formative to Early Intermediate (*c.* 500 BC–AD 200), or later, Late Horizon (hereafter LH; AD 1450–1532), occupation. Pockets of defensive settlement patterns dating to the LIP are known from the highlands and upper coastal valleys along almost the entire spine of the Andean cordillera (mountain range), aligning with high rates of violence in skeletal remains (see, for example, Covey 2008; Arkush & Tung 2013; Arkush 2022; McCool *et al.* 2022). Pukaras thus form an important component of LIP settlement systems oriented toward defence.

Scholars have proposed a variety of social and environmental drivers of conflict during the LIP. Political explanations have suggested that the disintegration of the expansive Middle Horizon states of Wari and Tiwanaku, which dominated the highlands from around AD 600–1000, produced a factionalised political geography composed of local settlement clusters and larger confederacies in variable relations of competition, complementarity and conflict (Hyslop 1976: 134; Kolata 1993: 299). Indeed, conflict at varied scales may itself have been generative of regional polity formation (Arkush 2011; Kohut 2022); confederations were likely reinforced by the militaristic expansion of the Inka state through the fifteenth century AD. These processes coincided with, and were likely exacerbated by, a prolonged phase of aridity and climatic volatility evident in several palaeoclimate proxies (e.g. Abbott *et al.* 1997; Bird *et al.* 2011; Thompson *et al.* 2013; Guédron *et al.* 2023). Nevertheless, significant regional differences imply that sociopolitical trajectories followed diverse paths (Covey 2008; Arkush *et al.* in press).

Many questions remain about pukaras, despite recent research. Data on the full extent and intensity of the pukara phenomenon and its distribution remain imprecise, in part because of the limited spatial coverage possible through ground survey. In addition, our understanding of variability among pukaras leaves much to be desired. While pukaras are defined by an evident concern for defence, they vary in size, the presence and density of residential occupation, defensibility, the form of defensive barriers (cliffs, stone walls and/or ditches) and other aspects (e.g. Covey 2008; Arkush 2011; Kohut 2016, 2022; McCool 2017; Housse 2021). Intensive field research has been biased strongly towards large, densely occupied residential pukaras. Non-residential pukaras, often called ‘refuges’, are a particular blind spot: they are noted in the literature but have not attracted much scholarly attention (Figure 1, G and H). Yet this defensive site type, characterised by one or more concentric walls on hilltops with minimal internal architecture or surface ceramics, is a major component of the pukara phenomenon (Parsons *et al.* 2000; Stanish 2003; Arkush 2011; Anderson 2014; Kohut 2016; Williams 2018; Connell *et al.* 2019; Housse 2021). In the absence of residential features, dating these sites is difficult and archaeologists have differed in their tentative chronological assignments (e.g. Bonnier 1981; Parsons *et al.* 2000: 1: 107–12). Our ground visits indicate that, in the south-central highlands, non-residential pukaras can generally be assigned to the LIP based on ceramic typologies and similarities to dateable residential pukaras in wall construction, preservation, mortuary architecture and, occasionally,





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proximity. However, the relationship between residential and non-residential pukaras is poorly understood. Some small non-residential pukaras are associated with residential pukaras and appear to be watch posts, but many do not fit this description, suggesting a diversity of functions.

Questions about the distribution, types and functions of pukaras call for a fundamentally different scale of data that is outside the scope of traditional archaeological field methods. Here, we bring together the results of three complementary systematic satellite survey projects, supplemented with targeted ground-checking and previous field research. Pukaras were defined broadly in these projects in order to encompass and investigate variation. Combined, these surveys provide the first comprehensive, large-scale view of the pukara phenomenon across a more than 150 000km$^2$ region of the south-central Andean highlands. The results presented here highlight the insights to be gained by the expanded spatial scale of this approach and its potential to complement traditional archaeological field methods.

## Methods

High-resolution (approximately 0.5m) satellite imagery is now widely available and has previously been used to detect archaeological features (see Liang *et al.* 2018; Luo *et al.* 2018). Pukaras are particularly well-suited to this approach; their large, linear and concentric arrangements of barriers and strategic hilltop positions make them exceptionally visible and distinctive in satellite imagery. Researchers have previously used aerial and satellite imagery to detect pukaras on a limited and *ad hoc* basis (e.g. Arkush 2011; Brown Vega *et al.* 2011; Kohut 2016); however, it has been difficult for researchers to ensure systematic coverage. By contrast, our projects utilise a systematic grid-based approach to satellite survey that ensures complete imagery coverage. By co-ordinating data collection across teams with experienced archaeologists and undergraduate students, we were able to cover an unprecedented 151 103km$^2$.

The final dataset presented here combines three independent and partly overlapping imagery surveys. The first survey includes two datasets produced using the Geospatial Platform for Andean Culture, History and Archaeology (GeoPACHA; for further details about the project, see Wernke *et al.* 2023), one in the southern highlands to the western shores of Lake Titicaca (regional editor: Wernke) and the other covering the eastern and northern Titicaca Basin to the southern provinces of Cuzco (regional editors: Arkush, Kohut and Smith). Separately and independently, a systematic imagery survey (Housse & Mouquet 2023) covered the southern Titicaca Basin and areas to the south. All surveys focused on highland areas above 2000m above sea level (masl) where pukaras are more frequent. While the specific methods employed by each survey differed somewhat, their overlapping extent offers the opportunity to evaluate their success, and demonstrates complementary approaches to satellite survey. For both surveys, methods and evaluation of results at every stage were informed by our personal field experience working on pukaras and related sites in this region.

For the GeoPACHA surveys, the areas of interest were divided into grid cells measuring 0.02° (approximately 2.2km) on a side, subdivided by 0.01° and 0.005° grids for fine-grain tracking. The south-western survey, shown in grey in Figure 2, was designed as a





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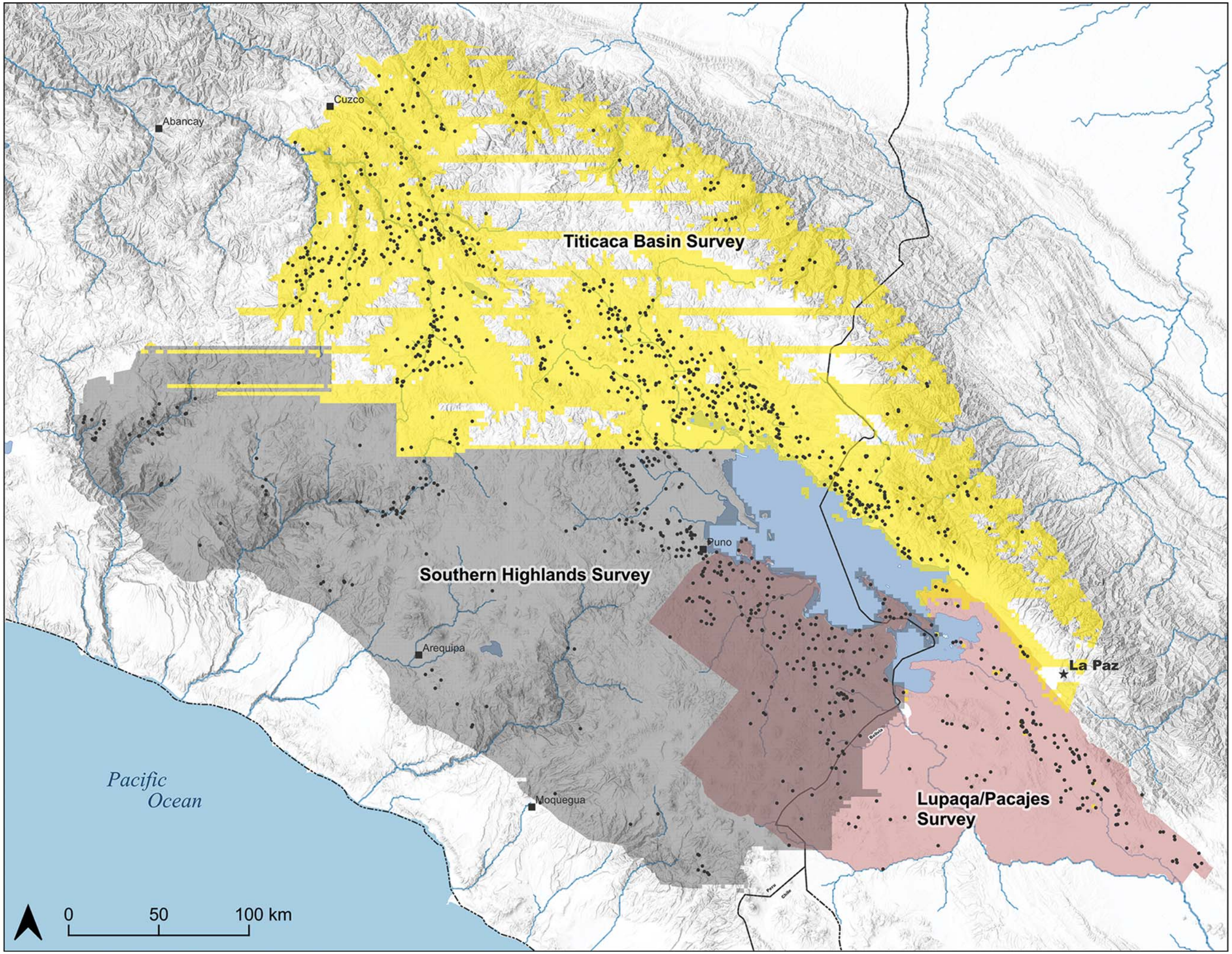


