Introduction: Droughts, Water Security, and the Rise and Fall of the Wari Empire

From Old World empires to the US Southwest and the Maya region, archaeologists have observed many cases of 'collapse' corresponding to drought events and agrarian disruption. Drought conditions bookending the Andean Middle Horizon ("MH," *ca.* 600 – 1100 CE) were also implicated in the rise and fall of the Wari Empire, the first in the Americas. Teasing apart the environmental and cultural factors at play in collapse and social regeneration holds immense promise for informing responses to oncoming climate challenges—so much so that the archaeology of human-environmental interactions is one of the five pillars of the "grand challenges for archaeology" (Kintigh et al., 2014). Because paleoclimate proxies reflect different scales and temporal resolution than archaeological ones, however, it is challenging to tease apart environmental and cultural causes implicated in periods of sweeping change. With recent advances in remote sensing and biogeochemistry, we can model ancient water use and climate to investigate relationships between water stress, sociopolitical organization, and imperial collapse. We propose to conduct pedestrian, UAV, and isotopic survey in the previously unstudied, archaeologically-rich, Caravelí Valley, focusing partially on the site of Kukuli (Fig. 1), which was likely integrated into the Wari imperial domain. We leverage cutting-edge geospatial and chemical techniques to investigate the role of water management in local agricultural production and settlement, Wari-local interaction, and how drought or resilience to it may have structured Wari collapse and regional reorganization in the valley.

Wari Expansion. An emerging body of data suggests Wari colonized some settlements and maintained indirect control in others, while communities in other regions avoided Wari influence almost entirely. However, the nature and timing of Wari expansion remains poorly understood, as do the links between Wari colonies and Wari-influenced sites (see Jennings, 2010). Wari's hydraulic mastery may have enabled imperial consolidation in some places. The rise of Wari coalesced with several decades-long droughts in the sixth century CE. Some have argued that Wari's expertise in canal and terraced field irrigation bolstered their influence in regions crippled by the cumulative impacts of these droughts (Glowacki & Malpass, 2003). The hyper-arid Peruvian coastal desert and mid-elevation *yunga* (a mid-elevation zone known for inter-zonal exchange and agricultural productivity, Fig. 2) comprised anthropogenic landscapes which required careful management. These communities may have been particularly susceptible to drought-induced food and water insecurity, which may have made cooperating with Wari appealing. In contrast, there was limited Wari control in desert Nasca where there was already sophisticated indigenous water management techniques in place, including wells (*puquios*), canals, and aqueducts for accessing groundwater where rivers ran dry (Lasaponara et al., 2012; Schreiber et al., 2003). Water technology and complex cosmologies related to water flows, huacas (sacred, animated landscape features), fertility, and agricultural productivity thus likely structured the differential course of Wari imperial expansion (Glowacki & Malpass, 2003), but further investigation in the Wari hinterlands is needed to understand how these factors and local conditions influenced the Wari imperial trajectory.

MH sites excavated in the Arequipa *yunga* show a spectrum of Wari integration: in the Majes Valley, Uraca shows virtually no Wari influence while La Real and Beringa traded with Wari or Wari agents; Quilcapampa in the Sihuas Valley was a Wari colony; Millo in the Vitor Valley was Wari-integrated; and the site of Corral Redondo in the Chorunga Valley is under investigation (Fig. 2). These sites are connected by petroglyph-lined transit corridors radiating from the Wari capital to the southernmost Wari colony in Moquegua (Fig. 1). Regardless of this connection, isotope data suggest mobility was limited for most, although prestige goods (e.g. trophy heads, feathers, and obsidian), foods like *chuño* (freeze-dried potato), and livestock (e.g. llamas and alpacas) were exchanged widely between the coast and highlands (Scaffidi, Biwer). MH water and agricultural management have not been systematically investigated at these sites, although they are strategically-situated along wide, fertile river oases with perennial rivers.

