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Ecological variation and early village organization in formative cusco, peru: A GIS-based approach

Matthew T. Brown[a,*], Camille Weinberg[b], Nicole D. Payntar[b], Lia Tsesmeli[c], Leah Larsen[d], R. Alan Covey[b]

[a] Museum of Anthropological Archaeology & Department of Anthropology, University of Michigan, 610 E. University Ave., Ann Arbor, MI 48109, United States
[b] Department of Anthropology, University of Texas – Austin, 2201 Speedway – Stop C3200, Austin, TX 78712, United States
[c] New Mexico Department of Transportation, 1120 Cerrillos Road, Santa Fe, NM 87505, United States
[d] Department of Earth and Environmental Sciences, University of Michigan, 1100 North University Ave., Ann Arbor, MI 48109, United States

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ABSTRACT

We utilize GIS to analyze regional settlement survey data to understand the transition to agropastoral village life in the Cusco region of highland Peru during the Late Formative Period (600 BCE – 200 CE) and long-term success of settlements on the landscape. We model cost catchment areas within 1, 2, and 4 h of travel from each of the eight largest Formative villages in the study region. We take into consideration the different ecozones each of these communities would have access to as well as the amount of potentially arable farmland within each catchment. To examine relationships between village locations and accessibility to other Formative settlements, we quantify the sites within each travel area and examine portions of the landscape where areas overlap. We also model viewsheds and cumulative visibility for each settlement to consider how visibility of the surrounding landscape and neighboring communities might have informed the selection and growth of certain sites. These data highlight 4 clusters or zones of interaction within the study region where established villages differ in terms of their accessibility, proximity, and overlap to smaller villages: 1) the Xaquixaguana Basin around Lake Huaypo, 2) the Chit'apampa Basin, 3) the transverse valleys to the north of the Sacred Valley, and 4) the Sacred Valley. Although we cannot presume the contemporaneity and continuous occupation of all settlements throughout the Late Formative Period, these data provide testable archaeological hypotheses as to how early villagers navigated different local landscapes as they developed agropastoral subsistence strategies, and how their social interactions shaped the coalescence of permanent villages. Some of these settlements grew to be significantly larger and continued to be occupied in subsequent periods, suggesting that the proximity and placement of sites on these landscapes influenced occupational trajectories and regional sociopolitics. Ultimately, we conclude that large sites settled in areas with access to arable farmland to cultivate maize and that had reduced risk of frost continued to be occupied past the Formative. Our results highlight the utility of synchronic analyses of survey data to generate testable hypotheses about long-term settlement continuity in ecologically diverse regions.

1. Introduction

During the Formative Period (2200 BCE-200 CE), the highlands of Cusco, Peru, experienced major social changes, including the widespread adoption of agriculture, the establishment of sedentary villages, and the production of the region's oldest-known pottery. Excavations at Formative sites in the Cusco region hint at local variations in the subsistence practices and social identities of the residents of early agropastoral villages. This diversity encourages the development of regional perspectives on the long-term transitions to early village life in the Andes, bringing regional archaeological data to bear on influential ethnographic models of the social organization and subsistence practices sustaining village life in the Andean highlands. The kin-based ecological complementarity model articulated by John Murra in the 1960 s used ethnography and ethnohistory to identify generalized social interactions that maintained economic self-sufficiency on heterogeneous landscapes

* Corresponding author at: Museum of Anthropological Archaeology & Department of Anthropology, University of Michigan, 610 E. University Ave., Ann Arbor, MI 48109, United States.
E-mail address: matybr@umich.edu (M.T. Brown).

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(e.g., Murra 1972, 1985a, 1985b), but the prehistoric origins and development of such practices have rarely been addressed using archaeological settlement pattern data (but see Stanish 1989).

As archaeologists develop more complex reconstructions of transitions toward sedentary village life and food production, the question of landscape variability still needs to be considered alongside other social dynamics (e.g., Bandy 2004; Bandy, 2010). The ecological diversity of the Cusco region and scale of regional survey work conducted there provide a distinct opportunity to identify and interpret multiple social and ecological arrangements that shaped subsistence practices and residential patterns in early agropastoral villages, influencing their long-term occupations.

This study uses settlement pattern data from a 1200 km^2 survey area in the Cusco region (Covey 2014), which identified the locations and provided size estimates of 146 Formative sites. Using multiple GIS-based spatial analyses, we identify ecological variations in early village settlement, as well as clear differences in the clustering, integration, and visibility from large villages and small sites. The large size of the study region and its ecological range complement other regional datasets that address Formative transitions in smaller or more ecologically homogeneous landscapes (e.g., Bauer et al. 2010: 47-55; Stanish et al. 1997; Stanish and Bauer 2004; Wernke 2003: 129-135). Our analysis identifies multiple coarse-grained settlement patterns that indicate a range of early community practices, making it possible to develop hypotheses for future testing through problem-oriented archaeological excavations. We conclude that early villagers in this region experimented with a diverse array of subsistence strategies and settlement practices in the transition to village life, and that settlement size and accessibility to low-risk and productive agricultural lands were important factors in the long-term occupation of sites.

2. Background

2.1. The formative period in Cusco

Currently, most evidence of Formative village life in the Cusco region comes from excavations at just a few sites: test units at Chanapata (Rowe 1944), Marcavalle (Mohr Chávez, 1977), Muyu Orqo (Zapata 1998), Chokepukio (McEwan et al. 1995), Minaspata (Dwyer 1971; Hardy 2019), and Conventomoqo (Delgado González, 2016), as well as horizontal exposures at Huillca Racay (Hey 1999), Yuthu (Davis 2011), Ak'awillay (Bélisle 2011, 2015), Cheqoq (Quave 2012), and Bandojan (Delgado González 2019a). Lake cores and excavated faunal and botanical remains indicate the foods that early herders and farmers cultivated and consumed. Early Formative (2200 – 1500 BCE) populations used wild and domesticated quinoa and kañiwa, which were suited to a cool, dry climate (Chepstow-Lusty 2011:576; Mosblech et al. 2012). They herded domesticated camelids for meat, wool, and possibly as beasts of burden. Convincing evidence for the transition to more sedentary villages coincides with an arid climatic interval beginning in 1500 BCE (Bauer 2004). Faunal remains from Marcavalle and Minaspata show continued reliance on camelids despite the potential reduction of moist pasturelands during this arid period (Chepstow-Lusty, 2011). Early villagers also consumed domesticated dogs and guinea pigs, and wild taxa such as deer, rodents and birds, while gradually intensifying farming of crops, including beans and corn (Bauer 2004: 4; Mohr Chávez, 1980).

During the Late Formative Period (600 BCE – 200 CE), agropastoral communities continued to diversify their agricultural practices (Delgado González 2019b, 2023). At Chanapata, villagers maintained a range of subsistence strategies, increasing quinoa, bean, potato, and maize production, while also herding camelids and hunting wild deer and other game. Mohr Chávez (1980) recovered maize dating to 200 BCE at Marcavalle. At Yuthu (400–100 BCE), the diet was centered on C3 plants, such as tubers and legumes (Turner et al. 2018). Villagers there focused on domesticated species, grazing camelids and cultivating quinoa in the rolling hills near their village, while probably raising guinea pigs in their homes (Davis 2011). Maize could have been cultivated on the warmer low-lying floodplains of the Sacred Valley within a half-day's walk from the village (Davis 2011). Quinoa was the most important crop at Bandojan, although maize, potato, tarwi, amaranth, and beans were found in small amounts (Delgado González 2019a). Evidence from Late Formative houses dating c. 200 BCE-200 CE at the nearby village of Ak'awillay shows residents farmed maize, hunted deer and birds, and raised (or at least consumed) camelids and guinea pigs (Bélisle 2011: 109-133). Overall, Late Formative data come primarily from the Anta/Xaquixaguana area and are too scarce to comprehensively reconstruct local variation in subsistence activities and social organization. The data we do have, however, show access to products of multiple, locally accessible production areas.

As excavation data accumulate for the Cusco Formative, settlement patterns offer a complementary regional approach to the diverse local subsistence patterns seen in different villages. Shifting from excavation to survey data requires a caveat regarding the interpretive limitations of such data. The settlement data presented here lack the chronological precision of a stratigraphic excavation; during survey, two early ceramic styles (Marcavalle and Chanapata) were used to identify a broad "Formative Period" site inventory (Bauer 1999). Marcavalle ceramics have been radiocarbon dated to as early as 2200 BCE, but it has been difficult to identify this style consistently across the broader survey region (Covey 2014). Virtually all "Formative" sites were identified from diagnostic features of the later Chanapata ceramic style, which is generally assigned to the period from 600 BCE-200 CE. However, the exact range of use for Chanapata ceramics remains unclear and there are radiocarbon dates as early as 750 BCE.[1] Regardless, the use of Chanapata as a diagnostic style to identify Formative sites means that sites in our study are most likely to date to the Late Formative.

