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Terracing in the Andagua Valley, Southern Peru: A Socio-Geomorphic Landscape in the Anthropocene

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Blaise Scarlett Murphy

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Dedication

To Alex. And to the community of Andagua.

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Abstract

Terracing in the Andagua Valley, Southern Peru: A Socio-Geomorphic Landscape in the Anthropocene

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Agricultural terraces and canals are ubiquitous across the southern Peruvian Andes, the patterns of their use and disuse a product of Indigenous engineering and social and environmental historical processes. Their construction creates a geomorphologically unstable landscape without the continued social relationships and practices to maintain the features that enable their use such as retaining walls and water management. This dissertation engages with these intensely humanized landscapes through a socio-(hydro)geomorphic lens, which meaningfully integrates geomorphic forms and processes with human practices, perceptions, and processes of power. This relational framework informed the collection and analysis of interviews and remotely sensed imagery on the terraced, intermontane landscapes in Andagua, a rural town in the southern Peruvian Andes, focusing first on the landscape scale and then moving across finer and coarser social, spatial, and temporal levels to better understand the physical and social variables on the landscape. Farmer interviews reveal that terraces are important not only for subsistence and local food security, but also for cultural relationships to the animate features on the landscape such as Earth Mother. Labor practices, such as kinship-based labor exchange

and community canal cleaning, contribute to strengthening social relations across generations and ensuring the agricultural productivity of the terraces through time. These practices and relationships are bound up in complicated and contradictory perceptions of social and climate change, altering decision-making about land use and impacting visions for the future. This dissertation explores local knowledge and local landscape analytics, revealing unique terrace typologies and patterns, new understandings of the physical manifestations of land tenure, refined knowledge of mid- to late-twentieth century Valley of the Volcanoes, and new uncertainties about the impacts of mechanized technologies and concrete canals on soil health and fertility and terrace stability.

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Chapter One: Agricultural Terraces in the Valley of the Volcanoes

Terracing is found all over the world, documented as far north in the Americas in Colorado and throughout much of the Andes (Wei et al. 2016) as a method of hillslope alteration that impacts geomorphic processes on the landscape (Brown et al. 2020).[1] The enduring use, maintenance and disuse of agricultural terraces create humanized landscapes that are locations of interacting social and physical processes and forms. The multiple practices around, perceptions of, and ways of thinking about terraces and their role in the landscape are critical to their continued geomorphic stability. However, the increasing rate and intensity of climate and social change correlating with the Anthropocene continues to threaten mountain environments (Zimmer 2022), and especially Indigenous groups marginalized through social, political, and economic processes tied to colonialism (Whyte 2017). This dissertation turns to a highland community in the Valley of the Volcanos in the southern Peruvian Andes to better understand the intertwined socio-(hydro)geomorphic relationships (see Ashmore 2015), processes and forms that constitute the terraced landscape (figures 1.1 and 1.2).

This dissertation specifically investigates the relationship between local people and the terraced landscape through the mid-twentieth and early twenty-first centuries in Andagua, Peru, incorporating local landscape analytics from farmer interviews into object-oriented analysis of remotely senses images. This approach draws attention to the importance of local knowledge as crucial to social and environmental sustainability of terraced landscapes. Investigating these in Andagua begins to clarify the impacts and perceptions of shifting power relations and a dynamic climate from the 1930s to the present. It specifically focuses on bottom-up terrace rehabilitation and infrastructure projects before the Peruvian agrarian reform in the late 1960s, land tenure dynamics stemming from colonial and post-colonial (uneven) reciprocal relationships, top-down infrastructure projects through the twenty-first century, and other social forces and processes. Andagua and its terraces are additionally located among and overlie Pleistocene- to Holocene-aged lava fields, ash, and scoria cones, evidencing the interplay of natural and social processes and practices on the landscape.

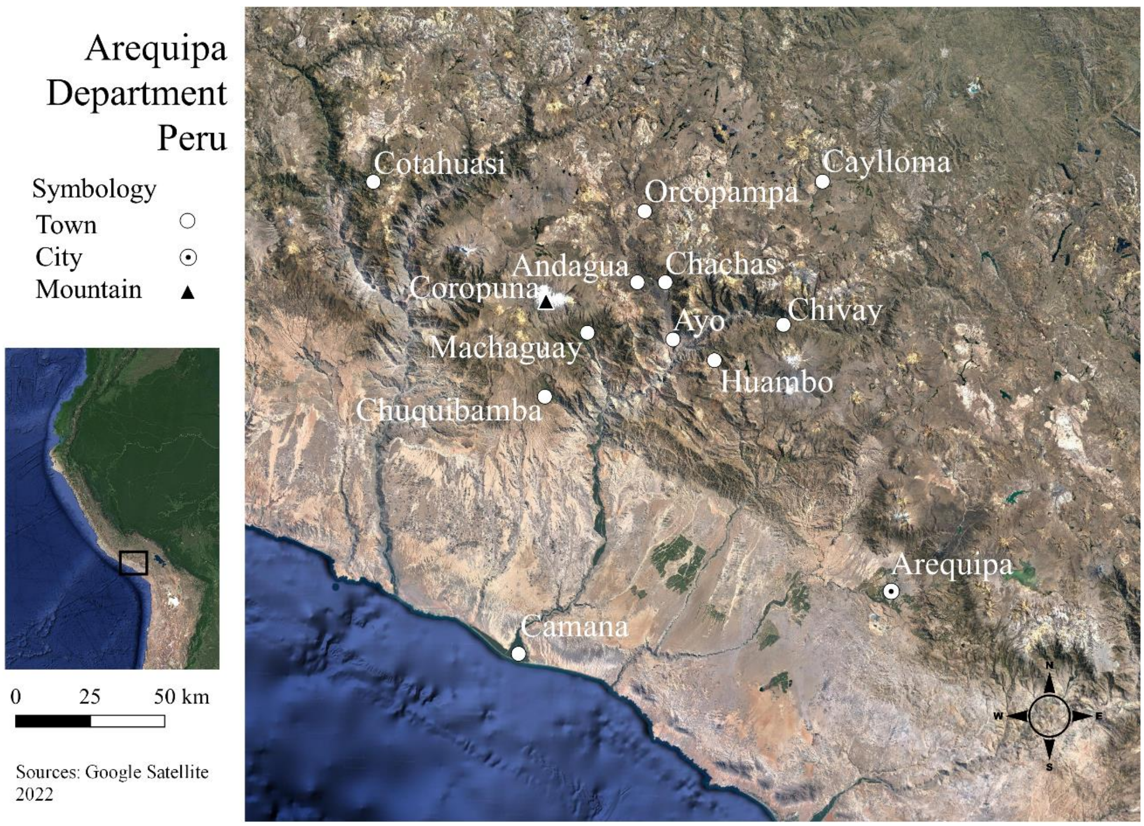


Figure 1.1 Regional map of northwestern Arequipa Department.

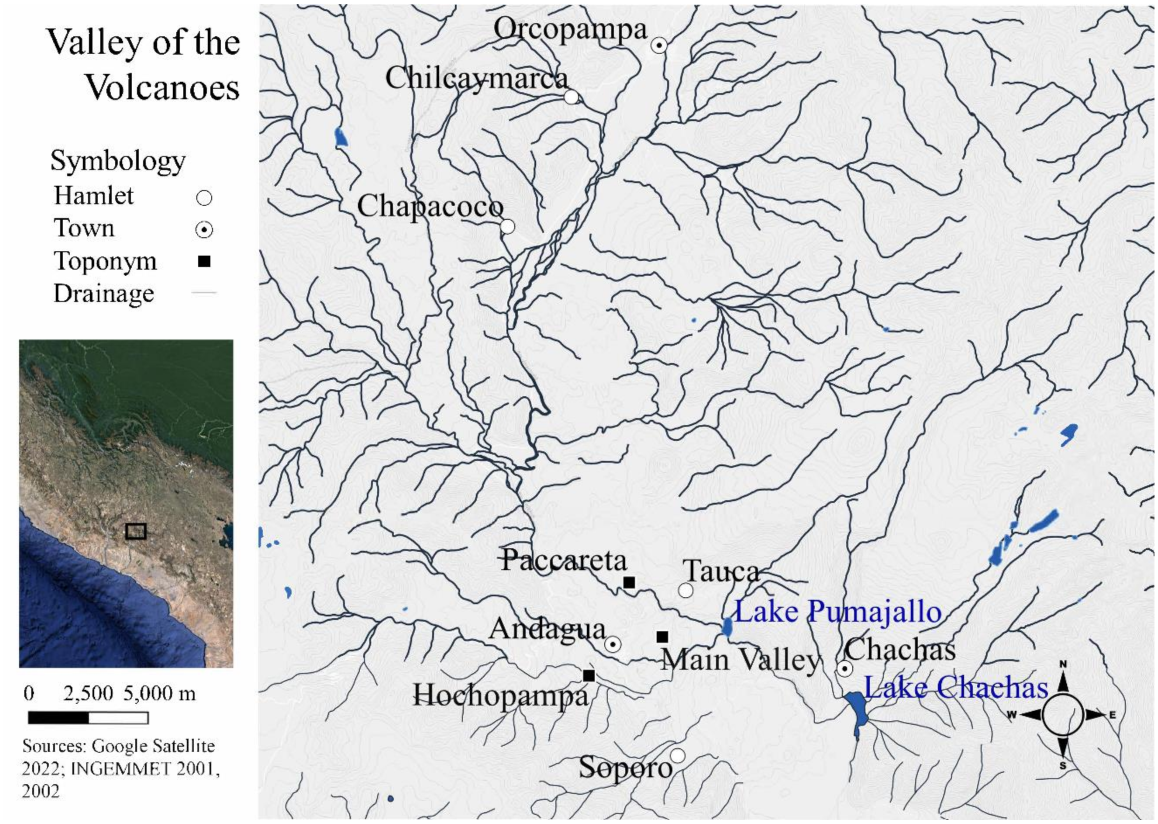


Figure 1.2 Major modern towns and villages mentioned in the text near the town of Andagua in the Valley of the Volcanoes, Peru.

BRIEF HISTORY OF TERRACING: WORLD, PERU, AND SOUTHERN PERU

Terracing is a place-based risk management strategy that considers both the micro- and macro-climates across complex ecologies in their construction (Earls and Cervantes 2015). They are found on hillslopes in marginal environments all over the world and provide ecosystem and geomorphic services at multiple scales on the surface and subsurface including changing hydrologic pathways, controlling erosion, decreasing flow connectivity, increasing soil depth, and improving soil nutrients (Wei et al. 2016; Brown et al. 2020; Deng et al. 2021). Ancient terraces are mapped along the coast of the Mediterranean and in mountains on the continents of Africa, Asia, the Americas, and

Europe (Wei et al. 2016; Cicinelli et al. 2021). Terracing is additionally found on volcanic, tropical islands such as the Pacific islands of Fiji (Kuhlken 2002) and the Atlantic Canary Islands (Cicinelli et al. 2021).

Dating the construction of agricultural terracing is difficult due to the continuously altered soil column, regular reconstruction of terrace features, depositions during irrigation and ephemerality of some types of terrace infrastructure (Treacy 1987; Kuhlken and Crosby 1999); however, technology such as optically stimulated luminescence of buried sediments extracted from excavations and fine-scale digital elevation models (DEMs) created from light detection and ranging (LiDAR) and other remotely and terrestrial sensed imagery are offering new and efficient ways to analyze and map terraces (e.g., Acobado 2008; Tarolli et al. 2014; Camera et al. 2018; Garrison et al. 2019; Brown et al. 2020; see Brown and colleagues (2021) for a comprehensive summary on dating techniques).

Early dryland and stone terracing are documented across the Middle East as early as 3050 Before the Common Era (BCE) and rice terraces are mapped as early as 50 BCE in modern day Philippines and China (see summary by Wei et al. 2016).[2] There is evidence of floodwater canal irrigation systems in the Bolivian Andes and agricultural terraces in the Colca Valley, southern Peru dating to as early as 1550 BCE (Zimmerer 1995; Brooks 1998). Terracing and lynchets in the Mediterranean were constructed as early as the Neolithic-Bronze Age, most of which date to the Roman period or about 50 BCE (see summary in Brown et al. 2020). Terraces in the Mediterranean today are mostly dry-stone construction, located on marginal lands and are largely abandoned, in addition to earth embankments and combination earth embankments and dry-stone walls (as summarized by Cicinelli et al. 2021). Terracing was constructed in the Maya Lowlands of central America beginning around 250 in the Common Era (CE) centered in the Río Bec of Mexico, Petexbatún of Guatemala and northern to central Belize (Beach et al. 2002). They may be present in a broader extent in this region; however, the dense forest cover and their degradation may have obscured their presence during past research (Beach et al. 2002), a problem being remedied by placing fieldwork in conversation with remote sensing technologies able to penetrate the tree canopy such as LiDAR (e.g., Dunning et al. 2019; Garrison et al. 2019).

Terrace Origins

Terrace function and origins are often tied to ecology, geomorphology, hydrology, and climate of the diverse locations in which they are found. As argued by Brown and colleagues (2020), the origins of this intensification of the landscape are coupled with both population growth and socio-political forces. Brown and colleagues (2020) additionally distinguish between terrace origins in the Americas and those of Europe by the presence or absence of the plow. Without a plow, they argue, terraces in the Americas were not designed in relation to geomorphic process like those in Europe, rather, they were designed to maintain soil moisture. Doolittle (1990) hypothesizes that terraces in the semi-arid and arid mountains of the Americas may derive from human observation and use of naturally occurring geomorphic and pedological phenomena in highland drainages and hillslopes, such as cultivating the accumulated sediment behind a fallen tree. Beach and colleagues (2002) note the morphologic similarities between terraces and fallen trees lying perpendicular to the slope, describing the differences in subsoil characteristics analyzed during excavations. Such “incipient” terraces were likely controlling for and using erosion possibly through combining active hillslope excavation and passive, incremental infilling (Doolittle 1984; Williams 1990).

Terracing of thin-soiled, karst escarpments in the hot, subtropical Maya Lowlands of modern-day Belize are dated to 250-600 CE, which, Beach and colleagues (2002) hypothesize, was to control accelerated soil erosion occurring between 1500 BCE to 250 CE correlating with the transition from a rural to increasingly urbanized landscape. This intensive form of agriculture diffused across the Lowlands for the next 300 years, a period associated with the widespread distribution of grasses such as *Zea mays* (maize), although terraces appear to be abandoned after this period (Beach et al. 2002; Beach et al. 2010).[3] Dating of these terraces is sourced both from ceramics' stratigraphic positions and typology and calibrated radiocarbon measurements of a buried ceramic (Beach et al. 2002). Ferro-Vásquez and colleagues (2017, 511) concluded that terracing in the UNESCO World Heritage site of Konso in southwest Ethiopia were constructed incrementally as features that capture eroding topsoil to enrich low-lying fields as a soil "harvesting" system. More stone walls were constructed on the exposed bedrock to continue to control surface runoff and eroding soil (Ferro-Vásquez et al. 2017). In the Americas, irrigation systems are found with terraces in many cases (Donkin 1979, 34); however, Williams (1990) notes the presence of irrigation without terraces. Regardless, while terraces have definable primary and secondary functions, described below, there is no way to conclude the reasoning of these early farmers (Denevan 1994, 95).

Terrace Functioning: Soil, Water, Geomorphology

Terraced infrastructure and fill are markedly different due to place-based variables such as climate patterns, socio-historic factors, soil-geomorphic landforms and processes, and ecosystems (Sandor and Homburg 2017). Generally, terraces are modifications of sloped landforms, enabling hillslope and channel cultivation through the creation of a permanent or impermeant wall perpendicular to the slope (Donkin 1979, 32). These obstructions may be actively taking advantage of natural erosion and runoff for the purpose of cultivation and directly related to the capture, control, and retention of irrigation water

(Treacy and Denevan 1994, 93-95). They subdivide the slope length of a hill (Sandor and Eash 1995), altering sediment distribution and surface and subsurface drainage networks, resulting in decreasing catchment connectivity, and shifting vegetation patterns (as summarized by Sandor 2006, 513; Moreno-de-las-Heras et al. 2019), especially when irrigating terrace surfaces (Nunes et al. 2018). Terraces can be constructed incrementally (Doolittle 1984) or may require engineering knowledge for more complex lateral bench terracing (Donkin 1979, 32). Terracing can increase soil depth in relation to surrounding soils (Treacy and Denevan 1994, 93-95; Eash and Sandor 1995; Goodman-Elgar 2008; Itkin et al. 2022), promote sediment retention (Nunes et al. 2018), improve soil phosphorus, organic carbon and nitrogen (Sandor et al. 2020), and improve soil water-holding capacity and fertility (Nanavati et al. 2016; Deng et al. 2021), for example, in combination with other practices such as camelid herding (Knapp 1987). In the humid tropics, terraces were likely created to capture and build soil for cultivation, their construction increasing the natural soil depth by more than double, in some cases (Beach et al. 2002). Other benefits of terracing include their function as a mitigation strategy for local environmental conditions such as by interrupting cold-air drainage (Brooks 1998, 17) through manufactured wind turbulence and altering tread aspect in relation to the angle of incoming solar radiation (Treacy and Denevan 1994, 93-95). Soils in poorly drained depositional positions may also be carbon sinks by burying carbon in buried topsoil and trapping it in aggregates or mineral complexes (Itkin et al. 2022). The sustainable use of these built features requires an understanding of place-based environmental knowledge and practices, as well as socio-political relations (Lave et al. 2018; Erickson 2019). Today, terraces are considered part of local "heritage" and have cultural importance beyond their use for subsistence or market-oriented production (Tarolli et al. 2014; Cicinelli et al. 2021, Deng et al. 2021; Bocco 2022).

Terrace Construction, Use, Maintenance and Disuse

Terrace construction varies, but generally interrupts prevailing geomorphic processes through retaining walls of different planform patterning and the management of water (Brown et al. 2021). In the southern Andes, farmers are documented excavating a 50- to 80-centimeter-deep trench for terrace construction in which alternating stones and wet soil are tightly packed until the wall reaches the appropriate height, usually dictated by the angle of the original slope (Guillet 1987; Treacy 1987). The bottom layer is typically placed on bedrock or hardened subsoil (Field 1966; Brooks 1998, 257). The hardened subsoil, called *tierra arcillosa* (clayey earth), was possibly purposely emplaced, or used to prevent water loss due to percolation and to direct water towards the downslope terrace tread (Field 1966; Donkin 1979, 33; Treacy 1987; Sandor and Eash 1995).[4] Farmers additionally may place a gravel and cobble fill behind the wall for water drainage to mitigate water pore pressure (Sandor and Eash 1995), a technique also noted in Maya terraces (Macreae and Iannone 2016). As wall collapse is often preceded by poor drainage and fill saturation (Guillet 1987), walls must be built to withstand high soil moisture but also allow for exfiltration through the wall when saturated to mitigate wall failure (Donkin 1979, 32) and allow water drainage (Sandor and Eash 1995).

For farmers, there is a continual cycle of collapse and maintenance of terrace features from single terrace walls to entire terraced hillslopes, both of which are labor-intensive activities (Denevan 1987, 1). Reconstruction in the Andes occurs during the rainy season to ensure the proper pack between stones (Guillet 1987; Treacy 1987). During reconstruction activities of larger extents of a hillslope noted by Treacy (1987), women were more often gathering and stacking stones while men held the role of masons, although Treacy documented older women laboring at masonry activities. Farmers backfill with loose soil and then perform a ritual on behalf of this new or newly reconstructed wall

(Guillet 1987). The reconstruction of walls requires a lot of heavy labor, with informants in the Colca Valley suggesting to Guillet that a 100-meter-long, 3-meter-wide, and 2-meter-high terrace would take 2 men working full time 43 days to construct (Guillet 1987). Farmers do occasionally construct a shelter in terrace walls where an individual might temporarily stay to prevent crop theft (Guillet 1987). Contemporary farmers do not typically include additional engineering features in wall construction, although older or distinctly Incan terraces may contain stone-lined irrigation spillways, staircases, and other features designed for water control or aesthetics (Donkin 1979, 33; Guillet 1987, 412; Ortloff 2019).

The Inca especially focused on engineering and design at imperial estates, creating large vertical staircases separating sets of terraces, the walls of which were shaped and placed in clear sequences, demonstrating an aesthetic that represents their power to command labor forces (Donkin 1979, 33, 132). Construction of these older walls were more "refined" than contemporary construction in that they included canals lined with stones behind the face called *colcha* as well as spillways (Guillet 1987, 412). Effective irrigation was especially important for the Inca to grow prestigious crops requiring the intensification and extensification of cultivation across their Empire (D'Altroy 1987). The functioning and design of irrigation systems at important Inca sites also demonstrate the engineering knowledge required for such complicated functioning (Ortloff 2019). The sets of ditches, channels, sluice gates, waterfalls, and other features were carefully designed to ensure control over water velocity and volume across sites such as Tipon (Ortloff 2019). Demonstrating water knowledge and control at both royal estates and for intensified cultivation across the empire contributed to the perception of their power.

The deintensification, alteration or disuse of terraces facilitated by local and non-local socio-political forces can create positive feedback that further drives human-environment relationship changes and negative impacts on the terraced landscape. For example, use of heavy machinery on terraces constructed before widespread mechanization is causing soil erosion and threatens the sustainability of land use (as summarized by Tarolli and Straffelini 2020). In the Mediterranean, Tarolli and colleagues (2014) report that many studies document the abandonment of narrow terraces because they were prohibitive of navigating large-scale agricultural machinery. In the Andes, Denevan (1988) estimated that over 60% of the total terraces were in disuse by the late twentieth century. Many of those terraces were unirrigated and from above 3600 meters above sea level (masl), while the rate of abandonment of irrigated, lower-level bench terracing varied by location (Denevan 1988). Large-scale abandonment in the Andes is attributed to colonial and post-colonial population shifts, depopulation from disease and increasing frost risk from the Little Ice Age (Wernke 2010).