Wari Dissolution. Wari collapse initiated the Late Intermediate Period ("LIP," ca. 1100 - 1474 CE), concomitantly with a centuries-long dry period that may have impacted the entire Andes. Oxygen isotope data (δ18O) from the Quelccaya glacier (350 km from the study location) reflect prolonged dry, hot conditions (18O-depleted) around 1100 CE (the Medieval Warm Period), followed by harsh cold (the Little Ice Age) around 1300 CE (Thompson et al., 2003: 149-150). These and other factors stressed water management in some places beyond their capacity to adapt. For example, in the Tiwanaku colony of Omo, up-valley water usage by Wari colonists along with drought resulted in water scarcity, and ultimately leading to unsustainable agriculture and abandonment (Williams, 2002). In the highlands, the LIP was a period of insularity and balkanization—high cranial trauma rates and the aggregation of dispersed communities into walled hilltop settlements (Arkush & Tung, 2013) suggests violent competition in the post-Wari era. But if Wari hydraulic technology helped MH communities adapt to drought, why did they still lack the hydraulic mastery needed to overcome drought's effects in the LIP? Did some communities collaborate and innovate to mitigate these LIP changes? Or was Wari collapse more decoupled from climatic drivers than has been argued previously?

These terminal Wari-LIP shifts have been well-studied in parts of the Wari sphere, but not in the roughly 600-km stretch of Arequipa coast and *yunga*. Climate effects may not have been uniform—some regions could have become warmer and wetter while LIP drought and cooling wreaked havoc in the highlands. Furthermore, local agricultural and water management practices may have mitigated drought effects. The best evidence of the MH-LIP transition in Arequipa comes from post-Wari Quilcapampa in the Sihuas Valley. Strontium isotope analysis of LIP human skeletons shows the community was insular—only 1/18 individuals had non-local $^{87}Sr/^{86}Sr$. Stable isotope data corroborate that diets consisted of local foods with little maize (Scaffidi), a staple at Wari sites. The cessation of intra-regional trade networks, dissolution of MH sociopolitical organization, and terminal Wari climate shifts must have dramatically altered lifeways, yet the causes and responses to these changes remain poorly understood.

Research Question, Objectives, and Preliminary Hypothesis

To understand how the rise and fall of Wari and concomitant droughts impacted lifeways, we aim to achieve the following objectives by collecting data (in parentheses), as explained in the methodology:

1. Document settlement, water management, and agricultural strategies of the MH-LIP (survey data on settlements, water management features, and agricultural terraces),
2. determine the extent to which Caravelí was integrated into regional and interregional circuits of trade, mobility, and imperial expansion (survey data on architectural and artifact styles; non-local strontium and oxygen isotope signatures in artifacts, foods, or skeletons), and i
3. identify possible periods of cooling and drying in the MH-LIP (serially-sampled, AMS-dated oxygen isotope data in human and camelid tooth enamel).

These data will allow us to test the broad hypothesis that MH Caravelí-Wari ties and local water management strategies buffered valley settlements from LIP stresses. Survey data will also enable us to formulate additional hypotheses regarding Wari-local interaction and diachronic changes in diet, health and mobility that we will explore in-depth during a subsequent four-year project.

