A Reduced Landscape: Toward a Multi-Causal Understanding of Historic Period Agricultural Deintensification in Highland Peru

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Abstract

This article examines the effects of depopulation, resettlement, and the Little Ice Age on local patterns of historic-era Andean agricultural deintensification. Situated in the Colca Valley of Peru, this analysis employs walking simulations between a colonial reducción village (Coporaque) and the locations of its reconstructed 17th century fieldholdings. Multivariate analysis shows how increased frost risk (due to the Little Ice Age) and increased distance to fieldholdings (due to resettlement) impacted the decisionmaking of local, dualistically-organized kindreds (ayllus) in distinct ways. For lower-ranking ayllus in this dualistic structure, distance outweighed frost risk, while for higher ranking ayllus, frost risk was more important. Colonial demographic decline was a distal factor for both.
Keywords: *agriculture, Andes, terrace abandonment, irrigation, Inka, colonial period, GIS*

Resumen

Este artículo examina los efectos de despoblación, desplazamiento de asentamientos (las reducciones), y la Pequeña Edad de Hielo para patrones locales de desintensificación agrícola andina durante la época histórica. Situado en el Valle del Colca del Perú, este análisis emplea simulaciones de caminatas entre una reducción (Coporaque) y las ubicaciones reconstruidas de sus campos de cultivo del siglo XVII. Análisis multivariable demuestra cómo el creciente riesgo de escarchas (por causa de la Pequeña Edad de Hielo) y de distancia (por causa de la reducción) afectaron las decisiones de los grupos locales de parentesco dualísticos (ayllus) de distintas maneras. Para los ayllus de menor rango político en la estructura dualística local, distancia tenía mayor importancia que el riesgo de escarchas, mientras que para los ayllus de mayor rango, el riesgo de escarchas era el factor más importante. La caída demográfica colonial actuó como un factor distal para ambos grupos.
Palabras clave: *agricultura, Andes, abandono de andenes, irrigación, Inka, periodo colonial, SIG*

Introduction

In villages throughout the central Andean highlands, the agricultural work day begins early, ends late, and almost invariably involves long slogs to and from one's widely scattered fields, often bearing a burden, with livestock in tow. The daily routine of hiking to and from the village is part of the taken-for-granted reality of "life in the *chacras* (fields)" today, but it was not always this way. The curious arrangement of nucleated, gridded villages amidst vast patchworks of terraced agricultural fields is a thoroughly colonial phenomenon. The majority of the "agro-villes" that dot the highland landscape were constructed when Andean communities were forcibly resettled from dispersed pre-Hispanic settlements over the course of just one decade—the 1570s—during the tenure of the Viceroy Francisco de Toledo (for overviews, see Gade and Escobar 1982, Hemming 1983:392-456, Stern 1982). One of the largest resettlement programs in history—affecting some 1.5 million native Andeans (Hemming 1983: 393)—the *reducción* (literally, reduction) project was part of an overhaul of the colonial state by Toledo following three tumultuous decades of plunder, civil war, neo-Inka insurrection, and indirect colonial rule. The newly constructed built forms of the reducciones were intended to inculcate social order (*policía*), enable the ready recruitment of draft labor and the collection of census-based tax levies, and establish a parish system for a more profound conversion to Catholicism. As the linchpin of the Toledan reforms, reducciones are thus traditionally depicted as the institutional framework through which Spanish colonial domination was decisively established in the viceregal countryside. But like all colonial projects, they also brought a raft of unintended consequences. Deaths from Spanish-introduced pathogens spiked as their transmission was exacerbated in the close living quarters of the reducciones. Many families fled to avoid taxation and the dreaded Toledan *mita* (labor draft). Those that remained were faced with maintaining their fields and the often elaborate irrigation infrastructure that supported them.

The daily hikes to and from fields by Andean farmers today is one reflection of that colonial legacy. The extensive areas of relict agricultural fields and irrigation systems around most highland villages may be as well. Today, abandoned agricultural terraces and canals are ubiquitous in the landscape of the Peruvian Andean highlands. About 50% of the agricultural terraces in Peru are currently abandoned (Denevan 2001:183). This statistic is even more remarkable when considering the demographic picture is one of dramatic growth, with intense pressures for increased production to feed the increasingly urban population. The great majority of modern funding for agricultural projects is focused on massive irrigation projects on the desert plains and valleys of the coastal area, which use high input, capital intensive methods. Documenting the sources and causes of agricultural deintensification in the highlands is therefore not only inherently important to a broader understanding of the forces that shaped colonial Andean history, but for informing ongoing decision making in agricultural and development policy generally.

The Colca Valley, located in the semiarid western cordillera of southern Peru, is one of the most intensively terraced valleys in the central Andes—irrigated bench terracing covers virtually all slopes below about 4000 m. With a lengthy history of research on the topic of terracing and irrigation in the valley (for an overview, see Denevan 2001: 185-211), combined with a rich documentary record, the Colca Valley is an ideal locale to investigate the phenomenon of historic-era agricultural deintensification in the Andes. The basic statistics are striking: approximately 61% of the bench terraces in the valley are abandoned (Denevan 1988b: 22, 28). In the reducción village of Coporaque, the site of most terrace research in the valley and the focus of this study, about 54% of fields (of all types) are abandoned at present. Some of these were sloping fields and segmentary terrace systems that were probably abandoned during the shift to irrigated bench terracing around Middle Horizon times (500-1100 CE) (Treacy 1994, Wernke 2003). These irrigated bench terrace systems remained in production and were expanded through the Late Intermediate Period (1100-1450 CE), and further expanded during the Inka occupation of the valley during the Late Horizon (1450-1532 CE). All indices suggest that these bench terraces and associated canal systems reached their apogee, along with population and settlement area, during the Late Horizon, and remained so until the eve of the Spanish invasion (Treacy 1994, Wernke 2003). Therefore, the abandonment of bench terraces and associated irrigation canals is largely or entirely a colonial- or republican-era phenomenon.

Why were so many terrace and canal systems abandoned during historic times? Frameworks for addressing this question tend toward prime-mover models, focusing on decreased water availability (Guillet 1992), changes in mean temperature (especially the cooler conditions of the Little Ice Age; see Brooks 1998), colonial depopulation, or colonial resettlement (Donkin 1979). William Denevan, whose pioneering Río Colca Abandoned Terrace Project of the 1980s stimulated much research on the topic (Denevan 1986, 1988a, 2001), has noted multiple correlations between terrace abandonment and changes in climate, demography, and social organization during the colonial period, and has suggested that multiple causal factors were likely at play. This paper builds on these insights by using GIS-based analyses and simulations to test the effects of each of these factors—climate change during the Little Ice Age, demographic decline, and colonial resettlement—on colonial era agricultural deintensification in the Andes. Through the case study of the village of Coporaque, located in the central portion of the Colca Valley, I show how all of these factors were mediated by particular structures of indigenous Andean community and land use organization to structure the specific spatial pattern of terrace and canal abandonment observed in the landscape today.

Labor, Community Organization, and Irrigation Infrastructure

Terrace abandonment has garnered the most attention and has framed most of the research questions on agricultural deintensification in the Andes (Denevan 2001). Terraces are the most visible features in Andean agricultural systems, and provide a number of beneficial functions for agricultural production. These include their function in creating level planting surfaces (which in turn enables the amassing of thick, humic topsoils; see Eash and Sandor 1995, Sandor 1992, Sandor and Eash 1991), their frost-risk abatement, which functions by radiating heat built up from daytime sunlight, and their ability to shed cool air that descends slopes at night (Evans and Winterhalder 2000). But, as demonstrated by John Treacy (1989, 1994), the primary function of terracing is hydraulic—terraces provide gently sloping surfaces that regulate the velocity of water flow, thus maximizing water absorption and mitigating topsoil erosion. In semiarid locales such as the Colca Valley (and other valleys of the western cordillera), where irrigation is required for reliable agricultural production, terracing and irrigation features (canals and reservoirs) therefore constitute complementary components of a single productive infrastructure.

Individual terraces, though linked and often constructed together in "irrigation clusters" (Guillet 1987, 1992), can be maintained and managed at the household level. Indeed, the land tenure system of the Colca valley and other irrigation-dependent systems of the Pacific drainages is at the highly individualized end of the land tenure spectrum, in contrast to variably divisible-to-indivisible communally-controlled systems (Bolin 1993, Guillet 1981). Even in this case, however, rights of use (e.g., when and which crops can be planted) and sale (e.g., extra-communal sale proscription) are restricted, and, most importantly for the considerations of this paper, decision making regarding terrace maintenance is impacted by higher-order management and the maintenance of irrigation networks upon which they depend (Treacy 1993).

Most irrigation systems here and elsewhere in the Andean highlands require supra-household level of coordination (Guillet 1978, Mitchell 1976), not only for day-to-day decisions regarding water distribution and management, but for the regular maintenance, repair, and cleaning they require (Denevan 2001, Gelles 2000, Trawick 2001a, 2001b, 2003, Treacy 1994). In the Colca Valley, some small spring-fed irrigation systems exist (Paerregaard 1993), but the great majority of the cultivated area of the valley is irrigated by extensive canal and reservoir systems that collect and carry water from glaciated peaks and alpine springs to terraced fields. Ranging from a few hundred meters to nearly 30 kilometers in length, the canals require frequent maintenance, including annual cleaning and repair *faenas* (community-based collective work fiestas), organized and supervised by community irrigation commissions (Gelles 1995, 2000, Guillet 1987, 1992, Treacy 1993, Valderrama Fernández and Escalante Gutierrez 1986, 1988). Annual cleaning faenas are likewise required to maintain reservoirs, as accumulated silt is excavated and heaped on their earthen berms.

Given these considerations, the observed pattern of large contiguous tracts of abandoned fields is likely epiphenomenal to the dereliction of their respective irrigation systems, and for this reason, "agricultural deintensification" is a more accurate descriptor of the process *in toto* than "terrace abandonment". By extension, it should be evident that politics and community organization are as central to agricultural deintensification as they are to agricultural intensification (Morrison 1996). Attempts to model deintensification must therefore consider the effects of political organization on what are otherwise seen as "adaptive" processes related to demographic, technological, or ecological changes. Thus, as I argue, and as the analysis below demonstrates, political organization—and specifically, political organization related to the constitution of community—acts as a mediating factor to the demographic and ecological factors that might impact deintensification (e.g., population decline, colonial resettlement, or climate perturbation). Tracking the effects of all of these potential causal factors through a multivariate approach enables approximation of the processes responsible not just for the extent of agricultural deintensification, but for the specific spatial manifestations of deintensification observed in local landscapes today.

The Colca Valley

The Colca Valley is among the largest Pacific drainages of the southern Peruvian highlands (Figure 1). Curving westward from its origins just west of Lake Titicaca, the Río Colca cuts through the high altitude plateau that dominates this region of the Andes, forming a relatively warm, montaine oasis in a region otherwise dominated by high altitude, semiarid grasslands of the *puna* ecological zone (Pulgar Vidal 1996). The stretch of the most populated section of the Colca Valley ranges from about 2200 m at the base of the lower valley to nearly 5000 m at the high valley rim. Within that altitudinal range are a great variety of vertically-distributed "production zones" (Mayer 1985), ranging from small orchards in the subtropical *yungas* zone of the lowest reaches of the valley near Cabanaconde to extensive areas of pasture in the high puna grasslands between 4000 and 4800 m. The great majority of the agricultural area of the valley falls between about 3200 and 4000 m, where virtually all slopes are covered with stone faced terraces (Figures 2). The average annual rainfall is around 400 mm, but it is highly variable inter-annually and highly concentrated between the months of November and March. Diurnal fluctuations in temperature far exceed seasonal ones, and frosts at this high altitude can occur any month of the year in the agricultural zone, though they are much more frequent during the dry season months of May through August. Irrigation is therefore required for reliable agricultural yields, both to augment the scanty, highly-seasonal, and unpredictable rainfall, and to extend the growing season—specifically, to enable planting in September, prior to the onset of the rainy season, in order to harvest prior to May frosts (Mitchell 1976, Treacy 1993: 100-101). Climatic conditions with insufficient rainfall for dry farming—with significant variability discussed below—were in place throughout the historic period, and extended back through prehispanic times at least to the Middle Horizon (ca. 500-1000 CE) (Treacy 1994, Wernke 2006a, 2006b).

Figure 1. Location of the Colca Valley in southern Peru, showing study area.

Figure 2. Panorama of irrigated bench terrace complexes (in use below, abandoned above) in the Chijra, Ccayra, and Waykiri toponym areas of Coporaque.

The valley was a major regional center of human settlement throughout prehistory, and was home to two major ethnic groups at the time of the Spanish invasion: the Collaguas and Cabanas. With a population of 33,900 in 1580, and roughly double that on the eve of conquest (Cook 1982), these were among the largest ethnic polities of *Condesuyo*, the southwestern quarter of *Tawantinsuyu*, the Inka imperial "union of four quarters". The Collaguas, who occupied the central and upper stretches of the valley, were Aymara speakers who practiced intensive agriculture in the valley proper, while outlying settlements of herders maintained extensive herds of Andean camelids (primarily alpacas, *Llama pacos*). They cultivated maize preferentially in areas below about 3600 m, and a mix of Andean chenopods (primarily quinoa [*Chenopodium quinoa*] and kañiwa [*Chenopodium pallidicaule*]), tubers [*Solanum spp., Oxalis tuberosa, Ullucus tuberosus*], and Andean beans (e.g., tarwi—*Lupinus mutabilis*) in the higher altitude areas below about 4000 m. The Collaguas were divided between two large sub-ethnic groups, the higher ranking Yanquecollaguas of the mid- to upper-part of the valley, and the lower-ranking Laricollaguas, of the central valley (Ulloa Mogollón 1965 [1586]). Each was headed by their eponymous capital villages—Yanque and Lari, under colonial administration.