Disused terraces are vulnerable to soil erosion and slope failures in relation to shifts in the surface and subsurface flow (Tarolli et al. 2014). Soil depth, plant cover, and climate all impact disuse (as summarized by Arnáez et al. 2015), resulting in saturation overland flow, piping, gullying, and mass movements (Tarolli et al. 2014). High energy storms are one major contributor to wall collapse, causing saturated soils and high soil pore pressure to overcome the wall's resisting force, releasing organic carbon and mineral-rich soils from the terrace tread (Inbar and Llerena 2000). Allowing cattle to graze on abandoned fields also can contribute to higher amounts of erosion during rainstorms (Lasanta et al. 2001). More recently abandoned terraces, in disuse for about 25 to 30 years, were measured as resulting in higher volumes of eroded sediment, largely originating from shallow landslides, than those terraces in disuse for a longer period (Brandolini et al. 2018).

Since low vegetation cover and a lack of infrastructure maintenance are often the biggest controlling factors of landslide processes on abandoned terrace systems (Moreno-de-las-Heras et al. 2019), mitigation strategies include vegetated treads (Harden 2001), water management technologies (Wang et al. 2022), alteration of terrace and canal morphology (Deng et al. 2021) and payments for geomorphic services (Cicinelli et al. 2021). For example, vegetation mitigates rain splash and enables higher infiltration capacities (Harden 2001). Water management, using a combination of local knowledge and new technologies, is especially important to mitigating adverse impacts to these landscapes from climate change and ensuring food security (Wang et al. 2022). The goal of payments for geomorphic services includes the continued conservation of terraces as "cultural landscapes" by traditional crop production or tourist development and, as such, preventing erosion and landslides (Cicinelli et al. 2021).

THE VALLEY OF THE VOLCANOES

Physiographic features, climate, tectonic and volcanic activity

Climate, Ecology and Hydrology

The Andagua valley is in the transitional ecological zone between the *mesoandina* or *quechua* (mountainous steppe) at 2600-3800 masl and the high *puna* or *altoandna* at elevations greater than 3800 masl (Clapperton 1993). Naturally occurring vegetation in this transition zone are *cacti genera* (e.g., *Weberbauerocereus*, *Haageocereus*, *Corryocactus*) *shrub genera* (e.g., *Ambrosia, Gochnatia, Krameria, Adesmia*) and herbs (e.g., *Eragrostis, Monnina Spergularia;* Kuentz et al. 2011). Andagua's weather station has been collecting daily precipitation and temperature maximum and minimum since 1951 (station name: Andahua). It is operated by a local person in town (at 15° 30' 3.24", 72° 21' 18.35) on behalf of the Ministerio de Ambiente in Peru (Servicio Nacional de Meteoroogía e Hidrología del Perú [SENAMHI]). The semi-arid environment has an annual precipitation of 367 $\pm$ 160 mm (millimeters) with an average of 93% falling within the rainy months of December through March and, since 1950, almost 50% of the rainy months falling in February, followed by January and then March (SENAMHI 2020; figure 1.3). This is congruent with the highly interannual precipitation and dry winter months (only 3% of annual precipitation concentrated in a few days during the winter months) in this region of the Andes (Imfeld et al. 2020). In total, 81% of recorded days from 1951 to 2018 had a value of 0 millimeters (mm; SENAMHI 2020). Since the 1960s, the total precipitation has been trending negative in the region around the Coropuna Volcano, although summer precipitation is increasing (Imfeld et al. 2020). Andagua is also recording fewer wetter than average years than in the past and a general downward trend in average precipitation since 1984 (figure 1.4).

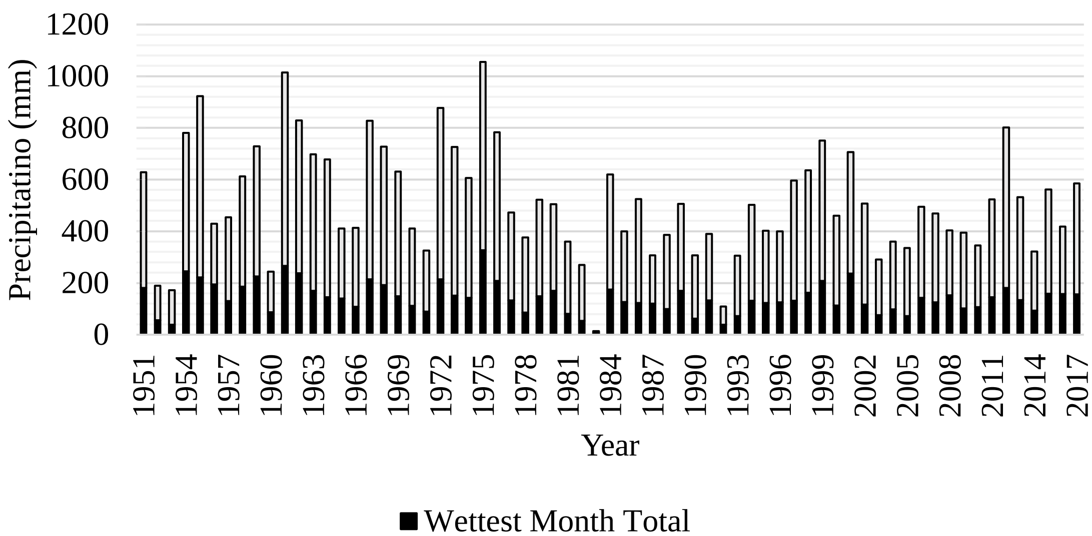


Figure 1.3 Total annual precipitation in Andagua from 1950 to 2017 highlighting the total contribution from the wettest month of that year (SENAMHI 2017).

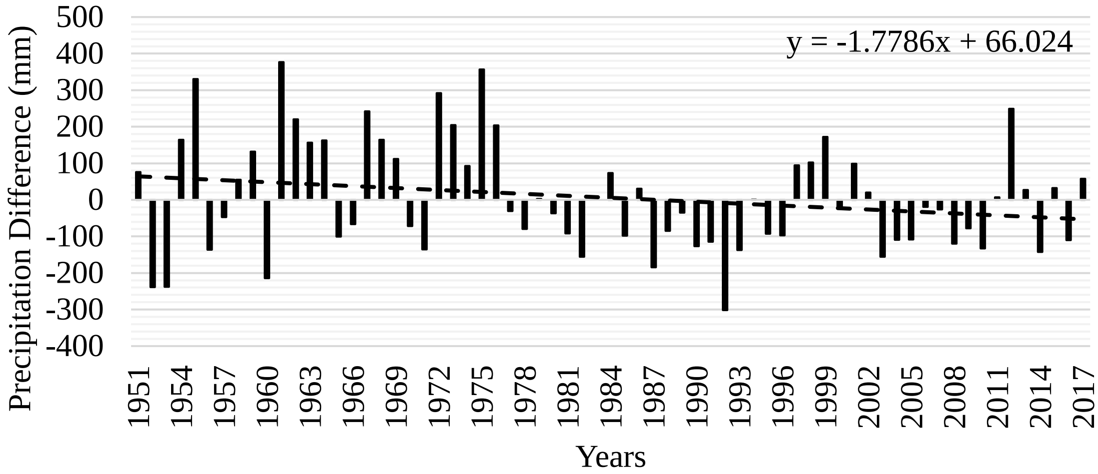


Figure 1.4 Difference in annual precipitation from the average total of 371.5 millimeters over time (with trendline) in Andagua, 1951-2017 (SENAMHI 2017).

In addition to changing precipitation patterns, the temperature is increasing in this region of southern Peru around 0.27° C per decade annually and 0.34° C in the winter months (Imfeld et al. 2020). Imfeld and colleagues (2020) posit that in this area of the Andes, the decreasing precipitation is causing increasing maximum temperature trends in the dry season, while cloud cover decreases the strength of the trend during the wet season.[5] The minimum temperature relates to the seasonality of longwave radiation from the sun and negatively correlates with frost days (Imfeld et al. 2020). There is also a regional seasonal variability of temperature maximum, which is largely driven by seasonal cloud cover differences and intensified by the presence of El Niño Southern Oscillation (ENSO; Imfeld et al. 2020). The average maximum temperature in Andagua is 16.5° C and the average minimum temperature is 3.9° C over the available data beginning in January of 2000 (SENAMHI 2020). The average daily minimum values per year did not significantly change over this period; however, the coldest days of the year are trending slightly warmer.

Similarly, the average maximum values are highly variable each year; however, the maximum temperatures are trending warmer (figure 1.5).

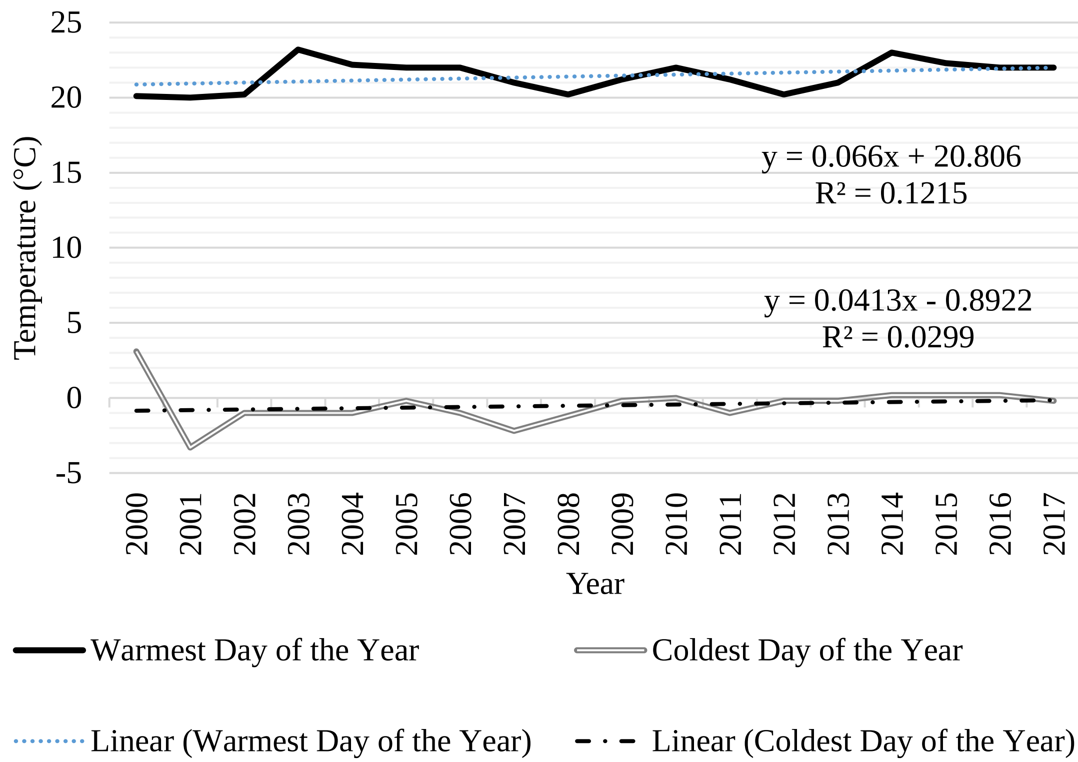
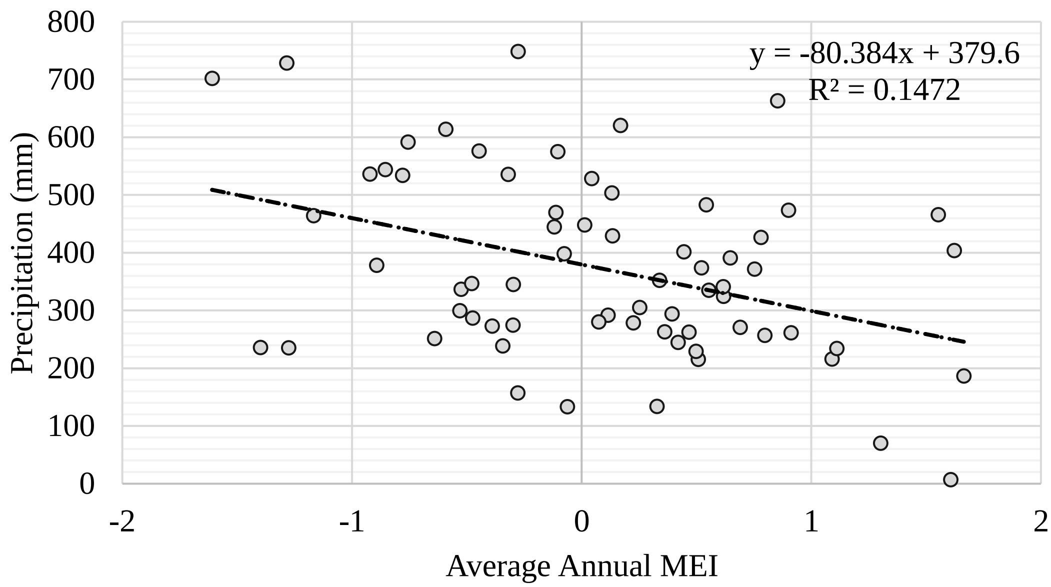


Figure 1.5 Warmest days and coldest days per year and trendlines in Andagua, 2000 to 2017 (SENAMHI 2020).

Conflicting results over impacts of ENSO events on the highlands of southern Peru evidence the uneven impacts across the highly variable topography. According to Jonaitis and colleagues (2021), El Niño events often cause fewer wet days and significantly decreased total annual precipitation in this area of the highlands, in comparison to La Niña years. Imfeld and colleagues (2020) concluded that strong El Niño events will increase the summer and fall temperatures in relation to the average trends and increase total summer precipitation (Imfeld et al. 2020). Additional factors can contribute to interannual variability of ENSO events including, as summarized by Imfeld and colleagues (2019), volcanic eruptions and westerly wind anomalies, although the relationship among them is not completely understood. According to the Monthly Multivariate ENSO Index (MEI), the weak to very strong El Niño event of 2014-2016 was followed by a la Niña event in 2016-2018 and another El Niño event in 2018-2019 (Wolter 2021). In Andagua, total annual precipitation is highly variable, even during strong El Niño or La Niña events (figure 1.6), however, like results reported by Jonaitis and colleagues (2021), generally, El Niño events correlate with drier years and La Niña events correlate with wetter years.



Note: A negative value indicates La Niña: moderate conditions between -1.0 and -1.5 and strong conditions between -1.5 to -2.0. A positive value indicates El Niño: moderate conditions between 1.0 and -1.5 and strong conditions between -1.5 to -2.0.

Figure 1.6 Relationship between Monthly Multivariate ENSO Index (MEI) and annual total precipitation in Andagua, 1951 to 2017 (SENAMHI 2017; NOAA 2021).

Pabón-Caicedo and colleagues' (2021) compilation and analysis of past and projected climate in the Andes significantly vary, especially concerning precipitation, due to the highly variable topography of the Andes, its impact on wind systems, and the low resolution of the models. The projected mean river discharge is uncertain, although researchers note the large role human alterations of the systems through diversions of water from the river (as summarized by Pabón-Caicedo et al. 2021). The higher-elevation Andes regions, especially highland grasslands, among other biomes, are projected to be significantly impacted by warming trends by the end of the twenty-first century, more so than lower elevation areas (Urrutia and Viulle 2009; Tovar et al. 2022). Glaciers in the central and northern Andes are decreasing in mass over the twenty-first century, causing impacts on river discharge and sea level rise (Dussaillant et al. 2019) as well as increasing the number of glacial lakes, the latter contributing to vulnerability of downstream residents to outburst floods (Veettil and Kamp 2021).[6]

Geology, Topography, Geomorphology, and Hydrology

Andagua is in an intermontane valley in in the Western Cordillera of the central Andes in southern Peru. The presence of dozens of volcanic features, tectonic activity, and mass wasting signal its location in the Central Volcanic Zone, which overlies the active subduction zone of the Peru-Chile trench (Clapperton 1993; Gonzalez and Pfiffner 2012).[7] There are scoria cones adjacent to fault lines and scarps ranging from 5 to 15 meters in height (Autoridad Nacional del Agua [ANA] 2015). The valley itself is a tectonic depression lined with longitudinal fault systems (Ministerio de Agricultura y Riego 2015).

The major volcanic features near the town of Andagua are composed of andesitic, basaltic, dacitic and an andesitic-basaltic rock (figure 1.7). Those on the valley floor are from Holocene- to Pleistocene-aged scoria cones, pyroclastic cones, lava domes, lava fields, ash, and tuff (INGEMMET 2001, 2002; Gałaś and Paulo 2005; Gałaś 2009; Gałaś 2014; Gałaś and Paulo 2005; Delacour et al. 2007; Gałaś et al. 2018). Some of the oldest underlie agricultural terraces in the main valley south of the Andagua River (Gałaś et al. 2023). The youngest date to the Holocene, are unterraced and flow south from the main valley, and those in intermediate ages date to the Pleistocene-Holocene and underlie terraces in Paccareta north of the Andagua River (Gałaś et al. 2023). The most recent effusive flow dates to 1451-1523 CE, which correlates with Inca imperial expansion into the region (Venturelli et al. 1978; Delacour et al. 2007; Sørensen and Holm 2008; Menaker 2019b). Flows from the Holocene dam the Andagua River creating a lake that drains along 17 kilometers of lava tubes before resurfacing and feeding into the Colca Canyon (Ministerio de Agricultura y Riego 2015). Valley walls are composed of sedimentary rocks including mostly Cretaceous-aged limestone with some Jurassic-, Cretaceous- and Oligocene-aged sandstone and conglomerates and Jurassic shale (Gałaś 2011; Gałaś et al. 2018). Alluvial sediments, including gravel, clays, and limestone matrix, are mapped along the Andagua River, its tributaries, and the floor of river valleys lining Andagua Valley's sides such as in Tauca and Soporo (Gałaś 2011; figures 1.8 and 1.9). These are exposed at the surface or underlie terraces and fields in incised drainages through the valley and on valley floors in Soporo and Tauca. Glacial moraines, composed of mostly volcanic fragments in a matrix of clayey silt, are present above 4000 meters in the direction of Coropuna Volcano and associated glaciers (INGEMMET 2001, 2002). The region is susceptible to mass wasting including a recently documented landslide that covered over 500 meters of roadway from Orcopampa to Andagua that obstructed the Andagua irrigation canal source at the river (INGEMMET 2020).

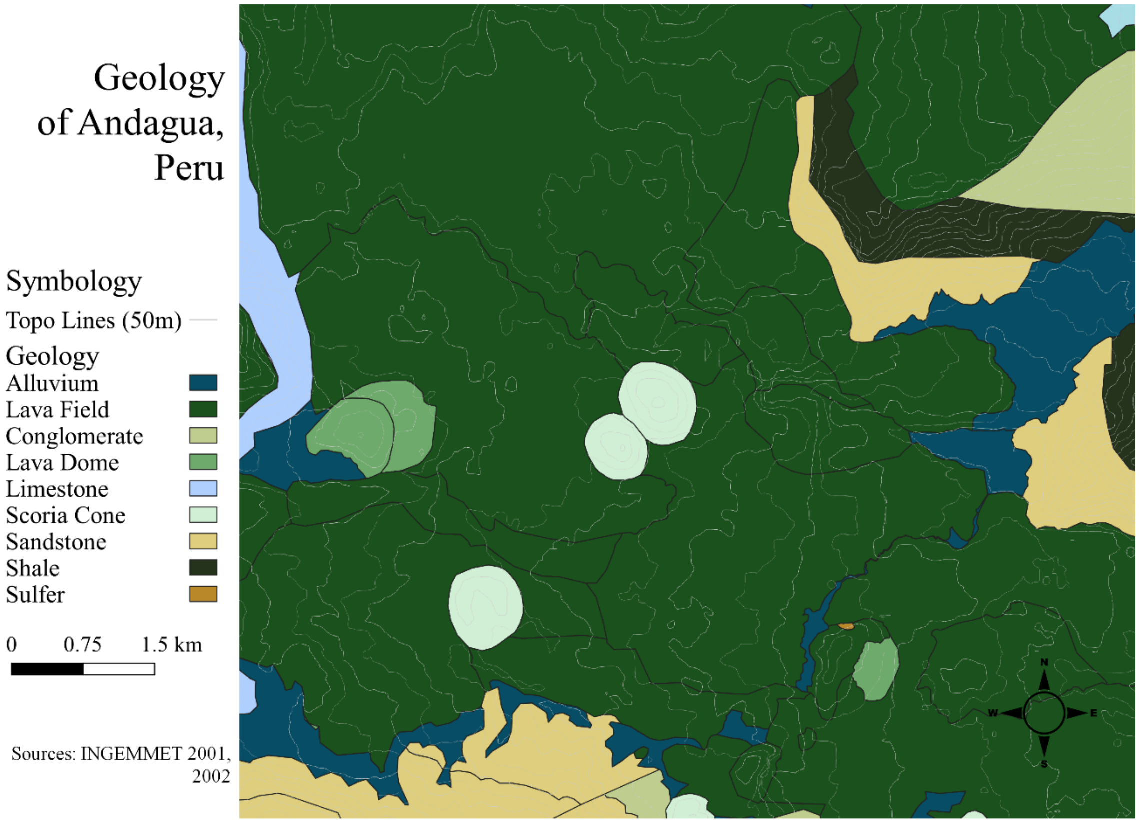


Figure 1.7 Geology of the valley around Andagua (INGEMMET 2001, 2002; Gałaś and Paulo 2005; Gałaś 2009; Gałaś 2014; Gałaś and Paulo 2005; Gałaś et al. 2018).

The Andagua River bisects the valley floor, descending into a canyon several kilometers before reaching the town of Andagua.[8] This river is in the Camaná-Majes watershed and drains a catchment area of 2716 square kilometers into the Colca River (ANA 2015f). Areas that capture (and seasonally contribute) water to the catchment include highland lakes, *bofedales* (wetlands), and the Coropuna and Ancojahua glaciers (ANA 2015f).[9] Coropuna is an important *apu* (local landscape deity) for many communities in the area and is one of the highest volcanos in the world at 6377 masl (Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña [INAIGEM] 2018). The areas underlying the Pleistocene- and Holocene-aged lava flows of the main valley and Paccareta are mapped as porous detrital aquifers while the areas underlying the sedimentary rocks are mapped as Fissured Sedimentary Aquifers and Sedimentary Aquicludes, providing variable sources of spring water (ANA 2015g).