The Caravelí Valley and the Kukuli Site

The Caravelí Valley is well-suited to address these objectives. Satellite imagery indicates this valley has the highest settlement density in the region—which is surprising given the paucity of perennial rivers. Perhaps the Caravelí River ran high in the LIP while other regions experienced drought. However, if ancient river conditions were like present-day, inhabitants must have had technological adaptations to acquire agricultural and drinking water. Ubiquitous huarango (*Prosopis* sp.) and molle (*Schinus molle*) trees mark abundant groundwater—perhaps inhabitants tapped into these stores, as did the nearby Nasca. Our initial site visit focused on the 3-4 km2 hilltop settlement at Kukuli (Fig. 3). Surface ceramics and architectural styles are consistent with occupation during the Wari to post-Wari transition. We documented a Wari imperial-style face neck jar and communal burial towers (Fig. 3a). This suggests the site was integrated into Wari imperial trade networks and mortuary traditions, even if it had no direct contact with imperial agents. We also documented a high density of painted stone grave offerings, placas pintadas (Fig. 3b), at Kukuli's tombs. These are an Arequipa mortuary tradition, so their omnipresence suggests the persistence of local traditions alongside imperial expansion and collapse. The thick cap of ash from the explosion of the Huaynaputina volcano in 1600 CE demonstrates that many areas of the site remain undisturbed, making this an excellent candidate for survey and eventual excavation.

Water management and defensive positioning seem to have been fundamental to life at Kukuli. We documented three stone *maquetas* (large, carved boulders) at the apex of Kukuli overlooking the valley (Fig. 3c). *Maquetas* were integral to water rituals throughout the region and may also have been used logistically to plan water apportionment (Berquist). Multiple walls protect Kukuli's domestic core high atop a defensible ridge with commanding valley views (Fig. 3d). Nearby petroglyphs depict military figures with weapons and decapitated human trophy heads (Fig. 3e), evincing a concern with violent inter-group conflict. Through pedestrian, UAV, and isotopic survey, we will gain an understanding of Wari-local interaction, resource management, and the local environment throughout the valley.

Research Design and Methodology

Pedestrian Survey. We will conduct a 100% coverage survey over 30 km, walking four-person transects, documenting habitations, ritual spaces, cemeteries, agricultural terraces, and water management structures (wells, canals, and *maquetas*) mostly along the densely-settled eastern valley. Beginning north at Cerro Amargoso, which contains the best candidates for Wari imperial architecture, we will proceed south to Kukuli, which shows non-Wari architecture and Wari-style artifacts (Fig. 4). We will use methods like timed ceramic density surveys and document ceramic decorations and vessel shapes to determine the cultural influences of site sectors. We will GPS-locate and surface collect loose teeth, un-articulatable skeletal fragments, and archaeobotanical and faunal remains for isotopic analysis.

UAV Survey. We will employ gridded flight plans with an Autel Evo II UAV collecting RGB orthomosaics to detect features and georeference orthomosaics to ground control points taken with Reach RS2 Multiband RTF GNSS receivers (centimeter-precision Total-station replacements). Visible architecture will be photogrammetized using pole-mounted DSLR cameras. We will stitch digital elevation models and structures with Agisoft Metashape and tie into ground control points. We will document canals in non-forests with aerial photography and use NDVI, an algorithmic measure of vegetation health that often correlates with groundwater, in forested dry riverbeds (Fig. 3f), to attempt to locate wells and canals. Following archaeological adoption of precision agriculture methods (e.g. González and Hernández, 2019), we will fly the Mavic II Pro with a near-infrared (NIR) sensor and conduct image analysis of NDVI in standard software. In the field, we will process and ground-truth a subset of NDVI imagery from the Kukuli forest. If NDVI performs poorly, we will return later with lidar.

Isotopic Survey. Strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotope analyses are well-established biogeochemical tools for identifying non-locals (Scaffidi). Because it varies predictably throughout landscapes and archaeological tissues, $^{87}Sr/^{86}Sr$ reflect the geological signature of foods consumed (Scaffidi). Oxygen isotopes ($\delta^{18}O$) reflect whether water consumed was highland (^{18}O-depleted) or lowland (^{18}O-enriched). Modern water and archaeological $\delta^{18}O$ studies demonstrate that Andean highland waters are ^{18}O-depleted relative to coastal, ^{18}O-enriched samples (Scaffidi). Where $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ in the local environment and food web are documented, non-matching archaeological values can be assessed as non-local. Finally, $\delta^{18}O$ from archaeological tissues is a valuable paleoclimate proxy—if a sample with local $^{87}Sr/^{86}Sr$ is ^{18}O-depleted relative to local source water, that individual likely consumed water during a period of cooling and drying. Serial sampling of human and faunal tooth enamel $\delta^{18}O$ can show evidence of temperature and aridity shifts that can align with other paleoclimate proxies.