The Cabanas, Quechua speakers, occupied the lower part of the valley around the village of Cabanaconde, and were especially renowned for the quality and abundance of the maize they produced—*maiz cabanita*—which still today commands a premium in regional markets (Gelles 2000). As is common among Andean highland peoples, each of the three provincial groups—Yanquecollaguas, Laricollaguas, and Cabanaconde—was internally divided between ranked moieties: *Hanansaya* (upper moiety) and *Urinsaya* (lower moiety), which in turn were composed of a number of *ayllus* (named, ancestor-focused kindreds).

Prehispanic Settlement and Land Use

An extensive and growing archaeological database permits characterization of the long-term trajectory of change in human settlement and land use patterning in the valley. The following discussion of these trends is necessary to differentiate agricultural complexes that were abandoned during pre-Hispanic times from those most likely abandoned during historic times.

The earliest agriculturalist occupations of the valley appear to be characterized by dispersed hamlets and villages associated with un-irrigated sloping fields, valley bottom stone-bordered fields, and segmented terraces which cluster around natural drainages (*quebradas*) on valley side escarpments. The dating of these occupations is imprecise because the Formative Period ceramic type (diagnostic based on certain pan-regional formal and technological attributes of Formative ceramics) still lacks a suite of absolute dates (Wernke 2003: 128-129, 134-136). All that can be said with certainty is that they post-date the earliest aceramic periods of food production in the Late Archaic (ca. 3300 BCE; see Tripcevich 2007), and pre-date the Middle Horizon (500-1100 CE). But this relative sequence is sufficient for the purposes of this paper, since it establishes that un-irrigated sloping fields, valley bottom fields, and segmented valley-side terraces pre-date irrigated bench terraces. As observed by Treacy (1994: 102-103), in several areas, un-irrigated segmentary terraces are directly overlain by the latter where they meet. Most un-irrigated stone bordered fields on the valley bottom were likewise superimposed by irrigated broadfield terraces and valley bottom fields. They remain visible (as abandoned fields) only in areas that were never overbuilt by irrigated fields (see video clip).

Irrigated field systems likely displaced older un-irrigated fields beginning during the Middle Horizon, a period when parts of the valley were under considerable influence, and possibly direct imperial presence, of the Wari Empire. Agricultural intensification and the construction of extensive irrigation systems have been associated with Wari imperialism in other southern valleys, especially the Moquegua valley to the south (Williams 2002). There is strong evidence for Wari presence in the mid- to lower-valley—in particular, at the large sites of Charasuta near Lari (Doutriaux 2004: 212-220) and Achachiwa near Cabanaconde (de la Vera Cruz Chávez 1988: 40-55, 1989: 56-70, Doutriaux 2004: 202-207). However, evidence for Wari presence drops off in the mid-to upper-valley. Systematic survey in the Yanque-Coporaque area revealed a decentralized hamlet and village settlement pattern, and ceramics only indirectly influenced by Wari imperial styles (Wernke 2003: 150-157). Basal levels of trench excavations in terraces near Coporaque—site of the present study—date to the Middle Horizon, suggesting the transition from un-irrigated sloping fields to irrigated bench terraces dates to sometime during or shortly after the Middle Horizon (Malpass 1987, Malpass and de la Vera Cruz Chávez 1990).

In the succeeding Late Intermediate Period (hereafter LIP; 1100-1450 CE), settlement and irrigated agriculture expanded steadily. The LIP is marked by a proliferation of hamlets and villages with distinctive local forms of domestic architecture located amidst irrigated bench terrace complexes. There are clear indices for growing inequalities and conflict during the LIP, as the size and elaboration of domestic structures show major differences in household wealth and status, and most settlements are either located in defensible promontory or hillside locales, or adjacent to hilltop fortresses. The overall pattern is one of a segmentary mode of organization that oscillated between coordination and conflict (Wernke 2006a, 2006b, 2009). While settlement and irrigated agriculture expanded throughout the LIP, they clearly reached their maximal extent during the subsequent Inka imperial occupation of the Late Horizon (1450-1532 CE). There is overall continuity of settlement from the LIP, but with considerable expansion at existing settlements (Doutriaux 2002, 2004, Wernke 2003, 2006a, 2006b, 2007b, 2009). For example, 87% of sites with LIP occupations in the Yanque-Coporaque area continue to be occupied during the Late Horizon (Wernke 2006b: 197). These later occupations tend to be commingled with earlier ones, complicating calculation of settlement expansion, but Late Horizon ceramics generally dominate assemblages (Doutriaux 2004, Wernke 2003, 2006b). Large administrative centers were built in each of the three zones of the valley, forming locally-centralized settlement hierarchies in each. Distinctive Inka great hall structures and central plazas were also emplaced at many of the largest LIP settlements with elite local domestic architecture as well, suggesting a centrally-organized but locally-mediated form of imperial rule that combined aspects of both direct and indirect administration (Wernke 2006a, 2006b).

Colonial Transformations

This general relationship between settlement and agriculture remained in place during the tumultuous early years following the Spanish invasion. The peoples of the Colca were granted as encomiendas in several separate grants by Francisco Pizarro to Spanish elites between 1535 and 1540 (Cook 2007: 29-46, Málaga Medina 1977). While the Cabanaconde and Laricollaguas encomiendas of the mid- and lower-valley were divided by moiety, Yanquecollaguas, with the largest population of the three areas of the valley, was granted singly, making it among the richest encomiendas of Peru. Befitting its great value, Francisco Pizarro granted the Collaguas to his half-brother Gonzalo in 1540. There is some local lore regarding the notorious Gonzalo passing through the valley, but plainly neither he nor the other *encomenderos* resided or spent any considerable time there (Cook 2007: 45). The only sustained Spanish presence in the valley before the 1570s was a small group of Franciscan friars. They established a series of *doctrinas* (doctrinal settlements) between the 1540s and 1560s at former Inka imperial centers and outposts. A number of these have been documented today and are the subject of ongoing research by this author (Wernke 2007a, 2010a). Documentary and archaeological evidence indicates that the friars experimented with some early attempts at consolidating settlement, but by and large, the peoples of the valley remained dispersed in a great number of hamlets, villages, and towns through the 1560s (Cook 2007: 74-75, Wernke 2007b).

It was during Toledo's *visita general* (general tour of inspection) that the pre-Hispanic settlements and doctrinas of the valley were either built over or forcibly abandoned. Around 1573, the Toledan visitador Lope de Suazo completed the censuses and ordered the resettlement of the valley's population to reducción villages (Málaga Medina 1977), which, with one exception (the reducción of Santa Cruz de Tuti), remain inhabited today. Though reducción effected a radical break in long-term relationships between settlement and land use, closer analysis, as discussed below, shows the reducciones were not established strictly by administrative fiat. Rather their emplacement in local landscapes was the outcome of negotiations between local interest groups and colonial officials.

The Reducción of Coporaque and its Landscape

Coporaque was chosen for this study because it is among the best-studied villages in the valley. The agricultural landscape of Coporaque was the main focus of the Río Colca Abandoned Terrace Project, the dissertation research of the late John Treacy, and part of my archaeological survey of the core area of Yanquecollaguas (Wernke 2003, 2006a, 2006b, 2007b). It is also among the best documented villages in the colonial visitas to the valley, with near-complete demographic and land use data in the 1604 visita of the Urinsaya moiety (APY Yanquecollaguas Urinsaya 1604) and the 1615-1617 visita of the Hanansaya moiety (APY Yanquecollaguas Hanansaya 1615-1617) and extensive prior ethnohistorical and archaeological research (Benavides 1986a, 1986b, 1986c, 1989, 1990, 1995, Denevan 2001, Malpass 1987, Malpass and de la Vera Cruz Chávez 1990, Robinson 2006b, Treacy 1994, Wernke 2006a, 2006b, 2007b). The visitas used for this analysis also have been published as an edited series that was initiated by the late Franklin Pease and completed by David Robinson (Pease 1977, Robinson 2003, 2006a, 2009).[1]

Consistent with the general discussion of late prehispanic settlement and land use above, a series of hamlets, villages, and towns were established in the Coporaque area during the LIP, forming a non-centralized settlement pattern. Locally, the largest settlement was San Antonio/Chijra, an 8.7 ha site with 136 rectilinear fieldstone domestic structures dispersed over agricultural and domestic terraces (Wernke 2006b: 189). During the Inka occupation, the site became a secondary administrative center, as an Inka great hall structure fronted by a plaza was constructed adjacent to the main residential area. During the early years following the Spanish invasion, San Antonio became one of the early Franciscan doctrinas. Ecclesiastical documents indicate that the site was originally named "Cupi", an Aymara term meaning "right side" (Echeverría y Morales 1952 [1804]:80)—a detail that has importance for the following discussion on land tenure and agricultural deintensification patterns. A small chapel was constructed on the prominent hilltop adjacent to the Inka great hall (both remain visible today). The site is also situated directly above a large amphitheater-like complex of bench terracing known as Waykiri—a toponym used to locate many fields in the visitas as well. Waykiri is noteworthy for its fertile soils and because it is the lowest-lying sector in Coporaque, making it especially well-suited to the cultivation of (frost intolerant) maize. It remains the most sought-after land in the village today (Treacy 1994). Thus, the largest late pre-Hispanic settlement with elite architecture and Inka administrative buildings were located directly adjacent to prime agricultural lands. It remained occupied through early colonial times until its forced abandonment with the construction of the reducción of Coporaque. Other late prehispanic hamlets and villages are dispersed among the fields of the pampas and rolling hills to the southeast of the reducción.

The agricultural field mosaic of Coporaque follows the general patterns described above. Un-irrigated segmented terraces and sloping fields abandoned in pre-Hispanic times remain visible on the high slopes above 3800 m, concentrated in natural drainages. Most of these relict un-irrigated fields are found on the high flanks of Pampa Finaya, a prominent massif adjacent to the east of Coporaque. Extensive areas of abandoned, un-irrigated stone bordered fields are dispersed among the rolling hills to the east of Pampa Finaya, a broken landscape formed by Quaternary volcanic flows that today is generally used as marginal grazing lands. In some areas, abandoned irrigated bench terraces are situated directly downslope of the earlier un-irrigated fields, and above currently-cultivated irrigated bench terracing. In most areas below 3600 m, irrigated terraces and fields remain under intensive cultivation by Coporaque villagers today.

In prior research (Wernke 2006a, 2007b), I reconstructed the land tenure patterns of the colonial ayllus of Coporaque by linking the toponyms used to locate fieldholdings in the visita declarations with their modern counterparts (described below). The resulting land tenure reconstruction reveals contrasting patterns between the two moieties of Coporaque, and between ayllus within the moieties. The lower-ranking Urinsaya moiety was composed of ayllus named by reference to Inkaic categories of tripartite and decimal ranking, indicating a penetrating reorganization by the Inka state. The higher-ranking Hanansaya moiety, by contrast, was composed of ayllus with Aymara names that suggested a pre-Inkaic dualistic organization—specifically, one organized around a directional, "left" and "right" sided logic. Such right/left dualism, common in Aymara polities (Albó 1972, Astvaldsson 2000, Bouysse-Cassagne 1986, 1987), was linked to the rank and spatial organization of their constituent ayllus. "Right side" ayllus were higher in rank, and were associated with maleness and higher topography, while the left side was lower in rank and associated with femaleness and lower topography. The reconstructed land tenure patterns reveal that the ayllu names within Hanansaya did indeed reflect spatially-discrete patterns of land-use and pre-reducción settlement. All ayllus in the Hanansaya moiety held fields that were concentrated to either the east or west of a prominent local quebrada (ravine), the Río Chillihuitira (Figure 3). The lower-ranking "left" side ayllus held lands concentrated to the east of the Chiillihuitira (to the "left" when facing downstream on the Chillihuitira), while the lands of the higher-ranking "right" side ayllus were concentrated to the west (to the "right" when facing downstream on the Chillihuitira). This is consistent with other known Aymara dualistic landscapes, in which the boundary between the right and left sides is constituted by water courses, with "right" and "left" oriented facing downstream (Albó 1972, Astvaldsson 2000, Bouysse-Cassagne 1986, 1987).

These insights have several implications for understanding both pre-Hispanic and colonial settlement and land use organization. First, they provide a basis for reconstructing where the ancestors of the ayllus of Hanansaya lived prior to reducción resettlement. Those of the right side almost certainly resided at the site of San Antonio/Chijra (discussed above), which lies near the center of the distribution of the right side ayllu landholdings. This seems beyond doubt when recalling that this site was independently documented as having been originally named "Cupi" ("right side"). The ancestors of the left side ayllus, by contrast, most likely lived in the late pre-Hispanic and early colonial settlements among the pampas to the east of the Chillihuitira.