Irrigation

Irrigation canals for many of the terraces in the main valley, Paccareta and Tauca funnel water from the Andagua River before it incises into a deep ravine. The canal offtake for the main valley from the Rio Andagua is labeled by the ANA as rustic and as having a capacity of 0.7 cubic meters per second (ANA 2015, 65). The Paccareta canal intake at the Andagua River is labeled as rustic and has a capacity of 0.105 cubic meters per second (ANA 2015, 67). The subgroup in Andagua irrigates a reported 1,006.860 hectares (ANA 2015), organized by an Irrigation Commission of 326 heads of household in the main Valley (Instituto Nacional de Estadística e Informática de Perú [INEI] 2012).[10] A subsection of 38.45 hectares is organized by the Irrigation Committee of 13 producers in Paccareta (INEI 2012). River contaminant sources mapped by the ANA include thermal, industrial, and mining sources around Orcopampa, a larger town up valley primarily dedicated to mining and support services (ANA 2015e). The mapped springs in the main valley are labeled “Andagua” and “Malata” with Andagua labeled as an “unknown” spring type while the Malata spring is labeled as “for human use” (ANA 2015d). While the water from the Canal Madre (Mother Canal or main canal) powers a micro-hydroelectric plant for town, it is not mapped in the inventories of damns and hydroelectric plants by the national water authority of Peru (ANA 2015b). The cementation of the Canal Madre began in 2016 and lasted through the winter months. The cementation required that water be held from running through the canal, temporarily halting energy production in the hydroelectric plant. With little means of storing energy, there was intermittent electricity for much of

June, July, and August. Although there are powerlines traversing the valley, supposedly constructed by former President Alberto Fujimori in the 1990s, it is not connected to the Andagua power grid. Political and economic policies and processes in twentieth century Peru, such as the unofficial *gamonal* system, the agrarian reform and Fujimori's neoliberalism, unevenly impacted the Andes and are important to briefly address here in addition to contextualizing these within the empires and non-state groups that preceded them.

Figure 1.8 Valley of the Volcanos in 1930 depicting the town of Andagua in the foreground surrounding the light-colored square, the twin volcanoes in the middle ground and Paccareta and Puca Mauras volcano and lava fields in the background, facing northwest (American Museum of Natural History, Shippee-Johnson Collection, Image ppcs551_l10).

Social History

Humans in the Andagua Valley have actively altered the landscape through the construction and use of terraces, roads, canals, sacred spaces, and other structures as early as the Formative Period or as far back as 1500 BCE (Menaker 2019a; figure 1.8). Around 1500 BCE to 1532 CE, people lived in decentralized settlements many of which are mapped across prominent topographic positions in the center of the valley in addition to the terraced canyon sides (Menaker 2019b, chaps. 3 and 4). Several of these sites date to 1500 BCE to 1400 CE and are pre-Inca and non-Inca settlements, referred to by Menaker (2019a) as *llactas*. These include no evidence of the Huari or Tiwanaku states, unlike neighboring valleys in the same period (Menaker 2019a). The *llactas* are surrounded by agricultural terraces and have access to water through intermittent and perennial streams, runoff, and canals.

The Inca arrival in the valley, sometime between 1400 and 1532 CE, altered the human-environment relationships through the reorientation of local people towards landscape deities, such as outcrops and mountains, under Inca authority and away from local deities (Menaker 2019a). The Spanish similarly altered settlement patterns and locations of authority through the creation of the *reducción* (Spanish-colonial planned settlement) through the forced resettlement of people into a gridded town centered around civic life (Menaker 2019b, 32). The location of the *reducción* correlates with architectural and artifactual assemblages dating to the Inca, non-Inca, and pre-Inca practices (Menaker 2019b, 33). As Menaker (2019b, 33) explains, the Inca and the Spanish constructed spaces that altered movement through perceptions of and ritual activity within the valley. For example, the contemporary chapel of the *Virgen de Asunción*, located near the contemporary bull ring, was constructed on top of an *ushnu* (Inca ceremonial platform). The Inca constructed this platform to shift ritual focus away from regional and local sacred landscape features and towards the volcanic lava of *Ninamama* (Fire Mother in Quechua), which is in the center of the valley (figure 1.9).[11] Colonial authorities similarly used this topographic position to reorient people away from the valley and its sacred spaces, and towards Christianity and the Spanish project. This is exemplified by the chapel's entrance facing towards the town square rather than the agricultural fields and sacred spaces across the valley important to Inca and pre-Inca political authorities. The Spanish colonial period additionally included a system of coerced labor and tribute of Indigenous people, referred to as an *encomienda*, that functioned through the cooptation of the hierarchical system that had *curacas* (local lords) continue to hold authority and enforce these practices that began under the Inca (Mumford 2012, 28). It is unclear what the impact of the early Spanish *encomienda* system was in Andagua, as there has been limited archaeological or historic evidence of this practice yet uncovered (Menaker 2019b, 241). Over time, the *encomienda* system transformed into the *hacienda* system, which consisted of large portions of land acquired, usually through coercive and violent measures, by *encomenderos* (Klarén 2000, 46). Race and gender were tied with class, and divisions among Indigenous, *mestizo* (people of mixed heritage), and Hispanic individuals were codified in law, generationally inherited, and practiced in everyday life through to Peruvian independence (Klarén 2000, 93, 134).

While the Spanish and Inca states physically moved people and worked to alter the way they think about the landscape through religion and labor, Peru as an independent Republic was plagued by political instability and focused more on its external relations. As the state was focused on external markets, international disputes, and Lima politics, rural property disputes were neglected, allowing other systems of authority to dominate the highlands (Thurner 1997, 45-48). As summarized by Klarén (2000, 136), *gamonal* (landowning elite) held political control in the highlands, owned large portions of land, and coerced local Indigenous people into laboring for them. Unlike the *encomienda* system, the *gamonal* was an active presence, asserting authority indirectly through performances of class and both non-indigeneity and indigeneity, and directly through acts of violence (Menaker 2019b, 281). In Andagua, there were multiple generations from one apparent lineage that took advantage of this power vacuum and seized local power and land (Menaker 2019b, 271). Farmers recall violence from the *gamonal*, who was *creole/mestizo* (*misti* in Quechua; for history of these terms, see Gose 1994, 21-22) exerting power in Andagua by controlling regional commerce and engaging in commodity transportation (Menaker 2019b, 281). The *gamonal* system in Andagua was not disbanded until the Peruvian agrarian reforms when much of their land was redistributed to the community (Menaker 2019b, 271). In 1968, the military government led by General Juan Velasco Alvarado implemented the agrarian reforms, shifting property ownership and redistributing land from the rural oligarchy, including *hacenderos* and *gamonal*, to local farmers and ranchers (Menaker 2019b, 189). A farmer interviewed by Menaker (2019b, 271, 274) recounted that his family recovered land during the agrarian reforms and through litigation at the regional seats of power. This required a three-day hike on a cattle trail over the mountains, as the road had not yet been built. Through the 1950s and 60s, increasing focus on foreign investments and the growing urban population at the federal level shifted the main source of foreign exchange from agriculture to extractive minerals and simultaneously increased the income inequality throughout Peru (Gonzales de Olarte 1997, 188). The reforms decreased land-ownership inequality; however, the federal government continued to focus on the coast at the expense of the highlands.

Narratives about Place: Construction and Rehabilitation

At a local level in Andagua, farmers asserted their control over the landscape, extending the arable land and increasing their connectivity to neighboring valleys and the coast. In the mid-1960s, 13 *socios* (founders), including one woman, put the area called Paccareta into reuse through rehabilitating the soil, canals, and terraces, increasing the extent of farmed land in the valley (Menaker 2019b, 290-291; figure 1.9). This was not a cooperative implemented through the agrarian reform, but a bottom-up project conducted by local farmers.[12] Additionally, a regional road was constructed in part by locals in Andagua connecting the town with its neighboring valleys. By the 1980s, a businessperson and engineer had rehabilitated the canal in an area called Tauca, the farmland of which is located on alluvial material in a side valley (Menaker 2019b, 275). This land then was sold to and rehabilitated by farmers from Moquegua whose ancestral land no longer had access to water (Menaker 2019b, 275-276). These valleys in Andagua, largely in disuse since Spanish reorientation towards the *reducción*, were put back into reuse during this period, expanding the areas under cultivation. This bottom-up reclamation increased regional connectivity and extent of farmed area, refining our understanding of what is occurring on a local level in the mountains during this period of rapid change. Farmers in Andagua worked within and beyond the state to cultivate the land, creating a livelihood for themselves and future generations. These social and physical infrastructural changes had significant impacts on everyday life and ways of thinking about the world.

The population of Andagua appears to increase from the early 1930s to the 1960s, but then fluctuates in the following decades, correlating with the construction of roads and the resulting access to the coast and to regional cities. Shippee (1932) reports an estimated population of about 1200 people in the 1930s, which increases to a documented 2,054 people by 1961 (ONERN 1973, 14).[13] Over only 10 years, the population decreased by about 32% by 1972, the period during which the regional road was constructed (ONERN 1973, 14).[14] Increasing to 1578 people by 2000, the population in Andagua again decreased to 1177 people in 2015 (INEI 2012). Of those remaining in town by 2012, 330 (194 men and 136 women) were reported to be heads of household with land and 34 (26 men and 8 women) were landless heads of household with livestock (INEI 2012).

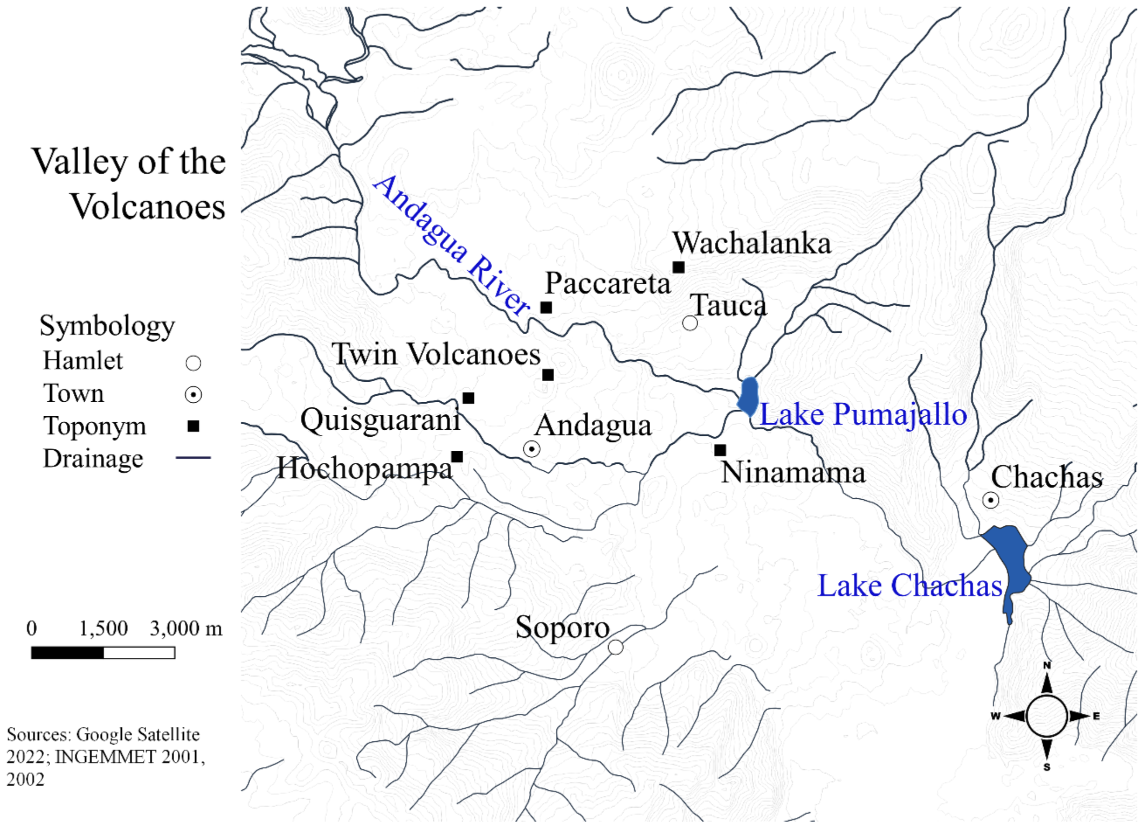


Figure 1.9 Hamlets and placenames mentioned in the text near Andagua.

THIS DISSERTATION: CHAPTER SUMMARIES

This dissertation focuses on the human-environment relationship between people in Andagua and the terraced landscape. First, chapter two explores the theoretical lens guiding the approach to the dissertation research design, practice, and analysis. It emphasizes the importance of drawing from local knowledge as a dynamic practice that is created through the long durée of generational experience and experimentation and supported through social relations and local ways of understanding the world (WinklerPrins and Barrera-Bassols 2004). Local knowledge can contain information on the composition, morphology, and typology of environmental and social data at different temporal and spatial scales, making it an important source when creating landform classification schemes and analyzing the resulting patterns on the landscape. This chapter details several influences for this approach including the relational landscape lens (Smith 2003; De La Cadena 2015) and Critical Physical Geography (CPG; Lave et al. 2018), both of which are put in conversation with a socio-geomorphic approach (Ashmore 2015) towards the study of terraced landscapes.

Chapter three recounts results from farmer interviews covering human-environment relationships in the context of social and climate change. It reveals local landscape analytics measuring climate, land tenure, and area, among others, that are imbricated in environmental and social histories and power. Practices and perceptions of change and continuity are different across gender, class, and generations. Information gleaned from this chapter guides the approaches, land classification schemes, and analyses in the following chapters.

Chapter four explores the manifestation of the terrace in Andagua, juxtaposing the condition and patterning of terrace types and retaining walls across different places and testing if top-down and bottom-up infrastructural changes to the landscape impacts terrace use through time. It uses object-oriented analysis of satellite and aerial imagery, implementing the mapping of terrace retaining walls, roads, and paths through the valley, focusing on the main valley near the town of Andagua and the rehabilitated terraces in Paccareta.

Chapter five investigates land tenure and the physical manifestations of this human-environment relationship to the landscape through the concept of the *tupu*, a unit used by local farmers to describe both land tenure and a measure of area. It first contextualizes the *tupu* with its shifting and enduring historical usages, then attempts to find it in Andagua by mapping, measuring, and analyzing land tenure boundaries. This inquiry explored both the tangible and figurative meaning of the *tupu*, considering it through bottom-up environmental knowledge and social relations and the top-down authority to bound physical space.

Each of these chapters draws from knowledge gained through attention to local perceptions, practices, and ways of thinking about the world, applying this information as context towards measuring and analyzing the landscape. This approach animates the landscape and its anthropogenic landforms, investigating their formation through the combined bottom-up and top-down social influences and the impacts of environmental forces through remotely sensed imagery.

Chapter Two: Terraces as Socio-Geomorphic Landscapes

INTRODUCTION

This chapter engages with the question: if humans are now considered globally impactful geomorphic agents, then how do we engage in research that is both anthropogenically and geomorphologically meaningful? The problem of integrating social and physical geographic research is a cyclical topic of study in the discipline of geography (Church 2010); however, this discussion is increasingly relevant due to the acknowledgement that humans have irrevocably altered environmental systems (Crutzen 2002). This is coupled with increasing technological efficiency and the need for historical contextualization and the incorporation of social theory to interpret the quantitative results (Braun 2021; Tarolli et al. 2019). Enduring tensions in physical and human geography, outlined below, simultaneously complicate this need for their entanglement but also offer locations of connections among these two sub-disciplines. To conduct an integrated physical and human geographic project on a terraced landscape, this chapter argues for a socio-geomorphic approach that draws from a nested framework within the emerging research perspective of Critical Physical Geography (CPG), a relational landscape organizing lens and a situated perspective, all animated by the social (Smith 2003; Ashmore 2015; De La Cadena 2015; Elmhirst 2020; Ulloa 2020b). The goal of this chapter is to outline the base of and need for a socio-geomorphic approach to the remote sensing of geomorphology on a terraced landscape in the Anthropocene using multiple approaches and methodologies that are both geomorphic and anthropogenic in significance and meaning.

To do so, it addresses enduring tensions in the discipline including the conflict between the particular and the universal, reflecting on the history of knowledge production and theorizing about human-environment relations (Cresswell 2013, 32-33). These tensions are overlapping and fuzzy, recurring over time and across sub-disciplines. This paper first outlines some of these tensions and then addresses the urgency that the Anthropocene places on solving them. It then presents a CPG framework as a means through which researchers reflect on the impact of power structures both on the landscape and within the research process and integrate both physical and social datasets by first asking integrated questions (Lave et al. 2018). Drawing from a feminist lens further teases apart the power of knowledge production at multiple scales and presences the situated perspective that allows for multiple ways of thinking about and acting in the world (Haraway 1988; De La Cadena 2015, 4; Elmhirst 2020, 532). Finally, I present a relational ontology as the means through which we can move between environmental systems and social relations (De La Cadena 2015; e.g., Ulloa 2020b); it is a framework for enabling datasets on a terraced landscape to inform one another to create a holistic and meaningful understanding of the landscape by iteratively integrating both social and physical geographic methods and processes in a socio-(hydro)geomorphology of the landscape (Ashmore 2015).

INCORPORATING THE SOCIAL INTO THE PHYSICAL AND THE PHYSICAL INTO THE SOCIAL

In *Geographic Thought: A Critical Introduction* Tim Cresswell (2013, chap. 2) argues that several enduring tensions in contemporary geography stem from its birth and development going back to the tenth century. Cresswell (2013, 32-33) describes these as the friction between the particular and the universal, the importance of reflecting on the history of knowledge production and theorizing on human-environment relations. Both physical and human geography have separately addressed these interconnected ideas over time, periodically calling for increased integration as a means of addressing one or more of these tensions (see Harrison et al. 2004; Church 2010). This first section will outline an abbreviated and recent history of discourse around integrating human and physical geography to contextualize the current turn towards a critical physical geography.

Technological innovation was one of the driving forces behind the changes in geomorphology in the late twentieth and twenty-first centuries, shifting focus towards systems theories, landscape history and human impact on the landscape (Church 2010). Leading up to the twenty-first century, as summarized in detail by Church (2010), geomorphology was increasingly applied through statistical analysis, quantification, and engineering. Technology, such as remote sensing, enabled a continuation of this quantification at fine and broad scales, including mechanistic explanations of landform change and human-induced change. It offered the opportunity for more impactful connections across spatial scales and the ability to combine multiple technologies, applications, or datasets for a more holistic perspective (Viles 2016). Additionally, systems science and modeling connected and analyzed features and processes over time through an historical context to uncover the particular or to understand general landform process (Church 2010). These systems store and exchange mass and energy and can take under consideration both internal and external thresholds in real or conceptual scenarios (Goudie et al. 1994, 490; Church 2010). In applied scenarios, the environmental layers, and forces such as slope, climate, and soil interact and change over time in complex ways (Phillips 1999). A threshold, in geomorphology, refers to a change caused by an intrinsic or extrinsic force or variable change that causes an imbalance between morphology and process (Goudie et al. 1994, 505-6). Ideas of thresholds are intertwined with systems, in that a threshold exists in a system at a particular scale, like a hillslope, and the study of thresholds can help predict or model hillslope stability over time. This multiplicity has implications for geomorphologists and their study of landforms, or natural features on the surface of the earth, and the processes that form them (Huggett 2017, 3). These relationships extend to different scales, depending upon the system under study. Goudie and colleagues (1994, 491) use drainage systems as an example of different scales from the first-order stream channel to the larger basin network. Each is connected to the other through processes; however, relationships may change. One of the difficulties lies in how to incorporate the human into these systems at different scales without resorting to representing humans as a simple change in force or energy.

Incorporating the environment into social theory has similarly changed through time. Through much of the twentieth century, various versions of environmentally determinist social theories presented as positivist explanations of human actions (Peet 1985). The names of theories have changed, but justifications for imperialism and expansionism are enduring through time (Lewthwaite 1966). Marxist critiques of environmental determinist theories emphasized their disregard for the roles of society, class struggle and the means of production in mediating human-environment interactions (Peet 1985). There was also a surge of integrated social and physical science research from a critical lens that is considered early political ecology, such as works by Piers Blaikie, Harold Brookfield, Susanna Hecht, Darrell Posey, and William Denevan, among many others (see Blaikie 1985; Blaikie and Brookfield 1987; Hecht and Posey 1989; Denevan 1992). They combined environmental datasets with reflections on historical processes to demonstrate that the perception of marginalized, often Indigenous groups, and the landscapes on which they lived were a product of complex, power relations. It is a continuation of past research on the environment and inequality but removes itself from historically essentializing narratives that would blame poverty on the poor and explain it as a natural, social process (Robbins 2004, 3). For example, attention to local knowledge grew out of researchers' challenges to reigning presumptions that local, usually Indigenous, practices degraded the environment (Blaikie and Brookfield 1987).[1] The enduring legacies of colonial narratives diminished the perceived role of Indigenous populations on the pre-colonial landscape, a view which supported the continued exploitation of the Global South and enabled Western, scientific technologies to proliferate. Blaikie and Brookfield's (1987) reevaluation of land degradation issues stimulated environmental research focusing on the people who possess long-term relationships with places.