We will collect modern reference materials for establishing the isotopic baseline—water, *in situ* plants, and fauna from non-fertilized fields. We will dessicate and export samples under a USDA permit to Scaffidi, and parafilm water collection tubes. We will collect GPS coordinates and photograph sampling locations with ArcCollector on cell phones with BadElf (< 2m accuracy) receivers. Biwer, paleoethnobotanist, will identify plants and document local food webs to inform future excavation.

Chemical Analysis. We will AMS-date 10 serially-sampled teeth at UC-Irvine, dating the isotopic record of climate, mobility, or diet shifts rather than archaeological features. We will clean and prepare samples at Scaffidi's lab and measure $\delta^{18}O_{enamel}$ at the UC Merced Stable Isotope Facility. We will separate Sr in Scaffidi's lab and measure elemental concentrations and $^{87}Sr/^{86}Sr$ in the W. M. Keck Isotope Laboratory at UC Santa Cruz. Testing surface-collected materials contextualized by local baseline data will elucidate whether inhabitants were i-mobile and how climate changed in their lifetimes.

Innovation Statement. While UAV survey is now standard, NDVI has not yet been deployed in the Andes to detect sub-vegetation structures. Furthermore, archaeological isoscapes have exploded globally, but are in their infancy in the Andes (Scaffidi). Our isoscapes will establish local signatures expected in this unsampled valley, while isotopic testing of AMS-dated surface-collected teeth will contribute to understanding mobility and climate in the MH-LIP. This project has the ability to transform our understanding of social-environmental interactions in the Andes, and address anthropological questions about colonial encounters, water management, and imperial consolidation and dissolution, through the innovative integration of empirical landscape and chemical data applicable to research worldwide.

Timeline and Outcomes. We will conduct a six-week survey from July 1-August 15, 2021, as outlined in full on the application form. Survey will produce four publishable datasets that also comprise preliminary data for four-year grants: 1) 3D maps of Kukuli and another site; 2) valley-wide maps of settlements, terraces, and water structures; 3) local isoscapes; and 4) archaeological $^{87}Sr/^{86}Sr/\delta^{18}O$ data.