The coarse-grained nature of surface collection data and the long span of the Formative period encourage conservative research questions that do not assume the contemporaneity of the site sample or depend on a high degree of accuracy in site size estimates. Rather, the systematic registration of diagnostic surface pottery in the study region represents a cumulative record of Late Formative activities for which subregional variations permit comparisons of long-term social practices. The general consideration of social and ecological variation in Late Formative Cusco capitalizes on the strengths of regional settlement pattern data to address some of the diversity in agricultural practices hinted at in the aforementioned excavations. The analysis of Late Formative settlement patterns can place agropastoral villages in their regional context, considering local resource availability and some ways that the subsistence practices associated with large sites overlapped with those of neighboring communities.

2.2. Ecology of the andean highlands

Many Andean archaeologists use ethnographically-derived ecozones to structure analyses of the modern landscapes where they encounter and study ancient settlements (e.g., Mayer 1985; Parsons et al., 1997: 11–15). In the Cusco region, the most common ecozones used for food production are the *kichwa, suni,* and *puna*.[2] The temperate *kichwa* (c. 2300–3500 masl) is optimal for rainfall and irrigation agriculture of beans, chenopods, and maize above the lower tropical extensions of the Andean valleys toward the upper slopes (Covey et al. 2014; Brush 1977: 34; Gade 1975). Today, *kichwa* lands are found along the floor of the

[1] For a discussion of Late Formative ceramic resolution, see Covey et al. (2014:10-12), and for a compilation of Late Formative radiocarbon dates see Davis (2011:161) and Delgado González (2019a).

[2] Ethnographic and ethnohistoric accounts describe long-distance colonization and trade that gave highlanders access to nonlocal lowland (*yunga*) products.

Sacred Valley and lower elevations of the Xaquixaguana Valley. The rolling hills of the Xaquixaguana Plain and hillslopes of the Chit'apampa Basin and other tributary valleys draining into the Sacred Valley are *suni* lands (c. 3500–4000 masl), which comprise the majority of the Hanan Cusco study region. Today, these are primarily dry farmed to cultivate quinoa, tubers, amaranth, and beans, but they could have also been used as dry pasture for camelids (Covey 2014: 60). Importantly, the *suni* would have been sufficient to produce most crops of the Formative Period diet, and most Formative sites show some degree of direct access to *suni* lands (Covey et al. 2014). Previous analyses of settlements patterns by Davis (2014) and Covey (2014: 67) demonstrated a preference for *kichwa* and *suni* lands in the Cusco region. From 4000 to 4800 masl, the high, cold grasslands of the *puna* support only limited tuber cultivation, and at this altitude, weather patterns are generally more extreme and unpredictable (D'Altroy, 2000: 364). *Puna* grasslands and the wetlands known as *bofedales* are preferred by alpacas and are therefore used primarily for herding. The resilience of *puna* grasses declines with elevation. Most areas above 4500 masl in the study region are too rocky and marginal for agropastoral activities. The Hanan Cusco survey registered Formative sites in all three ecozones.

Despite the heuristic utility of these landscape classifications for conceptualizing Andean subsistence landscapes, it is important to acknowledge the limits of their applicability deep into the past, especially within the essentializing ecological complementarity model that developed during the 1960 s and 1970 s. Driven by John Murra's substantivist reading of the ethnohistoric and ethnographic literature, this approach envisioned kin-based labor networks (*ayllus*) as economically self-sufficient entities that occupied *suni* hillsides and directly exploited different Andean ecozones lying at higher and lower elevations (e.g., Murra 1961). Although ethnographic literature has identified diverse strategies for doing so (e.g., Brush 1977), few archaeologists have explicitly addressed how local ecological variability might have influenced patterns of early Andean village life. Excavation data can be used to assess degrees of sedentism and transhumance (e.g., Delgado González 2023) and the processing and consumption of foods from different ecozones. However, a careful comparison of households from multiple villages would be needed to identify differences in local strategies of ecological complementarity. Regional survey data can offer a complementary record, but large site samples from ecologically diverse study regions are necessary to identify settlement pattern variations that might be attributable to zonation and ecology. Although other surveys have registered samples of *kichwa* and *suni* settlement patterns in some other highland regions (e.g., Bauer et al. 2010; Jennings 2002; Wernke 2003), the most extensive regional studies have focused on the distinctive *puna* landscape of the Lake Titicaca Basin, especially in lakeshore areas above 3800 masl (Albarracín-Jordan and Matthews, 1990; Stanish and Bauer 2004; Stanish et al. 1997, 2014).

Taking advantage of the ecological diversity found within the Hanan Cusco study region, this analysis builds on the zonal approach to Andean ecology and the general principles of the ecological complementarity model to describe patterns of early village life in the Cusco region. We use settlement distributions and geographic evidence to identify settlement patterns that suggest the coexistence of multiple configurations of early village life, some of which supported lasting communities. Mindful of the limitations of our data for early settlement periods, we focus on reconstructing and comparing some general attributes of the landscapes surrounding the Late Formative villages in the study region. Specifically, we consider (1) the ecological range for early settlement concentrations, (2) the distribution of small sites at different distances from large ones, (3) the degree of clustering and landscape overlap seen among large sites, (4) the extent to which the landscapes surrounding large sites were visible from other communities of similar size, and (5) how characteristics of the nearby ecozones may have aided or hindered long-term settlement in large communities.

3. Methods

To develop these landscape perspectives, we worked with regional settlement pattern data to identify eight large Late Formative sites and then used GIS analyses to evaluate relationships between site location, visibility, and proximity to other sites of the same period.

3.1. Field and laboratory

Survey work from 2000 to 2007 collected settlement pattern data from a region of approximately 1200 km^2 lying north and west of the city of Cusco (Covey 2014). All fieldwork employed a consistent methodology (Bauer 1999): crews of 3–5 workers traversed all safely passable areas in parallel lines, registering the presence of surface artifacts and other cultural remains on standardized field forms. Crews maintained a 50-meter survey interval where possible, although the variable landscape of the region required wider spacing on some hillslopes. Crews registered sites where artifact scatters were of sufficient density, making general collections of diagnostic material lying on the surface while reconnoitering the site to determine its size and other characteristics. Survey work in the Sacred Valley made purposive samples of surface artifacts. In some cases, the effects of slope, vegetation, and architecture from later occupations made the precise estimate of Formative occupation sizes difficult. In the Xaquixaguana Valley to the west of Cusco, the rolling terrain made it possible to place grids of intensive collection units at sites larger than one hectare, generating more accurate assessments of occupation size over time. Because of the lack of preserved architecture, Late Formative occupations were confirmed in the laboratory by identifying diagnostic ceramics using Bauer's (1999) regional artifact sequence. Analysis used a type-variety system that emphasized the identification of the presence or absence of Formative pottery from a surface collection. For the purposes of visual inspection, Formative pottery identifications focused on a suite of common attributes common to ceramic styles produced during the first millennium BCE and the early centuries CE: globular rims, exterior burnishing, and white nonplastic temper inclusions in the sherd fabric (see Davis 2014).

Altogether, more than 3,500 diagnostic sherds were used to designate 146 Formative sites in the study region. Sites range from small hamlets to the 14-hectare village site of Ak'awillay, which excavations show to have grown during the final centuries of the Formative Period, after 200 BCE (Bélisle 2015). Prior to the emergence of Ak'awillay, no Formative site in the study region was larger than 4–6 ha (Table 1), and there were a few dozen settlements in the 1–3 ha range. For the present study, we focus on the largest Late Formative sites (n = 8), which have surface scatters that are at least 4 ha in size and appear large and dense enough to be treated as intensively settled villages during the Late Formative (Fig. 1). These large sites were at least twice the size of the next largest Late Formative sites identified in the study region, making them qualitatively different from smaller sites from that period.

Table 1
Large villages of the Hanan Cusco region analyzed in this study. Site sizes are based on 1) intensive surface collections, 2) excavations, or 3) field estimates.