Similarly, Hecht and Posey (1989) disputed the idea that Indigenous agricultural systems diminish the quality of the soil. The prevailing theory at the time was that Indigenous cultures did not contain complex understandings of the environment and did not actively interact with their surroundings to improve properties like soil fertility. As outlined by Hecht and Posey (1989), the patches of organic matter-rich soils in the Amazon were previously explained as natural processes. However, the authors' found that contemporary, Indigenous soil management activities, such as adding ash and mulch to the soil, improves the fertility over time. Instead of prescribing to the Pristine Myth theory (Denevan 1992), the authors suggested the theory of swidden agriculture, a soil-crop management technique practiced by Indigenous populations in the Amazon that controls the fertility of the soil. Hecht and Posey (1989) suggested further study of Indigenous soil knowledge in the Amazon, and elsewhere, to improve the quality of tropical soil especially after deforestation caused by contemporary colonists. These early examples outlined broad topics of study for political ecology including environmental perceptions, uneven impacts and resource access, local knowledge, and social-environmental issues at different spatial, social, and temporal levels.

Further diverse, but critical, political ecological approaches include ecological knowledge, hazards, development studies, activism, adaptive capacity (and socioecological resilience), feminist perspective, and others (see reviews by Harden 2012 and Zimmerer 2020 and edited volume Perreault et al. 2020). While political ecology has not necessarily continuously included physical geographic methodologies (McCarthy et al. 2020, 623), the variance and openness of political ecological approaches suggests that there is room for conversation across geographic subdisciplines including physical geography. However, its critical position as contra to, supposedly, apolitical sciences require an ethical and experimental reconceptualization in order to address issues related to the Anthropocene (Wilcock et al. 2013; Braun 2020, 102-3; Sharp et al. 2022). This next section will consider some of these challenges presented by the Anthropocene and how they complicate the tensions presented above. It briefly discusses the Anthropocene as a concept, and the issues it creates concerning knowledge production and practices that are meaningful to both geomorphic and social approaches.

The Anthropocene

Paul Crutzen (2002) outlined the increasing rate and intensity of human alterations of the environment as a call for scientists to focus on environmental sustainability through coordinated human cooperation at varying scales. The Anthropocene generally refers to a global human-induced environmental change or the appearance of behavior that drove that change (Smith and Zeder 2013; Ruddiman et al. 2016; Ellis 2018). Scientists have used different biophysical and chemical proxies to debate its boundaries in time and those conversations are well summarized by Smith and Zeder (2013), who determined that the Anthropocene is most useful as a framework questioning humans' impact on the Earth. Brown and colleagues (2017) identify the ability to distinguish between human and natural forces and the intensity of human forcing as an important part of formally identifying the Anthropocene. However, the Anthropocene is complicated by the uneven impacts of these environmental changes in addition to the uneven distribution of the sources of human-induced environmental forcing (Smith and Zeder 2013). Additionally, the forces behind the process impacting and creating landforms on and below the surface of the Earth include human practice encompassed within varied historical processes and contexts, a complicating factor that cannot be easily explained through existing geomorphological methodologies and approaches (Biermann et al. 2021). This section outlines some of these issues and opportunities facing the holistic and iterative integration of human and physical geographic methods and datasets in the Anthropocene.

The deeply human and historically situated environmental processes composing the Anthropocene, such as sea level rise, glacial retreat or shifting ecological zones, are a product of carbon-intensive, globalizing activities related to capitalism (Whyte 2017). The Anthropocene, like capitalism, is a universalizing discourse that blames humans for global climate change. However, those most vulnerable to the material impacts of these changes are often historically marginalized, elation ss groups (Whyte 2017). These groups, then, are enduring a continuation of colonialism, forced to alter practices and their settlement locations (Whyte 2017). While it is important to continue to study the global biogeochemical processes related to the Anthropocene, it is also an opportunity to attend to the plurality and relational ways of understanding the world (Escobar 2011; Wilcock et al. 2013). To do so, it is important to conceptualize the Anthropocene not simply as a human-induced environmental change, but in relationship to these broader socio-historical and environmental processes manifesting in place. As Haraway (2015) says, we can never go back. Focusing on local difference can help us to tease out the uneven drivers of the Anthropocene and how and who they impact in order to contribute to the possibilities of a socially and environmentally sustainable future. These tensions between universalizing laws and models and local processes and forms are similarly reflected in geomorphology in the Anthropocene.

Epistemological perspectives in science have impacted how physical scientists have or have not incorporated humans over time. According to Karl Butzer (1976, 430) in *Geomorphology from the Earth*, scientists' perceptions and representations of the Earth are mitigated through their cultural understandings of the world. Physical landscapes "are real in terms of material, but their perception, articulation and analysis are products of the mind" (Butzer 1974, 430). To acknowledge the Anthropocene as a defining characteristic of any geographic study is to center the human within the environmental system. Mass transport laws, in isolation, cannot explain the heterogeneity of sediment distribution across a humanized landscape. Conceptualizing the physical world within the lens of the Anthropocene and acknowledging humans' dramatic impact on geomorphic process and form complicates the tension in physical geography between the generalizable and local difference (Knitter et al. 2019). The intensity and rate of the direct modification or creation of landforms by humans has increased dramatically in the mid- to late-twentieth centuries as technologies enabled the massive movement and redistribution of earth surface materials (Steffen et al. 2015). Thus, geomorphologists must decenter the "natural" and consider the local impacts of global human-induced change.

One goal of science is to solve problems, and the methods of solving these problems are iteratively connected to scientific ontology and epistemology (Richards 2009, 25). Following this logic, understanding the environment and environmental processes as deeply intertwined with Anthropogenic processes and forms must alter how we approach thinking about knowledge production, and the actual means through which we produce geomorphic knowledge. Physical geographers that engage reciprocal relations between anthropogenic impacts and the bio-geophysical system are uniquely positioned to refine the understandings of the human world through cross-disciplinary engagement with social theory (Ellis 2017). This next section summarizes discourse across geomorphological studies of terracing and its consideration of humans both conceptually and empirically in the research process. It also touches on the role of remotely sensed imagery in the study of landforms and the landscape, and how this impacted the study of terraced landscapes.

Science in the Anthropocene

The presence of human-induced, global environmental change alters how geomorphologists approach forms and processes. In physical geography, humans are relegated to second-order processes–those processes that are subject to laws of physics (Church 2010). In these systems, humans are now inseparable; however, there still is uncertainty in how to incorporate the sociality of humans into geomorphic study (Brown et al. 2017). Other issues include how to determine and measure the intensity and role of direct and indirect human influence on earth surface processes (Goudie 2010; Brown et al. 2017). Brown and colleagues (2017) consider the main issue the quantification of anthropogenic forces in a system and their spatial and temporal extent. In addressing these issues there have been several proposed subdisciplines and frameworks including anthropogenic geomorphology (Jialin et al. 2017; Szabó et al. 2010; Dunning et al. 2019; Tarolli et al. 2019), anthropogeomorphology (e.g., Goudie and Viles 2010, 70; Aguilar et al. 2020), ethnogeomorphology (Wilcock 2013), geomorphology of the Anthropocene (Brown et al. 2017), among others. This section will problematize geomorphology in the Anthropocene often focusing on agricultural terraces, to emphasize the importance of engaging with social datasets to contextualize and influence approaches to humanized surface forms and process.[2]

Brown and colleagues (2017) and Tarolli and colleagues (2019) are examples of geomorphologists working to reconcile how to study geomorphic process and landforms using remotely sensed imagery, among other tactile fieldwork, when many environmental forces are intertwined with human practices and their impacts. Brown and colleagues (2017) consider the characterization and identification of human landforms and forcing as the key to effectively incorporate the human into the physical mass and energy balances in a system. Tarolli and colleagues (2019) are similarly interested in identification and classification, but at a broader extent using remotely sensed imagery. For example, terraces can be identified using remotely sensed imagery through a topographic analysis called Slope Local Length of Autocorrelation (SLLAC) created by Sofia and colleagues (2014) that uses local difference in slope on Light Detection and Ranging (LiDAR) imagery to detect human terrace modifications. Relatedly, Cucchiaro and colleagues (2020) used aerial and terrestrial structure from motion (SfM), terrestrial laser scanning (TLS), ground control points (GCP), and unmanned aerial vehicles (UAVs) to create and test the accuracy of a high-resolution digital terrain model (DTM) of agricultural terraces with complex topography to develop management practices for monitoring degradation and other processes that may damage the stability of the landscape. Steadily increasing technology enables the monitoring, mapping, and modelling of human engineered landscapes for land management (see reviews in Tarolli 2014; Tarolli et al. 2019). Considering that these increasing automated data results are often used to make management recommendations, it is especially important that local social relations are integrated into these research projects.

Studying geomorphology within the context of the Anthropocene has also prompted discussion on how to identify and classify human forms and human-altered processes on the landscape (Tarolli et al. 2019). To address this issue, Tarolli and colleagues (2019, 98) offer an ontology for classifying individual forms through their function and morphology and a broader framework through which the assemblage of forms in use by a group of people in a particular place and time becomes a "sociocultural fingerprint." They are drawing from archaeological approaches that understand societies' material culture and practice as leaving distinct geomorphic patterns on the landscape that have the potential to be identified (they cite Karl Butzer's 1982 book *Archaeology as Human Ecology: Method and Theory for a Contextual Approach*). Tarolli and colleagues (2019) use niche theory, which understands that humans work within their cultural and environmental contexts at a particular place and time to modify the environment in a way that suits them (Smith and Zeder 2013). According to Tarolli and colleagues (2019, 98), the complexity of these forms, including the morphology and chemical features, increases over time. They refer to the well-used term "palimpsest" to define the layering of these patterned forms, or sociocultural fingerprints, that make up the contemporary landscape (96-7). Palimpsest has been used by those studying distribution of forms on a landscape, including by archaeologists and geomorphologists (e.g., Goudie and Viles 2010, 2). The key is that, unlike its original use to describe writing are rewriting on a parchment, its use in geomorphology implies a relationship among the multiple sedimentary, geological, biological, anthropogenic, and other features (Goudie and Viles 2010, 2).

Tarolli and colleague's (2019, 102-106) working framework for classifying human features is based on the societal functions and include symbolic, habitation, transport, exchange, subsistence, mining, water infrastructure, waste disposal and warfare features. This well-considered framework is applicable across places and time and can be adjusted for temporal and spatial scales appropriate to the group under study. However, the archaeological theory from which they are drawing often focuses on function of landforms rather than considering any further social processes, including that of power (Tarolli et al.

2019). In the previous example, Tarolli and colleagues (2019) assert that the integration of technologies offers a synoptic view; the benefit of increasing technology is the ability to efficiently map, quantify and compare forms and processes across broad areas and times. They focus heavily on function and form (for example, a contemporary road's function is to transport materials and people, and it can be identified through its linear, often leveled form) over time and space. This morphologic and practice-oriented classification system is effective and useful for its clarity. However, one of the issues the researchers identify is how to better understand the features being mapped over space and across time and how to capture older features altered by burial under more contemporary features or environmental processes (Tarolli and colleagues 2019, 110). The latter issue is one of technology while the former requires reorientation on local difference and meaning.

Anthropogenic geomorphology is defined as the study of human landforms and their influence on the environment through human modification of natural processes (Szabó 2010, 4). Szabó (2010, 6) divides activities into direct and indirect anthropogenic processes. Direct processes include construction, excavation and water management and indirect processes include sedimentation and erosion acceleration, subsistence, slope failure and earthquake triggering. Szabó (2010, 8-9) offers further divisions and classifications of these features in ways that are geomorphologically meaningful as well as meaningful to the original human function or "social activity." In this example, the author classifies a terrace as a primary landform because the planting surface was the intended function (Szabó 2010, 8). While continued focus on quantification and synthesis of broad technologies is beneficial to understanding implications of human-induced landform change, the focus is again on function without social contextualization beyond considering the broader capitalist considerations. A more detailed consideration of meaning and heterogeneity, rather than broad classification schemes, would more impactfully contextualize the Anthropocene.

To contextualize terraces in the Anthropocene, it is useful to consider their implementation across the globe over time, but also their integrated social-environment processes at the local level. Generally, agricultural terraces are slope modifications employed by humans for thousands of years to support the growth of agricultural activities on steep slopes (Brown et al. 2021). Terraces increase water infiltration, alter the velocity and volume of overland flow, facilitate soil production and manure retention, among other benefits (Sandor and Homberg 2017; Brown et al. 2021). However, terrace maintenance and use are intertwined with social organizations and everyday practices (Guillet 1987; LaFevor 2014). The positive environmental impacts of terraces rely on the physical maintenance and social practices that support them (Guillet 1987; LaFevor 2014). Additionally, social relationships in the Andes, such as kinship, extend not only to living and dead human relations but also to mountains and stones (Dean 2010, 2; de la Cadena 2015, 206; Gose 2018, 488). Everyday practices that result in forces or stresses in the terrace system may relate more to social relations than to what may be perceived as functional activities. Daily practices of maintaining terrace walls and turning fields are accompanied by nurturing relationships with Pachamama (Earth Mother), mountains and other important physical features on the landscape (Gose 2018). Additionally, what geomorphologists would consider as "natural" process may not be interpreted as so and actions related to this process, such as landslides, draw from local knowledge and existing relationships to these mountains (Gose 2018). Therefore, to fully understand the physical impacts of humans on terraced or other human landscapes, scientists must consider everyday practices, social relations, and ways of thinking about the world as important contextual knowledge.

The goal of an anthropocentric geomorphology should not simply quantify humans' impact on the Earth within a given society, but to couple the relational impact of social ontologies with those practices that alter geomorphic form and process. The tensions expressed by physical geographers lies in how to identify, classify, and find meaning in the social forms and processes on the physical landscape (Brown et al. 2017; Tarolli et al. 2019). Technology is typically the route to addressing these issues, offering a way to quickly and impactfully detect patterns and classify forms (e.g., Tarolli et al. 2019, 110-1). To further contribute to this research topic, there is a call for the theorization on the relationship between societies and forms at different scales and, while these typically focus on their function as the method to understanding (Brown et al. 2017; Tarolli et al. 2019), there is an opportunity to find more complex meaning by approaching these questions through a critical lens (Knitter et al. 2019; Braun 2021). Agricultural terraced landscapes are especially relevant topic of study due to the increasing awareness of their environmental services such as soil production, sediment capture and carbon storage as well as their role in local social relationships (LaFevor 2014; Brown et al. 2021). The next section will argue that the new turn towards CPG offers a framework for geomorphologists to explore the integration of a complex social component into research, generally, and terrace research, more specifically.

CRITICAL PHYSICAL GEOGRAPHY

Regardless of the Anthropocene establishing global human impact, humans have been altering the surface of the earth for thousands of years. Previous scientists were working within a colonialist framework and viewed the Americas as "Pristine" wilderness dominated by natural process rather than impacted by any Indigenous, human practices (Denevan 1992). This realization came through physical science analysis as well as a reflection on the history of the landscape and the research processes, both of which were embedded in colonial discourse (Denevan 1992; Hecht and Posey 1989; Heckenberger et al. 2003). Self-reflection in the geomorphic research process will tease apart the role of power in the production of knowledge at different scales, providing more contextual information for the data and analysis (Lave et al. 2018; Biermann et al. 2021). Additionally, acknowledging broad human alteration of Earth surface processes in a place changes the understanding of what is natural and what is not and complicates how geomorphologists characterize natural or human landforms and processes. This section will outline the CPG framework, how it would benefit from a more explicit feminist lens and describe how these complicate boundaries and boundary-making on the landscape.

Critical Physical Geography

CPG is a turn towards more integrated social and physical science research conducted through a lens that reflects on power relations (Urban 2018, 61). It was an "intervention" penned by more than a dozen scholars led by Rebecca Lave in The Canadian Geographer in 2014 in direct opposition to an article that called for the divorce of the increasingly disparate physical and social geography. Lave and colleagues (2014, 3) argued that these two fields of geography should not move further apart; rather, they should work together to co-produce knowledge and reflect on its production. This most recent call for an integrated human-physical geography was further refined for the 2018 book the Palgrave Handbook of Critical Physical Geography, edited by Rebecca Lave, Christine Biermann, and Stuart N. Lane. The three main components of CPG research that they describe in the book include reflections on knowledge production, the political impacts of research and a focus on processes of power in the research process and of the place under study contextualized within their relations to their material landscapes, (Lave et al. 2018, 5). This section will outline these in more detail, contextualize CPG within the history of discipline of geography, and discuss their suggested framework including epistemology and methodology.

Lave and colleagues (2018, 4) situate this subfield as an answer to calls for more integration of human and physical geographies in the Anthropocene that moves beyond globalized systems. One goal, in the early piece (Lave et al. 2014, 5), is to move away from a human-nature dichotomy through, for example, reassessing boundaries and classification systems that have material impacts on people and the landscape through applications like policy changes. They argue that critical geography and certain fields of physical geography, including geomorphology, theoretically and conceptually align, making the integration of these fields relatively easy (Lave et al. 2014, 6). Examples they use that are relevant to this dissertation include the study of historical legacies, thresholds, and multi-scalar ideas in geomorphology. These, in addition to the concept of boundaries, can be approached from both physical and social perspectives.

Potential barriers to this kind of research include the physical separation of human and physical geography in some academic environments, the difficulty of funding interdisciplinary research, a lack of cross-training, disrespect across sub-disciplines and career risks of publishing integrated research (Lave et al. 2018, 7-8). The authors assert that the increasing relevance of this kind of research in the Anthropocene, and the success of CPG research, is increasingly overcoming these barriers. Lave (2014) uses their own research success in hydrological policy in the US to demonstrate the potential, broad impacts of reflexive, integrative research. Moving beyond the hurdles, CPG integrates theory and method in the research process in a way that emphasizes and reflects on other systemic issues.

Epistemologically and practically, CPG incorporates multiple ways of approaching and thinking about the socio-physical world through outlining the importance of creating a research question that requires multiple methodologies (Lave et al. 2018, 9). To iteratively engage with the methodologies and datasets that will accompany this interdisciplinary research, Lave and colleagues (2018, 11-12) refine the epistemological spectrum of CPG research that ranges from a critical realist position to the idea that knowledge is morally imbricated in social justice. It does not take a fully positivist view or a constructivist view; science is neither a full reflection of the environment nor is it entirely a product of social relations lacking materiality. This perspective understands that science is socially engrained in everyday lived experiences, broader processes of power and history. It enables social and physical geographers to conduct integrative and iterative research that reaches across multiple approaches to answer a question (Lave et al. 2018, 10). For example, Lane and colleagues (2011), with residents of an area in the United Kingdom, co-produced food risk knowledge through flood modelling that decentered the physical scientist and co-created management recommendations for local populations. While the incorporation of local people's perspectives is not new to geographic research, CPG gives room for local knowledge to hold equal importance as the researcher's knowledge in physical science research.

The many methodological possibilities in CPG research draw from varied subfields of geography over time. Lane and colleagues (2018, 13-14) identify the broad research lineages they consider important for the development of CPG, especially Political Ecology, Science and Technology Studies and Land Use Land Cover change studies, in addition to the longer history of geographic calls for integrated research. They argue that contemporary political ecology no longer focuses on physical geography as an object of study in the same way it was integrated in the past. Additionally, they argue that while CPG pulls from science and technology studies' investigation of the history of the production of scientific knowledge, science is not actually conducted in that discipline. Finally, they distinguish LULC change studies from CPG by the former's focus on the use of quantitative spatial analysis methodologies. CPG, they argue, is a framework through which the researcher or researchers pull from both social and physical discourses and methodologies, including each of these subdisciplines.

A critical physical geographer studies systems in which the human has altered the "natural" processes–a system in which a physical geographer may have previously considered unfit for study (Urban 2018; Lane 2019). In CPG, systems in the Anthropocene often are neither exclusively social nor natural, but an integration of both. In studying human-modified landscapes, CPG fully integrates the human component into the physical system beyond a simple variable (Lane et al. 2018, 28). Geomorphology considers the interaction of endogenic and exogenic processes, but now must consider humans as dynamic variables, impacting landforms and places on the landscape. To be a critical project, physical geographers need to move away from analyzing human's quantitative impact and descriptions of land use towards incorporating meaning, behavior, perception, policy, and other social contexts (Lane et al. 2018, 31; Urban 2018, 50). For example, geomorphologists studying landscapes should incorporate more than the human's physicality as a force or process in a system altering the sediment distribution but consider the historic and contemporary power relations contributing to these patterns.

A critique of iteratively incorporating the social into physical science is that it alters the scientific process. However, a critical physical geographer would argue that all science is altered by the social, from individual scientific choices to broader institutional and colonial processes (King and Tadaki 2018, 67-8). An alternative critique may be that the incorporation of physical science methods and theories into the social, or social into physical, will alter human complexities into simple functionality and a generalized process. This critique will be addressed in the following sections through incorporating a feminist epistemology and a nested relational landscape framework into a CPG research framework. While CPG is a strong theoretical and applied concept, there is an absence of feminist literature in discussions on critiques of science studies and situated perspectives. For a definition of a critical perspective in human geography, they point to the turn in the 1970s human geography but offer no further explanatory lineage (Lave et al. 2018, 6-7). To follow CPG's own core tenant, this chapter will further reflect on the process of knowledge production and the politics of citations by briefly outlining feminist discourse relating to an integrated social and physical geographic study of the landscape. I argue that feminist theory offers a depth of discourse on critical theory from which physical geographers can glean a more complex understanding of the connectivity between humans and the environment.

Incorporating Situated Perspectives in CPG Research

CPG provides a framework to investigate and self-reflect while co-producing knowledge about the landscape. One component of this type of research is the epistemological position that dismisses science as a perfect reflection of reality (Lave et al. 2018, 11-12). This dissertation specifically takes the position that there are multiple truths situated within historical contexts and processes of power. For example, Haraway (1988) outlines the embodiment of situated truths within and across systems of power. The individual's local, embodied lens–the situated perspective–is the producer of knowledge, rather than a disembodied universal, science (Haraway 1988). Employing a situated perspective is not a social constructionist perspective; it does not dismiss the material reality of the world and embrace a totalized social construction of the material. Rather, ascribing to the idea of situated knowledges negates the seemingly objective, disembodied white, male scientific perspective. The embodiment suggests that a person is acting in the material world but coming from their own history. Knowledge is produced locally and, as such, retains its complexity and contradictions (Haraway 1988, 589). One example of this type of research is the critical, decolonial participatory methodology of *cuerpo-territorio*, which grounds itself in the body and in the political landscape of territories (Zaragocin and Caretta 2021). Through projects such as these, a feminist physical geographer recognizes the heterogeneity of the human landscape relations, emphasizing the multiple knowledges and everyday practice that produce and reproduce those relations.