*Figure 2. Overview of the separate survey areas, displaying all high-confidence pukaras identified in satellite imagery (black dots, n = 1210) (figure by authors).*





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complete imagery survey, in which all surface-visible archaeological loci were registered. The north-eastern survey (yellow) focused on pukaras only, broadly defined. In this latter area, the methods were refined iteratively to optimise coverage and efficiency. An exploratory stage surveyed the northern half of the survey area using east-west transects two 0.02° cells in height, spaced 10 cells apart, for 20 per cent coverage. The transect results showed that pukaras were rare to non-existent in the highest altitude zones. Based on these results, only grid cells with a mean elevation at or below 4367masl were surveyed (shown in Figure 2). This altitude exclusion was not applied in the south-western survey (grey) or the separate Lupaca-Pacajes survey (red); however, in those surveys, under three per cent of pukaras identified (13 of 478) were in cells above 4367m mean elevation. GeoPACHA grid cells were initially surveyed mainly by trained student volunteers and Peruvian archaeologists, who were given visual reference guides and step-by-step instructions. Regional editors who had field experience of pukaras then re-examined each surveyed cell to catch false negatives, review loci and attributes, and remove false positives. As a result, each cell was reviewed by at least two surveyors. Pukaras known from field observation or published studies were later added to the dataset and tagged as such. Finally, members of the team (Arkush, Kohut and Smith) conducted targeted field visits to several pukaras.

The Lupaca-Pacajes survey conducted by Housse and Mouquet in the southern Titicaca Basin followed a somewhat different procedure. The limits of the study area were based on early colonial records of the recognised territories of the Lupacas and the Pacajes ethnic groups (Capoche 1959 [1589]: 136). Next, the archaeological literature was inventoried for known sites. For the imagery survey phase, the whole 31 888km$^2$ area was divided into two survey zones and assigned to one of the authors. Each zone was then divided into a grid of 5 × 5km cells. All potential pukaras were recorded and ranked using the following classification: (1) low-confidence pukaras, with ambiguous wall features; (2) high-confidence pukaras with clear defensive arrangements but without visible residential structures; (3) high-confidence pukaras with residential structures. The authors then reviewed loci classified as 1 or 2 from the others' survey zone. Pukaras remaining in the low-confidence class (1) were removed from analysis. Finally, the authors made targeted field visits.

Satellite survey inevitably can result in a non-trivial volume of false positives: in this case non-sites or sites incorrectly identified as pukaras. To identify and remove false positives, after the conclusion of all surveys and the merging of the GeoPACHA and Housse-Mouquet datasets, each 'pukara' locus was systematically assigned a confidence score between zero and four based on location, presence of defensive architecture and presence of residential architecture (Table 1). Loci with confidence scores below 1.5 were removed from the dataset, while those scoring 1.5–2 were coded as low confidence. Low-confidence pukaras are indicated in Figures 3 and 4, but otherwise excluded from the presentation of results below. Once the combined dataset was confirmed, team members coded additional attributes for each pukara and digitised polygons of the enclosed areas.

While the geographic scale achieved through these methods is far greater than that possible with traditional field methods, we emphasise that ground studies remain essential for designing satellite survey and confirming results. Over the years, including projects before these surveys took place, we have collectively made field visits to 158 of these sites, including detailed architectural mapping, artefact collections and excavations. Our on-the-ground familiarity





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**Table 1. Criteria for calculating the overall confidence of pukara identification, which is expressed as the sum of scores across each criterion.**

| Criteria | Score | Description |
|---|---|---|
| Location | 0 | Location is not defensible |
| | 0.5 | Moderately defensible location (e.g. low-lying hill or hillside/slope) |
| | 1 | Defensible location (e.g. large, isolated hilltop) |
| Defensive architecture | 0 | No walls visible |
| | 0.5 | Walls visible, low confidence that they are defensive or ancient |
| | 1 | Natural defences without visible walls – OR – likely defensive walls |
| | 2 | Clearly defensive walls |
| Residential architecture | 0 | No visible residential architecture |
| | 0.5 | Possible residential architecture (e.g. structures, depressions, terracing) |
| | 1 | Residential architecture clearly visible |

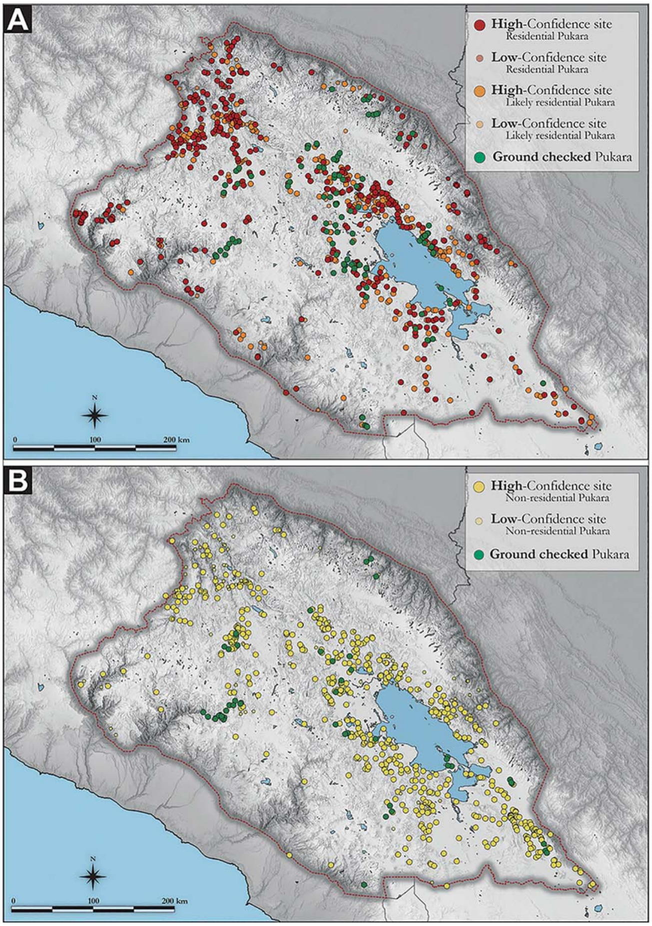


*Figure 3. Spatial distribution of residential (A) and non-residential (B) pukaras, distinguished by confidence level. All ground-checked pukaras are considered high confidence (figure by authors).*