Site	Region	Elevation (masl)	Size	Ecozone
Ak'awillay	Anta/ Xaquixaguana	3450	13.75 ha^1	Kichwa-Suni
Cheqoq	Maras	3500	4.50 ha^1	Suni
Yuthu	Anta/ Xaquixaguana	3550	4.50 ha^2	Suni
Huaypo Chico	Anta/ Xaquixaguana	3600	4.75 ha^1	Suni
Muyumoqo	Chit'apampa	3700	6 ha^3	Suni
Raqchi	Chit'apampa	3750	6 ha^3	Suni
Markasunay	Sacred Valley	3950	6 ha^3	Suni-Puna
Apu Sompechu	Sacred Valley	4100	4 ha^3	Puna

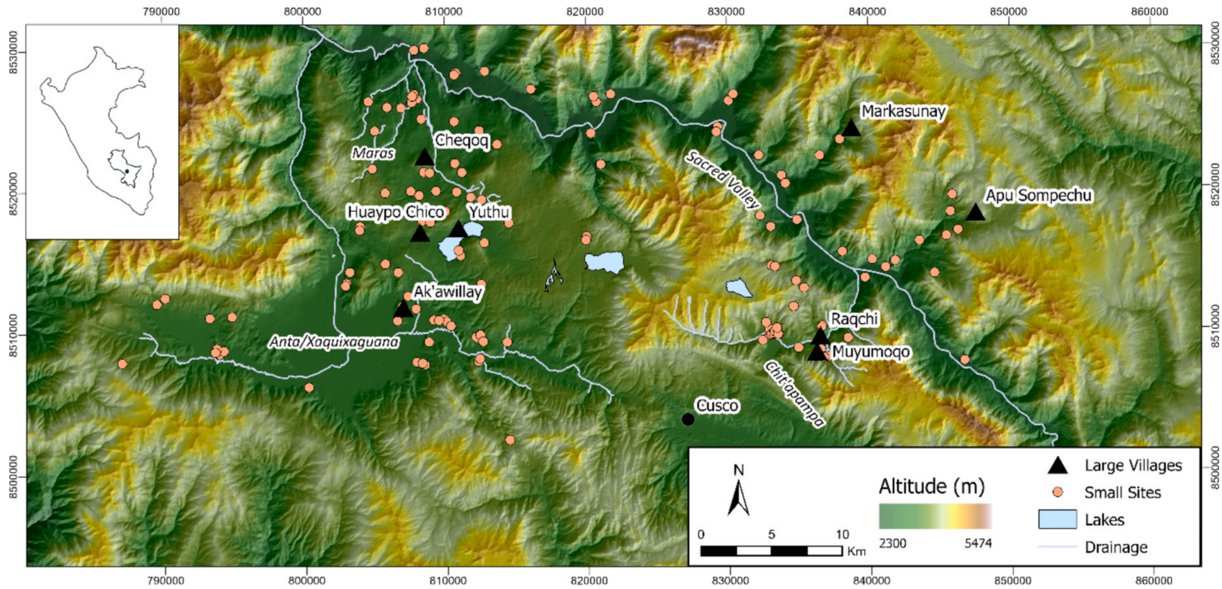

Fig. 1. Formative sites in the study region north of Cusco, including the eight largest villages.

Because it can be difficult to characterize the nature of occupation at smaller sites that may be classed as "non-village" occupations through surface material and smaller sites may be highly variable in their function, we take the settlement data presented here as an aggregate of human activity on the landscape and focus mainly on the clustering of small sites and large sites on the landscape (see Kowalewski 2003, 2008: 234-235; Peterson and Drennan 2005; Underhill et al. 2008). In our discussion, we provide some interpretations of the function of these small sites based on the relationship to the larger communities in our survey and their placement within different ecological zones within the Cusco region. While we cannot make definitive conclusions about the daily activities carried out at smaller sites in the survey region, our analysis reveals distinct choices in settlement location based on clustering, access to various ecozones, and views of the surrounding landscape.

3.2. GIS analysis

3.2.1. Hiking algorithms and logistical travel zones

Given the regional implications of the *lo andino* model for land use, it was important to consider the relationships between early villages and small sites, as well as the distribution of nearby resources. Focusing on travel costs from areas of concentrated settlement, we modeled zones of access surrounding the eight early villages by estimating 1, 2, and 4-hour catchment areas of pedestrian access in ArcGIS Pro 3.2. These catchment areas were configured using Tobler's Off-Path Hiking function to create an anisotropic surface that factors in terrain slope (Tobler 1993; Tripcevich 2009): Speed: (km/h) $= 6{*}e^{-3.5{*}|\text{slope}+0.05|}$. Walking time estimates were determined using the inverse equation for the slope/speed relationship: (h/m) $= (1/6000)\ {*}\ e^{3.5{*}|\text{slope}+0.05|}$. We utilized a vertical factor table created by Tripcevich (2009) based on the aforementioned Tobler algorithm. Given the altitudinal variance in the Cusco region, this method allows us to take into consideration change in the topography surrounding each site and the resulting effect on travel time (Contreras 2011; Cortegoso et al. 2016; Jennings and Craig 2001; Lucero et al. 2014; Lucero et al., 2021; Tripcevich 2007).

A 30 m digital elevation model (DEM) derived from one-arc second NASA Shuttle Radar Topography Mission GL1 (2013) data and the Distance Accumulation tool were used with the Tobler Hiking algorithm to create a cost raster with the time it takes to traverse the surrounding area taking deviations in topography into account. The Distance Accumulation tool generates a cost raster that represents how long, in hours, it would take to travel from an origin point to all areas on the surrounding landscape, as represented by the DEM. We reclassified the resulting cost rasters to give us estimated travel areas in 1, 2, and 4-hour intervals.

We modeled these arbitrary one-way travel intervals of 1, 2 and 4-hours from the eight large sites to conceptualize the everyday agro-pastoral routes of people living and conducting daily activities in and around those communities. We treat the resulting zones of access as representing characteristics of the landscapes that saw the most frequent movements and interactions between distinct settlements. The 1-hour catchment (Fig. 2) reflects the highest-traffic zone surrounding each occupational concentration—farmers and herders living in a village or homestead would either work within or pass through this area on a regular, if not daily, basis. The 2- and 4-hour catchments (Figs. 3 and 4) reflect broader zones with resources that could be accessed at different levels of intensity by people traveling to and from a village within one day.

These parameters focus on general logistical considerations to produce data for independent comparison with the traditional model of Andean ecological complementarity. Establishing an effective limit to ordinary subsistence activities for residents of large sites draws attention to extensive areas that contain small Late Formative settlements lying at a distance from any of the early village sites. Large stretches of valley-bottom *kichwa* land in the Sacred Valley fall beyond the easy access of some of the early villages, and the dozens of small sites located in those areas might reflect independent hamlets or small communities, satellite settlements related to larger early villages, or some overlapping combination of strategies that might require either seasonal or year-round residence.

3.2.2. Kernel density analysis

We confirmed interaction areas and settlement clusters identified in the catchment area analysis. This was accomplished using the Kernel Density tool in ArcGIS Pro 3.2. Kernel densities give an estimation of settlement density by converting the points on the landscape into a heatmap raster with values reflecting the closeness of sites to one another within a predefined search radius. Based on prior archaeological and ethnographic studies (Bintliff 2012; Flannery 1976; Farinetti 2011), a search radius of 2.5 km^2 was used as an approximation of where one could walk within one hour of every site in the dataset. This gives similar results to the catchment area analysis above but allows for statistical verification of the possible site clusters shown by the 1-hour catchments

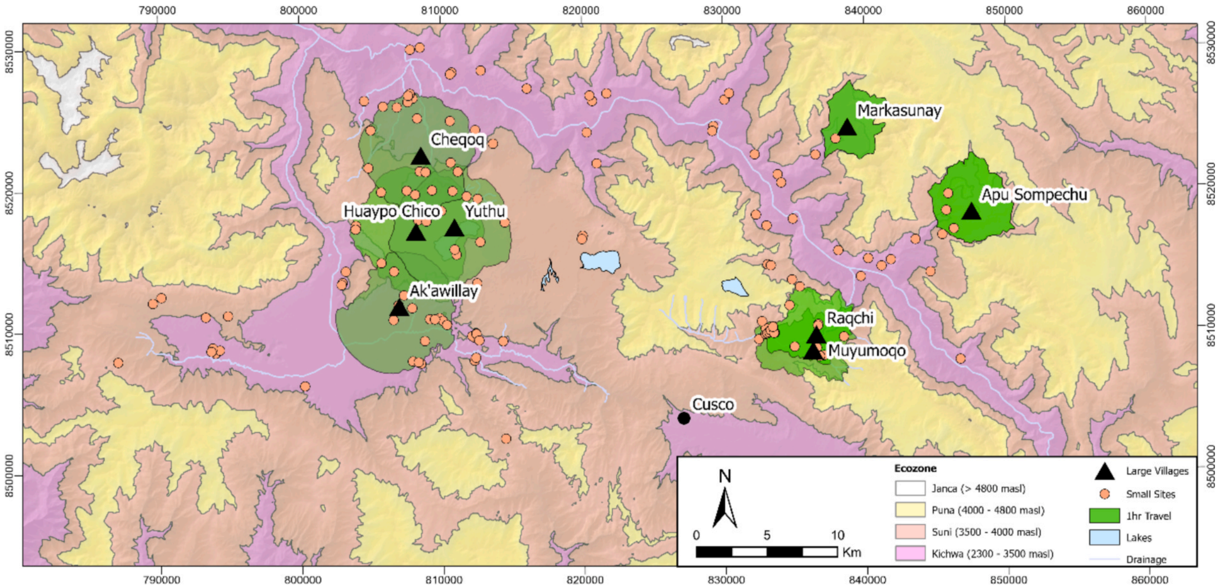

Fig. 2. 1-hour travel cost catchments for the eight large villages.