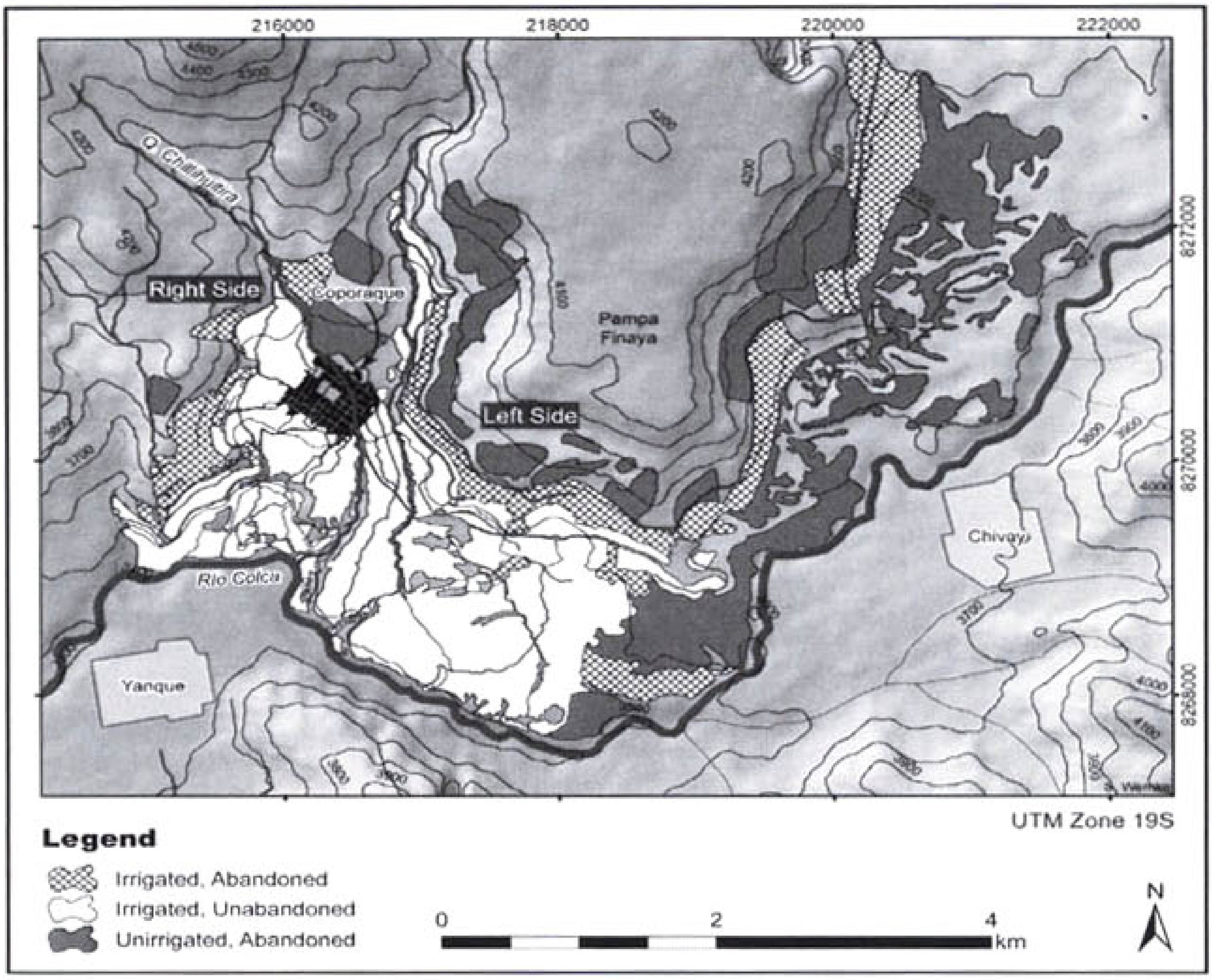

Figure 3. Field areas digitized from airphotos and satellite imagery. Only irrigated field systems (white and cross-hatched areas) are included in this analysis. The "right" and "left" sides of the landscape (discussed in the text) are divided by the Quebrada Chillihuitira, which runs through the reducción of Coporaque into the Colca River below.

(see video clip)

Inka administrative architecture (great halls and plazas) is present both at San Antonio/ Chijra and at settlements on the "left" side, suggesting that imperial administration reached down to articulate with these autochthonous structures of community organization (Wernke 2007b). Lands from the original inhabitants of the left and right side settlements would have been inherited by kin affiliation, so it is reasonable to infer that the visita declarations, recorded only one to two generations after resettlement, registers pre-reducción patterns of land use and residence.

Second, it is striking that the reducción village of Coporaque straddles the boundary between the right and left sides. The Chillihuitira literally runs through the northeast quadrant of the village grid (Figure 3). As I have argued elsewhere (Wernke 2007b), this specific emplacement of the reducción of Coporaque most likely reflects the negotiated outcome between colonial magistrates and the local leaders of the right and left sides. The reducción was not just a top down imposition, but worked within and reaffirmed the preexisting dualistic form of community organization, settlement patterning, and land-use. It was pulled into place by the competing interests of the ayllus of the two sides. Moreover, it was emplaced in a way that was between the two "sides", but in a location that favored the higher ranking right side. This would seem to be the case since fields of the right side appear nearer to the reducción than those of the left. Looking at the areas of abandoned irrigated terracing, it is evident that the bulk of the abandoned area is located in the domain of the lower-ranking left side, which is generally further from the reducción than those of the right side. Also, abandoned fields seem to be generally higher in elevation than unabandoned fields, and are uniformly so among the right side. The emplacement of the reducción relative to pre-Hispanic settlement and land-use patterns therefore may have been an important determinant in the specific spatial distribution of field abandonment observed around Coporaque today. The analyses below provide quantitative means for evaluating these impressions.

Methodology, Sampling, and Simulation Procedures

In outline, the methodology for analyzing the spatial patterning of historic period agricultural deintensification in Coporaque involved three steps: 1) digitization of abandoned and unabandoned field areas, 2) simulation of specific field locations for the implementation of a walking model to and from the abandoned and unabandoned fields, and 3) implementation of an anisotropic walking model over a digital elevation model (DEM) to and from these fields, using the center of the plaza of Coporaque as a starting point. Each is described in turn below.

Reconstructing Unabandoned Field Locations

Reconstructing the locations of unabandoned fields involved two steps: 1) spatializing the agricultural fields declared in the visitas to reconstruct areas in-use during the early colonial period, and 2) digitization of the entire area of unabandoned fields today. The first step functions to ensure that the currently unabandoned fields were in production during early colonial times and not simply put into production recently. The key data for spatializing the visita declarations is the toponymic information associated with the agricultural fields declared by each household in the visitas. Each field declared was listed not only with its size and the predominant crop grown in it, but its location by toponym. These toponyms, though ranging in size from a handful of fields to several dozen fields, tend to be quite small and discrete, given that they generally refer to "irrigation clusters"—that is, groups of terraces that share a common distribution canal—the most distal canals in the irrigation network. This link to irrigation, along with their continued salience in claiming title to landholdings (such as in the visitas themselves) has also contributed to the durability of the toponyms, since they continue to be used as referents in distributing irrigation water. Today, such toponyms are still used by the irrigation commission officials to coordinate the distribution of water. Thus, fields declared by toponym in the visitas can be located on the landscape by mapping the toponym mosaic today and finding their matches in the visitas. This methodology is described in detail elsewhere (Wernke 2007b), but in outline, it involved 1) conducting a modern toponym survey in which the local toponym mosaic was mapped via GPS in consultation with local irrigation commission members and farmers; 2) digitizing the toponym outlines as polygon themes; 3) sorting and matching the modern toponyms with those listed in the visitas, which were entered in a relational database, and 4) joining the polygon theme and attribute (visita) data to view the visita declarations as spatial distributions. The resulting base map consists of 51 modern toponyms in Coporaque with counterparts in the visitas. Within these toponyms lie 354 agricultural fields declared by the households of the Hanansaya moiety of Coporaque in the visita of 1615-1617, accounting for 22% of the total of 1,593 total fields declared.

The visitas are organized by ayllu, and within each ayllu, the household of the kuraka (ayllu headman) is listed first, followed by the mandón (second-in-charge), then tributary households (those with male heads of household between the ages of 18 and 50), followed by several categories of non-tributary households (e.g., infirm, widows, elderly, orphans). These categorizations were then repeated for each ayllu in that moiety for the village in question. Land tenure data can be therefore queried, sorted, and aggregated at varied scales—by household, ayllu, and moiety, for example—and displayed as spatial distributions in the GIS.

Digitizing Abandoned Field Areas

Digitizing abandoned fields is a more straightforward process, akin to the methods for identifying and calculating the area of abandoned terracing used earlier by Denevan (1988b), but in a digital, GIS-based environment. Two main sources were used for digitizing abandoned terrace areas (using ESRI ArcGIS): 1) high resolution (~40 cm pixel scale) georeferenced airphotos taken by the Peruvian Servicio Aerofotográfico Nacional (SAN, 1974 series[2]), and 2) from SPOT satellite imagery (~1 m pixel resolution) for areas not covered in the air photos (via Google Earth). As is evident in Figure 4, abandoned fields stand out distinctly from those still in use and are readily identifiable in the imagery (Denevan 1988b). The digitization process involved tracing the outlines of abandoned complexes as polygons, then entering basic field type attribute data in the corresponding attribute table. The resulting base map (Figure 3) shows abandoned terracing in crosshatching and gray and unabandoned terracing in white. As discussed below, for the purposes of this paper, which focuses on historic (primarily colonial) era agricultural deintensification, un-irrigated abandoned fields (gray field areas in Figure 3) are excluded from analysis since they were abandoned in pre-Hispanic times, most likely during the transition to irrigated agriculture.

Simulating Field Point Locations

Specific field locations are required to implement the walking model—that is, specific points are needed as destinations. This entailed generating a stratified sample of randomly distributed points for fields within their respective polygons digitized from the aerial and satellite imagery. The requirements for producing the sample were 1) an estimate of the actual area under cultivation within a polygon, exclusive of walls, trails, and other non-cultivated area, and 2) an estimate of the size of the fields within each polygon to derive a total number of fields for each abandoned area polygon, which could then serve as a theoretical population for sampling. For each of the abandoned polygons, 10% of its area was first subtracted to account for uncultivated area (field walls, paths, etc.), resulting in an estimated area (i.e. 90% of the total area digitized) used for cultivation. The field size estimate was then derived from the mean size of the fields declared in the visitas, which was 1135 m2. The estimated cultivated area of each abandoned field polygon was divided by this average field size to arrive at a hypothetical total number of fields in that polygon. From that value, a 20% sample was selected. Thus,

$$\text{Field Point Sample}=((A\times 0.9))/U\times 0.2$$

Where A is the area of each of the abandoned field polygons, and U is the mean area of the unabandoned fields. This number of points[3] for each abandoned polygon was then randomly distributed within the respective polygon to function as the destination points for the walking model.[4]

Field elevations were extracted from an underlying Digital Elevation Model (DEM), which was derived from imagery produced by the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) platform on the Terra satellite. This is currently the highest resolution DEM available at 30 m pixel resolution.[5]

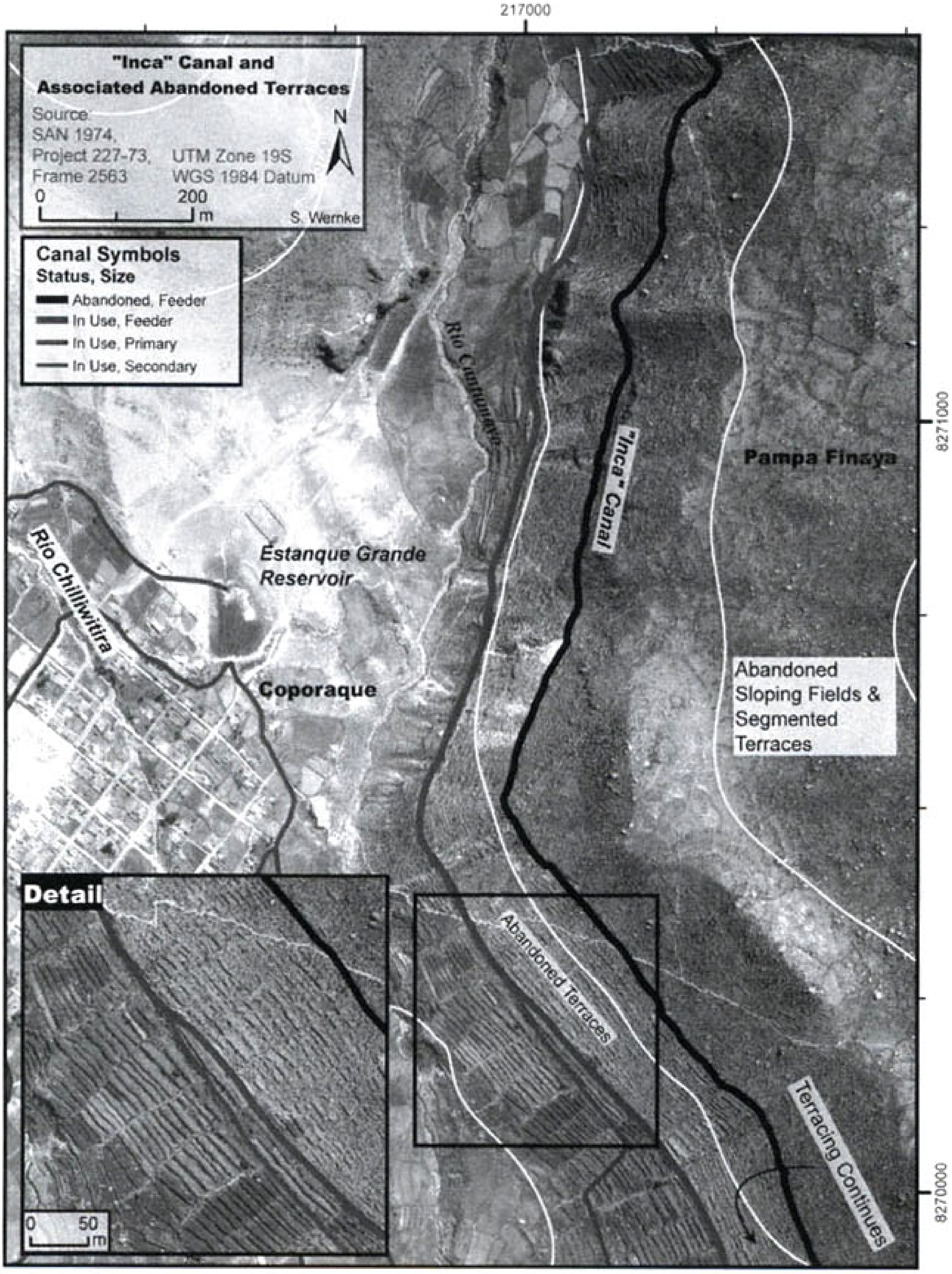

Figure 4. Georeferenced airphoto showing topographic relationships between in-use and abandoned irrigated terraces, which overlie earlier unirrigated sloping fields and segmented terraces on the western slopes of the Pampa Finaya massif to the adjacent east of the village of Coporaque.