Additionally, these bodies' boundaries are a product of these systems, defined through scientific technologies, classifications, and historical power structures (Haraway 1988). She summarizes the scientific, feminist project and its goals as follows (Haraway 1988, 579):

> So, I think my problem, and "our" problem, is how to have simultaneously an account of radical historical contingency for all knowledge claims and knowing subjects, a critical practice for recognizing our own "semiotic technologies" for making meanings, and a no-nonsense commitment to faithful accounts of a "real" world, one that can be partially shared and that is friendly to earthwide projects of finite freedom, adequate material abundance, modest meaning in suffering, and limited happiness. Harding calls this necessary multiple desire a need for a successor science project and a postmodern insistence on irreducible difference and radical multiplicity of local knowledges.

So, while geomorphologists are calling for more technology and broader theories of the whole (social and environmental) in the Anthropocene; perhaps, the Anthropocene, a period in which everything is connected, should also be a time when everything is differentiated. Communication is key among these, according to Haraway (although she is not necessarily talking about the "Anthropocene" here, per say, she is talking about the globalization that preceded it and makes it what it is; 1988). Haraway (1988, 580) identifies the issue that when science can be the only bearer of Truth and universality–a "positivist arrogance"–then science is the only language that can be the "standard." According to Haraway (1088, 580), "Feminist critical empiricism" is the way forward (580).

Additionally, geographers are turning towards decolonizing practices to address universalizing claims made in geographic research projects, including those from a posthumanist perspective (see Sundberg 2014; Sharp et al. 2022). Sundberg (2014, 34 and note 5) defines posthumanism as a perspective that broadly rejects human-nature dualisms and gives agency to both humans and non-humans, although there are multiple ways in which people use this term. Sundberg draws from Shaw and colleagues (2006) and others to define decolonial practice, which is one that disentangles the "ontological violence authorized by Eurocentric epistemologies both in scholarship and everyday life" (Sundberg 2014, 34). Shaw and colleagues (2006) are particularly approaching decolonial practice through Indigenous geographies, which presumes that people have different ways of understanding the world and that geography must reflect on the politics of knowledge production. In *Earth-Beings* (2015), De La Cadena describes the constant process of translation between the author, an anthropologist from Lima, Peru, and members of the local community in Peru, native Quechua, and Spanish speakers. Complex meaning is not always achievable due to the different embodied experiences and relationships. Thus, feminist theory enables empirical, local difference while actively working towards dismantling universalizing claims.

One example of approaches that recognizes local ways of conceptualizing the landscape are local knowledge studies. Local knowledge is a dynamic practice that is generated through the long durée of generational experience and experimentation, supported by social relationships and local epistemologies (WinklerPrins and Barrera-Bassols 2004). Hecht and Posey (1989, 175) define local soil knowledge as the "science that forms the material base of these societies." The definition by Hecht and Posey (1989), and their use of the word "science," implies practice that is reinforced by theory and methodology. Agrawal (1995) similarly asserts that local knowledge is not diametrically opposed to Western, scientific knowledge, but is simply formed in a different historical context. The assumption that all people perceive the landscape in a similar, usually capitalist, way obfuscates the local relationships to the landscape (Ulloa 2020a). Local knowledge, then, is the result of long-term human-environment relationships that involves practice and reflection directly related to the local environment and society. I use the term, local knowledge, rather than the term Indigenous knowledge, because it is more inclusive to broader groups of people given historical processes that unevenly altered and valued Indigenous identity over time and space (WinklerPrins 1999). In practice, this perspective is methodologically applied in, for example, participatory studies (e.g., Zaragocin and Caretta 2021), local knowledge studies (e.g., Sandor and Furbee 1996; Agrawal 2009; Barrera-Bassols 2016), development studies (e.g., Ulloa 2020a; Escobar 1995), among others (e.g., Skarbø 2014).

The difficulty in applying multiple perspectives and approaches includes communication across people with different backgrounds and way of thinking about the world, including across disciplines, for iterative work. The next section will expand upon this to consider ways in which human and physical geographic work can communicate meaningful classification systems and boundaries. It will consider the layered systems relevant to people and the environment, the scales of process and form and the act of co-creating boundaries on a terraced landscape.

The Terraced Landscape: Creating Boundaries

To study the physical and social world of terraces requires defining temporal and spatial boundaries across different scales. These boundaries, although often depicted as clear divisions in boxes as part of systems or on maps, are dynamic and fuzzy. They must also be geomorphologically and socially meaningful at multiple spatial and temporal scales. This dissertation suggests starting the research process at the "landscape" and then moving to finer and broader spatial scales to refine both the context and the local processes and forms that constrain and enable it. New technologies, such as those described by Tarolli and colleagues (2019), enable the researcher to quantitatively focus on landform and landscape features in increasingly efficient ways. These technologies distance the researcher from the meaning behind the digitized forms and processes, a tension outlined in previous sections of this chapter. This section argues that defining boundaries is an act of making meaning, and the human landscape, and its accompanying landforms and places, possess boundaries with multiple meanings. This section will briefly engage with social and physical definitions of the landscape, outline the complicating factors of spatial and temporal scale, and recommend an integrative process that considers both local and geomorphic ways of categorizing the landscape.

The landscape system is composed of an aggregate of characteristics that are more like itself than to others (Goudie et al. 1994, 299).[3] It is the most complex and unpredictable scale; it has a specific lithology, aspect, vegetation, weather regime, in addition to other environmental forces and resisting frameworks that, in combination, result in the physical world (Phillips 1999). Socially, landscapes are a collection of places that exist at the intersection of varying processes at local and global scales (Massey 1994). These places exist as a geographic point on the landscape scaled to humans' collective and individual identities in connection to historic and contemporary social relations (Massey 1994;

Castree 2009). These can be represented through a topological map, where social relationships are emphasized rather than absolute space (Cresswell 2013, 218). Then, landforms (and places), when considered in aggregate and in combination with the other biological, geological, and chemical features, make up the landscape (Goudie and Viles 2010, 33). This dissertation treats landforms and places as not mutually exclusive; rather, it treats these as simply different ways of classifying and drawing boundaries around the physical and social aspects of the landscape stemming from different sub-disciplinary lenses. Therefore, landscapes are subjective and infinite (Massey 1994; Castree 2009), creating a complex object of study that is meaningful to both social and physical geography.

Landscapes, then, are a collection of places that incorporate the form and meanings of the natural and built physical world (Smith 2003, 5, 32). These meanings are multiple and varied but are centered on the human at a particular place and time (Smith 2003, 10; Meinig 1979, 47). The complicated conception of a landscape described above is well suited to a study in the Anthropocene because its focus is on the material, both socially and physically inscribed. The Anthropocene complicates the heterogeneity at the landscape scale, requiring the consideration of human-induced landform change and climate change at the local level. Within these contexts, the researcher is required to define boundaries of both the landscape and the internal landscape features or places under study. Although I have established that the landscape is composed of landforms and places, the means through which processes and practices move through these boundaries at different spatial and temporal scales needs to be considered. In a landscape system, boundaries must be drawn around its associated properties; however, the boundaries are open, and energy/mass is exchanged across broader spatial scales (Goudie et al. 1994, 491). Goudie and colleagues (1994, 492) assert that its continued use as a pedagogical or analytical device in a variety of ways, including in ecology and geomorphology, is mainly beneficial as a conceptual tool and is plagued by issues of boundary creation and the difficulty with analyzing the heterogeneity of the landscape and saying anything about a "preferred" state. In this scenario of combined social and physical meaning, a system can be conceptually useful for quantitatively or qualitatively modelling the relationships among internal and external stressors at different scales. Systems, often represented as bounded boxes connected by lines or arrows, can be critiqued for the obfuscation of the internal processes within the boxes and for its perceived prescribed directionality or cemented relationship. This is a reasonable critique, but this dissertation suggests that systems as a conceptual tool enable the iterative connections among social and geomorphological theory and methodologies. In its application of the social, the system and relationships among and across it are open and fuzzy, enabling overlapping, integrative and reflective features and processes. The next section will expand further on how to iteratively connect these multiple ways of thinking about the world.

An important aspect of studying the landscape is a consideration of the spatial scale of the remotely sensed images under study, which depends upon the landform feature and process; however, the turn towards human landforms requires the consideration of the social scale, among other research-related factors like data availability and the research question. Like micro-, meso-, macro-, and mega-scale geomorphic landforms, the spatial extent can vary widely and is highly temporally and situationally dependent (Huggett 2017, 4). For example, geographer William Denevan (1988) and his team in the Colca Valley, southern Peru in the 1980s were interested in defining the geographic location of abandoned terraces, or terraces with visible signs of degradation from a long period of no management. This required classifying and defining boundaries of over 30,000 hectares of terraces slopes using aerial photos from the mid-twentieth century in addition to the aerial photos from the 1930s. The broad spatial scale of the project required defining boundaries around stretches of terrace types that were associated with specific historic and contemporary hydrologic, geomorphic, climatic, and social processes (i.e., upland, bottomland and those in-between in addition to specifying if they were cultivated or abandoned). While individual terraces can be treated as a single geomorphic landform, the extent of the project and research question guided the researchers to draw boundaries around collections of features that indicate broader, collective histories to find the geographic location across the whole valley of these different terrace types rather than a single terrace tread or another land unit. In another example, Preti and colleagues (2018) monitored the surface and subsurface hydrology in relation to wall stability of a restored nineteenth century vineyard terrace wall and tread in Florence, Italy. In this study bounded by a single terrace with a water-damaged wall, they used 1-m spatial resolution digital terrain model (DTM) resulting from terrestrial LiDAR from a previous study (Preti et al. 2013) to create a conceptual model of water flow and accumulation and its impact on the terrace wall stability. Preti and colleagues (2018) used the scale of a single terrace as their study area to investigate, in fine spatial resolution, the hydrologic patterns of a terrace with wall damage to assess a question related to management decisions at a finer spatial extent. This juxtaposition of datasets, spatial resolution and spatial extent demonstrates the diverse opportunities provided by twenty- and twenty-first century technologies to study terrace landforms and landscape. Each study resulted in a model of terraces, Denevan (1988) modelling the location of terrace types in relation to historical processes across a landscape while Preti and colleagues (2018) modelled water flows and stability across a single terrace, but each considered the logistics and research questions' social and physical contexts when choosing the spatial scale.

Another important aspect is temporal scale and the ability to identify and classify a feature related to the social group that created it, a problem presented by Tarolli and colleagues (2019). A way to address these issues is to incorporate archaeological, anthropological, and human geographical research conducted at a local level. Archaeology is a field that similarly studies the landscape but focuses more exclusively on the human. Archaeological investigation has been a tool consistently employed by geographers to investigate the distribution of humans on the landscape and their impact on the subsoil (e.g., Butzer 1982). Similarly, geographers studying geomorphology are looking to archaeology to answer questions about identifying and classifying humans' impacts on the landscape at different scales (e.g., Tarolli et al. 2019). When considering modelling a humanized landscape, geomorphologists must consider broader historical and contemporary social processes, like colonialism and capitalism, as well as the finer internal social processes over time, such as local water management and kin relationships, that may contribute to the contemporary landscape. An understanding of local history and of contemporary local social relations will address the heterogeneity captured at the landscape scale. Interviews, for example, can provide information that will tease apart some of the human and environmental forces behind the multiple land covers, processes and features visible on remotely sensed imagery. Complementary information includes the changes to sediment connectivity and hydrology related to the subdivision of a slope into risers and level surfaces, and the daily practices that maintain them. Mapping the geographical location of terraces in relation to interviews on local knowledge related to them creates more holistic understanding of a local landscape. Although Tarolli and colleagues (2019) additionally expressed the goal of using these remote sensing data to create a predictive theory of human landform features and social change, the Anthropocene provides an opportunity to investigate the heterogeneity on the landscape and in human ways of thinking about the world. While high temporal and spatial resolution remotely sensed images are now available and provide opportunities for predictive social theories, there must also be attention paid to local difference and room for research to expand our understanding of local complexity.

Looking to CPG through a feminist lens offers a way to impactfully classify and find meaning. A CPG lens would require iteratively integrating quantitative or qualitative social geographic methodology to reflect on the contemporary classifications. detail. Local ontologies and land use practices differ across regions, such as the Andes, and across similar anthropogenic features, such as terracing. This refocuses pursuits from a synoptic view of classification and boundaries to a more heterogeneous one. The ability to continuously quantify and draw boundaries without reflection ignores the sociality of knowledge production. Drawing from Haraway (1988), local knowledge production, while complex and contradictory, provides context to the material world. This embodied context adds depth to the (embodied) analysis of remotely sensed data and informs the increasingly quantitative results. Through this, the boundaries of human landforms have a deeper meaning beyond their functions. Finding meaning can occur through historical and contemporary engagement with social datasets. For example, Carolyn Dean (2010) studied Inca perspectives on stone and how that informed their relationship to the built and natural environment. Although not a remote sensing analysis, Dean engaged with the distribution of rocks as construction materials and animate features on the landscape, possessing multiple meanings and functions. Dean (2010, 66) analyzed mytho-histories and historical accounts to understand the meanings behind the Incan, and Andean, relationship with stones. Through this, she asserted that the “domestication” of stone occurs through its use as a construction material for structures or terraces (Dean 2010, 67). Terraced landscapes, then, are “tamed” nature and a representation of an ordered world, but also demonstrate the reciprocal relationship between Pachamama (Earth Mother) and the Inca (Dean 2010, 67, 75). The terraced soils encompassed by the stone walls "create a complete, procreative body" where the soils are flesh and stones are bones (Dean 2010, 75). This way of conceptualizing the terraced landscape animates the features. Stones, then, are not simply walls or outcrops, but features important to the reciprocal relationship among people and the landscape. This can either impact the classification system or inform the interpretation of these relations. Therefore, describing terraced fields in this scenario as simply for subsistence would diminish the local difference and meaning and remove an important relationship from the systems' model.

Additionally, reflection on the research process is necessary in both CPG and feminist perspectives. Remotely sensed imagery ranges in resolution, extent, cost, and availability. Technologies range from greyscale to multispectral cameras, LiDAR instruments and Radio Detection and Ranging (RADAR) instruments on land, drones, planes, or satellites that create 2- or 3D images of the land surface or subsurface (Tarolli and Mudd 2020, xiii-xiv). The finer resolution instruments, like LiDAR, are less affordable and not widely available across the globe. LiDAR is expensive, so structure-from-motion (SfM) is a more affordable option that uses ideas from photogrammetry to capture multiple sides of an object or topographic feature, creating a 3-Dimentional image (Tarolli and Mudd 2020, xiii). The more affordable and more widely available options, like the nationally funded Landsat satellite imagery from the US National Aeronautics and Space Administration (NASA), are at a coarser resolution but have a higher return period enabling comparisons over time (Department of the Interior [DOI] 2021). For example, this dissertation uses data US DOI declassified high-resolution satellite imagery taken between 1960 to 1972 for intelligence missions (DOI 2018). The allocation of resources necessary for these missions stems from the US government and their desire to extract information about areas of perceived interest at the time. Thus, this dissertation directly benefits from historical geopolitics and possibly luck, due to the likelihood that this dissertation's area of interest was a byproduct of other governmental interests. The limitations on spatial and temporal resolution and extent stem from uneven funding and study topics, leaving areas with and without certain datasets. Regardless of the data type, there is a need for identification, classification, and ground confirmation of objects, depending upon the topic of study.

Biermann and colleagues (2021, 809), in their analysis of empirical and conceptual papers on the Anthropocene, describe a "strongly integrative analysis" as a research process that meaningfully includes both social and biophysical data. Some examples of the integration of material landscapes, social dynamics, and knowledge politics on a local level include Uolla (2020, 2020b), Elmhirst (2020), Ashmore (2015), and De La Cadena (2015). This dissertation additionally turns to Smith (2003), an anthropological archaeologist who looks at the role of power in the material landscape, in addition to the meaning inscribed on and read from it. The use of Smith's relational landscape leaves room for different ways of thinking about the world, and the untangling of colonial epistemologies, to move between the local environment and the people who live there and complicate our understanding of the landscape. This paper offers a relational landscape as a framework nested within CPG through which the researcher can visualize all datasets, approaches and methodologies, each stemming from different situated knowledges, about the landscape.

RELATIONALITY FOR TERRACED LANDSCAPE STUDIES

Working within a relational ontology acknowledges the multiple relationships and interconnectivities that are important to both the research process and the location of study (Neely and Nguse 2020, 140-146). It offers complexity, rather than a broad explanatory model that results from the "permeable boundaries of an open-ended feminist political ecology" (Elmhirst 2020, 527). A relational ontology is associated with posthumanist perspective that removes the nature-society divisions and, in some cases, gives agency to nature, as summarized by Ulloa (2017). Through this, there is room for physical and human geography to communicate together on topics of mutual interest. For example, Massey (1999) argues against the idea that knowledge is only achievable through science and the idea that to represent space is to divorce time. Massey constructs this argument through conversations with both human and physical geographic approaches to understanding space and time, demonstrating that these different approaches can speak to each other beyond borrowing theories for alternative purposes (Massey asserts that physics is often borrowed from). Instead, the author argues that the multiplicity of relationality co-creates space-time and co-enacts change (Massey 1999, 274-275):

> …for time genuinely to be held open, space could be imagined as the sphere of the existence of multiplicity, of the possibility of the existence of difference. Such a space is the sphere in which distinct stores coexist, meet up, affect each other, come into conflict, or cooperate. This space is not static, not a cross-section through time; it is disrupted, active and generative. It is not a closed system; it is constantly, as space-time, being made.

This mixed use of human and physical geographic rhetoric demonstrates the potential for an integration and communication of these concepts and perspectives.

Some applications of relational ontologies emphasizing the importance of local sociality in physical systems include hydro-social studies (e.g., Boelens 2014; Stensrud 2016; Paerregaard 2018; Damonte and Boelens 2019). These studies of mountain "waterscapes" critically integrate relations between humans and water, and are an increasing topic of study, especially in its contributions to policy (Nüsser 2017). For example, Paerregaard (2018) interrogates the agency of water, local perceptions of water, and their iterative impacts on water struggles in the Andes. Boelens (2014) connects cosmology, human practices, and policies and demonstrates their interconnectivity in a community in Mollepata, Peru. Boelens (2014) goes further to tease out the historical power relations and the integration of elite power, cosmology and locally enforced practice. In an example of a relational ontological approach in feminist studies, Ulloa (2020b) gives an account of the Wayúu people in Columbia and their defense of the territoriality and rights of water itself against a mining company and their infrastructure. Through this, Ulloa takes a relational approach to understanding local peoples' ways of thinking about and acting in the world and emphasizes the importance of amplifying local voices.

These examples demonstrate the possibilities for approaching geomorphology through a relational lens and its multiple applications for policy. This next section will describe a way to approach thinking about the socio-geomorphic landscape drawing from the relational landscape approach (Smith 2003) animated by a "worlding" approach (De La Cadena 2015). These are both couched within CPG, feminist frameworks, and the historical discourses across several disciplines. This socio-geomorphic approach drives the research design and analysis of the multiple datasets involved in investigating the terraced landscape of Andagua in the Peruvian Andes.

Relationality of Socio-Geomorphic Landscapes

This dissertation draws from these relational perspectives to study both the physicality and sociality of terraces as measurable and meaningful socio-geomorphic landscapes. Socio-geomorphology, as conceived of by Ashmore (2015), recognizes that the physical landscapes and landforms studied by scientists are "co-productions" by both nature and people, and their relationships over time. While this perspective has largely been focused on the study and restoration of rivers (Ashmore 2015; Mould et al. 2018), there are broad opportunities to approach other geomorphic topics of study, such as agricultural terraces, through this lens.

Incorporating a relational understanding of the interactions between humans and the physical world within a socio-geomorphic lens creates animate landscapes that contain multiple meanings in tandem. A relational landscape perspective quantifies the socially created physical worlds and then populates that scaffolding with "worldings" or the "practice of creating relations of life in a place and the place itself" (De La Cadena 2015, 291, note 4). The conceptual utility of this combination, approached from a CPG lens, provides room for quantifying the physical world in tandem with the unquantifiable. In an example from the Andes, the "earth-beings" (De La Cadena 2015) that inhabit the world, (for example, rocks, hillslopes, and soil) possess multiple meanings dependent on an individuals' practice and ways of knowing and understanding the world, which is goes beyond (institutional) scientific meaning-making. Grounding "worldings" in the relational landscape approach simultaneously animates terraces as flesh and bones (see Dean 2010, 75) or maize as the offspring of Earth Mother and the god of thunder (see Silverblatt 2005, 38-39), while also giving room for mapping them as geomorphic landforms on remotely sensed imagery. Holding both relational landscapes (Smith 2003) and "worldings" (e.g., De La Cadena 2015) together allows the communication of multiple meanings across all datasets, creating a socio-geomorphic lens through which to study agricultural terraces in the Andes.

Power is a crucial part of a socio-geomorphic landscape, both in physical forces such as gravity and social forces such as the state. Uneven power relations mediate the ability to assemble and alter space (Smith 2003) and diminish some peoples' ways of being in the world over others (De La Cadena 2015, 4). Therefore, it is crucial to recognize the power of humans to shape and give meaning to the landscape as well as to self-reflect on the power of researchers to shape and give meaning to the data. This does not negate the ability to quantitatively measure the natural and human features and processes (Smith 2003, 69-70). Geomorphic processes are relational across space and can be subsequently measured and quantitatively analyzed. For example, slope failures on a landscape occur in relation to sediment resistance and internal and external stresses at different scales, including internal pore water pressure and the geographic distribution of precipitation intensity (Inbar and Llerena 2000; Lasanta et al. 2001). This leads to some slopes failing while others remain in place across a landscape at a particular point in time. The ability to measure and account for these processes in this way relates to the social practice of geomorphology. Alternatively, a landslide may be measured as an action of Earth Mother or the mountains and the alteration of the social relations between people and these beings (Gose 2018). Landscapes, then, are constructed through both the movements of people, but also their sociality and the meanings they assign. This relationality allows for both quantitative and qualitative investigations of the landforms (and people) on the landscape.