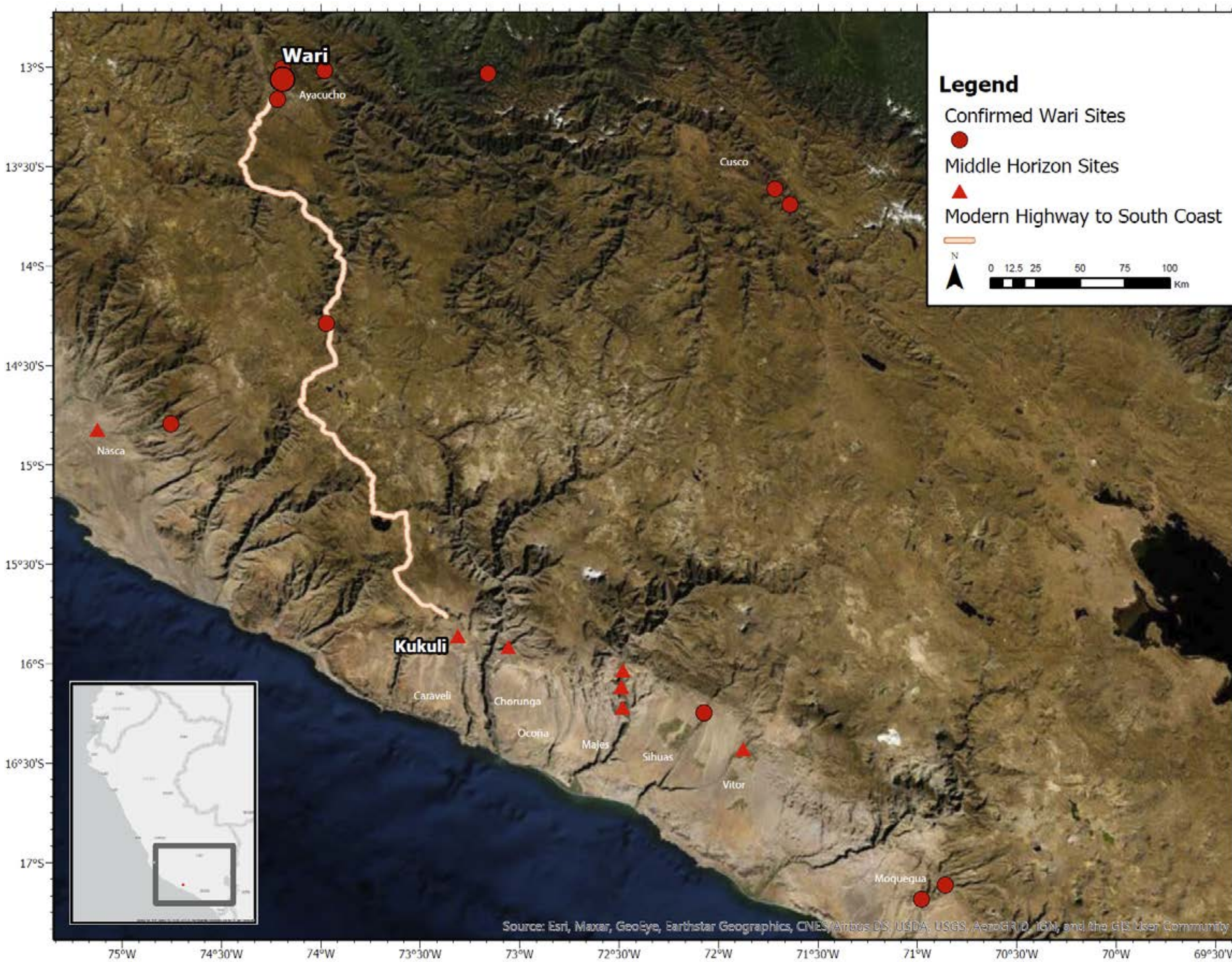

Figure 1. Location of Arequipa mid-elevation *yunga* river valleys relative to major cultural centers in the desert Nasca region, the Wari heartland in highland Ayacucho, and the Cusco highlands (WGS 1984 datum). Here we highlight the connection of the modern road between the Wari heartland and the proposed survey sites of Kukuli and the Caravelí Valley; this road may have been used in ancient times as well.