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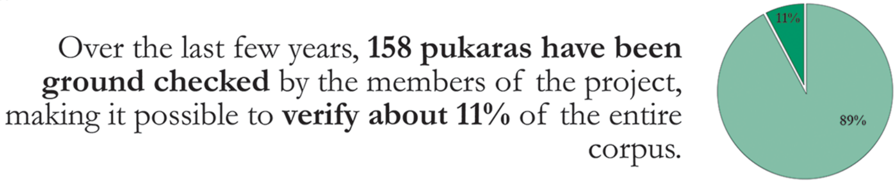
| | Residential | Likely residential | Non-residential | Total |
|---|---|---|---|---|
| High confidence | 443 | 239 | 567 | **1249** |
| → Satellite survey | 423 | 228 | 559 | **1210** |
| → Field visits | 20 | 11 | 8 | **39** |
| Low confidence | 21 | 58 | 132 | **211** |
| **Total** | **464** | **297** | **699** | **1460** |
| **Ground checked pukara** | **78** | **29** | **51** | **158** |



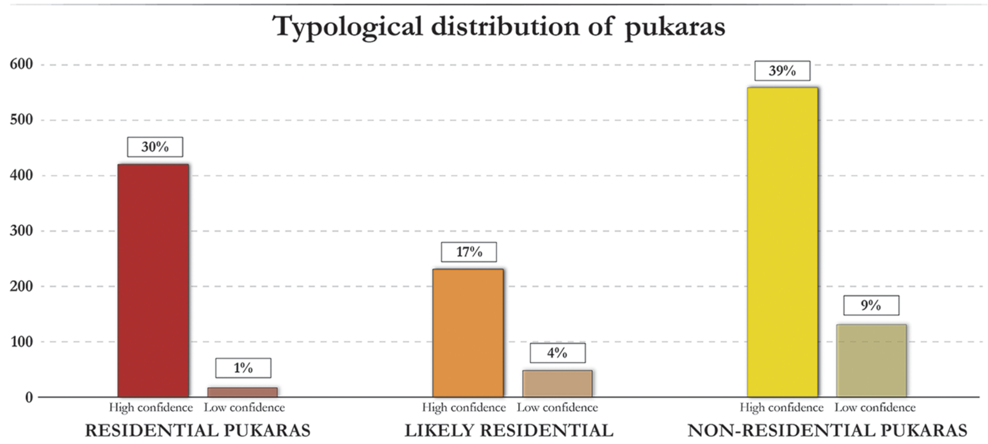




*Figure 4. Pukaras identified in the combined surveys (figure by authors).*

with pukaras, their position within the landscape, and their expression in various regions was invaluable at every stage. A more detailed consideration of the spatial distribution of pukaras and their attributes will be treated in a later paper; here we evaluate the effectiveness of our methods, and report on the most prominent patterns from the dataset.

## Evaluating effectiveness of satellite imagery survey

The final combined dataset includes 1249 high-confidence pukaras (1210 identified through satellite survey and an additional 39 not clearly visible in satellite imagery but identified through field visits by the authors or in published sources) and 211 low-confidence pukaras (Figures 3 & 4). From the outset it was obvious that satellite survey could not detect every pukara. For instance, thick vegetation obscures visibility, imposing a hard limit on the eastern reach of the survey. Even in regions with excellent visibility, naturally defensive landforms





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(e.g. mesas surrounded by cliffs) without substantial built defences could not be identified as pukaras from satellite imagery alone unless the site contained visible signs of residential use or other architecture. This built-in bias is reflected in the confidence-score system in Table 1. Loci with visible residential architecture were more clearly archaeological sites and scored higher than those without, and those with built defences (walls and ditches) scored higher than those with natural defences (cliffs). Furthermore, pukaras located on low hills that have been farmed intensively since abandonment are harder to detect. Here, residential architecture has often disappeared, and defensive walls have been incorporated as terrace walls. Repurposed or modified walls are harder to distinguish, although their long contiguous and concentric forms may actually be easier to identify from above than in ground survey.

We compared the results of our satellite survey to full-coverage pedestrian surveys that fell within the GeoPACHA analysis area (the Housse-Mouquet survey integrated known sites from the outset) and found that smaller pukaras on low cultivated hills and mesa-top pukaras without visible residential architecture were sometimes missed. For example, a 580km$^2$ area in the northern Titicaca Basin near Arapa and Taraco was covered in a pedestrian survey in 2002 (Stanish *et al.* 2018). Our satellite survey identified 10 of the 14 pukaras recorded in Stanish's survey, with one coded as low confidence. Of the missing four, one was defended almost entirely by cliffs and another was on a low cultivated hill. Other regions may have been more problematic. Only two of six pukaras recorded in a 79km$^2$ pedestrian survey south of Lake Umayo (Arkush & Chávez J. 2010) were independently identified in the satellite survey. Three of the others were cliff-walled mesa landforms with no architecture visible in the satellite imagery. In the areas of the Tacna precordillera surveyed in the field by Housse (2021: 182), vegetation and low walls obscured sites, and only three of six pukaras were identified in satellite survey.

Despite these limitations, systematising imagery survey with a grid clearly yields superior results compared to *ad hoc* methods. A working dataset developed earlier by one of us (Arkush) from non-systematic satellite and air photo survey and ground reconnaissance in the northern Titicaca Basin had missed 166 out of 376 (44.1%) high-confidence pukaras identified here. One evident way to improve results is simply through redundancy: to survey each cell multiple times. A total of 193 high-confidence pukaras fall in the 20 580km$^2$ area where the GeoPACHA and Housse-Mouquet surveys overlapped. Of these, 95 (49.2%) were identified independently by both surveys. Clearly, more surveyors are better.

In short, the dataset obtained from combined satellite surveys is certainly not a complete census of every pukara in the surveyed region. Instead, it is a minimum count, showing that they are extremely prevalent. The dataset also presents strong patterning both in the density of pukaras across regions, including clusters and gaps, and in certain pukara characteristics (see below). We are confident that the dataset has identified almost all pukaras with anthropogenic defensive features visible in high resolution (approximately 0.5m) satellite imagery and is representative of their overall distribution. Of course, satellite survey cannot capture less visible kinds of sites, so complete settlement patterns are not achievable through this method. Overall, the limitations of satellite survey must be counterbalanced by the immense and cost-effective geographic coverage achievable. We see it as a complementary method to field research, providing broader contextual framing and generating insights and research questions that would not otherwise be possible.





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## Results and discussion

Our results both confirm and refute current understanding of the distribution and density of pukaras. Pukaras are densely concentrated in places such as the Lake Titicaca Basin and the Colca Valley where previous field surveys had documented defensive settlement patterns (Hyslop 1976; Stanish *et al.* 1997; Frye & de la Vega 2005; Arkush 2011; Neira Avendaño 2011[1961]; Wernke 2013; Kohut 2016), but our satellite survey also found substantial concentrations of pukaras in many other parts of the south-central Andes. Pukaras coded as non-residential are surprisingly frequent; they are present throughout the study region in only slightly smaller numbers (n = 567) than residential pukaras (n = 682; Figure 3). There are also areas where pukaras appear to be absent or infrequent, including extremely high-elevation zones, expansive plains where defensible landforms are largely absent, and other areas where the absence of pukaras is harder to explain. A second important finding is the spatial patterning of pukara variability in size, defensibility, residential occupation, and other traits. While space limitations do not permit a full discussion of these results, as a first order characterisation we assess the extent of pukara clustering and the location of clusters—the basis for generating hypotheses for future investigation. We also highlight and briefly explore two specific dimensions of pukara variation—site size and the presence/absence of residential architecture—to demonstrate the potential for this dataset to elucidate inter-regional diversity in defence.