The human alteration of the environment ranges from indirect impacts such as acceleration of erosion, to direct impacts such as excavation and construction (Szabó 2010, 6). However, the ability to transform a broad areal extent in a direct way often requires access and control over human and natural resources (Smith 2003, 70). This power relates to the uneven ability to transform and constrain practice, experience, and imagination in the same capacity across all people. Therefore, the power to alter the physical world correlates with the power to alter meaning (Smith 2003, 71). For example, the Inca enforced the construction of estates, terraces, transportation infrastructure and administrative centers across an expansive areal extent because of its ability to reorder and use existing social relations across the Andes (D'Altroy 2015, 352). While local people in the Andes had knowledge on how to build agricultural terraces and canals, the Inca imposed construction in places of prestige conforming to a particular aesthetic and designed to produce maize for rituals (Hyslop 1990, 284-285). In this example, the political authority at the level of the state had the power to shape everyday lived experiences. While this is an important factor on the landscape, it is also crucial to attend to local power differentials and social relations that impact movement, thought and perception of the landscape.

A socio-geomorphic landscape is also relational in that the physical features are given meaning through everyday human engagement with them through social practices, forming an integrated social and physical world. They are the result of "our ways of knowing, practicing and making our distinct worlds" often in relationship to the other beings that inhabit it (De La Cadena 2015, 4). The material space of a landscape evokes feelings, physically mediates social relations and practices, and is the subject of discourse through which landscape has authority (Smith 2003, 76-7). These intersecting locations of power, people and the physical world are measured by landforms, both human and natural, and the ways in which they are altered by human practice; the existing landscape constrains movement but is also subject to human action (Smith 2003, 25). Practices also "create (forms of) being with (and without) entities, as well as the entities themselves" (De La Cadena 2015, 291). These entities can be measurable and categorizable features and forms on the landscape (Smith 2003, 73) and is translatable to the work conducted by Tarolli and colleagues (2019), Brown and colleagues (2021), and others who are mapping landscapes and classifying terraces and terrace soils (e.g., Sandor 2006; Sofia et al 2014; Guengerich and Berquist 2020). Through classification, identification and analysis of the landscape, the human practices (and functions) can be discerned. The everyday practices and social relations tied to these can also be gleaned from participatory observation and interviews of local individuals. This can remove some of the uncertainty in terms of the process of contemporary practices and their impact on the landscape on a local level. This knowledge enriches a researcher's understanding of local heterogeneity and complicates universalizing models of human-environment relations. Additionally, spatial practice leaves room to include the movement of nonhumans through physical space such as water, wind, sediment, volcanic material, animals, vehicles, and others. These nonhuman beings and their related processes can be measured, accounted for, modeled, and analyzed using quantitative and qualitative social and physical science methodologies to uncover their impact on the physical world. For example, locations and extent of soil erosion on terracing can be discerned through visible features such as rills and measured and extrapolated through sediment concentration in runoff (e.g., Nunes et al 2018). This explanation of these processes and features on the landscape are the result of the intersection of geomorphological social relationships that result in agreed upon methods, theories, and language. Similarly, local ontologies and situated perspectives will have alternative approaches and explanations of sediment erosion that also draw from local observation and measurement practices. The socio-geomorphic landscape, then, can be approached from multiple perspectives and integrated into a coherent whole.

Different ways of knowing, categorizing, and understanding the world also shape the phenomenological experience of individuals as they move through space (Smith 2003, 73; De La Cadena 2015, 100-101). It is the signs they read from the landscape or the affective nature of a place. (Smith 2003, 73). These are embedded within how people perceive aesthetics and form, and their relationships to other people and the landscape. The turn towards embodiment acknowledges the different ways in which people, specifically women or other marginalized populations, feel about and in a space (Haraway 1988). For example, Sultana (2011) revealed how gendered, embodied emotions related to acquiring drinking water intersected with local conflicts over diminishing resources. Through ethnographic data, Sultana argued that the verbal and physical abuse suffered by women in their attempts to source safe drinking water for their families altered how they moved through and felt about space. It impacted both their physical health–they were forced to use contaminated water–and altered their social relationships where they would try to move in groups rather than alone. In another example, a persons' *ayllu* (kinship-based extended family) in the Andes is the location in which both the earth-beings and the *runakuna* (Quechua people; human beings) are formed, meaning their relationships stem from histories, mytho-histories, family, friends, and other sensual and material aspects of that place (De La Cadena 2015, 101). There are other methodologies and approaches related to embodiment, including body mapping through decolonial, feminist, Latin Americanist community-orientated lens, which reject human-nature dualisms and refocuses on local lived experiences in relation to power and ecologies (Zaragocin and Caretta 2021). This dissertation used interviews and participatory observation to discern the heterogeneous ways in which people of different classes, identities, occupations, and genders felt about the terraced landscape. I was limited by peoples' willingness, or not, to share their perspectives about change on the landscape to a stranger and considering my own positionality as a white, North American academic entrenched within colonial histories of violence (Zaragocin and Caretta 2021). Despite the limited capacity of interviews and participatory observation to reach a deep knowledge on peoples' emotions about the landscape, my existing relationship with the community built enough trust for diverse individuals to express some of the affective qualities and communications of places.

Another important "dimension" to consider is that of spatial imagination or the discussions about space discoverable through written text, visual representations (Smith 2003, 74), or discourse. For example, these can include written or spoken mytho-histories, stories, and interviews of people to provide local interpretations of data. For example, De

La Cadena (2015, Interlude 2) recorded stories by an Andean shaman east of Cuzco, Peru during ethnographic interviews to outline how Indigenous peoples' struggles with enduring colonial and state power structures their impact on local relationships to the landscape. This discourse of violence and resistance relayed by the shaman revealed local conceptualizations of the dispossession of land from Indigenous people by the state; they feel abandoned by the state and this abandonment is manifested through expressed difficulty accessing clean water and a lack of a paved road, among other resource access issues (De La Cadena 2015, 154). This example demonstrates the interconnectivities of the socio-geomorphic landscape as well as the importance of power in the ability to alter the physical environment.

This dissertation draws from multiple methods and datasets, including remotely sensed imagery, interviews, and participatory observation to iteratively compose a more holistic understanding of a terraced landscape in the Andes of southern Peru. A socio-geomorphic perspective animates these with earth-beings and people, both *runakuna* and others, to blur landform boundaries and physical and metaphysical forces. In research practice for this dissertation, it is the iterative incorporation of social information into the classification and quantification of the physical landscape. It is this flexibility of a relational landscape lens of a socio-geomorphic project that enables the researcher to approach landforms through multiple perspectives and integrate these into a coherent whole. This perspective incorporates the idea that the physical landscape is socially engrained in diverse everyday lived experiences, processes of power and history.

MOVING FORWARD IN THE ANTHROPOCENE

A socio-geomorphic perspective with a CPG research framing impactfully enables the study of landscapes in the Anthropocene through iteratively incorporating data from both social and physical research in addition to reflecting on the research process itself. It allows the interpretation of a human landscape, the continued stability of which is reliant on human practice and social relationships. Through this research practice, the landscape is treated as created and transformed through the relations among features and processes, social practices, and ontologies (Smith 2003). This situated perspective approach applies to both the researcher and the research subject and places their knowledge as equally as important to understanding the material world. As such, both the researcher and local people are recognized as having a social relationship to the material world that, through contextualization, contributes to a more holistic understanding and the ability to discern the appropriate temporal and spatial scale of study. This project starts at the landscape scale because of its social and physical complexity and ability to be broken down into other socially and geomorphologically meaningful units of study.

The next chapters will go into detail on my application of these nested frameworks in Andagua, working to uncover the changing patterns on the landscape over the past 60 years through interviews and remotely sensed data. My positionality as a white, female US citizen from a North American university was coupled with my relationship with the community as the partner of an archaeologist who had led a community-engaged research project that was well received. I accompanied my partner almost from the beginning, working as a field archaeologist and engaging with the community on a personal level. These existing relationships situate my position in the community, influencing the research process. Within this brief personal context, this dissertation covers the complexity of agricultural terracing by teasing apart the social practices, perceptions, and imagination of terracing and how these have changed through time. It then incorporates this information into defining local analytics that are both socially and geomorphologically meaningful for mapping the terraced landscape over time in order to discern the socio-geomorphic relationship among humans and the environment through the increasing intensity and rate of changing human and environmental processes and forces in the Anthropocene.

Chapter Three: Local Perspectives, Practices, and History

INTRODUCTION

Agricultural terraces and canals are widespread Indigenous and pre-Hispanic infrastructural features in the Peruvian Andes, and elsewhere, that are important for supporting both subsistence and market-oriented farming and ranching activities (Camara and Mesquita 2019; Denevan 1988). This method of agriculture creates anthropogenic landscapes that are geomorphologically unstable without further human practice to ensure their primary (or secondary) functioning (Tarolli et al. 2014). These crucial human-environment relations are threatened by social change, such as mechanization and demographic shifts (Tarolli and Straffelini 2020), and climate change such as alterations in precipitation seasonality and temperature increases (Imfeld et al. 2020). These issues call for scholarly focus on local knowledge of the terraced landscape to help farmers document and communicate their needs, perceptions, and practices across community, regional, and state social levels. This chapter contributes to these conversations through qualitative interviews that addresses peoples' perceptions, and daily and ritual practices in relation to the continuance of the terraced landscape in the rural Andes of Andagua, Peru. It does this through a socio-geomorphic perspective of the terraced landscape, which recognizes the intertwined relationship between natural processes and forms and social practices and ways of thinking about the world that ensure the continued stability of these anthropogenic landforms.

Interview results reveal complicated and contradictory perceptions and practices across gender, race, and class, demonstrating complexity across these highland communities. They document perceived changes in climate, class and power communicated through local analytics such as maize, potatoes, land tenure units, transportation infrastructure and canal cementation.

First, this chapter will briefly review the importance of conducting interviews through an understanding of mutually situated, local knowledges and power relations. It will then provide background information on the daily and ritual practice required to maintain agricultural terraces, focusing on the Andes through time and briefly review the existing local, and relevant regional and national history in Andagua, Peru to contextualize the interviews. Finally, it will then outline the methodology before describing and analyzing the interview results in detail.

RELATIONAL LANDSCAPES AND LOCAL KNOWLEDGE

Local knowledge of terrace ritual and daily practice illuminates the socio-geomorphic dynamics of terraces as a landform that requires both natural and human agents to ensure its continued stability. There are many named approaches to studying local knowledge including ethnoecology (Toledo 2002), ethnopedology (e.g., WinklerPrins and Barrera-Bassols 2004), Traditional Ecological Knowledge (e.g., Berkes 1999), local knowledge (e.g., Bocco 1991), Indigenous knowledge (e.g., Sandor and Furbee 1996) among others that may not have directly engaged with these terms, many of whom were concerned with conservation efforts often in nations with histories as colonial possessions. Local knowledge is additionally created within an individual through their embodied lens (Haraway 1988). This knowledge is not held equally across a population but is heterogenous. It is specific to different genders, ages, classes, races, and familial histories, among an infinite number of other factors. For example, children in the Andean highlands learn through helping their parents and family members such as by practicing properly preparing coca leaves for consumption by their parents before being able to participate fully in gender-specific activities through which they can chew the leaves like the adults (Allen 2005, 423). These knowledges and practices must be approached considering power at multiple scales, including the enduring processes related to colonialism (Sundberg 2014) and the market economy (Denevan 2019). Individual actions are also an important factor, indicating that heterogeneity within and across a single community is additionally impacted by farmers making decisions about their own lifeways (Doolittle 2001). There are also local power struggles that need to be considered, although these may be more difficult to tease apart without prolonged community engagement. In general, both local knowledge, as described above, and institutional academic knowledge, such as geomorphology, are the products of social relations and processes of power. As such, there are multiple truths situated within historical contexts and processes of power that must be held together to understand human-environment relations on a landscape across time.

The goal is not to test local knowledge against geomorphic knowledge but to conduct additive research through the understanding that there are multiple ways of knowing the world. Local perceptions and knowledge directly impact decision-making and everyday local practices. The interviews and participatory observation in this chapter particularly focuses on perception and practice on the landscape, drawing from archaeological and ethnohistorical accounts in the area to contextualize the contemporary world within local history. These embodied accounts of interactions with and feelings about different features on the landscape, specifically terraces and canals, gives crucial context at a finer scale. This context guides future analysis with remote sensing datasets of the landscape, giving social and geomorphological meaning to locally defined analytics. This chapter interrogates these dimensions on a terraced landscape in the Central Andes by first outlining the social and environmental contexts through which they operate, and then by discussing interview data that touches on knowledge of practice and perception to uncover locally informed meaning on the landscape.

TERRACED LANDSCAPES: PRACTICE AND SOCIAL RELATIONS

Human practice, crucial to the maintenance of terraced hillslopes, is done in concert with social relationships among people and the animate landscape. To ensure stability and sustainability of infrastructure and cultivation, communities practice collective social management and labor exchange to clean canals, organize water distribution, help with harvest, repair walls, and perform offerings (Guillet 1987; LaFevor 2014). For example, water irrigation distribution and canal maintenance in many parts of the southern Andes are organized by a hierarchy of water officials performing a *cargo* (obligatory responsibility) overseeing and negotiating irrigation sectors (Gelles 2000, 101). In addition to stipulations to contribute to work parties for communal resources, some farmers practice kinship-based labor exchange where they give and receive agricultural work (Mayer 2002, 105-6). There are several kinds of these obligatory exchanges, referred to as reciprocity, each defined by the type and symmetry, or asymmetry, of the exchange (Mayer 2002, chap. 4). One common example is the symmetrical *waje-waje* (work-food) exchange where one person offers help and the other feeds them during this activity, which is then reciprocated in kind (Mayer 2002, 109). Another is a *minka* exchange, where a person who is not necessarily kin receives goods or monetary payment in return for the service (Mayer 2002, 111-112). A single plow event may include a mixture of reciprocal exchanges to acquire sufficient labor for the day (Mayer 2002, 112-113). The nature of these exchanges has changed over time; for example, unequal exchanges developed between wealthy landowners and farmers (or other, usually Indigenous, people) during the post-colonial period (Mayer 2002, 116-117).

Reciprocal relationships are not reserved for human exchange, but also include the non-human. The relations among *Pachamama* (Earth Mother), mountains and other deities, and individuals must be nurtured for successful harvests (Dean 2010, 68). These rituals vary from offering a few drops of *chicha* (maize beer) to Earth Mother during agricultural work to more formalized *pagos* (ritual payments) to regional mountains for their protection and generosity (Gelles 2000, 82-84). The material culture of ritual payments can be composed of different combinations of incense, camelid fetuses, maize, coca, alcohol, popping maize, and maize flour, among other items. Rituals, offerings, and maintenance practices are performed at water sources and along canals, maintaining the reciprocal relationships to Earth Mother and other important figures for the irrigation water and reaffirming social relationships among both people and the landscape (Boelens 2015, 80). Farmers giving offerings to regional mountains to maintain these relationships has been documented throughout the Andes since at least the Spanish colonial period (De La Cadena 2015). Mountains are perceived as beings who act in the world as either kin relations (de la Cadena 2015) or as uncontrollable "metapersons" (Gose 2018, 488). Changing mountain hydrology and landslides, for example, can be navigated through such practices maintaining social relations (Gose 2018). Other rocks of varying sizes, from small stones to large boulders, can also carry social meaning (Dean 2010, 70). For example, stones of terrace walls are considered "domesticated" through their use as construction materials, and other rocks may be considered important agents in local mytho-histories (Dean 2010, 2, 8). While individual interest in the cosmologies behind rituals varies, many farmers continue to conduct offerings because of a belief in their sacredness and how it relates to family prosperity (Gelles 2000, 81).

Farmer decision-making can rely on factors such as the environmental characteristics of individual terraces, agricultural cycles, water availability, crop rotational cycles, household demands, and yields, among other factors (Guillet 1987; Sandor and Furbee 1989). Murra (2002, 380-386) analyzed Guaman Poma de Ayala's descriptions of agricultural practice in the early Spanish colonial period, relaying his accounts of microclimates, agricultural cycles, and a variety of domesticated plants and animals. Figure 3.1 demonstrates an example of an annual maize cycle as described by Guaman Poma de Ayala. Farrington (1980, 22-23) documented farmers irrigating the land before planting to soften the soil at lower elevations but waiting for the end of the rainy season to plant unirrigated high elevation fields to ensure moist fields. Farmers stagger harvest dates for different crops in consideration of their maturation rates to ensure availability for a longer period (Mura 2002, 384). They also practice multiple preservation methods for the same reason. For example, *chuño* (naturally freeze-dried potato) is created from the smaller potatoes and by storing others under *itchu* grass. Other cycles were interannual, integrating rest periods and rotations between crops with different nutritional requirements. For example, Farrington (1980b, 15) documented the rotational system called *mañay* practiced in a high elevation potato zone where a field is rested for five to seven years in between each planting.

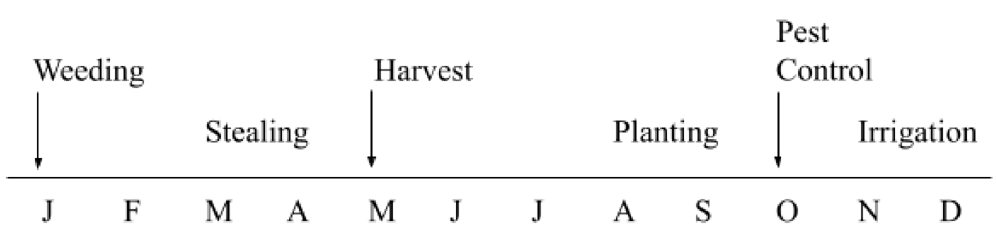


Figure 3.1 Guaman Poma de Ayala's description of maize cycle as described by Murra (2002, 380-5).

In addition to ritual and agricultural cycles, farmers cultivate relationships with the soil to ensure its fertility. Farmers provide natural manures such as camelid dung (Knapp in comment on Guillet 1987), *guano de isla* (bird droppings), household trash and crop residues, which increases the fertility of the soil (Sandor and Eash 1995). *Guano de isla* is prevalent on coastal islands where birds congregate to take advantage of the nutrient- and fish-rich waters upwelling from the Peru-Chile current (as summarized by Knapp 2019, 23). *Guano de isla*, commonly called *guano*, was an important fertilizer through several phases of Peruvian history, most especially during the Inca Empire and during the Peruvian post-independence era of the mid- to late-nineteenth century (Klarén 2000,158-159). The later period enabled Lima elite to garner large profits by facilitating the mining and export of the natural fertilizer to the Global North (Klarén 2000,158-159). *Guano* was also crucial to sixteenth-century maize cultivation in the arid lands surrounding Arequipa (Julien 1995, 185). These manuring practices increase the phosphorus, organic carbon, pH, and total nitrogen in the cultivated soils as compared to unterraced, uncultivated soils (Sandor and Eash 1995).[1] Long uncultivated terrace soils are also enriched in Phosphorus, which suggests that farmers used natural fertilizers in the past (Sandor and Eash 1995).

In addition to manuring, farmers practice fallowing, mixed cropping, and rotational systems (Donkin 1979). Mixed cropping, or intercropping, reduces the occurrence of diseases and insects, allows for dietary diversification, utilizes sun and shade, and can offer nitrogen balancing (Donkin 1979; Yamamoto 1985, 89-90). Alfalfa (*Medicago sativa*) also improves the nitrogen content in the soil and provides fodder for cows, who further fertilize the soil (Furbee 1989), although it is a water intensive crop. For planting and harvesting, farmers use metal plows, metal mattocks and other technologies that have generally replaced other tools such as the wooden *chaqui-taclla* (foot plow) in the Andes (Rowe 1946, 211; Donkin 1979, 13-15).[2] Many of these activities require expansive human labor and, therefore, social organization and relationship maintenance.

Changes to household practices in the Andes are already occurring due to perceived climate and social change. In a study that interviewed and conducted focus groups with a wide range of farmers and ranchers in the Southern Peruvian Andes, Postigo (2014) found perceived changes in the climate and ecology including decreased frequency and increased intensity of rain, shortened rainy season, pests at higher elevations, and larger differences in diurnal temperatures. Farmers recounted that the increase in pests range correlates with increased pesticide use, which increases the cost of crop production and pollution (Postigo 2014). Decreased volume in rivers and overland flow also correlates with lower water availability for irrigation (Postigo 2014).[3] In highland areas under study in the Arequipa Department, Postigo (2014) notes that water boards have created new irrigation schedules and local farmers and ranchers are looking to these institutions to produce infrastructural and organizational responses to these issues. At a local level, Postigo (2014) gives several examples to illustrate the importance of local knowledge in the farmers' ability to predict future climate. In summarizing Biemans and colleague (2019) and Ochoa-Tocachi and colleagues (2019), Postigo (2019) highlights the potential to integrate multiple knowledge systems, including both Indigenous and institutional scientific, to address the stresses associated with these climate issues.