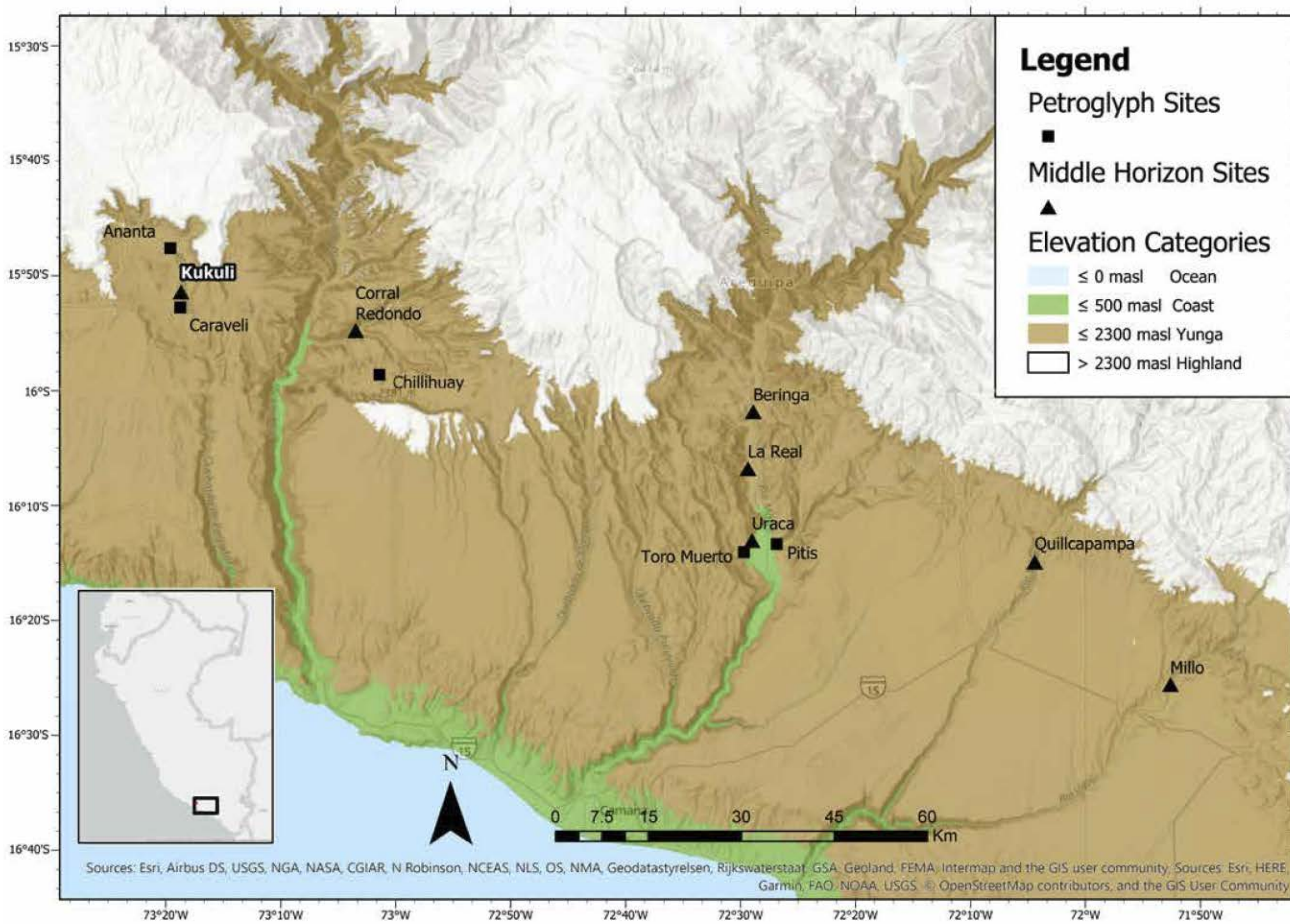

Figure 2. Location of Kukuli and other Caravelí sites relative to known petroglyph sites and previously excavated sites in neighboring Arequipa *yunga* valleys.