Simulating Distance To and From the Fields

In this high-relief, high altitude setting, calculating distance from the village to agricultural fields in terms of straight line Euclidian distance units would be highly problematic, since walking speed, and thus, travel time, varies as a function of slope, altitude, and a variety of other factors. To account for some of these factors, an implementation of two walking simulation models was used: least cost path (LCP) analysis, combined with the anisotropic hiking algorithm devised by Waldo Tobler (1993). In basic terms, the simulation finds the easiest path to and from each agricultural field using the center of the plaza of Coporaque as the starting point, then implements the Tobler hiking algorithm, which increases or decreases walking speed according to slope angle. This results in walking time for each agricultural field, rather than only straight line or least cost path distances, thus providing a measure of human movement over the landscape. As such, it assumes a perfectly rational (in terms of energy expenditure and time allocation) and does not account for actual paths or the multitude of field walls that impede free movement to the fields, which were not mapped in sufficient detail for this analysis. The simulation thus functions as a heuristic model, providing a common baseline for comparison that is superior to straight line distance (which would distort actual distances much more). The model was run using a custom AML script written by Brian Frizzelle (Spatial Analysis Unit, Carolina Population Center), which deploys Tobler model-derived cost surface tables, created by Nicholas Tripcevich (Archaeological Research Facility, University of California, Berkeley).

Colonial Demographic and Deintensification Parameters in Coporaque

The basic measures of the field area digitization in Coporaque reveal the extent of deintensification since the maximal extent of production under Inka rule (Figure 3). Overall, the total area of fields is 1315 ha,[6] of which 806 ha are composed of irrigated fields (the remaining 509 ha are un-irrigated fields abandoned during pre-Hispanic times, and are excluded from analysis here, as discussed above). Of the 806 ha of irrigated fields, 34% (272 of 806 ha) are abandoned (see Table 1 for summary statistics). As is evident in Figure 3, the overall pattern is one of large contiguous blocks of abandoned fields—entire irrigation sectors—rather than abandoned fields intermixed with unabandoned fields. This pattern is consistent with the abandonment of irrigation sectors, rather than "fields" or "terraces" per se, as discussed above, suggesting that labor required for irrigation maintenance infrastructure was a major concern. As discussed below, this scenario is consistent with the long term picture of dramatic demographic decline in Coporaque during the colonial period.

As is evident in Table 1, the area of agricultural fields were not evenly distributed between the two sides of the dualistic landscape of Coporaque. Three quarters (74%, 594 of 806 ha) of the irrigated field area (unabandoned and abandoned) is situated on the lower-ranking left side. This imbalance owes not to greater land wealth among left side ayllu households: landholdings per capita of the left side ayllus was 0.33 *topo*[7] (about 0.12 ha), while the right side ayllus held 0.37 topos (about 0.13 ha) per capita. The bulk of the imbalance owes to the larger population of the left side ayllus, which constituted 56% (904 of 1595) of the population of Hanansaya in 1616.

Colonial Demographic Decline and Deintensification

As Cook (1982) has demonstrated in a detailed demographic study of the Colca Valley, the population declined markedly through the colonial period, primarily as a result of several epidemics of Spanish-introduced pathogens. Demographic retrodictions estimate a pre-contact population between 62,500 and 71,000 on the eve of the Spanish invasion (Cook 1982: 83-85). The population of the valley suffered a series of Spanish-introduced epidemics (primarily smallpox and measles) soon after the conquest, but also secondary epidemics—fostered by the close quarters of the reducciones—including a particularly virulent strain of smallpox that swept through the southern region in 1589-1590. Sharp population declines may have been followed by periods of high fertility and partial recovery, but the documentation lacks the diachronic granularity required to register such short-term variability. Overall, the trajectory is clear: an average rate of population decline of 0.8% annually between 1570 and 1600, and continued declines through the 17th and 18th centuries, before reaching a nadir of just 4,496 in the mid 18th century. This represents a decline of 87% from the earliest reliable colonial census (33,900 in 1572), and 93% from the (low estimate) pre-Hispanic population. In Coporaque, the population declined from 2,927 in 1572 to just 619 in 1876, a decline of 79% (Cook 1982).

Table 1. Areas (ha) and categories of abandoned and unabandoned fields in Coporaque

	Unabandoned	Abandoned, Unirrigated	Abandoned, Irrigated	Totals
Right Side	166	5	46	217
Left Side	368	504	226	1098
Totals	534	509	272	1315

In the abstract, declining populations could lead to greater per capita landholdings and a relative abundance of irrigation water, resulting in an overall enrichment of the surviving population. As discussed above, however, the terrace and canal systems of this and other Andean valleys are labor-intensive and require regular maintenance. Shortages of labor for infrastructural maintenance as populations declined was therefore almost certainly a factor in agricultural deintensification. The area under cultivation probably contracted in rough parity with the decline of the labor pool. Moreover, disparities in the distribution of such dwindling colonial agricultural resources—landholding inequality—contributed to hardship and famine risk even when aggregate surpluses were possible (Wernke and Whitmore 2009). Clearly, demographic collapse was an important factor in agricultural deintensification. But, as discussed below, the spatial patterning of terrace and canal abandonment cannot be accounted for by demographic decline. Understanding how and why particular agricultural complexes were abandoned while neighboring ones remained under cultivation requires analysis of other factors.

Climate Change and Deintensification

Although there were no prolonged severe drought periods in the colonial period (as recorded in the Quelccaya ice cap data; see Thompson, *et al.* 1994) there was a prolonged period of cooler than average temperatures beginning in the mid- to late-13th century and culminating in the mid-16th through mid-19th centuries—corresponding to the Little Ice Age (Grove 1988, Rabatel, *et al.* 2008, Thompson, *et al.* 1986).

In high altitude, high relief settings such as the Colca Valley, even minor variance in average temperatures can have large local effects, significantly altering the altitudinal zones of production for different crops. Gade (1975: 104) makes the important distinction between the "effective" and "absolute" limits of crops in relation to altitude, where the effective limits are emically-defined as the range beyond which optimal or satisfactory levels of risk and yield are no longer possible, while the absolute limits are the most extreme conditions under which a crop can survive. A prolonged cooling period would have the effect of lowering effective limits, as the mean elevation of the diurnal frostline would descend. As pointed out by Cardich (1985) and Hastorf (1993), even modest (1-2 C°) decreases in average temperature can effect significant shifts in ecological zonation at these altitudes. In the Mantaro Valley of the central Peruvian highlands, crop cultivation is estimated to have been lowered by about 150 m below present upper limits (Seltzer and Hastorf 1990: 402). Locally, Brooks has argued that this kind of frostline depression led to the abandonment of the upper 70-150 m of terraces in the upper reaches of the Japo drainage, located adjacent to the study area of concern here (Brooks 1998: 69-73, 384). Though Brooks dates that abandonment episode to the earliest phase of the Little Ice Age (the 13th century) more widespread abandonment of the valley's upper terrace complexes might be expected during the most extreme phase of the Little Ice Age, between the mid-16th through mid-19th centuries (Thompson and Mosley-Thompson 1989: 18)—that is, from mid-colonial through early republican times.

A period of prolonged cooling therefore should be reflected in the spatial correlate of a disproportionate abandonment of higher irrigated terrace complexes, as the effective limits of even frost-tolerant crops (such as potatoes and quinoa) were exceeded. Therefore, if climatic cooling was a factor in terrace abandonment, then abandoned terraces should be concentrated in the higher valley slopes as a group when compared to unabandoned fields. Figure 5 shows a 3D perspective of the elevational relationships between abandoned and unabandoned fields. The distributions of elevation values for the abandoned and unabandoned fields, derived from the underlying DEM, are displayed in the boxplots of Figure 6. Higher overall values for the abandoned fields are visually evident, and a T-test shows the difference is highly significant, $t(731.28) = -31.872$, $p < .001$. The analysis thus shows that abandoned bench terraces are significantly higher in elevation as a group than unabandoned fields.

Colonial Resettlement and Deintensification

Reducción resettlement not only disrupted patterns of residence and exacerbated the effects of epidemics, it also moved communities away from their agricultural fields. Such increased walking distances to and from fields has also been hypothesized to be a prime cause of colonial terrace abandonment. Therefore, if distance is a causal factor, then abandoned terraces should be significantly further away from the reducción of Coporaque than unabandoned terraces.

Figure 7 presents the LCP map to unabandoned and abandoned fields. As is evident in the map, distances to abandoned fields appear to be generally further than for unabandoned fields. Boxplots comparing round trip LCP walking times comparing unabandoned and abandoned fields shows greater variance, but generally these are much higher walking times to abandoned fields (Figure 8). A t-test shows these differences to be highly significant $t(464.78) = -55.94$, $p < .001$. The LCP and walking simulations thus shows that abandoned terraces as a group are indeed significantly further away from the center of the village than the unabandoned fields.

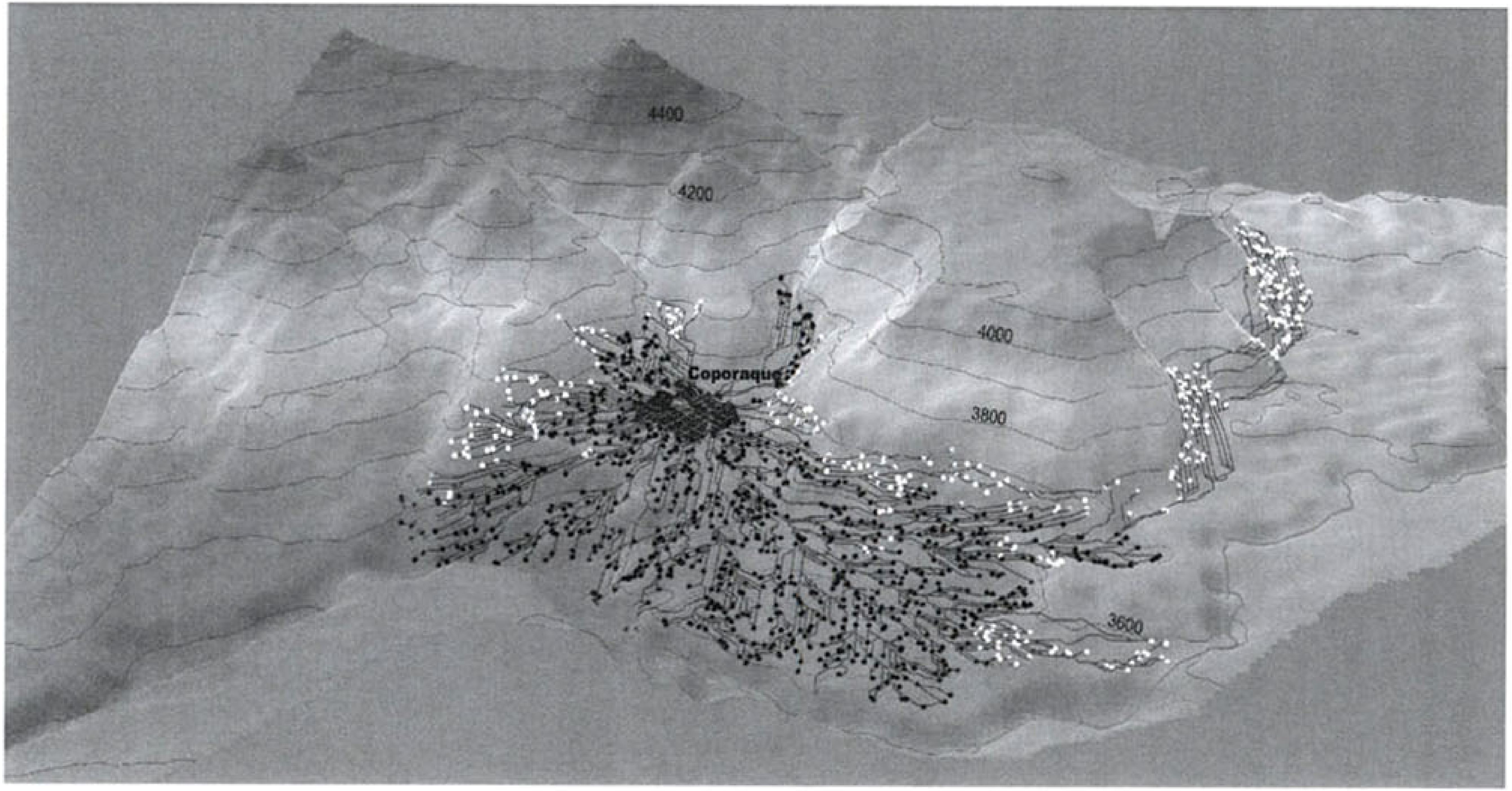

Figure 5. 3D view of the distributions of abandoned (white) and unabandoned (black) fields.