Practice and Imagination in Andagua

The negotiation between external powers and local populations in Andagua is evident in shifting settlement patterns and landscapes of power. These struggles are exhibited by new patterns of ritual space, altered ritual and daily practice, and enduring mytho-histories. For example, pre-Inca settlements in Andagua are oriented around local and regional *wak'as*, or scared landforms and landscape features such as springs, rivers, boulders, caves, and volcanoes (definition of *wak'a* as summarized by Dean 2010, 2;

Menaker 2019a). A particular local type of *wak'a* is a *wank'a,* a stone outcrop that has ownership over a place at scales ranging from a field to a larger valley (Dean 2010, 44). *Wank'a* are found in *llactas* (pre-Hispanic settlements) and across other prominent topographic positions in the Andagua valley, often in sight line with important, named mountains and volcanic features (Menaker 2019a). These stone features were representations of the relationships among local people, the ancestors, and figures of authority in the valley (Menaker 2019a). Stones and mountains held, and continue to hold, power on the landscape, and visually impacting peoples' perception of and movement through space. Knowledge of the social relations among people and the landscape of authority during the pre-Inca period was locally inscribed rather than a mediation between the local and an external state (Menaker 2019a). However, these patterns of power changed with the arrival of the Inca to the valley, sometime between 1400 and 1532 CE (Menaker 2019a).

The changing relationships to and perceptions of *wank'a* and *wak'a* with the expansion of the Inca into the area are represented in a local mytho-history recorded by Andagüeño Victor Julljuye (2004) and put into archaeological context by Menaker (2019b, 222-223). In the story, local extrusive volcanic features under the regional power of the Coropuna Volcano, such as the Puca Mauras volcanic cone, the two scoria cones (Los Mellizos), and others, fight against the non-local Inca who was constructing a canal through the valley. The fight commences when Wachalanka, a prominent sedimentary outcrop on the eastern side of the valley and the daughter of Coropuna Volcano, becomes pregnant after standing near where the Inca figure urinated. After giving birth to the Inca's son, Wachalanka turns to stone and Coropuna's servants chase the Inca out of the valley. Despite the story resulting in the Inca's expulsion from the valley, there is widespread archaeological evidence of Inca state power including in the construction of several sites and possibly the intensification of agricultural infrastructure evidenced by extensive, integrated irrigated bench terraces and canals proximal to the sites (Menaker 2019a). These shifts in relationships to the physical world changed the landscapes' affective qualities and the ways in which people interacted with the landscapes of power.

Figure 3.2 Offerings for Earth Mother led by the then town President on behalf of archaeologist Alexander Menaker's dissertation project and the Author's masters project, July 16, 2016 (photo by Author).

The material culture of rituals includes incense, camelid fetuses, maize, coca, and alcohol, among other items. In Andagua, *pagos* are a regular occurrence as offerings buried and/or burned at the beginning of agricultural seasons or before significant events or holidays (figure 3.2). I attended several important *pagos* including one where offerings like popping maize, llama fat, and other features were burned on a prominent hillside in collaboration with the town President at the time to ask for the blessing of Earth Mother for archaeological and geographic research, practices that often break through Earth Mother. Another was where offerings like llama fat, maize flour and other materials were buried in the courtyard of the small hotel where we stayed to ensure a good agricultural harvest for our host.

Additionally, painted, and unpainted rounded stone tablets and disks were placed in groups throughout the valley, often found in ritual contexts related to *wank'a* and other landscape features such as at the mouths of caves and cliff edges (Menaker 2019b). *Wank'a* are "rocks that were understood to petrified owners of places" and may be lithified ancestors or places belonging to ancestors (Dean 2010, 44-45). The tablets and disks found at these locations were painted in geometric, often striped patterns or with anthropomorphic and zoomorphic figures such as camelids and lizards (Menaker 2019a). According to Menaker (2019a), the offering of stone tablets and disks to these landscape features was a practice that ensured a continued relationship with the ancestors and figures of authority in the valley. These were uncovered in pre-Inca and non-Inca contexts, but were absent at Inca sites, suggesting these were not in use as a ritual practice in those places (Menaker 2019a.). Additionally, Inca ritual spaces deemphasize local *wak'a* and reorient local populations towards other features of Inca authority such as specific andesitic rocks called Ninamama (Quechua: Fire Mother; Menaker 2019a). This feature is a ropey aa-type lava that erupted around the time the Inca expanded into the region (Delacour et al. 2007). Chilcayoc Grande, a lava dome in lava fields to the south of the contemporary town, is concurrent with Ninamama, with charcoal dating it to between 1451 and 1523 CE (Delacour et al. 2007). Other contemporaneous or early Spanish colonial volcanic activity includes ashfall layers associated with the Jenchaña cinder cone, which are overlain by Huaynaputina ash deposits, a pyroclastic layer from eruptions from the Huaynaputina volcano in southern Peru during 1600 CE that had global impacts (Delacour et al. 2007). All of this suggests active volcanic and social processes during this pre-Hispanic period in Andagua, which was followed by the continued alteration of local social relations to the landscape by the Spanish, Peruvian State and the *gamonal*.

In summary, everyday practice and ways of thinking about the world were actively reoriented by the various processes of power that altered land ownership and autonomy. Like Inca plazas and platforms, Spanish chapels and plazas were places of ideological indoctrination and transformation attempting to supplant the former through the mediation of everyday movement (Wernke 2013, 206). The lower-elevation, side-valley terraces in Andagua were largely put into disuse with the arrival of the Spanish, likely because of their distance from town or water availability. The *gamonal* continued to exert authority across the landscape, using his power to take ownership of land by force, altering the physical movement through space, which created a landscape of power and fear (Menaker 2019b, 271). The expansion of fields under use during the late twentieth century was largely a bottom-up reclamation of land in combination with the agrarian reform's imposition of redistribution of fields to farmers. The *communidad de campesinos* (community of farmers) of Andagua additionally was formed as a political entity, independent of the local municipality, under the reform. While the town is under the jurisdiction of the municipality, the terraces are under the jurisdiction of the *communidad de campesinos*. Power on the landscape shifted during this period, altering how people moved through space and the pattern of land use.

Population, Perception and Agricultural Practice

Through the twenty-first century, the population in Andagua decreased from a recorded 1528 people in 2000 to 1177 people in 2015 and 1038 in 2017 (IV Censo Nacional

Agropecuario [INEI] 2015; INEI 2017). Of those, 330 are listed as landed producers, more than half of whom partly sell crop yields to local or national markets (INEI 2012). Less than 5% of the land units owned by those producers are exclusively dedicated to growing crops for the national market. These crops include largely *Maiz choclo* (a maize with larger kernels), variations of tubers (mostly *Papa blanca* [white potatoes]), and *habas* (broad beans), with one or two land units each of carnations, *papa amarilla* (yellow potatoes), quinoa, *Maiz amilaceo, Cebada grano* (barley), and *avena grano* (a type of oat).[4] Deciding on what to grow, farmers reported, included considerations of water availability, cost, and consistency. The main reasons given for leaving fields fallow include a lack of water, seeds, or labor, with less than 10% reporting land degradation, which is defined as salinity, erosion, or poor drainage.

Over half of the respondents in the INEI 2012 were between the ages of 45 and 65 and own an equivalent percentage of the available land. Only 18 producers were between the ages of 15 to 29, indicating an older population. Fewer than 10% of the farmers and ranchers have additional professions including an engineer, electrician, artisanal carpet weaver, mason, mechanic, tailer, cosmologist, chauffeur, and merchant. Only 9 people report transforming their agricultural products into secondary material. Additionally, 91% of both landed and landless producers report that their agricultural or ranching activities are not sufficient to cover household expenses, some of whom take on additional work while others multi-person households likely have additional income.

Humans impact the landscape through everyday practice are mediated by ways of thinking about the world and the broader social and environmental forms and processes. This goal of this chapter is to further complicate the understanding of the impacts of twentieth and twenty-first century social and physical processes and forces on local practice and perception, to contribute to a broader project focused on their relations to human and natural landforms and processes on the landscape.

METHODOLOGY

The research process takes a reflexive approach that considers power relations at multiple scales, including at the research process. This approach takes into consideration my positionality and how it constrains the interview questions, answers, and interpretation (Sultana 2007). It needs to consider power, responsibilities and hierarchy between each interviewee and interviewer–this can apply to multiple variables including where the interview location–and it results in "findings [that] will always be interpretive and partial yet telling of stories that may not otherwise be told…and revealing broader patterns that may or may not be stable over time and space" (Sultana 2007, 382). The perceived separation of myself from the interview process and interpretation is an ineffectual quantification. Undertaking this perspective can elucidate a more complicated understanding of changing local human-environment relations and perceptions within the context of social and climate change.

The interviews were semi-structured, focusing on the terraced landscape and its management; however, the interviewee was encouraged to talk about whatever they felt was important. Interviews from summer 2019 were recorded, with consent, and transcribed. Responses were hand coded using categories informed by the research project, previous knowledge of the area and the broader theoretical framework. The broad categories were as follows: human landforms, natural landforms, environmental process, local practice, social process, and ecology. Sub-categories were refined through both inductive and deductive practices, leaving room for the addition or subtraction of sub-categories when appropriate (table B.1).

RESULTS AND DISCUSSION

The Interviews

Navigating interviews with busy farmers required the use of both personal connections and simply being available where farmers are–in their fields. I had visited the town in previous years as the partner of archaeologist, Alexander Menaker, who did preliminary observations for and then conducted intensive survey and excavations across the valley (see Menaker 2019b for detail). Having received my undergraduate degree in anthropology with a focus in archaeology, I assisted with excavations in 2016 and participated in local festivals and was invited to familial events during this time. As such, I used my personal connections to organize my first interview with Señora A, suggesting we meet in her fields to speak. Señora A is a prominent figure in the community, is involved in several community groups and has an important government position in town. She was generous and kind, relaying to me information on social and environmental change, generational practice, and infrastructural transformations. I found that meeting with people in their fields served two purposes. One, it shifted power dynamics in that we spoke where they were comfortable and on topics they were interested in, and I was unfamiliar (figure 3.3).[5] Additionally, people were more often found in their fields or on paths and roads walking to and from their fields. Simply walking down paths and across the valley led people to stop and ask what we were doing, inviting the opportunity for me to ask if they would like to participate in my study. Complicated power relations involving colonialism, race and gender permeate these interactions; however, I benefited from my partner's good relations with the community and peoples' perception of us as a respectful family unit.

Figure 3.3 Author with an interviewee in their agricultural terraces in main valley, July 23, 2019 (photo by Alexander Menaker).

I was able to speak with only three women; however, they each represented diverse personal experiences with class, the economy, and social relationships. While Señora A had extensive family ties in town, Señora C and Señora E had few to no local familial connections. Señora C had few capital and familial resources but had extensive knowledge of local plants and animals. While conducting another interview, she was walking past and good naturedly showed me how to acquire nectar from a local flower and, later, demonstrated how to prepare and chew on a maize stalk for the sugar. Alternatively, Señora E lives in Arequipa, exclusively uses hired labor and only returns for planting and harvests, or when otherwise needed in her fields. She has apprehensive feelings towards her fields' neighbors and is suspicious of other peoples' use of the landscape. Each was enthusiastic in sharing information with me and chatting about themselves and their fields. Señora A and Señora C were especially thoughtful and expressed their enjoyment in speaking about their daily practices and perceptions about the landscape. Señora A was knowledgeable about climate change discourse as well as non-local agricultural practices, the latter partly implemented by or learned from visiting Intergovernmental Organizations (NGOs) or governmental institutions. I tried to schedule an interview with a fourth woman, our neighbor who was always busy with household activities, entertaining neighbors, and family, and engaging in multiple businesses; however, we were unable to find a time to speak at length.

The male interviewees similarly represented diverse class, economic and social experiences. I met up with Señor B while walking down the road from town. He and his son were riding their beautiful horses, and he showed off horse skills by having the horse stand on its hind legs. He agreeably answered my questions although his son, a college student living full-time in Arequipa, would usually elaborate his father's answers, demonstrating his concern for and knowledge about his fathers' businesses and the landscape. Later in the summer, while my partner was working on another project in town with an ethnographer, we helped Señor B herd his (very large) bulls across the valley as a paid laborer did not show up that day to assist the move. In addition to Señor B, Señor D and Señor F were both farmers with multiple incomes, including through raising cattle for milk and meat.[6] We met up with Señor G along the path between the twin volcanoes (Los Mellizos; figure 1.9). Señor G has a property in Andagua Antiguo near town and my partner and him first caught up about the archaeology report. He still practices *Ayni* with his family, although his sons must travel to town for the occasion. Señor H was the only farmer with fields in Paccareta to whom I spoke. We first met up with him at his family's house in town a few blocks from the plaza. He is from a prominent family in town, and we have attended several parties at their house in the past.[7] His family is one of the 15 founders in Paccareta. The final interview was with Señor J, another person with high social status in town and multiple businesses across the valley. He is kind and a wonderful storyteller, his eyes lighting up as he speaks about family, his land, and the future. As we hiked up to some of his fields, higher in elevation than town, we spoke about history, mytho-histories, and the landscape.

Each of the farmers reflect the diverse makeup of this rural town in southern Peru, highlighting the differences between decision-makers on the landscape. People are complex and have conflicting goals at different temporal and spatial scales. These goals additionally change over generations. My interviews were with people mostly in their 40s or above, with only one person's son contributing to his interview. The oldest farmer, at 65, lamented several times over the loss of local practices and the importance of generational knowledge. The following sections first summarize the cyclical practices of planting and harvesting and then outlining the multiple patterns and perspectives expressed by the farmers in Andagua, Peru, each reflecting the heterogeneity of the landscape and attempting to find social and physical meaning on the landscape through local terms and analytics.

Planting and Harvesting

Planting, harvesting, and other agricultural practices occur in annual and long-term cycles, expressed in flexible models subject to farmer decision-making in relation to climate change, social and economic needs, and individual fields capabilities. For example, Señor D described a multi-year cycle including alfalfa (*Medicago sativa*), tubers (*tuberaceae*), maize (*Zea mays*), and fava beans (*Vicia faba*). He first plants alfalfa, which he harvests for four to five years, before a period of rest. Then, he plants potatoes, rests the field, plants potatoes again and rests again. After this cycle, he plants maize or fava beans for two to three years before beginning the cycle again. Several other farmers also report planting alfalfa for four to five years in a row, although Señora A says there are other types of alfalfa that last longer–up to ten to twenty years–but the cows do not enjoy eating the longer-enduring strains.

Annual cycles include general planting seasons depending on individual crops' tolerance of cold and frost, and field location (table 3.1). Generally, planting occurs between September and December, before and through the beginning of the rainy season. Fava beans are an exception and are planted at the end of the rainy season and at the beginning of winter, which is likely due to its tolerance of the cold. Elevation is also a factor in planting and harvesting seasons as it relates to elongated warm seasons and warmer temperatures, in general. For example, maize's range is longer at lower elevations. According to Señora A, maize is planted between September and October in higher elevations and December and January at lower elevations, which she attributes to the warmer temperatures at lower elevations. Señor F reports harvesting maize, potatoes, wheat (*Triticum aestivum*), oat (*Avena sativa*), quinoa (*Chenopodium quinoa*), *kiwicha* (*Amaranthus caudatus*), onion (*Allium cepa*), and fava beans twice per year. Perhaps this is dependent upon individual field capacities and their location. Farmers with fields across different microclimates have a broader capacity for planting diverse crops throughout the year. Farmers additionally report farming *ollucos* (*Ullucus tuberosus*), and *ocas* (*Oxalis tuberosa)*, which are other tuber varietals.

The processes of preparing the ground, planting, irrigating, fertilizing, and harvesting were also reported as different cycles, likely dependent on crop type, location, labor availability, water availability and season. Ground preparation after rest included irrigation, turning of the earth, resting and fertilization either through spreading animal dung or allowing cows to graze for their dung. While this practice was observed throughout Andagua, only the farmer in Paccareta mentioned allowing cows to graze on their field. The majority of farmers in landed farmers in Andagua possess cattle, half possess pigs and a few possess sheep, suggesting this practice is a widespread occurrence (INEI 2012).[8] One farmer mentioned that they would *barbechar* (to rest or to trim) and *solear* (to rest in the sun) before planting. To *barbechar* is to irrigate, allow weed growth and then plow through the weeds (Jonathan Sandor, pers. comm., July 25, 2022). Other practices for preparing the ground include controlled fires of shrubs on the terrace tread or wall, although no farmer mentioned this during my interviews. While no farmer mentioned this, it has been observed on several occasions across the valley.[9]

Table 3.1 Annual planting, harvesting and resting seasons reported by farmers.

Month	Plant	Harvest	Other Action
January	Maize		
February		Fava	
March		Fava	
April	Fava		
May		Crops	
June	Fava	Crops	Rest
July		Crops	Rest
August		Crops	Rest
September	Maize; Quinoa; Crops		Rest
October	Maize; Quinoa; Crops		Rest
November	Potato; Crops		Rest
December	Potato; Onion; Maize		

Note: This table only reflects non-systematic reports by farmers and is not inclusive of all planting and harvesting cycles. “Crops” refers to a generalized season mentioned by farmers.

Labor

Out migration in Andagua influences agricultural practices and land use patterns through shifts in population and labor availability, although the impacts are uneven and contingent. People identify social relationships as crucial for the transfer of land and for the maintenance of cultural practices related to agriculture. Increasingly, generational differences in labor are prompted by younger peoples' relocation to Arequipa or Lima and their desire for capital. There are also differential changes across class, gender, and the strength of local social ties echoed in the heterogeneity of people and the landscape.

Most farmers identify their current land holdings as inherited from their parents. For example, Señora C's field on which she was harvesting maize were inherited, pointing out their contributions to the current use value of the small plot:

> [The plot] is from my ancestors, from my grandparents. Yes, there is a lot of history. For example, these trees are used for the house. The thatch houses with [unclear], this is the columns. That is why these trees have worth. It is called an *aliso*.

She describes the field itself as well as the straight-trunked trees that mark its boundaries, which she identifies as *aliso* (alder). These trees planted by her ancestors have additional value as construction material for thatched-roof homes or storage spaces, important for storing crops. Señor F also identifies his fields as his inheritance and his responsibility to pass along to his own son:

> [The fields] are from my ancestors - from the ancestors. It's from my father and he left me this field. When I die, I will leave it to my son, also. The land is like that, from the grandparents. It is our turn to manage, our turn.

He uses the term *herencia* (legacy or inheritance) to explain that he is only a manager of the land, and it is his responsibility to ensure its successful transfer to his son. Señora E similarly feels a responsibility towards her mother's fields and laments others who abandon their parents' legacy: "I mostly live in Arequipa…and this is the legacy of my mother. So, I cannot abandon it…I have my title. I have my papers, also." In addition to lamenting those who abandon their fields, she resents those who farm fields allegedly without proper identification. Señora E is the only farmer who mentions official paperwork in this way, which is perhaps related to her own frequent absence from town and tenuous relationship with the community. Her position as someone who is local but does not reside locally, likely informs her perspective on ownership, land use, and the relationship to the land. Farmer-field relationships mark both the ability to produce from them but also a responsibility to ensure their continuity to the past, present, and future.

Some farmers, when leaving town for temporary or permanent work, either sell their fields to other farmers or simply leave them uncultivated. Señor F describes an "abandoned" field as one left without its owner and caretaker, which can happen quickly: "It is [when] the owner suddenly is not there. They are in Arequipa or Lima. Like that they leave their land abandoned. Those are like this. Without an owner." Señora E connects this decision to leave with abandoning the material relationship to one's parents: "They decide or not to leave it abandoned, too. But it is a shame that the land is abandoned. It is a shame, a shame…" In this sense, the land is a representation of one's own personal relationships. While Señora E migrated to Arequipa when she was only one year old, she maintains the land in part because of its connection to her mother and her ancestors. Others may disuse their fields or decide to sell some or all of them to the remaining farmers. Half of Señor G's land is purchased from people who have migrated elsewhere, and all Señor D's land was purchased because his parents have not allocated him any of the ancestral land. Land of those who have migrated to the city is either in disuse or concentrated in the hands of fewer farmers, meaning there are fewer decision-makers on the landscape. Señor H has inherited his land in Paccareta, as has his brother who farms the neighboring terraced fields. Through this process of generational changes, such as inheritance, marriages and out migration, he no longer recognizes some of his neighbors. He says they are his cousins' children and spouses who he is a little ashamed he does not always recognize. Those who remain, through purchase, inheritance, or other acquisitions, continue to manage the land, leaving fewer decision-makers to ensure the social and cultural sustainability of the landscape.

Figure 3.4 Farmers participating in reciprocal labor practices at a potato harvest, July 3, 2016 (photo by Author).

In addition to changing patterns of land use and disuse, migration and movement impacts the social relations that are historically intertwined with plowing, planting, and harvests. Most farmers identify *Ayni* (a type of reciprocal labor exchange) to be a contemporary, if slowly discontinued, practice learned through generations (figure 3.4). *Ayni* is a practice among friends and family often accompanied by singing, dancing, eating, and drinking. It is considered part of local customs and stems from ancestral traditions. To Señora A, *Ayni* is when "you give me a hand working in my field today and tomorrow I go with you to your field and I will work without compensation" and "like this with family, we have chicha, we plant, and everyone is happy." Señor G describes it similarly as something that he does:

> [W]ith my family, my brother, my spouse, my brother-in-law, my children. We go and we work in my field. After my brother harvests, I go with all my family and plant…it is like *Ayni* or a turn.

Señor D describes it as a *mink'a* (another type of reciprocal arrangement) and a reciprocal "debt." It is a work exchange among family members and the debt is continuously paid and repaid across space and over time.

In addition to the mutual labor exchange, *Ayni* involves other *costumbres* (customs) such as gendered singing performances people describe as to *wank'ar* (to sing during work), which can involve the creation of an arrangement of crops and flowers into a tall, stalk-like feature placed in the center of the field to represent fecundity (figure 3.5). Señora A describes this activity:

> We organize the planting, we always *wank'amos* like this with family. We bring flowers, so that I know the seeds. We tie them up [unclear] the potatoes, with the flowers, with the wool lure. Then, we top with the potatoes.