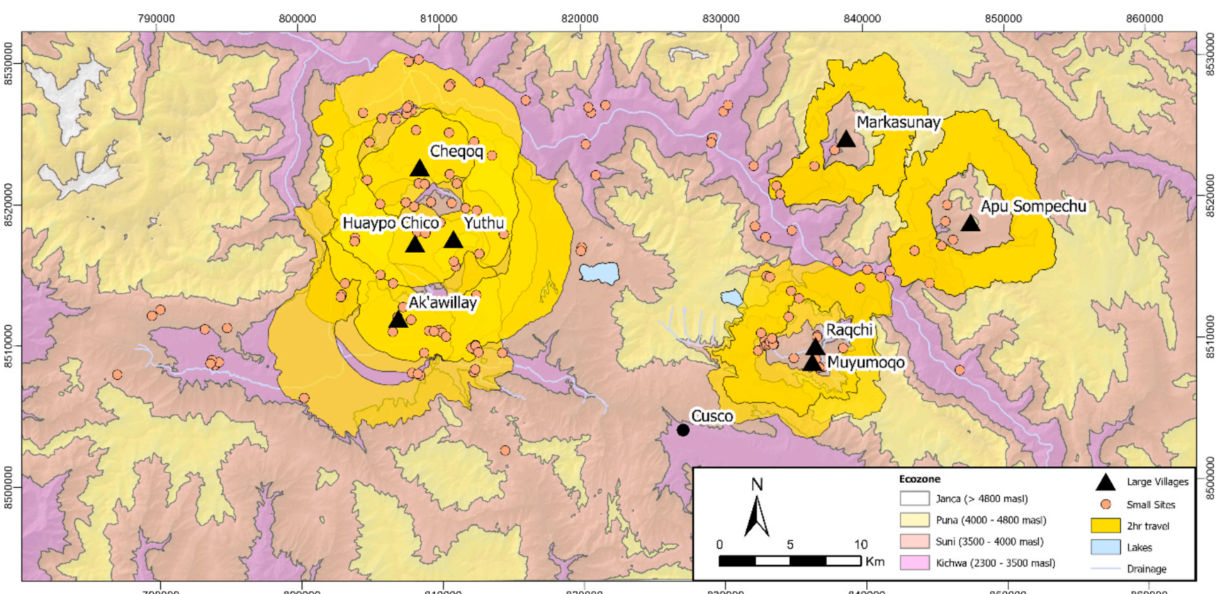

Fig. 3. 2-hour travel cost catchments for the eight large villages.

as well as easier visualization of settlement density on the landscape (Fig. 5).

3.2.3. Landscape visibility

Visibility would facilitate the observation of farming and herding practices in lands close to an emerging village, which might include places occupied and worked by people from other communities. Landscape visibility would allow people living in the same place to monitor the movements of their kin and neighbors, which might be significant for social and economic reasons, or for defensive actions in times of conflict. In addition, the ability to view expanses of the surrounding landscape could have enhanced the ritual significance of a site, as Davis (2011) has argued for Yuthu.

To assess these issues, we generated a cumulative viewshed for the eight large sites, to consider how visibility of contemporaneous sites, routes, lands, or geographic features might have informed settlement location and growth. We used this cumulative viewshed to consider intervisibility among the eight early village sites and the intervisibility of strategic viewpoints or potentially sacred natural features. Individual viewsheds were also generated for each of the eight large sites to assess intervisibility of small sites and total visible area from each individual community. The individual viewsheds and cumulative visibility were generated using the Visibility tool in ArcGIS Pro 3.2 with an observer height offset of 1.5 m to simulate a standing individual, and the same 30 m DEM derived from SRTM (2013) data was used for this analysis. In order to capture both the potential to see other communities on the landscape as well as prominent natural features, an outer radius of 30 km was set. While this can exaggerate the number of communities visible from each large site, the resulting viewsheds mimic what can be seen on a clear day from each of these large communities, especially the surrounding landscapes and distant mountain peaks. Further, the visible, smaller sites surrounding each large site are within a 5 km radius or just outside, within a reasonable distance for the human eye to discern people moving on the landscape (see Ogburn 2006). Thus, the resulting

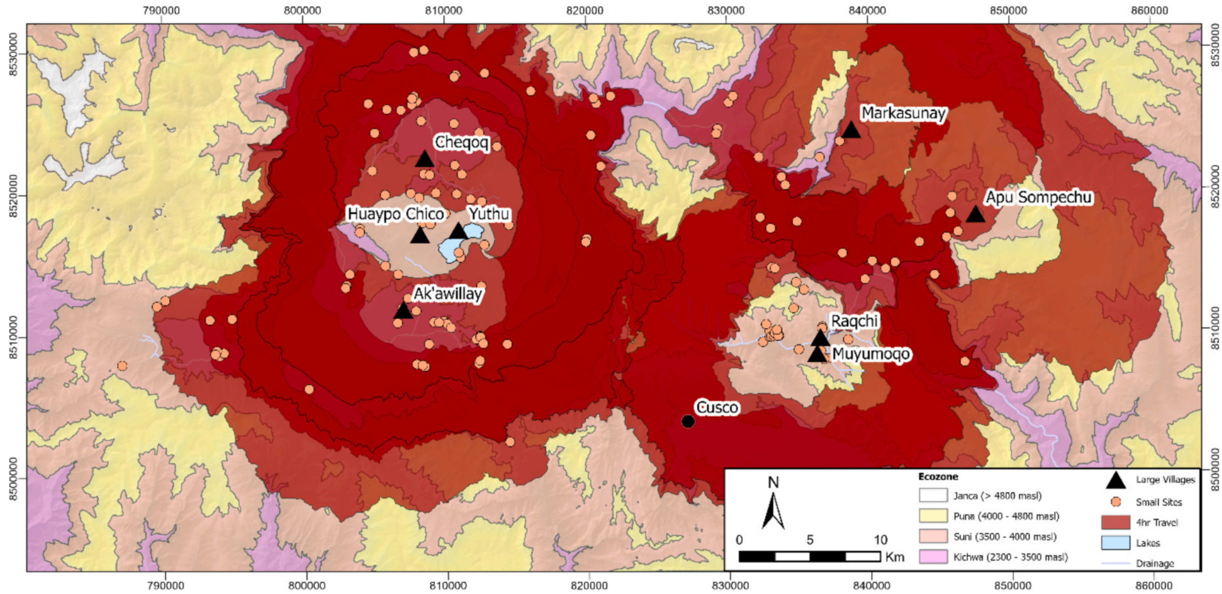

Fig. 4. 4-hour travel cost catchments for the eight large villages.