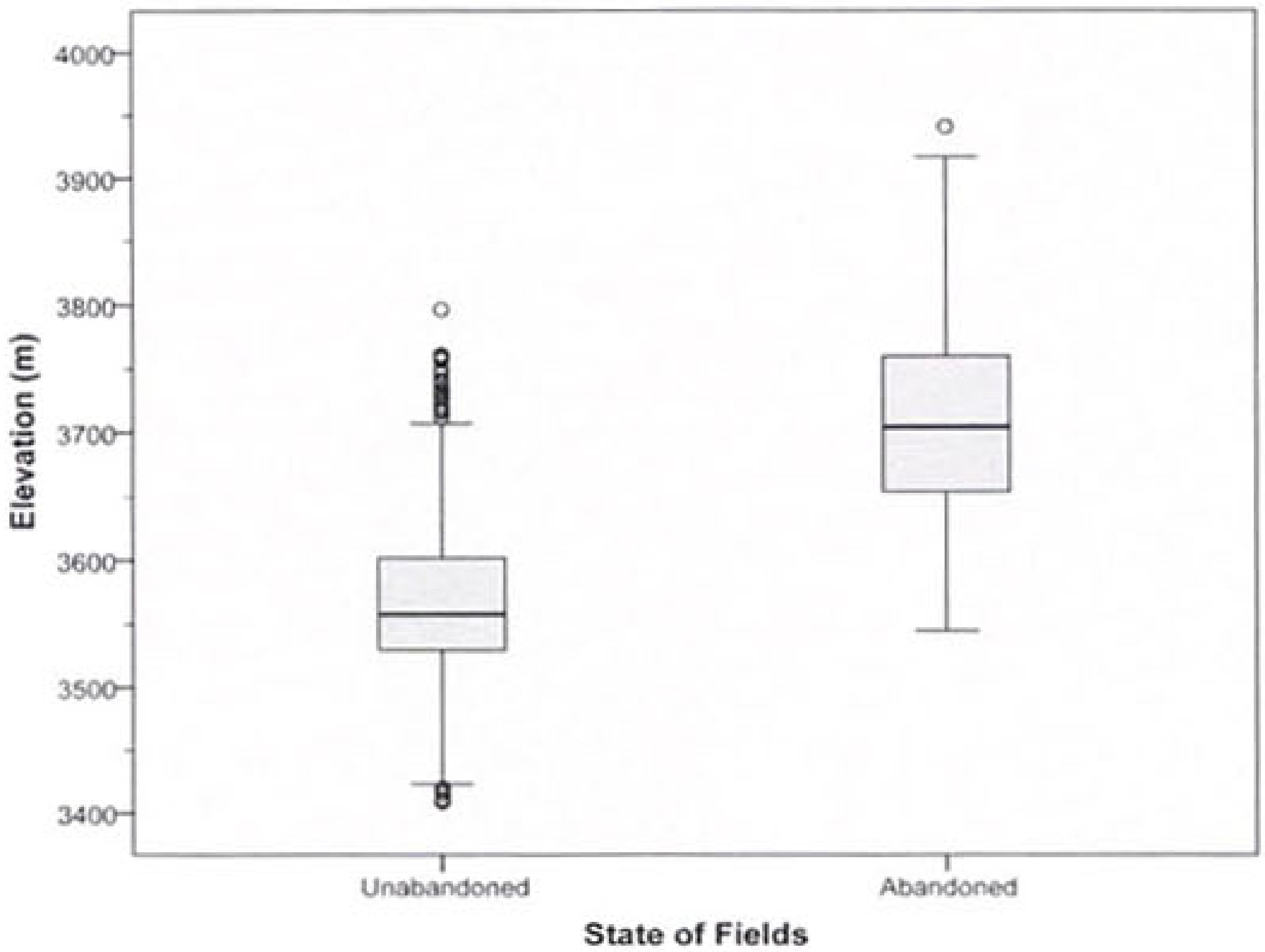

Figure 6: Boxplot of elevations of unabandoned (n = 846) versus abandoned (n = 430) fields.

Community Organization as a Mediating Factor in Deintensification

Depopulation, climate change, and colonial resettlement therefore all appear to have played some role in colonial agricultural deintensification. Population decline was likely a distal causal factor, lowering the overall pool of available labor to maintain irrigation and field systems. Climate change and resettlement appear more proximal constraints to which the dwindling population adapted. But looking back to the insights that led to this study, the manner in which the autochthonous dualistic community organization articulated with the radically reconfigured reducción resettlement seems a likely mediating factor. First, the areal parameters of the two sides clearly indicate a lopsided amount of abandonment on the left side: while 74% of the total irrigated field area is on the left side (abandoned and unabandoned), fully 83% of the abandoned area (226 of 272 ha) is on the left side. Thus, the extent of abandonment in the land of the left side ayllus outstripped even their high proportion of irrigated lands. Was this because their fields were further away, because their fields were in less desirable, more frost-prone (higher) areas, or both? If colonial resettlement disfavored the lower ranking left side ayllus and households of Coporaque, distances to the left side fields should be greater than those of the right side. Alternatively, if the fields of the left side were disproportionately abandoned because of frost risk, they should be situated in significantly higher elevations than right side abandoned fields.

First, an LCP analysis of the locatable fields under cultivation during the 1615-1617 visita provides a comparison of left-versus-right side walking times among unabandoned fields. Figure 9 shows the resulting map of the field distributions and least-cost paths. The mean walking time for left side fields was 45.8 minutes (n = 399, SD = 16.6), while the mean of the right side fields was 37.8 minutes (n = 277, SD = 14.8), a highly significant difference $t(634.2) = -6.6$, $p < .001$ (Table 2). These results indicate that the households of the left side ayllus had significantly longer walking times even among fields that remained under cultivation.

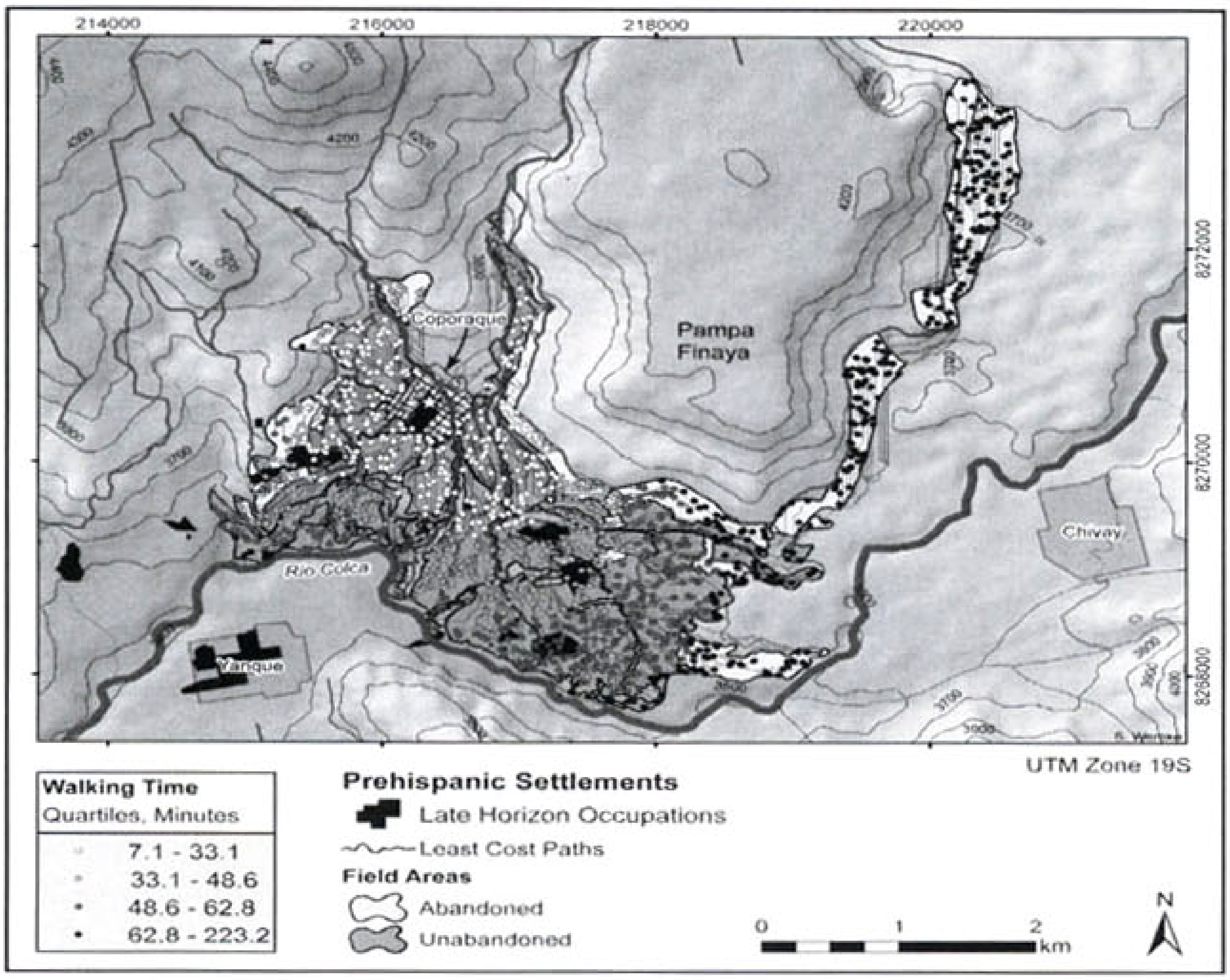

Figure 7. Least-cost paths between Coporaque and a stratified sample of unabandoned and abandoned fields. Field point shading varies in proportion to the simulated round trip walking time. Note the generally longer walking times to the abandoned fields.

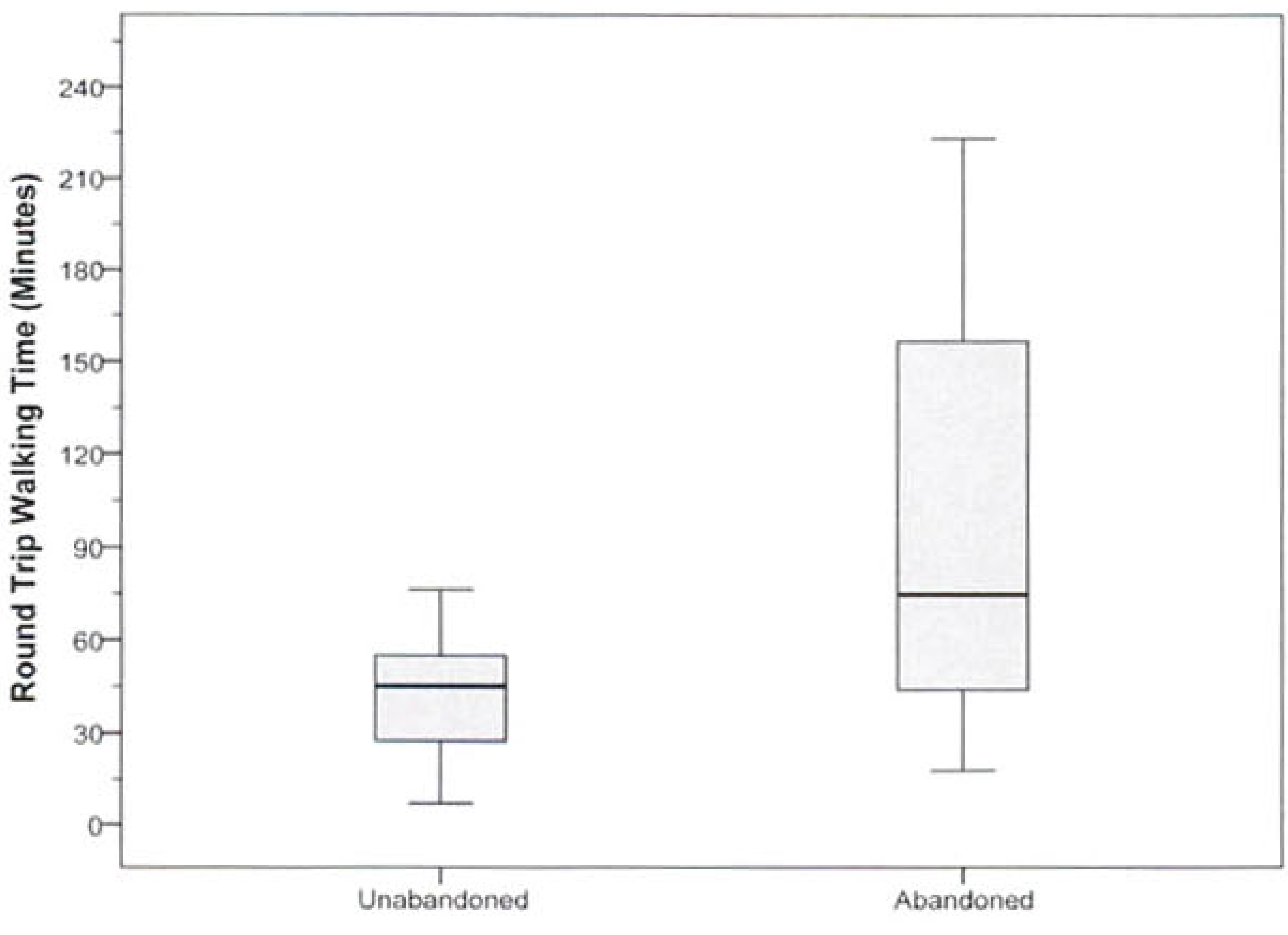

Figure 8. Boxplots of round trip walking times for unabandoned (n = 846) and abandoned (n=430) fields.

Table 2. Summary of average walking times and elevations of currently abandoned and unabandoned fields, separated by conceptual side.