### *Inter-regional pukara distributions*

Visual inspection of the results suggests that hilltop fortifications are strongly concentrated in parts of the Lake Titicaca Basin, with other concentrations in the altiplano (highland plateau) and upper drainages to the south-east and north-west. These patterns were confirmed by Getis-Ord Gi* hot-spot analysis (ESRI ArcGIS Pro optimised hot-spot analysis) to identify statistically significant concentrations of pukaras. In the analysis, pukara point locations were aggregated using a hexagonal grid of cells 7.3km wide. We then ran Getis-Ord Gi* iteratively to identify the most appropriate neighbourhood size, each time increasing the fixed distance bands by 5km. A 15km fixed distance band was appropriate for identifying smaller-scale clustering. This result (Figure 5) shows large but discrete high-confidence hot spots in the northern and southern Titicaca Basin, a separate hot spot in the altiplano to the south-east, and smaller hot spots to the north-west in the Colca Valley and provinces of southern Cuzco.

It is possible that significant concentrations of pukaras are associated with larger and more politically integrated societies, corresponding to the *señoríos* described in later colonial documents, although recent field research on several LIP societies has failed to find evidence for coherent, well-integrated regional polities (Sillar & Dean 2002; Frye & de la Vega 2005; Bauer & Kellett 2010; Arkush 2011). Alternatively, concentrations of pukaras may have reflected defensive strategies associated with particular economic lifeways, such as reliance on camelid pastoralism. Finally, it is possible that areas with high concentrations of pukaras faced especially adverse climate conditions during the LIP; or, alternatively, areas resilient to climate adversity may have seen a destabilising influx of populations from elsewhere (e.g. McCool *et al.* 2022). Any of these models requires further analysis, but for the first time we have a dataset with a scale appropriate to addressing such questions.





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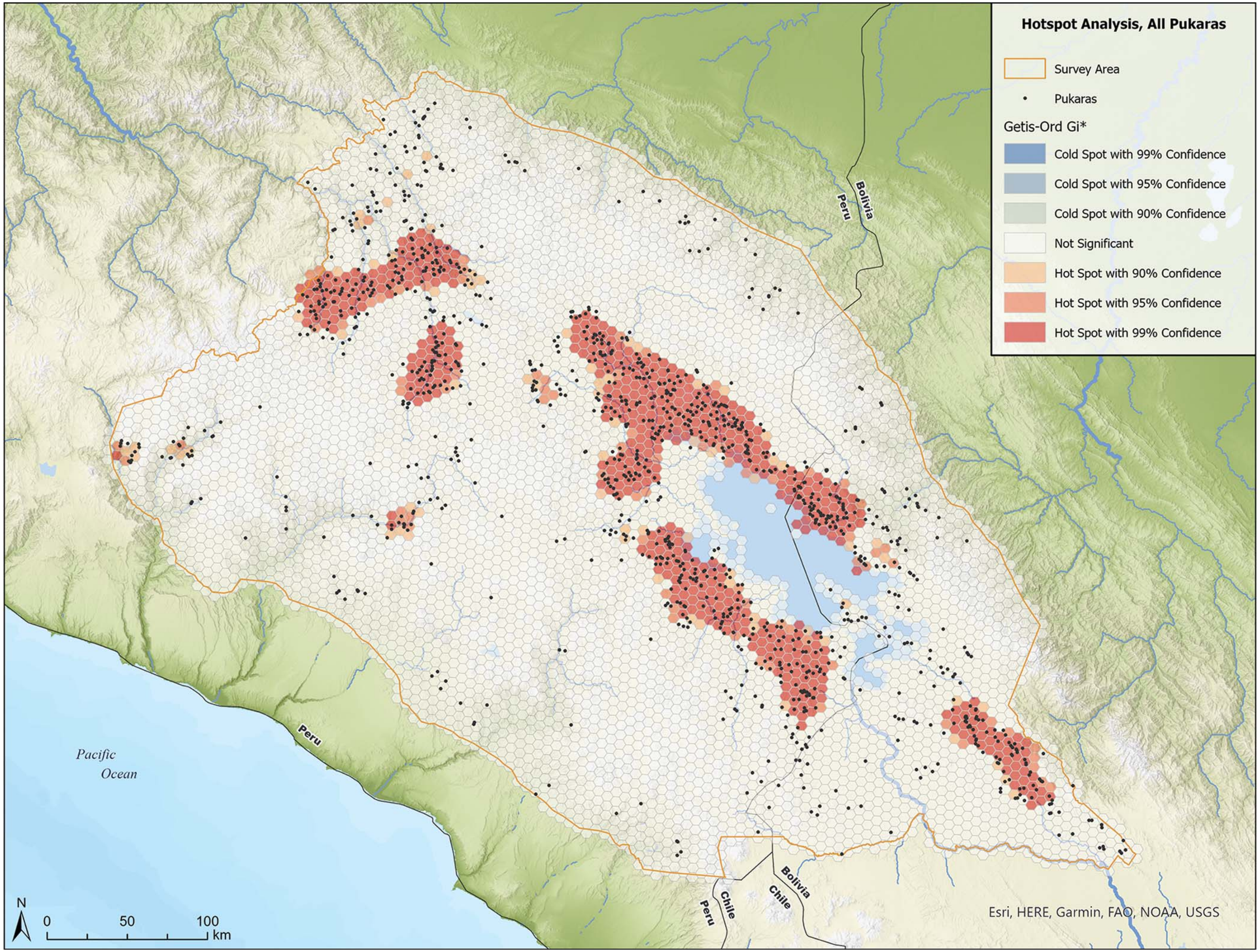


*Figure 5. Hot-spot analysis (Getis-Ord Gi*, 15km fixed-distance band) of all high-confidence pukaras identified in satellite survey (n = 1210). Hot-spot analysis excluded the 39 pukaras identified only in ground-based field survey, to avoid artificially biasing local 'clustering' toward localities where field survey had previously taken place (figure by authors).*