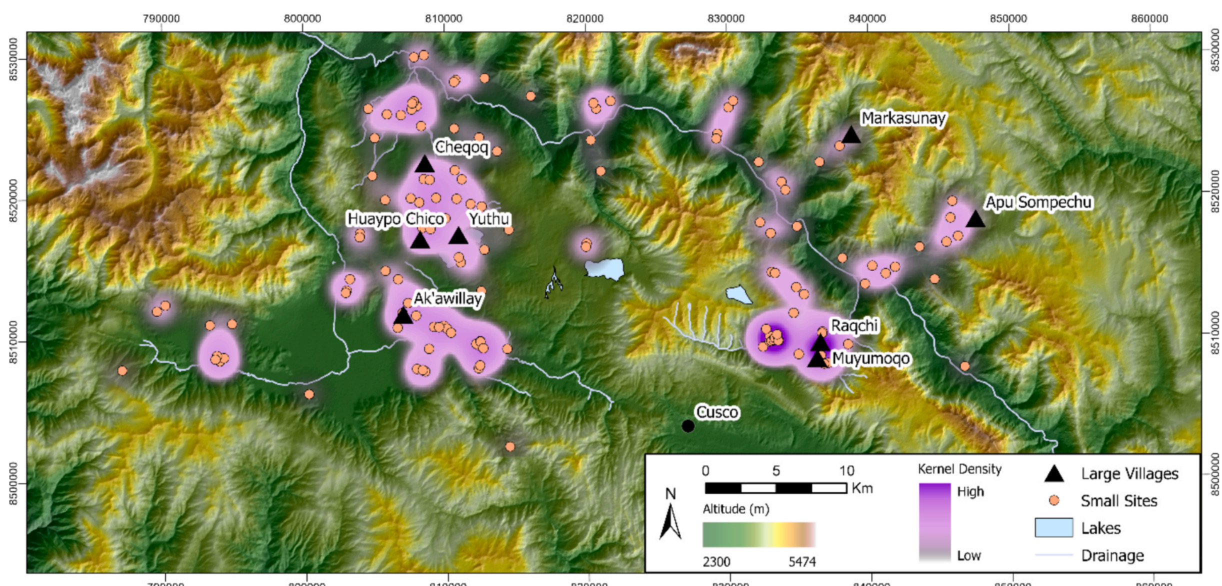

Fig. 5. Kernel density estimates representing density of settlement in Formative Cusco. Note dense cluster near Raqchi and Muyumoqo.

viewsheds represent what could be seen on a “functional” as well as a “symbolic” landscape.

3.3. Landscape risk

Based on the prior discussion of the ecological variability in the Hanan Cusco survey region, we categorized areas in and around settlement clusters into broad categories of low, medium, and high risk. These heuristic categories of landscape risk are based on 1) general characteristics of the dominant ecozones surrounding each site discussed in Section 2.2 with some further detail below and 2) access to arable farmland in and around each site.

As discussed in Section 2.2, each of the three dominant ecozones in our study present unique opportunities and challenges to long-term settlement. Limited soil deposition, risk of frost, altitudinal limits on common Andean crops, and unpredictable weather patterns prevent the *puna* from being used for substantial agricultural activity. While it can support camelid herds as pastureland and some low-intensity tuber cultivation, this leads to a settlement pattern with a low population density occupying dispersed homesteads with some nucleated settlements (Flores Ochoa, 1979). As discussed previously, *suni* and *kichwa* lands have a much greater capacity to support agriculture with Formative sites in the survey region preferring *suni* lands. While both ecozones are amenable to agriculture, settlements in the *suni* would have been faced with higher frost-risk as opposed to those utilizing more low-lying *kichwa* lands. In addition, the irrigation potential of these ecozones in our survey area differs. Most of the *suni* lands have low irrigation potential and would likely have mostly been dry farmed and dependent on fluctuations in yearly precipitation.

In addition to these landscape heuristics, we categorized the landscape based on areas of arable land in the *kichwa* and *suni* ecozones and calculated how much arable land was available to each site within their respective 1, 2, and 4-hour travel zones. We created a binary category of “arable land” as regions exhibiting a slope of 15 degrees or less. This was based on prior works (Bonnier et al. 2019; Weiberg et al. 2021; Whitelaw 2000) that noted land with a slope of 10 degrees or less was amenable to farming while a slope between 10–15 degrees could be farmed but with some risk of erosion. Areas with a slope of 15 degrees or greater would either be completely unsuitable or would have required extensive landscape modifications in the form of terracing. While terracing was a common feature of Inca agricultural practice and continues to be utilized into the modern day, there is no evidence that such extensive landscape modifications were being carried out during the Formative period in Cusco.

An important caveat to this analysis is the possibility of interannual variation in climatic conditions due to drier or wetter years. While lake and glacier core data from the Cusco area indicate several possible dry periods during the Formative (Chepstow-Lusty et al. 2003), the currently available climate data along with the coarse-grained nature of our survey data do not permit a more detailed modelling of changes in site placement due to larger climatic changes. While we also cannot readily assume that today's climate matches the average climate of the Late Formative, significant shifts in ecozone location were an unlikely occurrence year-to-year. As more excavation data becomes available, it may be possible in the future to better delineate changes in settlement in response to ecozone shifting and sustained arid periods.

4. Results

4.1. Ecological characteristics of early village sites

The locations of the eight large Late Formative sites in the study region represent considerable ecological variation. The largest, Ak'awillay, is situated on an alluvial terrace overlooking well-watered valley bottom *kichwa* lands. Three sites (Cheqoq, Yuthu, and Huaypo Chico) lie within an expanse of rolling *suni* lands that lack reliable sources of irrigation water in most parts. Two other villages (Muyumoqo and Raqchi) are located in the *suni* lands of the Chit'apampa Basin, a small river basin that drains into the *kichwa* lands of the Sacred Valley, and both had easy access to large expanses of *puna* with abundant *bofedales*. The final two sites (Markasunay and Apu Sompechu) are located high in the side valleys to the north of the Sacred Valley, in areas of marginal *puna* grassland (Fig. 1). Together, these large settlements span a significant elevation range (~3450–4100 masl), which corresponds ecologically to the *kichwa-suni* ecotone, the *suni*, the *suni-puna* ecotone, and the *puna*. Although the ecological conditions of the study region were not identical to those seen today, site locations correspond to significant differences in precipitation, hydrology, and temperature, making it reasonable to infer variations in agropastoral practices between early village communities.

The zones of access immediately surrounding the eight early village sites varied significantly in terms of size and resource availability. Ak'awillay had a relatively large 1-hour zone of access (Fig. 2), with expansive areas of wet *kichwa* lands close to the village. The three village sites (Cheqoq, Yuthu, Huaypo Chico) located on the plain to the north of Ak'awillay also had extensive 1-hour zones, but those areas consisted almost entirely of *suni* lands that had no irrigation potential. To the east, the villages in the Chit'apampa Basin occupied a much steeper – and more variable – landscape for their 1-hour zones of access. A cluster of smaller sites was located near permanent streams that could be used for small-scale irrigation, but they lacked local access to *kichwa* lands where the risk of frosts was low. The two larger Chit'apampa Basin sites lacked sources of easy irrigation. Finally, the remote upland villages of Markasunay and Apu Sompechu were surrounded by steep hillsides that presented high travel costs. For these sites, most of their 1-hour zones consisted of *puna* grassland or more marginal *suni* land, whereas access to *kichwa* lands required a significant round-trip journey. As with the preceding discussion of site ecology, it is important not to overreach in the evaluation of the nearby zones of access, but it is reasonable to infer that these differences may have contributed to the emergence of distinct social and subsistence strategies that sustained village communities for long periods of time.

4.2. Clustering and access overlap

The Late Formative village sites in the study region show different patterns of small site distribution within their different zones of access as demonstrated by the 1-hour zones of access and kernel density estimation. It is important to consider that chronological ambiguities do not permit us to consider these sites as contemporaneous with one another. We approach the settlement pattern data conservatively, treating smaller sites as a cumulative measure of Late Formative human activities in the area, which can signal different degrees of overall nucleation or dispersal of population on the landscape surrounding the village (see Rowe 1963 for an early approach to this variation in the Andes).

There are three apparent patterns of small site clustering in our village sample. The villages with the largest 1-hour zones of access have the highest count of small sites, suggesting a more dispersed pattern of settlement and resource exploitation on the landscapes where these villages are found. This might reflect higher degrees of transhumance or residential mobility than other parts of the study region (cf. Delgado González 2023) with larger sites serving as seasonal population centers. The two large village sites of the Chit'apampa Basin have smaller zones of access, but the cluster of small sites lying within an hour's hike represents a higher density than is seen for the Xaquixaguana Basin villages (Fig. 5). The two remote *puna* village sites have very few small sites within an hour's travel, suggesting a more nucleated residential pattern when these communities were occupied. As travel time from all villages increases, small site distributions become more comparable for sites in the Anta/Xaquixaguana area. A similar trend is found in the Sacred Valley area, but to a lesser degree given the large expanses of unoccupied *puna* in the 2 and 4-hour catchment zones (Figs. 3 and 4). Many of these remote, small sites lie within the zones of access of more than one village, so that there were parts of the Cusco landscape where Late Formative villagers might find themselves interacting with people affiliated with other communities as they carried out some subsistence activities.