	Mean Walking Time, 1616 Visita	Mean Walking Time, Currently Unabandoned	Mean Walking Time, Abandoned	Mean Elevation, Unabandoned	Mean Elevation, Abandoned
Right Side	37.8*	31.0**	38.1***	3565	3681.9****
Left Side	45.8*	46.0**	109.4***	3565	3709.8****

*$t(634.2) = -6.6, p < .001$
**$t(431.6) = -12.357, p < .001$
***$t(422.3) = -21.9, p < .001$
****$t(118.7) = -3.1, p = .002$

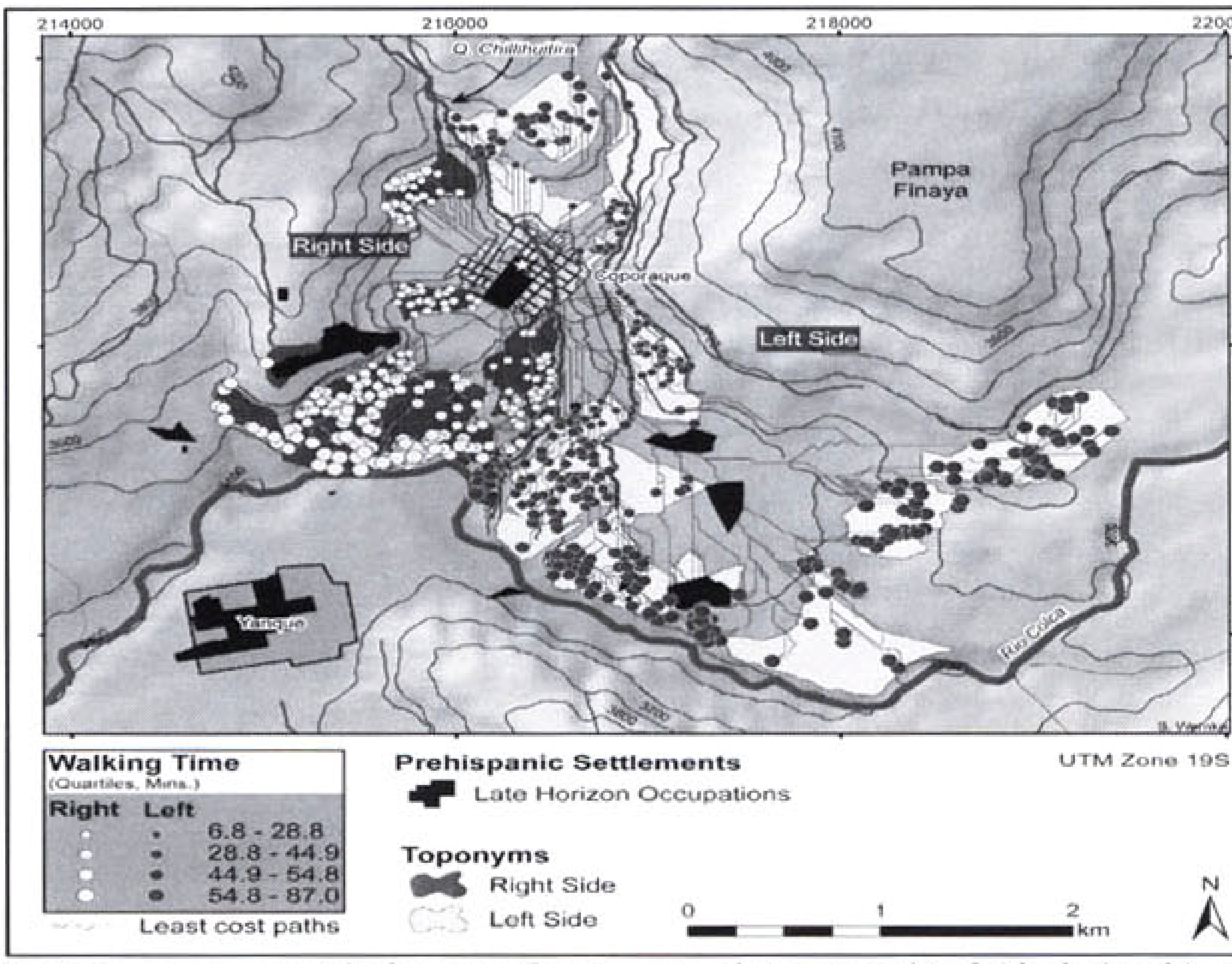

Figure 9. Least-cost paths between Coporaque and the mappable fields declared in the 1615-1617 Hanansaya visita, grouped by the "left" and "right" sides. Field point sizes are classified by round trip walking time (in minutes). Note the generally longer walking times for the fields of the lower ranking, "left side" ayllus.

This establishes that the people of the lower-ranking, "left" side ayllus had to walk significantly further from the reducción to reach their fields than the people of the higher ranking right side ayllus. Is the same true for abandoned fields? To provide commensurate samples between abandoned and unabandoned field areas, the 20% sampling method described above for total digitized abandoned and unabandoned areas must be used. Figure 10 shows the resulting field distributions for currently unabandoned and abandoned areas of each side, while the boxplots of Figure 11 show the longer round trip walking times for both unabandoned and abandoned fields of the left side. A t-test shows the mean time for unabandoned left side fields is 46.0 minutes (n = 585, SD = 14.5), while only 31.0 minutes for right side fields (n = 261, SD = 17.1)—a highly significant difference $t(431.6) = -12.357, p < .001$.

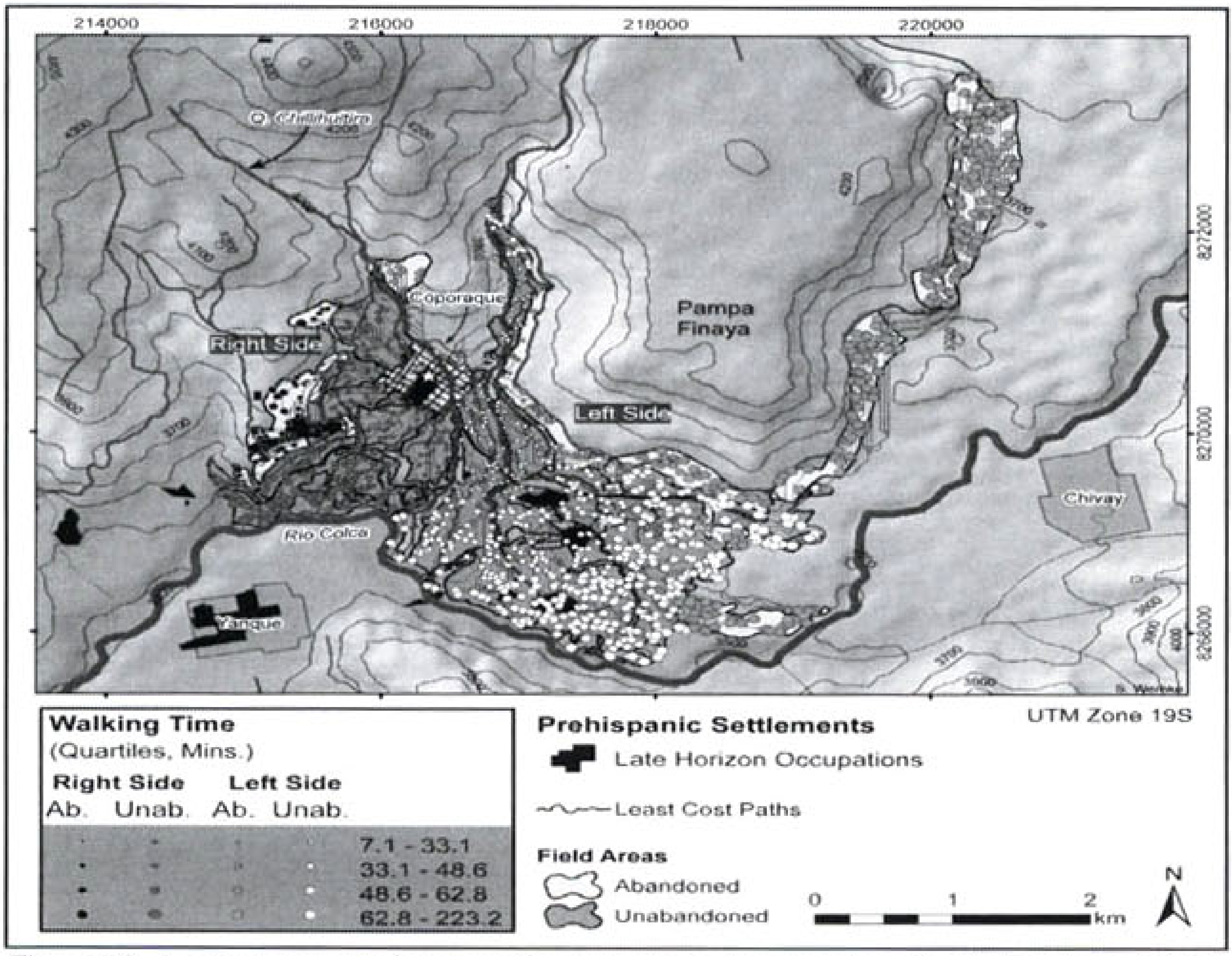

Figure 10. Least-cost paths between Coporaque and unabandoned and abandoned fields categorized by the "left" and "right" sides. Field point sizes are size-classified by round trip walking time (in minutes). Note the generally longer walking times for the lower ranking, "left side" fields for both unabandoned and abandoned fields.

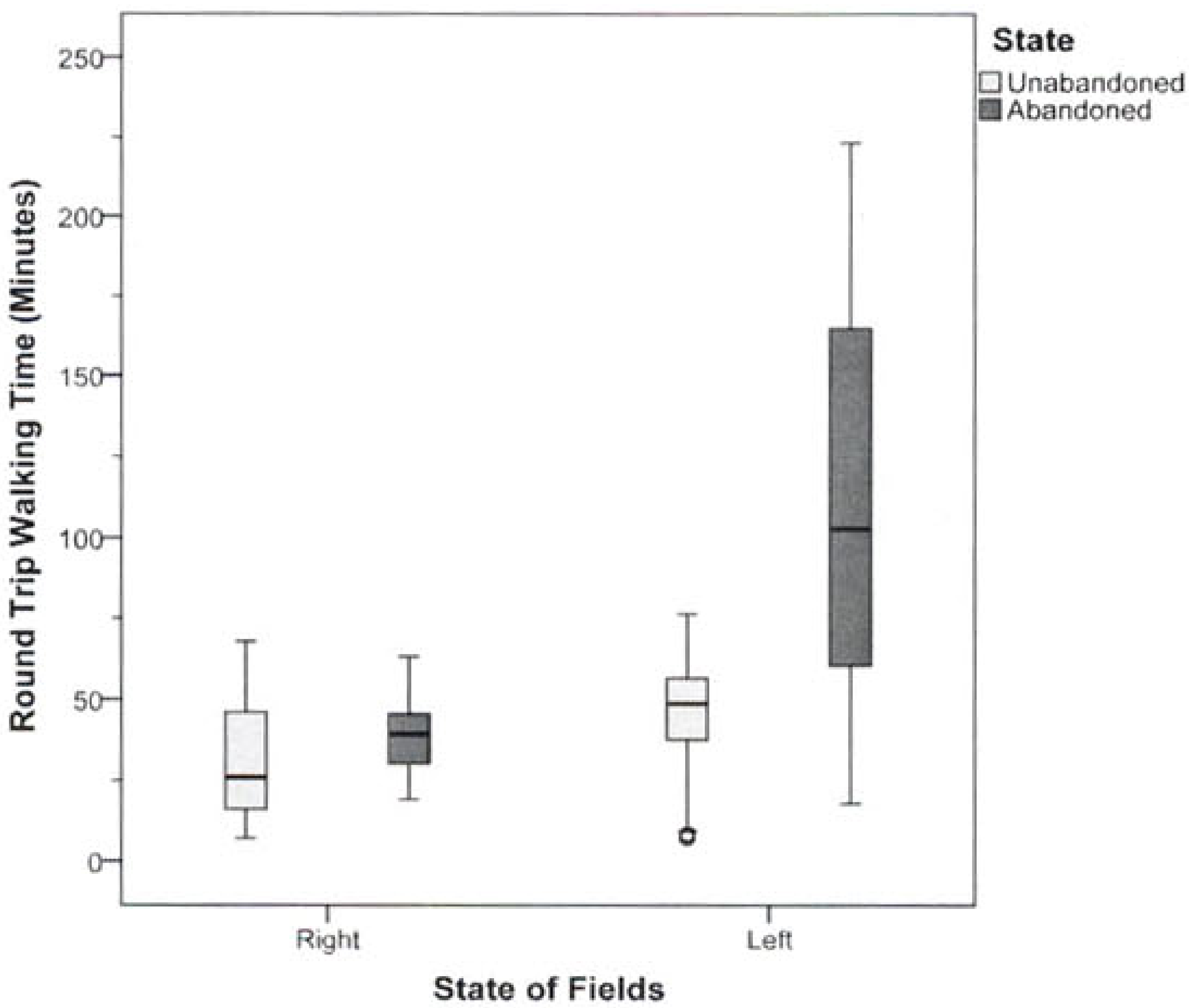

Figure 11. Boxplots comparing round trip walking times for left versus right side fields and for unabandoned and abandoned fields.

Among the abandoned fields of the two sides, the average round trip walking time of 109 minutes for the left side fields (n = 357, avg. = 109.4 minutes, SD = 57.6) is nearly three times greater than that of the right side fields (n = 73, avg. = 38.1 minutes, SD = 9.8, t[422.3] = -21.9, p < .001). Therefore, the particular way in which reducción resettlement was refracted through local community organization—by more dramatically displacing the people of the lower-ranking left side ayllus—appears a significant factor that resulted in the particular spatial distribution of field abandonment observed today.

However, it could also be that the fields of the left side are significantly higher in elevation on average than those of the right side counterparts, and ths more susceptible to frost. Comparing the elevations of the 20% sample of right and left side fields shows that abandoned left side fields were significantly higher (3710 m, SD 80.1) than those of the right side (3682, SD 66.6), t(118.7) = -3.1, p = .002. This may signal a significant shift downslope as frostlines descended during the Little Ice Age, disproportionately affecting the higher fields of the left side ayllus. As discussed above, even minor variance in average temperatures can have major impacts on frostlines at these elevations. It is also notable that the average elevations of the unabandoned fields of the two sides are not statistically different. In fact, their average elevations are the same (3565 m), suggesting that both sides opted for lower and roughly altitudinally-equivalent field distributions (Table 2).