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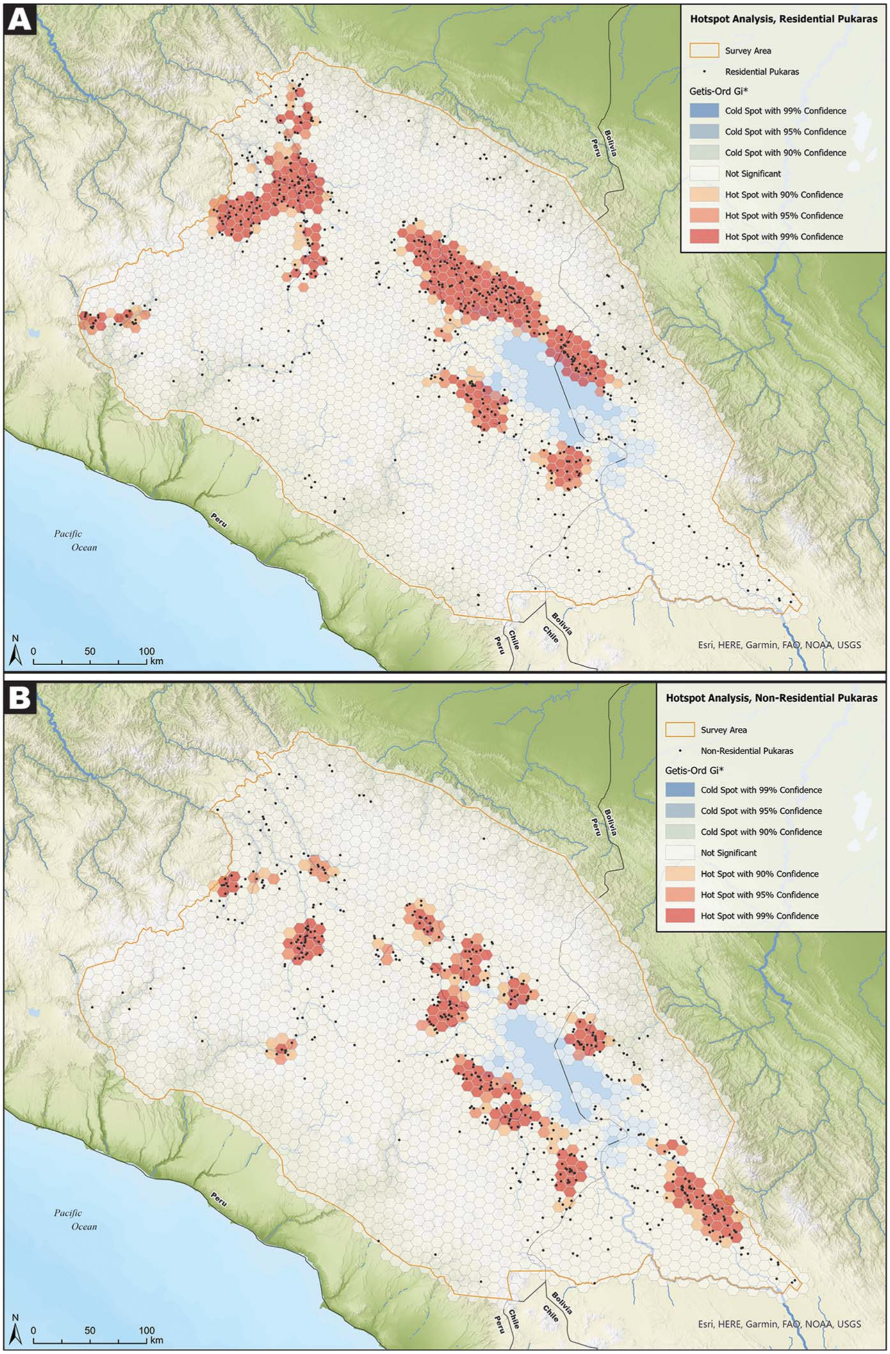


*Figure 6. Hotspot analysis (Getis-Ord Gi*, 15km distance band) of high-confidence residential (A, n = 651) and non-residential (B, n = 559) pukaras. Pukaras identified only in ground-based field survey are excluded (figure by authors).*





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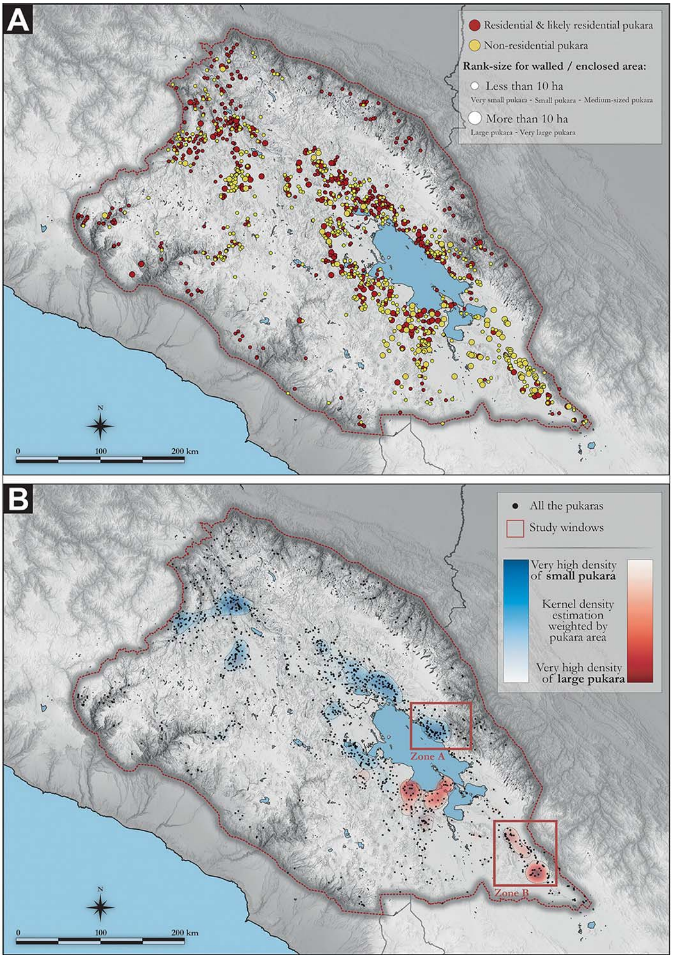


*Figure 7. Pukara sizes across the dataset (A) showing significant regional disparities (B) (figure by authors).*

## *Pukara variability*

The variability of pukaras in size, defensibility, residential occupation and other traits is well documented (e.g. Covey 2008; Arkush 2011; Kohut 2016, 2022; McCool 2017; Housse 2021), yet the large number of non-residential pukaras identified in this survey (n = 567) was surprising. Despite the challenges associated with identifying them, noted above, our classification of residential versus non-residential pukaras from satellite imagery appears to be relatively reliable. In May and June 2022, four researchers (Arkush, Kohut, Smith and Housse) made field visits to 29 pukaras identified in the survey. Our ground-truthing found that these 29 sites had been correctly classified, except for two residential sites with dense surface ceramics but no remaining architecture. While there is the potential that additional sites have been misclassified, our dataset radically expands the known corpus of non-residential sites and makes possible some statements about their distribution.





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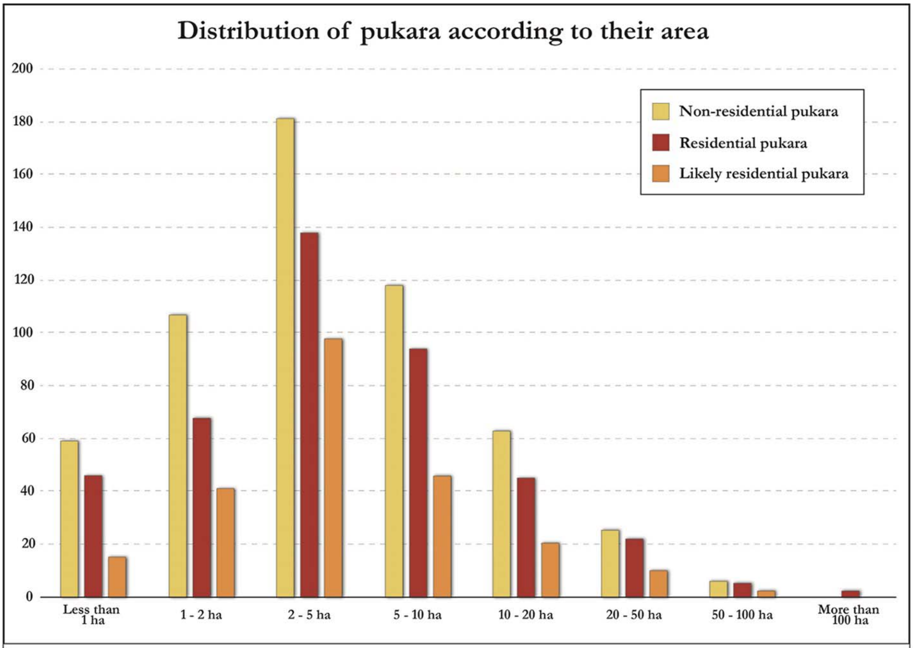