If the village sites were occupied simultaneously, their overlapping zones of access could indicate ways that different communities interacted with each other during the Late Formative. The travel catchments and kernel density estimates highlight two areas with possible village clusters: (1) the Xaquixaguana Basin Cluster (Ak'awillay, Huaypo Chico, Yuthu, and Cheqoq), and (2) the Chit'apampa Basin Cluster (Muyumoqo and Raqchi). It is important to note, however, that the dense cluster of smaller settlements in the Chit'apampa area is unusual when compared to the other settlement systems, indicating a more intensively occupied local landscape. By contrast, radiocarbon dates from Yuthu and Ak'awillay suggest that different ceremonial sites and population centers in the Xaquixaguana Valley waxed and waned during the Late Formative, indicating greater settlement mobility in that area (Delgado González 2023). The two villages located in the *puna*—Markasunay and Apu Sompechu—were located close enough to participate in social interactions that necessitated a much greater investment in travel between the two villages, if they were both occupied at the same time. Those two sites only cluster together in their shared remoteness relative to other Late Formative villages in the study region and access to similar ecological zones. It is important to point out that if the largest sites in these different areas were *not* occupied at the same time, the differences in settlement patterns would still reflect village settlement histories that vary based on local ecology.

4.2.1. The Xaquixaguana basin settlement system

Cheqoq, Yuthu, and Huaypo Chico form the densest cluster within the *suni* hills north of Ak'awillay. As noted above, the 1-hour zones of access for these villages contain more small sites than those of the other villages in the study region (Table 2). The three villages all lie near the

Table 2
Total land area and number of small sites within 1, 2, and 4 h travel from each of the large villages calculated by ArcGIS cost distance analysis. Site count does not include the large village itself.

Large village	Travel time to nearest large site (min)	Travel distance 1 hr		Travel distance 2 hrs		Travel distance 4 hrs	
		Sites	Area (Km^2)	Sites	Area (Km^2)	Sites	Area (Km^2)
Cheqoq	76	15	51.35	24	133.17	36	407.33
Yuthu	35	16	54.05	33	171.85	31	451.46
Huaypo Chico	76	19	59.06	37	173.07	26	457.61
Ak'awillay	85	15	50.97	26	149.49	37	524.45
Raqchi	40	11	21.47	15	74.02	12	365.55
Muyumoqo	40	17	21.19	6	85.44	11	390.60
Apu Sompechu	236	3	25.82	3	83.88	10	389.47
Markasunay	236	1	15.91	3	57.58	15	320.14

edge of each other's 1-hour zones of access, and there are 15 small sites distributed within an hour's walk of more than one village. The settlement pattern for these villages indicates a more dispersed and overlapping set of social and subsistence activities, a landscape where villages might need to coordinate some aspects of resource access, and where kin ties might be expected to spread across close-by communities. Further, excavations at Yuthu (Davis 2011) and Bandojan (Delgado González 2019a) suggest that ceremonial activities might have served to pull a more dispersed population to some sites, even if populations in the area maintained some degree of mobility during the Late Formative (Delgado González 2023).

Although Ak'awillay has zones of access that overlap somewhat with those of the *suni* villages, its size and ecological setting present important contrasts. Ak'awillay is roughly as large as the combined sizes of the three nearby *suni* villages, and its location overlooks well-watered *kichwa* lands in the Xaquixaguana Valley, most of which lie within a few hours' walk. Further, Ak'awillay has the highest area of potentially arable *kichwa* land within a one hour's distance in the survey area with Cheqoq as a close second (Table 3). As will be discussed later, Ak'awillay has a distinct settlement history from that of the *suni* villages, suggesting the development of social hierarchies and a growing dependence on maize agriculture in the final centuries of the Formative Period (Bélisle 2015; Bélisle et al. 2023; Brown and Bélisle 2019; Turner et al. 2018).

4.2.2. The Chit'apampa basin settlement system

East of the Xaquixaguana Plain and south of the Sacred Valley, Muyumoqo and Raqchi are situated on *suni* hilltops lying on opposite sides of a small river basin that offers a high degree of ecological variability. The Chit'apampa villages' 1-hour zone of access overlap, but they differ in their proximity to the cluster of smaller villages. The cluster of small sites lies comfortably within the 1-hour catchment of Muyumoqo but sits just at the edge of Raqchi's. A broad range of lands lies beyond the 1-hour catchment for the two villages, and these include valley-bottom *suni* lands that could be accessed by people living in either community. For Raqchi and Muyumoqo, there is considerable overlap in the small sites found within their 4-hour zones of access. Both villages are located in places with access to high *puna* pastures within a few hours' travel time, but those possible pastoral resource zones lack Late Formative sites. These pastures also lie far from the zones of access of other villages. Overall, the villages in the Chit'apampa Basin are situated in a more "vertical" landscape where many everyday subsistence activities could be carried out without the need to coordinate with the other large village populations. The exception to this picture is the cluster of small valley-bottom settlements located within an hour of Muyumoqo, where well-watered lands could be accessed by both communities.

4.2.3. Apu sompechu and markasunay

On the northeastern edge of the study region, Markasunay and Apu Sompechu occupy steep terrain. Markasunay is situated at the *suni/puna* ecotone, whereas Apu Sompechu is atop a prominent hill that overlooks an upland basin that contains extensive areas of *puna*. It is important to recognize that the northern limit of the study region truncates the 4-hour zones of access for both sites, which largely comprise remote areas of *puna* grassland and rocky mountaintop (Fig. 4). The zones of access for the two villages do not overlap with one another, indicating a more autonomous form of village organization than the *suni* villages lying to the south. The paucity of small sites in the zones of access surrounding the two villages suggests different subsistence strategies to access nonlocal ecozones.

Only a few small sites were found within 2 h of travel from either Apu Sompechu or Markasunay (Table 2), although some small sites appeared in the lower valley areas beyond that limit. It appears that high elevation horticulture and herding were largely carried out using the villages as a residential base, although it is likely that more remote herding stations lie beyond our study area or were too ephemeral to detect during survey. To the extent that the two villages interacted economically if they were contemporaneous, it might have been through less frequent economic or ritual interactions that focused on herding or the sharing of horticultural knowledge, which is documented in the ethnohistory and ethnographic literature for these uplands (Covey and Skidmore 2014:27-32). The only small sites found within the 4-hour zones of access for the two villages lie in the natural corridors to the southwest, which lead to the lower basins and the *kichwa* lands of the Sacred Valley. These small sites are situated at the *suni/kichwa* ecotone.

Table 3
Total arable land in each ecozone within 1, 2, and 4 h travel from each of the large villages. Arable land defined as areas with less than or equal to 15 degree slope.

Large village	Travel distance 1 hr		Travel distance 2 hrs		Travel distance 4 hrs	
	Arable Kichwa (Km^2)	Arable Suni (Km^2)	Arable Kichwa (Km^2)	Arable Suni (Km^2)	Arable Kichwa (Km^2)	Arable Suni (Km^2)
Cheqoq	27.08	18.83	31.76	59.61	124.24	94.34
Yuthu	2.83	42.5	56.12	84.52	136.48	77.58
Huaypo-Chico	7.03	71.21	69.19	63.44	122.37	102.62
Ak'awillay	35.41	7.9	60.92	47.87	76.77	190.89
Raqchi	0.42	6.23	5.25	13.35	70.5	40.48
Muyumoqo	0.41	8.54	4.91	14.03	4.91	14.03
Apu Sompechu	0.17	11.55	2.79	8.19	16.61	36.91
Markasunay	0.42	1.88	1.43	0.43	23.91	24.45

4.3. Visibility

Overall, the large Formative villages in the Hanan Cusco survey had little overlap in visibility of their surrounding landscapes, as demonstrated by cumulative visibility analysis (Fig. 6). The exceptions to this statement are Raqchi and Muyumoqo, owing to their more compressed landscape. However, as discussed below, despite the high overlap there are still important differences in the strategic placement of each site within the Chit'apampa Basin.

4.3.1. The Xaquixaguana basin settlement system

Sites in the Xaquixaguana area were afforded more extensive areas of visibility, largely due to the less steep terrain surrounding each of the sites. Ak'awillay has an especially strategic view of the large Anta plain as well as the entrance to the plain from the Cusco Basin, although its location does not provide visibility to the rolling hills around Lake Huaypo, where other early village sites were located. Ak'awillay would have been well positioned to monitor both local movements as well as those passing through the plain coming from other parts of Cusco. Further, people living at Ak'awillay would have also been able to observe the residents of numerous small sites in the Xaquixaguana/Anta plain as they carried out daily subsistence work and other activities. Yuthu and Huaypo Chico also have rather large areas of visibility, with Huaypo Chico being the larger. However, these two sites differ in that Yuthu's viewshed included more surrounding small sites than that of Huaypo Chico. In addition, Yuthu has a clear view of the nearby Lake Huaypo. To the north, Cheqoq enjoyed an expansive view of sites clustering near it.