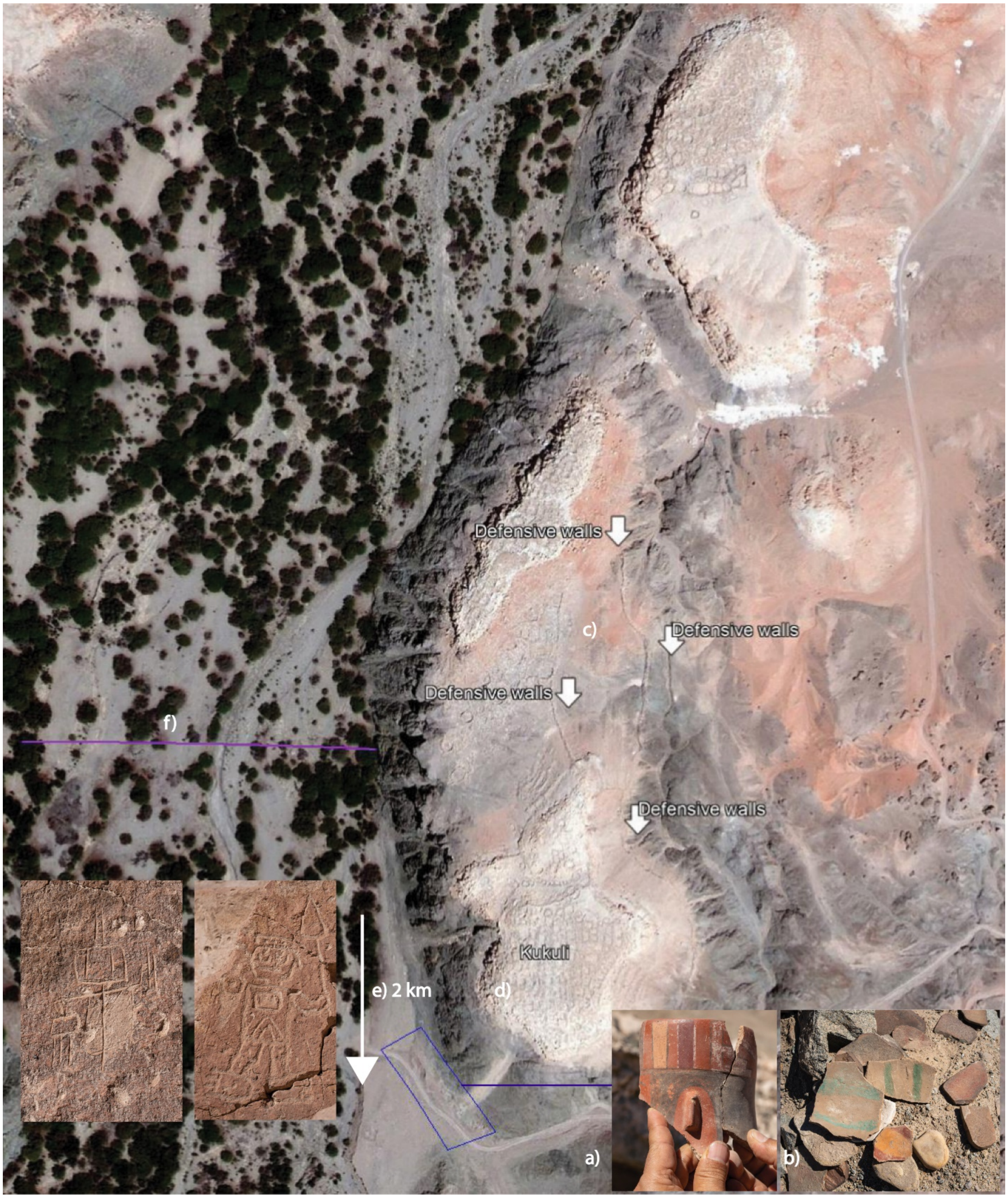

Figure 3. Preliminary observations at the Kukuli site to be formally surveyed by this project: a) evidence of Wari imperial integration from a Wari face-neck style jar on the surface of Wari-style burial towers at the base of the hilled settlement; b) *placas pintadas* from the cemetery sector; c) three or four defensive walls protecting the domestic core; d) location of three *maquetas* overlooking the valley, possibly related to water rituals or management; e) violence-related petroglyphs documented at the southern limits of the proposed survey; and f) forested dry riverbed to be surveyed with NDVI to locate possible wells and canals.