**ALL PUKARAS - High confidence**

| | | All pukara | Residential & Likely residential | Non-residential |
|---|---|---|---|---|
| | **Total** | **1249** | **682** | **567** |
| Surface area (ha) | Mean | 6.93 | 7.13 | 6.69 |
| | Median | 3.46 | 3.51 | 3.46 |
| | S.D | 13.78 | 16.37 | 9.79 |
| **ZONE A** | | | | |
| | **Total** | **97** | **59** | **38** |
| Surface area (ha) | Mean | 4.06 | 4.21 | 3.82 |
| | Median | 2.92 | 3 | 2.59 |
| | S.D | 3.69 | 3.57 | 3.86 |
| **ZONE B** | | | | |
| | **Total** | **79** | **11** | **68** |
| Surface area (ha) | Mean | 15.24 | 48.22 | 10.99 |
| | Median | 8 | 26.59 | 7.66 |
| | S.D | 25.23 | 65.85 | 12.14 |

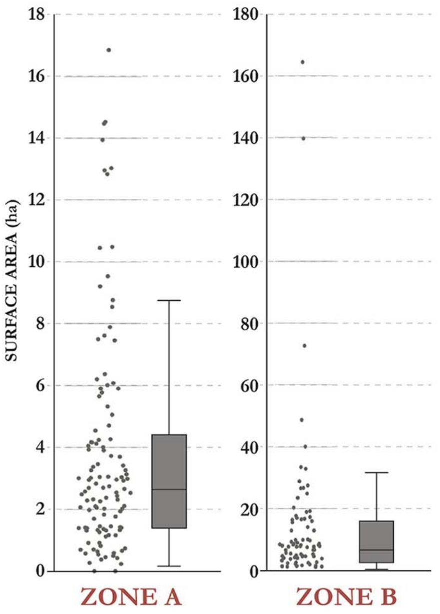


*Figure 8. Sizes of residential and non-residential pukaras across the dataset and in Zones A and B. Note: graph of Zone A and B pukara surface areas uses different vertical scales (figure by authors).*

Non-residential pukaras likely had distinct defensive purposes and interacted with local geographies and residential pukaras in different ways. Most regions where pukaras are found display a mix of both residential and non-residential pukaras, but their prevalence





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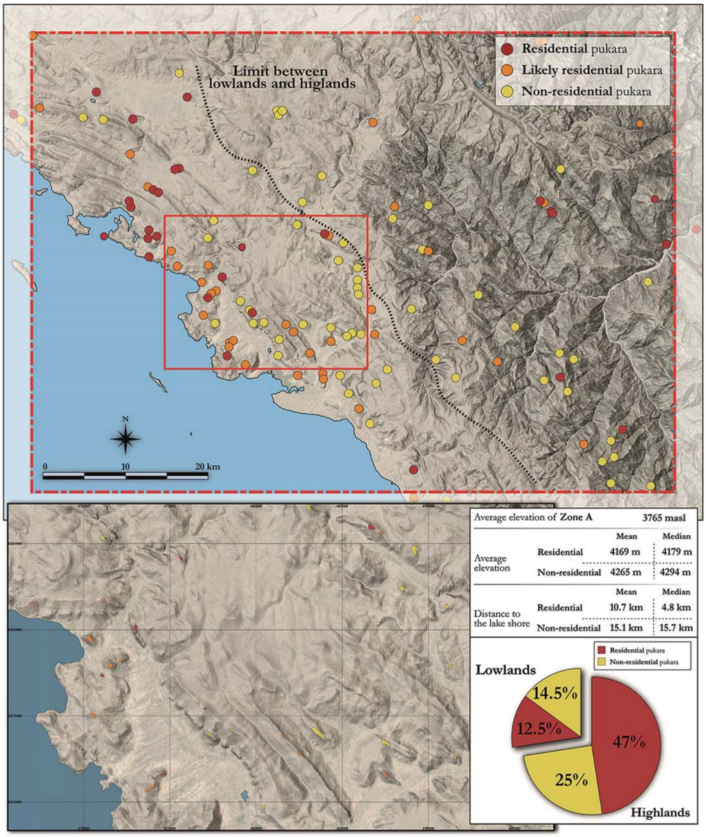


*Figure 9. Zone A appears to show differences in location of residential and non-residential pukaras. Residential pukaras tend to be closer to the lake and on lower landforms (figure by authors).*

and size vary in important ways (Figure 6). Hot-spot analysis (15km distance band) shows distinct distributions for residential and non-residential pukaras. The distribution of residential pukaras (Figure 6A) shows similar patterns of clustering to the dataset as a whole (Figure 5). By contrast, non-residential pukaras (Figure 6B) form smaller, more discrete clusters, suggesting that more localised processes account for their distribution.

In addition to residential and non-residential classes, pukara site size (defined by the outer extent of walls and barriers) clusters along distinct regional lines. The largest pukaras are concentrated in the uplands to the south and south-east of Lake Titicaca. Over three-quarters (76%) of the 74 large and very large pukaras—those greater than 20ha—are located in the Lupaca-Pacajes survey area (Figure 7). This is also where we see the greatest concentrations of non-residential pukaras. Small pukaras, by contrast, are concentrated around the northern margins of Lake Titicaca and areas in the southern provinces of Cuzco located in the north-western part of the survey area. Also notable is the preponderance of very small and primarily residential pukaras dispersed throughout the eastern valleys lining the north-eastern edge of the survey area.





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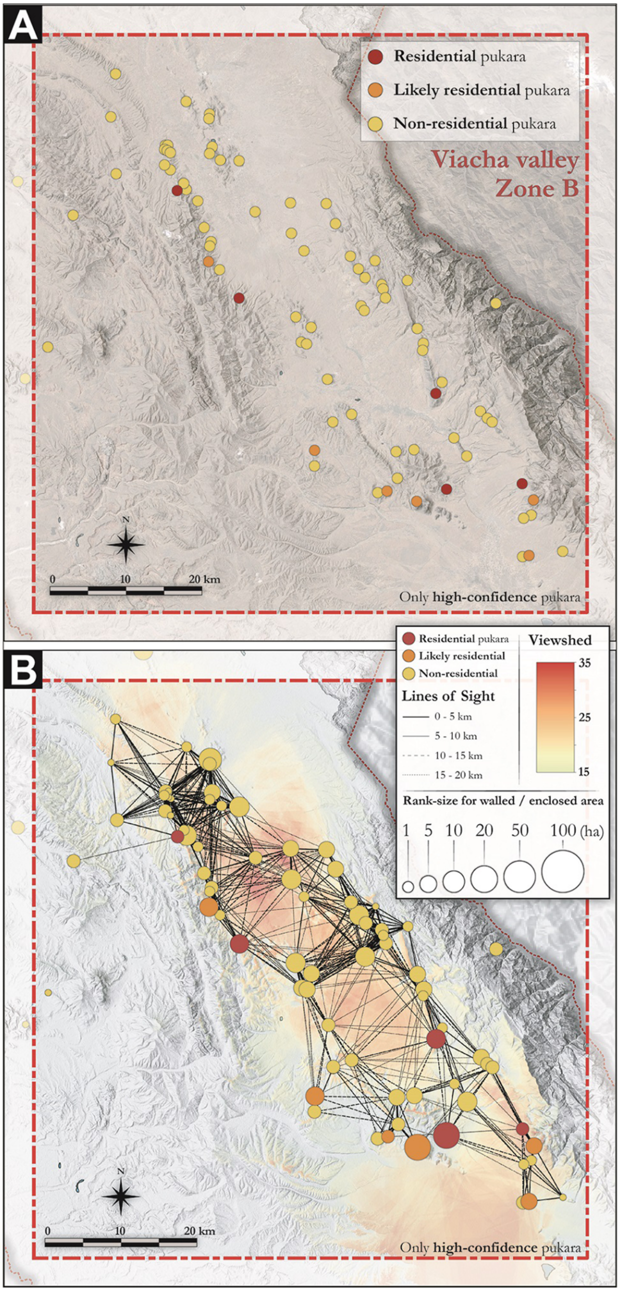