4.3.2. The Chit'apampa basin settlement system

Within the Chit'apampa Basin, the visible areas of Muyumoqo and Raqchi initially appear largely comparable, but a closer look demonstrates differences in what each site's location made visible. Raqchi, despite being settled at a higher elevation than Muyumoqo, has a limited view of the cluster of small sites due to a large hill to the west of the site. However, Raqchi does have a strategic view of the entrances to the area from the Cusco Basin and the Sacred Valley. Raqchi has a slightly larger total visible area, but this is mainly due to its ability to see more distant mountain peaks compared to Muyumoqo (Table 4). In contrast, Muyumoqo has a much better view of the cluster of small sites compared to Raqchi, while also maintaining strategic views of the entrances from the Cusco Basin and the Sacred Valley; in addition, Muyumoqo could see traffic entering and exiting the *puna* behind the site. This *puna* landscape might have been a potential connection between sites in the Chit'apampa Basin and sites to the south of Cusco (e.g., Minaspata and Chokepukio). Overall, while Raqchi and Muyumoqo's areas of visibility largely overlap, Muyumoqo enjoys a more strategic location that was better suited to observe the dense cluster of smaller villages and hamlets as well as traffic moving in and out of the Chit'apampa Basin.

Table 4
Percent of total catchment area (1, 2, and 4 h) and number of sites visible from each large village. Total area for each cost catchment (km^2) is in Table 2.

Large village	Number of visible sites	Total area visible (km^2)	% Travel distance 1 hr	% Travel distance 2 hrs	% Travel distance 4 hrs
Cheqoq	15	177.29	13.49	14.43	20.02
Yuthu	15	100.88	17.86	5.49	27.48
Huaypo Chico	5	186.12	5.56	6.94	21.48
Ak'awillay	13	199.38	18.27	26.12	24.51
Raqchi	10	39.28	31.87	32.84	17.34
Muyumoqo	10	35.7	33.05	35.80	16.95
Apu Sompechu	10	103.02	15.59	29.83	14.95
Markasunay	5	53.48	20.33	31.62	15.48

4.3.3. Apu sompechu and markasunay

Both Markasunay and Apu Sompechu have high visibility of their surrounding landscapes, but they were not visible to each other (Fig. 6). This could suggest non-overlapping occupation periods, or alternatively a relationship in which defensibility or monitoring of neighboring communities was less important than visibility of the surrounding landscape, including small downslope villages. Apart from one small site located near the Sacred Valley, people at the two large villages could not observe activities taking place in and around the same small sites. As already discussed, few small villages were situated near these larger sites.

5. Discussion

Overall, the eight Late Formative village sites in the study region show significant variations in size, ecological diversity, nucleation, and visibility. These differences appear in patterned ways that indicate the

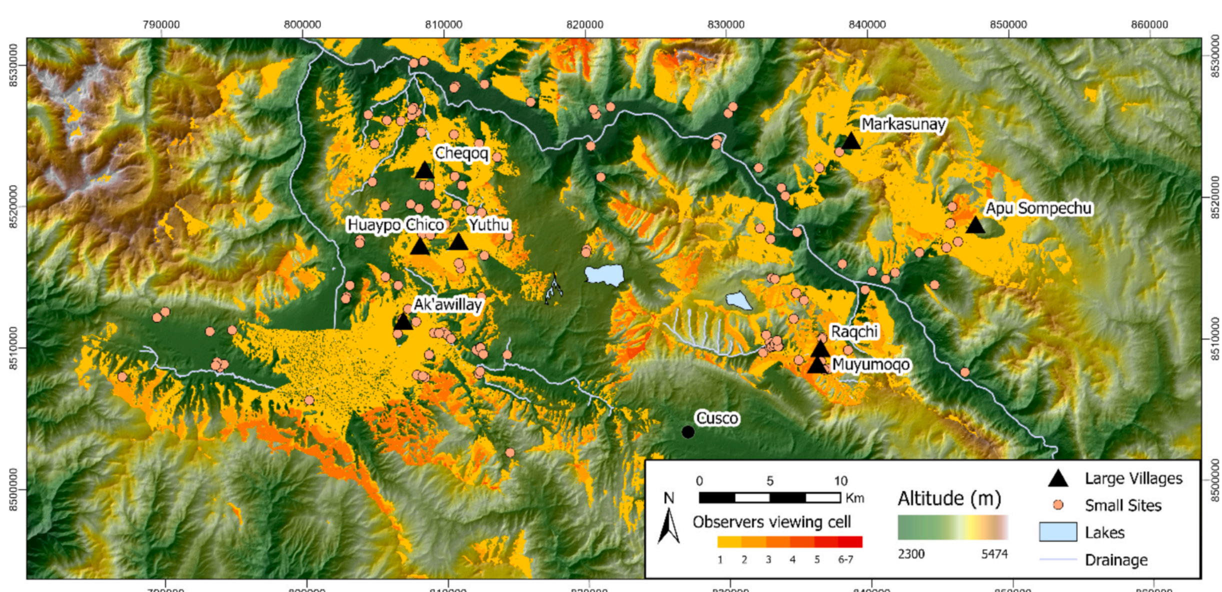

Fig. 6. Cumulative visibility from the eight largest villages showing how many sites could see which portions of the surrounding landscape.

coexistence of multiple local settlement systems in the Cusco region during the Late Formative, which differed in their population sizes, subsistence activities, and possible intergroup relationships. Although the preceding discussion has emphasized traditional ecological zones and ecotones, overall landscape risk is a useful way to approach the long-term patterns and success of village life in these very different landscapes. In the following discussion, we examine the various site locations in terms of their long-term viability for settlement and ability to support growing populations over time. Drawing on our earlier discussion of creating heuristic categories of landscape risk, we divide the landscape into three broad classifications: 1) low-risk; 2) medium-risk; and 3) high-risk.

5.1. Villages in high-risk landscapes

As described, the high elevation villages of Markasunay and Apu Sompechu are situated on marginal landscapes where temperature, soil quality, and slope would have presented significant constraints on agropastoral production. On these uncertain landscapes, early villages selected highly visible site locations where tuber cultivation and herding could be carried out by people who brought their harvests and animals back to a nucleated settlement. The presence of small sites in strategic lower valley areas, several hours' walk away from the village, might indicate the use of permanent colonies or transhumant settlements to produce crops that would not grow in the marginal uplands.

To the extent that Markasunay and Apu Sompechu interacted with one another, it probably would reflect the seasonal movements of herders, including participation in caravan networks, as well as the periodic coordination of common ceremonies, marriage exchanges, or economic alliances. The ecological setting and social dynamics of these villages probably sustained slower rates of surplus production. Their nucleated pattern and non-overlapping landscapes suggest limited options for dealing with the social effects of population growth, a socio-ecological circumscription that might have presented a modest avenue for the emergence of social inequality over time.

5.2. Villages on moderate-risk landscapes

Whereas camelid pastoralism would have needed to play a significant role in the high elevation villages once they reached a certain population level—to exploit lands too marginal for farming—the landscapes of most Late Formative villages in the study region had more productive lands in their closest zones of access. The rolling hills of the Xaquixaguana area offered more room for people to pursue different household strategies and to "vote with their feet" if village life lost its social appeal. Some villages—Cheqoq, Raqchi, and Yuthu—were situated near visible promontories, or in places with good views of sacred landmarks (Davis 2011; cf. Delgado González 2019a, 2023). Along with Huaypo Chico and Muyumoqo, these villages had local access to moderately risky agropastoral resources: mid-elevation lands with limited irrigation potential and few locations that were not vulnerable to seasonal frosts. These villages appear to have grown into dynamic social and economic networks that shared many of the same resources. With the exception of Huaypo Chico, many of the sites in the Xaquixaguana system could have observed the coming and goings in surrounding, smaller communities. However, many of these sites lie beyond the 1-hour catchment zones.

In contrast, Muyumoqo would have had an exceptional ability to monitor activities occurring at the small cluster of villages within the Chit'apampa system. While Muyumoqo and Raqchi also occupy a similar ecozone to that of the other sites mentioned, the more compressed landscape of the Chit'apampa Basin may have prevented easy site relocation, in contrast to sites in the Xaquixaguana area. It is also likely that populations affiliated with these aforementioned villages were among the occupants of small sites in or near the warm lands of the Sacred Valley, and such sites could have been temporarily occupied during the harvest season or served as permanent colonies.

5.3. Ak'awillay and the settlement of low-risk landscapes

Ak'awillay stands apart from other nearby villages for its size and proximity to the lowest risk agropastoral resources. The site's 1-hour zone of access contains the most frost-free lands and the best irrigation prospects of any Late Formative village in the study region, and the site has an expansive viewshed looking out onto the flat valley-bottom lands where low-risk farming and herding could be done. The location of the village also offers local access to a range of diverse microclimates on the hillslopes and nearby plains. Ak'awillay was a densely settled site that also had dozens of small sites lying within a few hours' walk, suggesting a larger and more hierarchical settlement pattern than the village clusters of the Xaquixaguana Plain or Sacred Valley.