A Multivariate Approach

If analysis were to stop here, a reasonable conclusion would be that terrace abandonment was an over-determined, multi-causal phenomenon in which frost risk (exacerbated by the Litte Ice Age), distance, and community organization all played significant roles. Systemic relationships between them, or the relative importance of each factor, would remain unknown. A multivariate approach is required to assess the relative importance of these factors, and how they may have interacted to produce the observed outcome.

Given the observed prevalence field abandonment on the left side of the Coporaque landscape, a binomial logistic regression using the conceptual side (right/left) as the dependent variable and field state (unabandoned/abandoned) as the independent variable is a logical place to start. The resulting odds ratio of this test shows that fields on the left side are over twice as likely to be abandoned as those on the right side (odds ratio [OR] 2.18, 95% confidence interval [CI], 1.63 – 2.91). However, abandoned fields on the left side are significantly further and higher than those of the right side, so the increased likelihood of abandonment of fields on the "left" is likely a reflection of those factors. But by how much, and which of the factors is more important?

These questions can be approached by modeling the binomial logistic regression a few different ways. First, a model with the state of the fields (abandoned/unabandoned) as the dependent (response) variable and conceptual side (left/right) as the independent variable, while holding elevation and distance constant (elevation/distance adjusted) can provide a view of how patterns of left/right abandonment vary if distance and elevation were not factors in the decision. The results of this regression indicate that fields on the left side are 61% less likely to be abandoned than right side fields if distance and elevation are held constant between the two sides (OR 0.398, 95% CI, 0.231 – 0.685). Clearly, either distance, elevation, or both, were important factors in the disproportionate abandonment of left side fields, since these results indicate that—distance and elevation being equal—the people of the left side ayllus would work harder than the right side ayllus to maintain their fields in production.

Given the clear importance of distance and/or elevation on deintensification, models were constructed to address the impact of the two factors as they relate to the dualistic pattern of right/left community and land use organization. For these models, the state of fields (abandoned/unabandoned) was used as the dependent variable and distance and elevation were used as independent variables. Separate iterations were run for the fields of each side (right/left), testing for the effect of distance, distance adjusted for elevation (i.e., elevation held constant), elevation, and elevation adjusted for distance (i.e., distance held constant).

The results of these models are the most insightful of the calculus for abandonment. The key finding here is that *elevation* was the more important factor for decision-making regarding abandonment for the fields of the right side, while *distance* was the more important factor for the left side fields. Specifically, for the right side fields, if distance is held constant, abandonment becomes almost twice as likely (OR 1.962, 95% CI, 1.381 – 2.788), so some factor other than distance must be at play. Conversely, if elevation is factored out (held constant), they become 67% *less* likely to be abandoned (OR 0.328, 95% CI, 0.217 – 0.494). This points to elevation as a key factor in the decision to abandon right side fields. In other words, for the right side ayllus, if the elevations of their fields were not a concern, they would be significantly more reticent to abandon their fields—by a margin of 67%—compared to a scenario in which elevation did play a role in decision making. Elevation (a proxy for frost risk) therefore played a more important role than distance for decision-making regarding the abandonment of fields on the conceptual right side of the Coporaque landscape.

The picture that emerges for the left side ayllus is the reverse: when the elevation of agricultural fields is held constant and only distance is considered, abandonment becomes 300% more likely (OR 3.053, 95% CI, 2.023 – 4.608). In other words, when elevation is factored out in decision making for the people of the left side ayllus, abandonment becomes significantly more likely—three times as likely—so some other factor (or factors) must account for this increase in likelihood of abandonment. The model holding distance (walking time) constant for left side fields indicates that it was among those key factors: abandonment becomes 51% less likely when walking time is factored out (held constant) (OR 0.510, 95% CI, 0.359 – 0.724). Therefore, distance was clearly a significant concern for the people of the left side ayllus, since their fields were significantly less likely to be abandoned—by a margin of 51%—if distance was not a factor in deciding whether to maintain or abandon a field.[8]

Discussion and conclusion

To summarize, these findings indicate that both distance—specifically, displacement away from ancestral fields by reducción resettlement—and climatic cooling (and the attendant lowering of frostlines) were significant factors in terrace abandonment. Their effects were not homogeneous, however, but instead were refracted through the structures of indigenous community organization in distinct ways. For the households of the higher-ranking, right side ayllus, frost risk (as measured through the proxy of elevation) was the prevailing preoccupation, while for the lower-ranking left side ayllus, distance was a stronger factor in decisions to abandon fields and the irrigation systems that supported them.

At first glance, these findings may seem paradoxical: how could frost risk be the decisive factor in abandonment for the fields of the right side ayllus, while distance is the decisive factor for the fields of the left side ayllus? They make sense more intuitively when looking back at the maps and recalling that the fields of the right side—both abandoned and unabandoned—were significantly nearer and lower in elevation than those of the left side. Thus, for the right side ayllus, who were not displaced as radically by reducción resettlement as the left side ayllus, distance to their fields was not as much of an issue. Indeed, as discussed above, even their abandoned fields were within the range of the unabandoned fields of the left side ayllus. Thus, frost-risk minimization—shunting off upper field systems as frost lines descended during the Little Ice Age—was foremost in their decision making calculus. For the left side ayllus, even though their abandoned fields were significantly higher in elevation than those of the right side, sheer distance outweighed elevation as an overarching factor in decision making for most of their abandoned fields. Just as clearly, however, not *all* of the abandoned fields of the left side were further away than those of the right. Figure 4, for example, shows part of a large strip of "left side" abandoned irrigated terraces on the flanks of Pampa Finaya that are right next to the village. In a sense, these appear an exception that proves the rule, since they are high in elevation: they lie directly above unabandoned terraces, above the 3700 m contour, suggesting they were abandoned with frost risk in mind. Therefore, what was likely at play was a *sliding scale of the two factors*: the nearer the fields, the more elevation (frost risk) played a role; the greater the distance, the more distance factored in the decision-making calculus—reaching parity with frost risk and at very far distances outweighing it as a factor driving abandonment.

On these points it is important to return to the discussion of labor, terracing, and irrigation as they relate to agricultural deintensification. Up until now the discussion has focused on "terrace" or "field" abandonment, much as in previous research. But as argued above, field abandonment is merely the most outwardly visible and quantifiable symptom of larger systemic stresses on irrigation systems, which in turn are affected by decision-making regarding the labor projects required for their maintenance. Declining populations in the village through the colonial period must have forced a series of difficult decisions by irrigation communities and their authorities regarding which irrigation systems to abandon (or at least allow to slowly lapse into dereliction). For those of the right side irrigation sectors, which already benefitted from the lion's share of the nearest and most productive fields and warmest microclimates in Coporaque, the pattern is one of concentration of production in areas of highest productivity and shutting down maintenance of irrigation and field systems in areas of highest frost risk as the labor pool declined. This appears an eminently rational decision given that frost risks were probably noticeably growing (and in any case would be greatest among the highest fields) as a result of the effects of the Little Ice Age. Farmers of the left side irrigation and field systems, on the other hand, had to deal with both frost risk and the great distances of some of the fields affected by their more radical displacement by reducción resettlement. Irrigation sectors of comparable elevation and distance to those abandoned on the right side were likewise abandoned on the left, while more distant ones—which were also primarily in higher elevations—were also taken out of production as the labor pool shrank.

What remained was a "reduced" landscape—one of contracted production, shaped not only by demographic processes but by the particular manner in which colonial resettlement impacted the two ranked communities of the Hanansaya moiety of Coporaque. This GIS-based model therefore provides an otherwise-inaccessible view into the complex, multicausal processes involved in agricultural deintensification during historic times in the central Andean highlands. Certainly it does not capture the full complexity of the confluence and sequence of factors involved—better chronological controls and more diverse data sets would be required—but it does take the discussion beyond unicausal or prime mover models to show how demography, ecology, and colonial policy were refracted through local political structures to effect the patterning of deintensification.

These findings also hold some important implications for modern planning and sustainable development schemes aimed at rehabilitating relict terraces and canals for community benefit. Most broadly, they suggest that that not only technical and ecological factors (water availability, soil fertility, frost risk, etc) need to be addressed, but also how vested interests within the community should be considered through open debate and negotiation in the implementation of infrastructural rehabilitation efforts. Finally, these findings call attention to the need to link multiple scales of irrigation and field system management in development schemes for reclaiming abandoned agricultural zones in the highlands. As pointed out by Zimmerer (2000), agricultural development projects predicated on a primordialist view of the canal as the essential, organic unit of community action and cohesion further reify the atomizing effects of colonial policies, which sought to divide formerly integrated social networks and make "community" isometric with "village". These results thus point to the potential benefits of a broader-based, inter-village or watershed-scale paradigm for sustainable agricultural development in the rural Andean highlands.

Acknowledgements

The research for this article was funded by a Research Grant from the Wenner-Gren Foundation for Anthropological Research (Grant number 6431), a Vanderbilt University Center for the Americas Faculty Research Fellowship, a Vanderbilt University Research Scholar Fellowship, and a Vanderbilt University Undergraduate Research Supervision Grant. Spatial analysis was supported by the facilities of the Vanderbilt University Spatial Analysis Research Lab. Logistical support was provided by the Center for Archaeological Research in Arequipa (CIARQ) and the Municipality of the District of Coporaque. Special thanks are owed to the community members of Coporaque for their warm hospitality. Archaeological survey was conducted under the co-direction of Ericka Guerra Santander, with the authorization of Resolución Directoral 615 of the National Institute of Culture of Peru. Maria Benavides and William Denevan graciously provided access to copies and transcriptions of the Colca valley visitas. The hard work of Travis Williams was integral to an earlier iteration of this project. Thanks are owed to Keivan Stassun and Jennifer Lena for their advice on statistical methods. I am especially grateful to Jane Read for the invitation to participate in this special issue. Tiffiny Tung provided critical feedback on a draft. Though I am indebted to many for their help, all errors of fact and interpretation are solely mine.

Notes

[1] This analysis used the original transcriptions by Laura Gutiérrez Arbulú, which were provided to the author by Maria Benavides and William Denevan. The versions in the series edited by Pease and Robinson are based on the same transcriptions. These volumes make available to the scholarly community some of the most detailed and probably the largest series of colonial visitas for any single locale in the Spanish Americas.

[2] The SAN images used were derived from 1200 dpi scans directly from the original negatives.

[3] For very small abandoned field areas that resulted in fractions of a field using the sampling equation, a minimum sample of n = 1 was used.

[4] Stratified random field point locations were generated using Geospatial Modeling Environment, a free geoprocessing and analytical application for ArcGIS (Beyer 2010).

[5] Free absolute global ASTER DEM data are now available through the Ministry of Economy, Trade and Industry of Japan (METI) (http://www.gdem.aster.ersdac.or.jp/).

[6] These figures are within 4% of the total area (1367 ha) reported independently by Treacy (1994:88), and Denevan and Hartwig (1986:104), who arrived at a figure of 1360 ha.

[7] Sizes of fields in the visitas were most often declared in the unit of the topo, an Andean unit of measure that varied relative to soil quality and other factors affecting agricultural productivity (see D'Altroy 2002:246-247; Rowe 1946:324). The modern standardized area of 3496 m2 is likely a rough average of topo sizes, and is used here to convert topos to hectares.

[8] A model testing the interaction effect of distance and elevation combined was also run. It did not impact the odds ratio of either side.

References

Albó, X. 1972. Dinámica en la estructura intercomunitaria de Jesús de Machaca. *America Indígena* 32 (3): 773-816.

Astvaldsson, A. 2000. The dynamics of Aymara duality: change and continuity in sociopolitical structures in the Bolivian Andes. *Journal of Latin American Studies* 32(1): 145-174.

Benavides, M. A. 1986a. Coporaque in the 1591 visita of Yanquecollaguas Urinsaya. In W. M. Denevan (ed.), *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society*, Volume 1, pp. 390-405. Madison: Department of Geography, University of Wisconsin-Madison.

__________. 1986b. Coporaque in the 1604 visita to Yanquecollaguas Urinsaya. In W. M. Denevan (ed.), *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society*, Volume 2, pp. 406-425. Madison: Department of Geography, University of Wisconsin-Madison.

__________. 1986c. Coporaque toponyms: comparison and analysis of place names in the 16th, 17th, and 20th centuries. In W. M. Denevan (ed.), *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society*, Volume 1, pp. 450-492. Madison: Department of Geography, University of Wisconsin-Madison.

__________. 1989. Las visitas a Yanquecollaguas de 1604 y 1615-1617: estructuras de mando y tenencia y herencia de tierras. *Boletín del Instituto Francés de Estudios Andinos* 18(2): 241-267.

__________. 1990. Tenencia de tierras agrícolas en el valle del Colca (Caylloma, Arequipa). *Revista Peruana de Ciencias Sociales* 2(1): 49-76.

__________. 1995. Cambios en el paisaje agroecológico de la provincia de Collaguas: un análisis de documentos en los archivos de Arequipa, Perú. *Revista del Archivo Arzobispal de Arequipa* 2: 15-46.

Beyer, H. L. 2010. *Geospatial Modelling Environment, V. 0.3.2 Beta.* http://www.spatialecology.com.

Bolin, I. 1993. Levels of Autonomy in the Organization of Irrigation in the Highlands of Peru. In W. P. Mitchell and D. Guillet (eds.), *Irrigation at High Altitudes: The Social Organization of Water Control Systems in the Andes*, pp. 141-166. Washington, D.C.: American Anthropogical Association.