*Figure 10. The pukaras of Zone B are organised along a north-south axis, following the geography of the Viacha Valley (A). A line of sight and cumulative viewshed analysis indicates a densely interconnected space from which a very large number of pukaras can be seen (B). From certain locations in the bottom of the valley it is possible to observe nearly 35 pukaras simultaneously (figure by authors).*





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To illustrate the striking differences in pukara size and type between the north-central and southern parts of the lake basin (Figure 7), we briefly contrast settlement patterns in two small zones with dense but very different defensive patterns: Zone A on the eastern shores of the lake and Zone B to the south-east in the Viacha Valley (Figures 7–10). Zone A is characterised by a high density of relatively small pukaras: median size is 2.99ha and no site exceeds 20ha. In this zone, 60 per cent of pukaras are residential. By contrast, pukaras in Zone B are much larger, with a median size of 8ha, and 86 per cent are non-residential. These latter sites are built on low relief but locally prominent hills and extend over tens or even hundreds of hectares. Residential sites, though scarce, are even larger on average than non-residential pukaras.

Zone A straddles a limit between the highlands of the altiplano and the lowlands of the eastern Andean slopes (Figure 9). Pukaras are densest in the former area, with its less rugged terrain and access to lake and agricultural resources. The majority (72%) of pukaras are concentrated along the densely terraced shores of the lake, in a strip of land less than 20km wide. But the bias is greater for residential settlements, which are significantly closer to the lake on average (Figure 9). In contrast, non-residential pukaras, which have a slightly higher average elevation, are more commonly located further from the lake, and may have corresponded to more pastoral activities.

There is no parallel pattern in Zone B. Here, almost all the sites are very large non-residential pukaras located on small hills on either side of the heavily cultivated Viacha Valley; no sites were found beyond this area in the surrounding highlands. These immense pukaras are surrounded by thin, low walls of poor construction quality. The relative scarcity of residential pukaras and the prevalence of large non-residential pukaras with low, unostentatious walls seems to indicate a different logic to pukara-building that is not clearly tied to differences in domestic economy. Meanwhile, the exceptionally high visibility—and high intervisibility—of the Viacha Valley sites (Figure 10) may suggest distinctive functions in this area, whether to appropriate and assert claims to territory, send visual signals or monitor potential enemies. More field research is needed to better understand these distinct patterns of residential and non-residential sites.

## Conclusions

Many fundamental questions about the pukara phenomenon in the highland Andes remain unanswered despite nearly two decades of close archaeological investigation. These gaps in our knowledge reveal broader challenges associated with studying large-scale phenomena through the more limited lens provided by the scale of traditional field methods. While the now-widespread availability of high-resolution satellite imagery has provided archaeologists everywhere with a birds-eye view, leveraging birds-eye views into robust observations requires more than new technologies. The strength of this project lies in the co-ordination of data collection and validation across a large team of regional experts, experienced archaeologists and trained undergraduate students, including those working on GeoPACHA.

The result is systematic imagery survey of 151 103km$^2$ of the southern Andean highlands and a registry of 1249 high-confidence pukaras identified in satellite imagery. We found that





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systematic satellite survey generated a more complete and comprehensive dataset than non-systematic imagery prospecting, and that results were significantly improved by having multiple surveyors independently review each grid cell.

The results resoundingly confirm previous impressions about the prevalence of pukaras in the south-central Andean highlands. Prior to this research, it was impossible to ascertain the extent to which local defensive settlement patterns were representative of the wider pukara phenomenon, or of more distinct localised processes. While this survey shows that pukaras were broadly distributed, it also demonstrates significant variation in the density of pukaras, raising important questions about the underlying social, political, economic, geographic or environmental contexts that propelled pukara construction in some regions and deterred it in others. In addition, even considering only those areas where pukaras are densely clustered, our research is beginning to show significant regional variation that had previously remained largely undetectable. These pukara patterns appear to reflect distinct defensive logics that were likely driven by regional differences in domestic economy, territorial concerns, and the size and scale of socio-political units.

The great majority of pukaras investigated in field studies in the south-central highlands date to the LIP. If this holds true for the pukara dataset here, then our survey indicates how extremely prevalent a concern for defence was during this phase. At the same time, the scale of this dataset also reveals that responses to warfare were localised and varied. Investigating these variations will be critical for resolving long-standing questions about the LIP, including elucidating the role of competition in polity formation; unravelling the extent to which local environmental conditions provoked or discouraged conflict; and understanding how pukara-based societies responded to Inka expansion.

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## Data availability statement

The data that support the findings of this study will be available as part of the complete archived GeoPACHA dataset after processing for the postGIS is complete. Prior to that time the data are available from the corresponding authors on request.

## References


Abbott, M.B., M.W. Binford, M. Brenner & K.R. Kelts. 1997. A 3500 $^{14}$C yr high-resolution record of water-level changes in Lake Titicaca, Bolivia-Peru. *Quaternary Research* 47: 169–80. https://doi.org/10.1006/qres.1997.1881

Álvarez Larrain, A. & C. Greco (ed.) 2018. *Political landscapes of the Late Intermediate Period in the Southern Andes*. Cham: Springer. https://doi.org/10.1007/978-3-319-76729-1

Anderson, A.M. 2014. 'More than forts': a study of high elevation enclosures within the Pambamarca fortress complex, Ecuador. Unpublished PhD dissertation, State University of New York at Buffalo.

Arkush, E. 2011. *Hillforts of the ancient Andes: Colla warfare, society and landscape*. Gainesville: University Press of Florida. https://doi.org/10.5744/florida/9780813035260.001.0001

– 2022. *War, spectacle, and politics in the ancient Andes*. Cambridge: Cambridge University Press.

Arkush, E. & C. Chávez J. 2010. Informe del Proyecto de Investigación: Proyecto Machu Llaqta: Jerarquía en la Cuenca del Titicaca, Puno – Etapa 1 (Prospección). Unpublished report submitted to the Ministerio de Cultura, Lima.

Arkush, E., W.C. McCool & R. Smith. In press. The Late Intermediate Period in the south-central highlands: key problems in timing. *Quaternary International*. https://doi.org/10.1016/j.quaint.2023.10.002

Arkush, E. & T.A. Tung. 2013. Patterns of war in the Andes from the Archaic to the Late Horizon: insights from settlement patterns and cranial trauma. *Journal of Archaeological Research* 21: 307–69. https://doi.org/10.1007/s10814-013-9065-1

Bauer, B.S. & L.C. Kellett. 2010. Cultural transformations of the Chanka homeland (Andahuaylas, Peru) during the Late Intermediate Period (A.D. 1000–1400). *Latin American Antiquity* 21: 87–112. https://doi.org/10.7183/1045-6635.21.1.87

Bird, B.W., M.B. Abbott, M. Vuille, D.T. Rodbell, N.D. Stansell & M.F. Rosenmeier. 2011. A 2,300-year-long annually resolved record of the South American summer monsoon from the Peruvian Andes. *Proceedings of the National Academy of Sciences USA* 108: 8583–88. https://doi.org/10.1073/pnas.1003719108

Bonnier, E. 1981. Las ruinas de Tantamayo: vestigios de una ocupación tardía (Provincia de Huamalíes, Departamento de Huánuco). *Boletín de Lima* 14: 38–53.