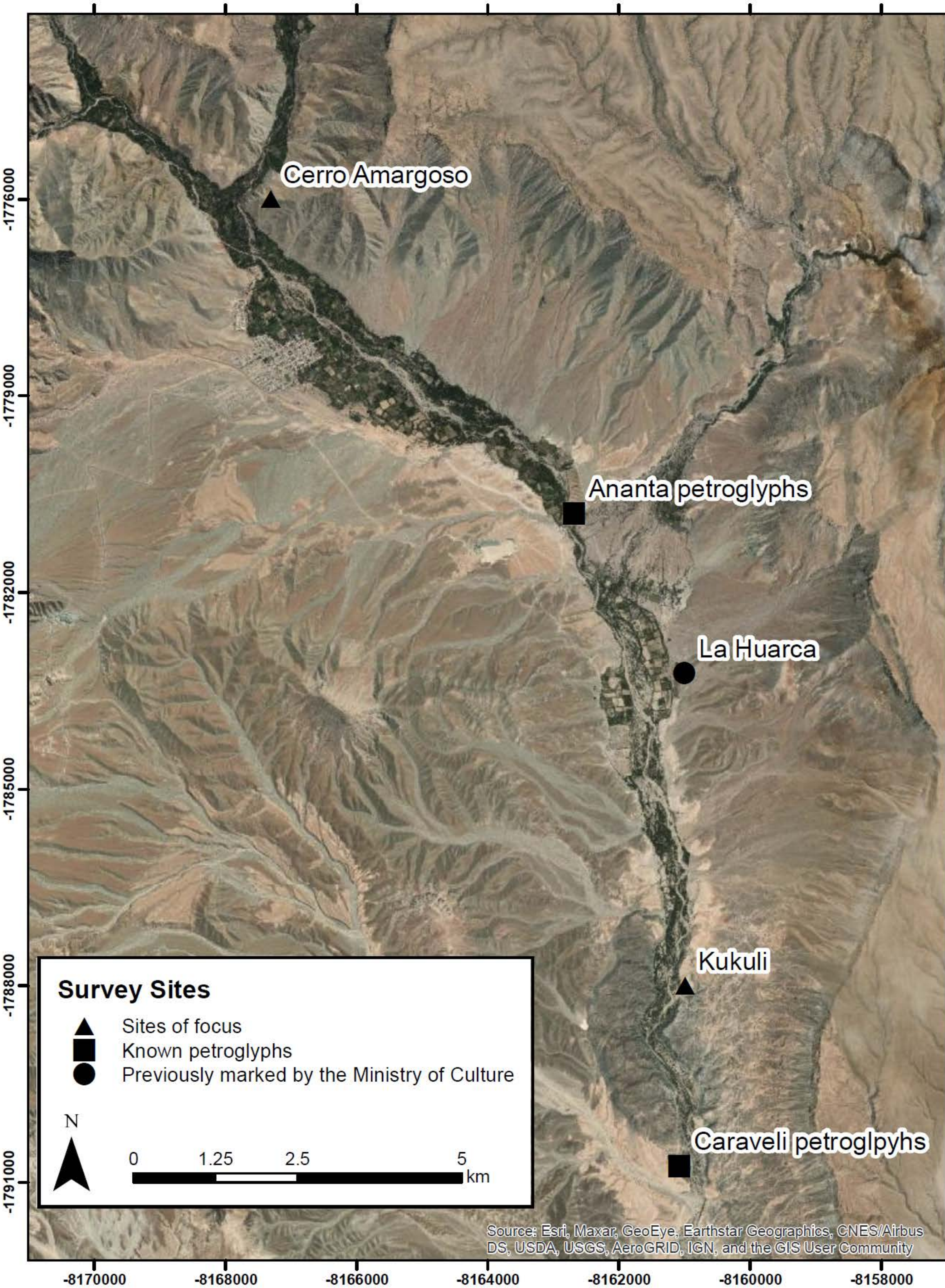

Figure 4. Portion of the Caravelí Valley to be surveyed in relation to previously documented habitation and petroglyph sites (UTM Zone 18L, WGS 1984 datum).