Bouysse-Cassagne, T. 1986. Urco and uma: Aymara concepts of space. In J. V. Murra and N. Wachtel (eds.), *Anthropological History of Andean Polities*, pp. 201-227, Cambridge: Cambridge University Press.

__________. 1987. *La identidad aymara: aproximación histórica (siglo XV, siglo XVI).* La Paz: HISBOL-IFEA.

Brooks, S. O. 1998. Prehistoric Agricultural Terraces in the Río Japo basin, Colca Valley, Peru. Doctoral dissertation, Department of Geography, University of Wisconsin-Madison, Madison.

Cardich, A. 1985. The fluctuating upper limits of cultivation in the central Andes and their impact on Peruvian prehistory, *Advances in World Archaeology*, Volume 4, pp. 293-333. New York: Academic Press.

Cook, N. D. 1982. *The People of the Colca Valley: A Population Study.* Boulder: Westview Press.

__________. 2007. *People of the Volcano: Andean counterpoint in the Colca Valley of Peru.* Durham: Duke University Press.

D'Altroy, T. N. 2002. *The Incas.* Malden, Massachusetts: Blackwell.

de la Vera Cruz Chávez, P. 1988. Estudio arqueológico en el valle de Cabanaconde, Arequipa. Baccalaureate thesis, Department of Archaeology, Facultad de Ciencias Histórico Arqueológicas, Universidad Católica Santa María, Arequipa.

__________. 1989. Cronología y corología de la cuenca del río Camaná-Majes-Colca-Arequipa. Licenciate thesis, Department of Archaeology, Facultad de Ciencia Histórico Arqueológicas, Universidad Católica Santa María, Arequipa.

Denevan, W. M. (ed.). 1986. *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society,* Volume 1. Madison: Department of Geography, University of Wisconsin-Madison.

__________. (ed.) 1988a. *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society*, Volume 2. Madison: Department of Geography, University of Wisconsin-Madison.

__________. 1988b. Measurement of abandoned terracing from air photos, Colca valley, Peru. *Yearbook, Conference of Latin Americanist Geographers* 14: 20-30.

__________. 2001. *Cultivated landscapes of Native Amazonia and the Andes.* Oxford: Oxford University Press.

Denevan, W. M. and L. Hartwig. 1986. Measurement of terrace abandonment in the Colca valley. In W. M. Denevan (eds.), *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society*, Volume 1, pp. 99-115. Madison: Department of Geography, University of Wisconsin-Madison.

Donkin, R. A. 1979. *Agricultural Terracing in the Aboriginal New World.* Tucson, Arizona: University of Arizona Press.

Doutriaux, M. 2002. Relaciones étnicas y económicas de poder: la conquista incaica en el valle del Colca, Arequipa. *Boletín de Arqueología PUCP* 6: 411-432.

__________. 2004. Imperial Conquest in a Multiethnic Setting: The Inka Occupation of the Colca Valley, Peru. Doctoral dissertation, Department of Anthropology, University of California, Berkeley.

Eash, N. S. and J. A. Sandor. 1995. Soil chronosequence and geomorphology in a semiarid valley in the Andes of southern Peru. *Geoderma* 65: 59-79.

Echeverría y Morales, Francisco Xavier. 1952 [1804]. *Memoria de la Santa Iglesia de Arequipa.* Arequipa: Imprenta Portugal.

Evans, T. P. and B. Winterhalder. 2000. Modified solar insolation as an agronomic factor in terraced environments. *Land Degradation and Development* 11: 273-287.

Gade, D. W. 1975. *Plants, Man and the Land in the Vilcanota Valley of Peru.* The Hague: W. Junk.

Gade, D. W. and M. Escobar. 1982. Village settlement and the colonial legacy in southern Peru. *Geographical Review* 72: 430-449.

Gelles, P. H. 1995. Equilibrium and extraction: dual organization in the Andes. *American Ethnologist* 22(4): 710-742.

__________. 2000. *Water and Power in Highland Peru.* New Brunswick: Rutgers University Press.

Grove, J. M. 1988. *The Little Ice Age.* New York: Methuen.

Guillet, D. W. 1978. The supra-household sphere of production in the Andean peasant economy. *Actes du XXLe Congrés International des Américanistes* 4: 89-105.

__________. 1981. Land tenure, ecological zone, and agricultural regime in the central Andes. *American Ethnologist* 8(1): 139-156.

__________. 1987. Terracing and irrigation in the Peruvian highlands. *Current Anthropology* 28(4): 409-430.

__________. 1992. *Covering Ground: Communal Water management and the State in the Peruvian Highlands.* Ann Arbor: University of Michigan Press.

Hastorf, C. A. 1993. *Agriculture and the Onset of Political Inequality Before the Inka.* New York: Cambridge University Press.

Hemming, J. 1983. *The Conquest of the Incas.* New York: Penguin Books

Málaga Medina, A. 1977. Los Collagua en la historia de Arequipa en el siglo XVI. In F. Pease (ed.), *Collaguas I*, pp. 93-130, Lima: Pontificia Universidad Católica del Perú.

Malpass, M. A. 1987. Late prehistoric terracing at Chijra in the Colca Valley, Peru: preliminary report II. In W. M. Denevan, K. Mathewson and G. W. Knapp (eds.), *Pre-Hispanic Agricultural Fields in the Andean Region,* Volume 359 (I), pp. 45-66. Oxford: BAR International Series.

Malpass, M. A. and P. de la Vera Cruz Chávez. 1990. Cronología y secuencia de la cerámica de Chijra, valle del Colca. *Gaceta Arqueológica Andina* 18/19: 41-57.

Mayer, E. 1985. Production zones. In S. Masuda, I. Shimada and C. Morris (eds.), *Andean Ecology and Civilization: An Interdisciplinary Perspective on Andean Ecological Complementarity*, pp. 45-84, Tokyo: University of Tokyo Press.

Mitchell, W. P. 1976. Irrigation and community in the Central Peruvian Highlands. *American Anthropologist* 78 (1): 25-44.

Morrison, K. D. 1996. Typological schemes and agricultural change: beyond Boserup in precolonial south India. *Current Anthropology* 37(4): 583-608.

Paerregaard, K. 1993. Why fight over water? Power, conflict, and irrigation in an Andean village. In W. P. Mitchell and D. Guillet (eds.), *Irrigation at High Altitudes: The Social Organization of Water Control Systems in the Andes*, pp. 189-202. Arlington, Va.: American Anthropological Association.

Pease, F. (ed.). 1977. *Collaguas I*. Lima: Pontíficia Universidad Católica del Perú.

Pulgar Vidal, J. 1996. *Geografía del Perú: las ocho regiones naturales, la regionalización transversal, la sabiduría ecológica tradicional*. Lima, Peru: Peisa.

Rabatel, A., B. Francou, V. Jomelli, P. Naveau and D. Grancher. 2008. A chronology of the Little Ice Age in the tropical Andes of Bolivia (16°S) and its implications for climate reconstruction. *Quaternary Research* 70: 198-212.

Robinson, D. J. 2003. *Collaguas II: Lari Collaguas. Economía, sociedad y población, 1604-1605*. Lima: Pontificia Universidad Católica del Perú.

__________. (ed.). 2006a. *Collaguas III: Yanque Collaguas. Sociedad, economía y población, 1604-1617*. Lima: Pontificia Universidad Católica del Perú

__________. 2006b. Estudio. In D. J. Robinson (ed.), *Collaguas III: Yanque Collaguas* pp. xxxvii-cvii, Lima: Pontificia Universidad Católica del Perú.

__________. 2009. *Collaguas IV: Cabanaconde. Economía, sociedad y población, 1596-1645*. Lima: Pontificia Universidad Católica del Perú.

Rowe, J. H. 1946. Inca culture at the time of the Spanish conquest. In J. H. Steward (ed.), *Handbook of South American Indians*, Volume 2, pp. 183-330. Washington, D.C.: Smithsonian Institution Bureau of American Ethnology.

Sandor, J. A. 1992. Long-term effects of prehistoric agriculture on soil: examples from New Mexico and Peru. In V. T. Holliday (ed.), *Soils in Archaeology: Landscape Evolution and Human Occupation*, pp. 217-245, Washington, D.C.: Smithsonian Institution Press.

Sandor, J. A. and N. S. Eash. 1991. Significance of ancient agricultural soils for long-term agronomic studies and sustainable agricultural research. *Agronomy Journal* 83: 29-37.

Seltzer, G. O. and C. A. Hastorf. 1990. Climatic change and its effect on prehispanic agriculture in the central Peruvian Andes. *Journal of Field Archaeology* 17: 397-414.

Stern, S. J. 1982. *Peru's Indian Peoples and the Challenge of Spanish Conquest*. Madison: University of Wisconsin Press.

Thompson, L. G. and E. Mosley-Thompson. 1989. One-half millenium of tropical climate variability as recorded in the stratigraphy of the Quelccaya ice cap, Peru. In D. Peterson (ed.), *Climate Change in the Eastern Pacific and Western Americas*, pp. 15-31, Washington, DC: American Geophysical Union.

Thompson, L. G., E. Mosley-Thompson, W. Dansgaard and P. M. Grootes. 1986. The Little Ice Age as recorded in the stratigraphy of the tropical Quelccaya ice cap. *Science* 234: 361-364.

Thompson, L. G., E. Mosley-Thompson and M. E. Davis. 1994. Glacial records of global climate: a 1500-year tropical ice core record of climate. *Human Ecology* 22 (1): 83-95.

Tobler, W. 1993. *Three Presentations on Geographical Analysis and Modeling: Non-Isotropic Geographic Modeling, Speculations on the Geometry of Geography, Global Spatial Analysis.* Technical Report 93-1, National Center for Geographic Information and Analysis.

Trawick, P. 2001a. The moral economy of water: equity and antiquity in the Andean commons. *American Anthropologist* 103(2): 361-379.

__________. 2001b. Successfully governing the commons: principles of social organization in an Andean irrigation system. *Human Ecology* 29(1): 1-25.

__________. 2003. *The Struggle for Water in Peru: Comedy and Tragedy in the Andean Commons.* Stanford: Stanford University Press.

Treacy, J. M.. 1989. The Fields of Coporaque: Agricultural Terracing and Water Management in the Colca Valley, Arequipa, Peru, Department of Geography, Doctoral dissertation, University of Wisconsin, Madison.

__________. 1993. Teaching water: hydraulic management and terracing in Coporaque, the Colca Valley, Peru. In W. P. Mitchell and D. Guillet (eds.), *Irrigation at High Altitudes: The Social Organization of Water Control Systems in the Andes*, pp. 99-114 Washington, D.C.: American Anthropological Association.

__________. 1994. *Las chacras de Coporaque: andeneria y riego en el valle del Colca.* Lima: Instituto de Estudios Peruanos.

Tripcevich, N. 2007. *Quarries, Caravans, and Routes to Complexity: Prehispanic Obsidian in the South-Central Andes.* Doctoral dissertation, Department of Anthropology, University of California, Santa Barbara.

Ulloa Mogollón, J. de. 1965 [1586]. Relación de la provincia de los Collaguas para la descripción de las Indias que su magestad manda hacer. In M. Jimenez de la Espada (ed.), *Relaciones Geográficas de Indias*, Volume 1, pp. 326-333. Madrid: Ediciones Atlas.

Valderrama Fernández, R. and C. Escalante Gutierrez. 1986. Sistemas de riego y organización social en el valle del Colca: caso Yanque. *Allpanchis* 27: 179-202.

__________. 1988. *Del tata mallku a la mama pacha: riego, sociedad y ritos en los Andes peruanos.* Lima: Centro de Estudios y Promoción del Desarrollo.

Wernke, S. A. 2003. An Archaeo-History of Andean Community and Landscape: The Late Prehispanic and Early Colonial Colca Valley, Peru. Doctoral dissertation, Department of Anthropology, University of Wisconsin, Madison.

__________. 2006a. Collagua 'eco-logistics': Intermediate elites and hybrid community structures in the Colca valley, Peru. In C. M. Elson and R. A. Covey (eds.), *Intermediate Elites in Pre-Columbian States and Empires*, pp. 175-211, Tucson: University of Arizona Press.

__________. 2006b. The politics of community and Inka statecraft in the Colca valley, Peru. *Latin American Antiquity* 17 (2): 177-208.

__________. 2007a. Analogy or erasure? Dialectics of religious transformation in the early doctrinas of the Colca valley, Peru. *International Journal of Historical Archaeology* 11(2): 152-182.

__________. 2007b. Negotiating community and landscape in the Peruvian Andes: a trans-conquest view. *American Anthropologist* 109(1): 130-152.

__________. 2009. La interfaz política-ecológica en el valle del Colca durante la época inkaica. *Andes* 7: 587-614.

__________. 2010a. Convergences: producing colonial hybridity at an early doctrina in highland Peru. In M. Liebmann and M. Murphy (eds.), *Enduring Conquests: Rethinking the Archaeology of Resistance to Spanish Colonialism in the Americas*, Santa Fe: School for Advanced Research (in press).

Wernke, S. A. and T. M. Whitmore. 2009. Agriculture and inequality in the Colonial Andes: a simulation of production and consumption using administrative documents. *Human Ecology* 37: 421-440.

Williams, P. R. 2002. Hydraulic landscapes and social relations in the Middle Horizon Andes. In M. Forte, P. R. Williams, J. Wiseman and F. El-Baz (eds.), *The Reconstruction of Archaeological Landscapes Through Digital Technologies.* Oxford: B.A.R. International Series, vol. 1151.

Zimmerer, K. S. 2000. Rescaling irrigation in Latin America: the cultural images and political ecology of water resources. *Ecumene* 7(2):150-175.