Brown Vega, M., N. Craig & G.A. Lindo. 2011. Ground truthing of remotely identified fortifications on the central coast of Perú. *Journal of Archaeological Science* 38: 1680–89. https://doi.org/10.1016/j.jas.2011.02.035

Capoche, L. 1959 [1589]. *Relación general de la villa imperial de Potosí, un capítulo inédito en la historia del nuevo mundo* (Biblioteca de Autores Españoles 122). Madrid: Ed. Atlas.

Connell, S.V., A. Anderson, C. Gifford & A.L. González. 2019. Inka militarism at the Pambamarca complex in northern Ecuador. *Latin American Antiquity* 30: 177–97. https://doi.org/10.1017/laq.2018.80

Covey, R.A. 2008. Multiregional perspectives on the archaeology of the Andes during the Late Intermediate Period (c. A.D. 1000–1400). *Journal of Archaeological Research* 16: 287–338. https://doi.org/10.1007/s10814-008-9021-7

Frye, K.L. & E. de la Vega. 2005. The Altiplano period in the Titicaca Basin, in C. Stanish, A. Cohen & M. Aldenderfer (ed.) *Advances in Titicaca Basin archaeology I*: 173–84. Los Angeles (CA): Cotsen Institute of Archaeology. https://doi.org/10.2307/j.ctvhhhfn9.17

Guédron, S. *et al.* 2023. Holocene variations in Lake Titicaca water level and their implications for sociopolitical developments in the central Andes. *Proceedings of the National Academy of Sciences USA* 120: e2215882120. https://doi.org/10.1073/pnas.2215882120






https://doi.org/10.15184/aqy.2023.178 Published online by Cambridge University Press

Hastorf, C.A. 1993. *Agriculture and the onset of political inequality before the Inka*. Cambridge: Cambridge University Press.

Housse, R. 2021. Fortification et territorialité entre la côte pacifique et l'altiplano méridional andin durant l'Intermédiaire récent (1000–1450 apr. J.C.). Unpublished PhD dissertation, École Doctorale d'archéologie 112 – Université Paris 1 – Panthéon Sorbonne.

Housse, R. & A. Mouquet. 2023. Pucara hilltop settlements in the Lupaca and Pacajes Territories, southern Andean altiplano, during the Late Intermediate Period (1000–1450 AD). *Latin American Antiquity*: 1–19. https://doi.org/10.1017/laq.2023.9

Hyslop, J. 1976. An archaeological investigation of the Lupaqa Kingdom and its origins. Unpublished PhD dissertation, Columbia University.

Kellett, L.C. 2010. Chanka settlement ecology: hilltop sites, land use and warfare in Late Prehispanic Andahuaylas, Peru. Unpublished PhD dissertation, University of New Mexico.

Kohut, L. 2016. Cooperation through war: Late Intermediate Period warfare and community formation in the south-central Andes. Unpublished PhD dissertation, Vanderbilt University.

– 2022. Warfare and alliance: a human-scale GIS analysis of defensive alliances in the Colca Valley, Peru, in H.C. Ikehara-Tsukayama & J.C. Vargas Ruiz (ed.) *Global perspectives on landscapes of warfare*: 247–72. Boulder: University of Colorado Press.

Kolata, A.L. 1993. *The Tiwanaku: portrait of an Andean civilization*. Cambridge (MA): Blackwell.

Lavallée, D. & M. Julien. 1983. *Asto: curacazgo prehispanico de los andes centrales*. Lima: IEP ediciones.

Liang, J., J. Gong & W. Li. 2018. Applications and impacts of Google Earth: a decadal review (2006–2016). *ISPRS Journal of Photogrammetry and Remote Sensing* 146: 91–107. https://doi.org/10.1016/j.isprsjprs.2018.08.019

Luo, L. *et al.* 2018. Google Earth as a powerful tool for archaeological and cultural heritage applications: a review. *Remote Sensing* 10: 1558. https://doi.org/10.3390/rs10101558

McCool, W.C. 2017. Coping with conflict: defensive strategies and chronic warfare in the prehispanic Nazca region. *Latin American Antiquity* 28: 373–93. https://doi.org/10.1017/laq.2017.28

McCool, W.C., B.F. Codding, K.B. Vernon, K.M. Wilson, P.M. Yaworsky, N. Marwan & D.J. Kennett. 2022. Climate change–induced population pressure drives high rates of lethal violence in the Prehispanic central Andes. *Proceedings of the National Academy of Sciences USA* 119: e2117556119. https://doi.org/10.1073/pnas.2117556119

Neira Avendaño, M. 2011[1961]. Los Collaguas. Unpublished PhD dissertation. Universidad Nacional de San Agustín de Arequipa, Edición y Prólogo de Félix Palacios Ríos.

Nielsen, A.E. 2002. Asentamientos, conflicto y cambio social en el altiplano de Lípez (Potosí). *Revista Española de Antropología Americana* 32: 179–205.

Parsons, J.R., C.M. Hastings & R. Matos M. 2000. *Prehispanic settlement patterns in the upper Mantaro and Tarma drainages, Junín, Peru*. Vol. 1. Ann Arbor: Museum of Anthropological Archaeology, University of Michigan. https://doi.org/10.3998/mpub.11395652

Sillar, B. & E.M. Dean. 2002. Identidad étnica bajo el dominio Inka: una evaluación arqueológica y etnohistórica de las repercusiones del estado Inka en el grupo étnico Canas. *Boletín de Arqueología PUCP* 6: 205–64.

Stanish, C. 2003. *Ancient Titicaca: the evolution of complex society in Southern Peru and Northern Bolivia*. Berkeley: University of California Press.

Stanish, C. *et al.* 1997. *Archaeological survey in the Juli-Desaguadero region of the Lake Titicaca Basin, southern Peru*. Chicago (IL): Field Museum of Natural History. https://doi.org/10.5962/bhl.title.3578

Stanish, C., C. Chávez J., K. LaFavre & A.M. Plourde. 2018. *The northern Titicaca Basin survey: Huancané-Putina*. Ann Arbor: Museum of Anthropology, University of Michigan. Unpublished database available from authors upon request.

Tarragó, M.N. (ed.) 2000. Chakras y pukara: desarrolos sociales tardíos, in *Los pueblos originarios y la Conquista, Nueva Historia Argentina Tomo I*: 257–300. Buenos Aires: Editorial Sudamericana.

Thompson, L.G., E. Mosley-Thompson, M.E. Davis, V.S. Zagorodnov, I.M. Howat, V.N. Mikhalenko & P.-N. Lin. 2013. Annually





https://doi.org/10.15184/aqy.2023.178 Published online by Cambridge University Press

resolved ice core records of tropical climate variability over the past ~1800 years. *Science* 340: 945–50. https://doi.org/10.1126/science.1234210

WERNKE, S.A. 2013. *Negotiated settlements: Andean communities and landscapes under Inka and Spanish colonialism*. Gainesville: University Press of Florida. https://doi.org/10.5744/florida/9780813042497.001.0001

WERNKE, S.A *et al*. 2023. Large-scale, collaborative imagery survey in archaeology: the Geospatial Platform for Andean Culture, History and Archaeology (GeoPACHA). *Antiquity*. Published online December 2023. https://doi.org/10.15184/aqy.2023.177

WILLIAMS, V.I. 2018. Regional dynamics in the high Quebradas of the Valle Calchaquí Medio (Salta, Argentina) between the eleventh and early seventeenth centuries, in A. Álvarez Larrain & C. Greco (ed.) *Political landscapes of the Late Intermediate Period in the southern Andes*: 131–56. Cham: Springer. https://doi.org/10.1007/978-3-319-76729-1_6