Although Ak'awillay is unique in the study region, its resemblance to other Late Formative centers is noteworthy. In the Cusco Basin, Muyu Urqu (3400 masl) occupies a similar prominent position just above large areas of low-risk valley-bottom lands (Bauer 2004). Farther to the southeast, the Lucre Basin sites of Chokepukio (McEwan et al. 1995) and Minaspata (Dwyer 1971; Hardy 2019) both appear to have been significant Late Formative centers situated just above the valley floor (Bauer et al. 2022). Batan Orqo in the Urcos area occupies a comparable location (Zapata 1998). Several of these sites are known to have modest public architecture that dates to the Late Formative period, suggesting greater social coordination than smaller villages occupied at the same time (cf. Davis 2011; Delgado González 2023).

5.4. Small sites on low-risk landscapes

Given the association between larger settlements and local concentrations of low-risk agropastoral resources, the settlement pattern of the Sacred Valley presents an interesting example of what appears to be a low-risk landscape where all Late Formative sites are small and scattered. One explanation for this pattern might be that the floor of the valley was more flood-prone than the neighboring Xaquixaguana and Huatanay valleys, and that its high mountains and steep slopes made the arrival of Amazonian monsoon rains more unpredictable. Even if the valley presented risks that discouraged large village settlements, the presence of more than 20 small Formative sites indicates that there were populations that occupied the lower slopes of the valley and took advantage of places where there were low-risk lands to be found. Some of these were probably independent hamlets, but the distribution of small sites suggests that there might also have been modest farming colonies affiliated with the larger villages located several hours' walk from the valley. Although it is impossible to associate small sites with specific villages, the Sacred Valley appears to have been a place that could have facilitated the production of *kichwa* crops, as well as exchange activities involving villagers from different areas.

5.5. Long-term settlement trends

Of the three models of Late Formative village life in our study region, only one survived into the subsequent period. Ak'awillay's population grew in the early centuries CE, as some of its neighbors waned (Bélisle 2015; Davis 2011). During the Middle Horizon, the site was a local center of at least 10 ha (Bélisle 2014), surrounded by a network of small valley-bottom *kichwa* sites. Isotopic data (Turner et al. 2018) indicate a shift toward maize consumption at the site, which is consistent with the establishment of numerous small *kichwa* sites in the Xaquixaguana Valley and Maras area during the Middle Horizon. At least some of the population of the new *kichwa* settlements appears to have come from the area of *suni* village settlement in the Xaquixaguana Plain. The villages of Yuthu, Huaypo Chico, and Cheqoq show decline and abandonment in the early centuries CE (see Davis 2011; Quave 2012), and most of the small Late Formative sites in that area had no Middle Horizon material in surface collections.

To the east, the *suni* villages in the Chit'apampa Basin showed a similar pattern of village abandonment and shift toward irrigable valley-bottom lands (Covey 2006). Muyumoqo shows no subsequent occupation, whereas the ridgetop site of Raqchi had evidence of a small Middle Horizon component, as well as a village occupation in the Late Intermediate Period that was replaced by an early Inca fort. Surface collections from the high elevation *puna* villages (Markasunay and Apu Sompechu) had no pottery from 400 to 1000 CE. Although both sites were reoccupied during the Late Intermediate Period (1000–1400 CE), they declined in Inca times and then were reoccupied in recent centuries.

In sum, it appears that areas surrounding larger sites that had more access to arable *kichwa* land, in this case Ak'awillay and Cheqoq, continued to be important areas of social and political activity into subsequent periods. As previously discussed, Ak'awillay continued to grow into an important community into the Middle Horizon. In contrast, Cheqoq never grew to the size of Ak'awillay and reduced in size during the Middle Horizon. However, the area surrounding Cheqoq saw an increase in settlement as the areas surrounding Lake Huaypo, where Yuthu and Huaypo Chico once existed, were depopulated (Bélisle 2014). While a shift towards maize-focused agriculture is only one part of this puzzle of resettlement, there is a clear preference for lands that could farm maize more easily as the Late Formative ended and the Early Intermediate/Middle Horizon began.

6. Conclusions

As demonstrated by the areas of access derived from the catchment analysis, early villagers faced different kinds of subsistence risks on their local landscapes, which informed the choices they made about where to settle, what foods to produce, and how to interact with people from neighboring communities. The distribution of dispersed small sites in low lying areas, such as the sites in the Sacred Valley, suggests that the colonization practices described by the ecological complementarity model may have been useful for producing nonlocal crops, especially for smaller communities living on higher-risk landscapes like Markasunay and Apu Sompechu. Excavations at these large sites and the valley bottom settlements would be needed, with an eye towards establishing connections between the satellite settlements and the large population centers. Further, for sites in the Xaquixaguana area, views of distant, natural features important in ritual life may have been just as important for choosing where to settle down, especially in a comparably less vertical environment with expansive views.

Although the early villages of Cusco's *suni* and *puna* landscapes resemble the ethnohistoric and ethnographic communities used to develop the ecological complementarity model in several regards, it is important to observe that economic growth and the development of complex societies in the region occurred in landscapes that offered both the diversity of the hillslopes, as well as the intensification potential of the low-risk *kichwa*. Ak'awillay was the only Late Formative village to grow much larger than 6 ha, and it functioned as a population center for centuries after neighboring villages were abandoned. In the Cusco Basin, Muyu Orqo was abandoned at the end of the Formative Period, but populations moved to nearby sites like Tankarpata to exploit *kichwa* lands directly (Bauer and Jones 2003). Other valley-bottom centers continued to be occupied into the Middle Horizon, and Wari colonization favored the same kinds of lands that had long supported the populations of Chokepukio, Minaspata, and Batan Orqo (Bauer et al. 2022; Hardy 2019; McEwan et al. 1995; Zapata 1998). Many of these sites remained occupied up to the Inca period, a time when imperial elites transformed vast areas of *kichwa* lands into royal estates. Thus, it appears that between the Formative and Early Intermediate a shift towards lands conducive to maize agriculture coincided with increasing social complexity and the drawing of peoples to population centers with access to these lands.

The identification of multiple patterns of Late Formative village life in the future Inca heartland affirms aspects of the ecological complementarity model, but it also raises some significant questions about how archaeologists approach ancient land use in the Andean highlands. Murra's model focused on the resilient lifeways of Indigenous agropastoralists who were largely excluded from low-risk production landscapes—by Inca elites, Spanish *hacendados*, and Peruvian landowners. Based on the emphasis on upland resources over those produced in valley-bottom lands, the model's bottom-up orientation treats highland states as extensions of the kind of *ayllu*-coordinated practices that reduce the risk of farming and herding on *suni* and *puna* landscapes. This assumption may need to be revisited, given the diversity of early village settlement patterns in the Cusco region and the association between a distinct *kichwa*-oriented village model and the long-term development of social power and settlement continuity in the region.

Archaeological settlement pattern data represent a valuable means for studying the general ecological and social landscapes surrounding the Late Formative village sites of the Cusco region and other areas in the Andes. With site-catchment and visibility analyses, we have identified the existence of multiple arrangements of village life that developed in the same region at approximately the same time. Many studies of early village/community emergence and landscape use focus primarily on placing sites within an evolutionary framework to document increasing social complexity and changes in subsistence practices in a region through time (see Kowalewski 2008 for several examples; Underhill et al. 2008; Weiberg et al. 2021). While these studies are valuable for documenting change in social organization over the longue-durée, our work highlights that established GIS methods, such as cost-distance, kernel density estimation, and visibility analysis, can be utilized with regional survey data to illustrate important variation at a synchronic scale. Applied to other regional datasets, synchronic approaches such as ours can provide avenues for future inquiry into early settlement, relations with the surrounding environment, and interactions with possible satellite settlements. We have also highlighted that views of the surrounding landscape, both for strategic and ceremonial purposes, may have been just as important for choosing where to live as access to certain ecological zones. The approach taken in this paper can be applied to other regions to generate testable hypotheses that can act as a guide for targeted and problem-oriented excavations, especially in areas with rich landscape diversity like the Andes.

CRediT authorship contribution statement

Matthew T. Brown: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Camille Weinberg:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Nicole D. Payntar:** Writing – review & editing, Writing – original draft, Methodology. **Lia Tsesmeli:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Leah Larsen:** Writing – review & editing, Visualization, Formal analysis. **R. Alan Covey:** Writing – review & editing, Writing – original draft, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The authors do not have permission to share data.

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