To *wankar* is a Hispanicized version of the Quechua verb to *wankay*, which describes a work chorus or to sing in chorus during work (Hornberger and Hornberger 2013, 130). Señor G spoke with reverence for this practice and describes the processes:

> We drink, and in the center of the planting, the center of the maize seeds and the potatoes, we start to sing. We start to sing to Earth Mother, to the seeds, with our very characteristically old and beautiful songs. We sing to the plant, the seeds. It is the custom. For this, now, we are losing it. We are already losing it because, in turn, my children no longer live here. [unclear]…they have not conserved this tradition. It is being lost. But I also, I have lived it. The songs to the seeds in a site, like this. We sing to them, the very beautiful seeds. After the harvest, we hug [unclear]. Of course, *wank'ar*. The women *wank'an*. They sing. To *Wank'ar* is to sing. The women *wank'an* and the men happily applause [unclear]. Only the women. It is very special.

He notes that this practice is being lost and that the next generation, like his own children, has migrated elsewhere and is not learning or continuing these practices. This is resulting in fewer people practicing this custom, especially as people age and there are fewer kin for labor exchange.

Ayni and its associated social practices are decreasing across generations related to both younger peoples' desire for alterative incomes and, relatedly, peoples' lack of a large enough network to ask for *Ayni* participation. Paid labor and tractors are replacing these reciprocal relationships. As Señor G mentioned in the above quote, he has not continued to *wank'ar* with his children, although they do return home to help with harvests. He notes that other peoples' children do not come home at all. Additionally, according to Señor H, participants in a turn of *Ayni* usually receive a portion of the harvest; however, younger generations would rather be paid in money, impacting peoples' ability to continue reciprocal relationships, especially if they lack money to pay. Despite Señor H coming from a large and prestigious local lineage, he also partially relies on paid labor. Señora C pays for labor because she no longer has family to help with her harvest. However, it is difficult for her to acquire money to do so: "I don't have family, or husband, no one. I have to pay money. We sell a cow, a goat and from that we pay." In addition to selling livestock, she will sell clothing made from her own sheep wool to pay for help. Señora E also lacks family in town; however, being from Arequipa she appears to have additional sources of revenue to pay for labor as she does not own any animals. As such, class and monetary capital are increasingly important factors in access to agricultural labor; however, strength and extent of social relationships continue to drive labor availability in Andagua.

Figure 3.5 Evidence of social practices, possibly of *wank'ar,* in a field in the main valley, July 24, 2016 (photo by Author).

Crops, Cows and Class

The planting of and practices around potatoes and other crops additionally reflect change and continuity in Andagua. The discourse around the use or non-use of additions to fields, such as natural or chemical fertilizers and pesticides, reflects farmers' complicated relations to sustainability, subsistence agriculture and economic needs. For example, seed sourcing and storage for potatoes and other crops differ according to who the farmer intends to consume most of the crop. In other words, the practices and seeds change if the entire crop is intended for the market or if the majority is intended for subsistence. Potatoes for the market are usually grown from seed potatoes sourced from Cusco, Arequipa, Caylloma, Andahuaylas and elsewhere. In contrast, for their own consumption, farmers will source the seeds and seed potatoes from their own, ancestral supply. According to Señora A "maize, quinoa, everything is still from here from our ancestors. Fava beans, everything is from here. Yes, we do not buy these." Señor D directly connects his ancestral supply of seeds to other local practices that are not as common such as house construction styles that use *ichu*, an Andean bunch grass species, for roofing material, which increase the longevity of crop storage (figure 3.6):

> But most of the rest are our own seeds. The fava beans, Maize, quinoa, are from our own seeds that we have here…Yes, we always keep our seeds. So, this too, perhaps, before, for example, the houses were made of *ichu*. This is being lost. They have allowed me to conserve them. We call the sites that keep our fava beans and potatoes *cuyones*. They keep them fresher, for longer. But now that houses are made of metal, they spoil faster, much faster.[10]

Señor D wants to continue to practice this construction style and storage method, including keeping the *cuy* (guinea pigs) inside this space to protect his crops and seeds more effectively from degradation.[11] He expresses respect for and nostalgia around these practices that protect the connection to his past. Señor D, one of the oldest farmers that I spoke with at 65 years old, laments losing these important practices and continues to maintain them through constructing *ichu* roofs and raising protectant *cuy*.

Farmers spoke about how everything in Andagua is natural and that they instead make use of different types of *abono* (animal dung) to enrich the soil such as bird, lamb, *cuy*, camelid, and cows. Señora A does not often use *guano* because it attracts bugs but will use the other types of *abono* that are readily available. She recounts that she will add *abono* on the field after they turn the earth to help the soil hold water more effectively. Señora A says that the natural additions contribute nutrients and flavor to the crops, contributing to the demand for products from Andagua in places like Arequipa and Orcopampa: "All of the products are highly sought after because the flavor is something else when it is organic. The flavor is different." There is a clear emphasis by Señora A, and by others who spoke to me of the importance of not using chemical additions, and that there is a local demand for these products because of their flavor and the quality imparted by the natural additions. Señora A, a highly successful farmer with multiple local leadership positions, was the only person to phrase farming in this way–as "organic."[12] All the other farmers use the terms "natural" to describe the use of *abono* and other local practices, perhaps reflecting her connection to the discourses within the tourism industry.

Figure 3.6 A mixture of *ichu* thatched roofs and corrugated metal roofs on the structures. Camelid shown in the foreground carrying potatoes, July 4, 2016 (photo by Author).

Farming with *abono* is connected to other practices, some gradually lost to generations and others continuing to be important for both European and American crop varieties. For example, Señor D recounts the practice of using camelids or donkeys to carry camelid *abono* from the highlands to town for fertilizer.[13] While Señor D still gathers camelid *abono* from the highlands, he now does so by car: "But now, I have a car to facilitate this, and we go. We have forgotten these great customs." Señor D says that this practice enables farming alfalfa for four to five years between resting the land without resorting to chemical fertilizers. Señora E says she only uses *abono de corral* (dung from farm animals), preferably from lamb, rabbits, and birds, although she will farm without any additions, like the maize field she was harvesting during our conversation. Señora E is not the only farmer saying they did not put any *abono* on their fields that year, although they are speaking about chemical fertilizers, in particular. For example, Señor F said that he and other farmers in Andagua would never use chemical fertilizers or chemical pest control:

> Us, here, never use these *venenos* (artificial poisons). Purely healthy, nothing else, natural. We planted this maize that is up here. This maize is natural, without any *abonos*, nothing. It has nothing, nothing. Like this, nothing more. But now, we are planting potatoes, too. The potato also is like this, without *abono*. Yes, [fertilizers] are not economical. We don't use fertilizers. All Andagua is like this, without *abono*.

Señor F is adamant that farmers do not use chemicals both because they are unhealthy and because they are expensive. These are values linked to both consumption and economics, although these may be linked more strongly with crops grown for subsistence. He, like other farmers in town, takes pride in producing crops for personal consumption, such as maize, without artificial additions. At parties and events, people proudly proclaim the natural quality of the ingredients in their soups and the ancestral source of their seeds. Alternatively, the price of artificial additions would likely be offset if their use would result in higher yields for sale. Señora A reports growing organic potatoes and says that the use of insecticides will result a larger harvest because it kills a destructive bug; however, the quality is less.[14] Alternative methods for removing pests on alfalfa, for example, is to water the plants at night. Señora A described learning this natural method from a visiting engineer and recounted that it was very successful. The discourse in Andagua of everything being "natural" or "organic" is mediated by the fact that the "natural" crops are grown for their own consumption. Alternatively, farmers report using small amounts of insecticides for potatoes that they sell to the market. This juxtaposition exemplifies the differences between subsistence and market-oriented practices and crop types.

In addition to planting crops for consumption or for sale, farmers plant alfalfa and other forage for milk cows, meat cows and *toros* (bulls). Farmers plant several alfalfa varietals that vary in quality, maturation rates and longevity. According to Señora A, alfalfas' maturation rates directly correlate with quality. To demonstrate this, she uses human fetus growth as a metaphor: a baby that takes nine months in the womb is healthier and stronger than one that only takes six months. Equivalently, alfalfa that takes longer to mature is more nutritious and tastier to cows. Farmers will use the same alfalfa plants for four to six years, depending upon the field and alfalfa type, periodically leaving cows and other animals to graze. After this period, they will leave the field to rest and "recuperate." Señor G says this field recuperation period involves the reconstruction of terrace walls that collapse from irrigation water and from the grazing animals:

> So, the cows come and the bulls to eat. They topple over the walls, and the walls collapse and, again, you must put them back up to maintain them. After the animals eat, they eat the alfalfa, you must water it again for another round, for another campaign…You must irrigate it and maintain it.

The cycle of the growth of the alfalfa, irrigation practices, grazing animals, and terrace maintenance continues every year. This is partially why Señora E says she does not own any animals. She lives in Arequipa full time and animals require too much work to ensure that they are fed and have enough water. Like subsistence and market-oriented cultivation, feeding and animal maintenance are tied to social relations, economic capacity, and climate in addition to historic legacies, each of which contributes to prestige, race, and class.

Of the types of cows, milk cows are the most widespread, their production sold to a local cheesemaker or to a national, industrial milk dairy supplier. Every day, the milk truck will drive around the valley, picking up tins of fresh milk (and farmers looking for a ride). One farmer expressed disdain for the industrial milk supplier, preferring the local cheesemaker as the buyer for his milk. Other farmers and ranchers invest in prestige bulls and meat cows, which require higher input but result in larger profits. For example, Señor B and Señor H almost exclusively raise prestige animals and farm plants that support those animals, in addition to subsistence crops like maize and quinoa (figure 3.7). This disparity in wealth, as represented by the ability to afford these higher prestige plants and animals, is succinctly summarized by Señor B: "We are not equal." He says he does not grow potatoes or other crops perceived as lower status. Señor H ranches meat cows and *toros bravos* (bulls bred for bullfighting). He explained that oats, the remnants visible in the field, result in rapid weight gain and a particularly marbled and high-quality meat. The oats, in this case, are grown specifically for the consumption by the meat cows and, by this explanation, is not likely a large-scale practice. Señor H will additionally use his own *toritos* (diminutive term for bulls) for plowing his fields, a convenience he appreciates because others need to rent animals for plowing.[15] Señor H and Señor B both are members of powerful and large families with a long history in town. While Señor H and Señor B also grow prestigious crops for their own consumption, the class differences are stark among those who can afford to buy and rear certain breeds of animals versus those who cannot.

Figure 3.7 Some of Señor B’s bulls being herded across the valley, July 22, 2019 (photo by Author).

In addition to domesticated milk cows, there are what local people call *vacas salvajes* (wild cows) or *vacas cerranas* (highland cows). Señor J posits that these wild cows escaped several generations ago, breeding in the highlands and adapting to the cold. They have no owners but are occasionally captured for milk or to sell. Señor J and Señora A both describe the high-quality milk from wild cows. Señora A exclaims that:

> [T] they produce little milk, but it is rich, rich, rich! It is very different from a *vaca criolla* (cow of mixed heritage) that produces, for example, the cow produces 20 liters. It is different milk from a highland cow. The milk from the highland cow that my parents would always get…the milk is purely rich.

While the wild cows produce less milk than the mixed heritage cow, the milk is especially rich in flavor, nutrition, and fats. The higher percentage of fat in the milk, which Señor J estimates is around 30%, produces more cheese with less milk. During droughts, farmers would capture the wild cows and allow them to graze on alfalfa to mitigate the decreased natural editable vegetation. Alternatively, during rainy seasons that generate ample natural vegetation, Señor D recalls accompanying his family to the highlands with their domestic cows to graze. However, he notes, there has not been enough natural edible vegetation to practice this anymore, a pattern he attributes to climate change increasing temperatures and decreasing rain.

Infrastructure Changes

Canals

Farmers describe how physical changes to the canal and organizational changes to its distribution of water have altered land use patterns and extent, both facilitated by non-local institutions. Despite these changes, land measurement and water distribution are still based on socially prescribed units mediated by the physical world. This section outlines embedded sociality on the landscape and its reciprocal impact on water and land.

Irrigation across the valley is immensely important to the cyclical patterns of everyday life, seasonality, planting and harvesting. Organized rituals among water users ensure the maintenance of springs and hierarchy of canals. For example, Señor D recalls practices related to raking sediments around a water source flowing past the Jenchaña Volcano in the Coropuna watershed, west of town. He says that today this practice and much of the water source is lost; the water that does flow is no longer sufficient for large-scale irrigation. Instead of using water from the Coropuna watershed for those fields, he now relies on irrigation water from the Inca Canal sourced from the Andagua River. Cleaning of the Canal Madre in this system and their offshoots is a crucial social practice in Andagua. Together, farmers drink chicha, play music and work to clear the Canal Madre.

The clearings of smaller canals are similarly organized by the canal leader and the users. These work parties are becoming less necessary and less "strenuous" because, beginning in 2016, a mine upstream of town donated cement to line the major canals. According to Señor D, the canal upkeep dramatically decreased largely due to the diminished need to maintain the edges. In adding cement, both the physical landscape and the social relationships are beginning to change.

The organization and methods of irrigation distribution in the main valley have changed over time. Currently, the president of the irrigation commission oversees the Canal Madre while each area has its own *partidor* (a rotational position as a canal manager). Señora A explains that previously farmers would request water during irrigation meetings according to their fields' environmental characteristics and their planting decision-making. According to the farmers, an NGO conducted a study and decided that this was inefficient, implementing a new system organized around a *turnación* or *turno* (turn). A turn allocates an assigned water time for each terrace set, regardless of need. Water is then distributed beginning with those closest to the intake and proceeding downslope among a hierarchy of feeder canals (figure 3.8). Señor G describes this turn as such: "For a turn: my neighbor has their field. My neighbor receives water and then me and then my other neighbor, continuing to the end, to the last field in Andagua." This process is stressful for Señora A because the volume of water during this period is often not sufficient for her fields. When her allotted time is up, her neighbor in the fields below will begin their own turn and the irrigation "will not wait for you, for any reason." While the previous system also caused strife, Señor G describes the turn system as unjust. People can be assigned times in the middle of the night, requiring them to work in the cold to irrigate their plants: "Andagua is 3500 meters in altitude…and the cold and the climate. The poor people, the weather freezes us. It does not end!" To Señor G, this "antiquated" system would be improved if they built a larger reservoir to hold the water during the unfavorably timed irrigation turns.

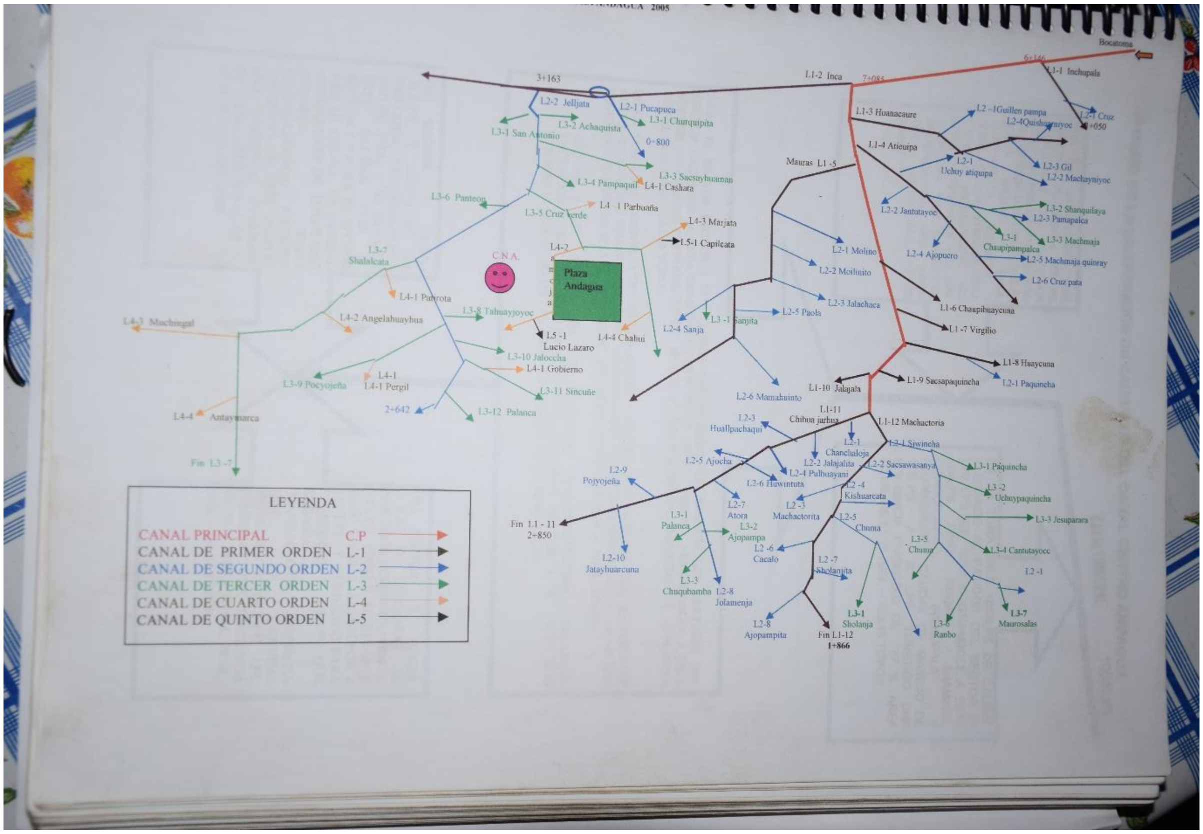


Figure 3.8 Photograph of canal schematic arranged within a hierarchy from 1st to 5th order (where 1st is closer to the mouth and 5th is furthest), with the canal *bocatoma* (canal inlet) labeled the Principal Canal. The portion of the canal named the Inca Canal is labeled as a 1st order canal, April 9, 2016 (photo by Alexander Menaker).

According to Señor G, the current reservoir holds 1200 liters of water, which can only store water for a few hours, insufficient to alter the current irrigation arrangement. This system is causing tension among farmers especially if their allotted times are not ideal. While no one explained in detail the workings of the previous water distribution system, farmers expressed dissatisfaction with its current iteration. This irrigation concern is most prominent in the farmers living full-time in town. For example, Señora E does not live in Andagua and was unsure of the source of her irrigation water, asking the hired laborer to confirm. The positive attitudes towards the cement canals are partially related to increased water volume in them, increasing the spatial extent of irrigatable land. Social relations to water and the organization of it are crucial to maintaining the terraced system; however, perceptions of inequities and altered social practices and rituals may exacerbate the stated issues.

Tupu

The pattern of irrigation turns is additionally connected to a local landscape analytic assigned to a bounded plot of land called a *tupu*.[16] Señora A gestures to her terraced fields bounded by large walls and says: "the fields, like this one, all [of this] is a *tupu.* All of this is a *tupu,* from the top to the bottom." She says that one turn irrigates a single *tupu* in three hours with 180 liters of water, a time corroborated by Señor D. While one turn is measured by three hours of irrigation, the environmental characteristics of a *tupu* are relative across space and time. It is not enough water for some of Señora A's *tupus*, an issue for which she criticizes the NGO study. She says there was no engineer to calculate the proper allotment, creating inequities in its distribution. Considering this, a *tupu* is both a measure used to communicate field boundaries of different decision-makers across the valley and to organize irrigation for the Inca Canal regardless of the individual units' needs.

According to farmers' definitions, a *tupu* is a land unit defined through social and environmental relationships that are locally understood. Physical boundaries of dry-stacked stones mark these individual land tenure units. In one example of farmers' use of the *tupu*, Señora A described the differences in potato yields achievable between organic practices and insecticide use, initially reporting the yield in weight per *tupu* but then converting it to weight per hectare. The conversion to hectares was likely for my benefit–she assumed my unfamiliarity with these locally contingent units of measurement. Señora E and Señor G use *tupu* to describe the distribution of their fields mentioning multiple places across different elevations and with different environmental characteristics. Señor G uses diminutive suffixes and modifiers to illustrate the size of his small fields, referring to his *chiquitito* and *chiquito* (small fields) as a *medio tupu* (half *tupu*) or a *tupitu* (a diminutive version of *tupu*, meaning small *tupu*). The ability to modify these terms implies that there is a socially prescribed definition of what encompasses a *tupu.* While they are not standardized areal units of measurement, it is appropriate to refer to them fractionally.

The *tupu* also defines field units in Paccareta, manifest as dry-stacked stone walls. Señor H attributes these units to the rehabilitation of terraces in Paccareta in the 1960s. While the terraces were rebuilt during this time, the land tenure boundaries are new. According to Señor H, the large, stacked stone walls were added to divide the older, terraced landscape among them. This suggests that the *tupu* walls were not a defining feature of them in the past. In other words, the walls date to after the abandonment of Paccareta, which was likely before or during the early Spanish colonial period. Today, *tupus* are a socially ascribed means of measuring, characterizing, and dividing the landscape, and are important to multiple practices including farmer decision-making, water ritual, and practice.

Roads

Roads accommodating cars and trucks within the terraced valley and over the Coropuna pass directly connect the fields of Andagua with neighboring valleys, Arequipa, and the coast, and facilitate the movement of people and goods at different spatial scales. The original dirt road was built, in part, by the people of Andagua in the 1960s and was recently rebuilt in the late-2010s by the state as a modern engineering project complete with asphalt and concrete drains. Over the last 10 years, the municipality constructed dirt roads in Andagua through the valley and across terraces, widening old paths and altering canals. Today, both are top-down modern projects that provide farmers with transportation, tractors, and access to markets, academic opportunities, and jobs; however, it also opens conflicts between the Indigenous community and local state authorities. This section outlines farmers' conflicting perspectives on these projects.

The twenty-first century municipal road construction through the valley expanded old paths and bulldozed through terraces, revealing buried ancestors and material culture, which angers residents. However, when asked about the proximity of roads to their terraces, farmers speak positively about the decrease in labor inputs for transportation of people, equipment, and harvests across local and regional levels (figure 3.9). For example, Señora A speaks about how the roads directly connect her with external markets, saving time and labor:

> The road, yes, is a really important help for us. For example, I have the harvest here. I have a bag with my potato harvest, for example. I take this by way of the road and the car brings it from there. Before, it was not like this. So, for example, this little road that you can see here, the path there, from there I would carry my potato harvest using a burro or bring it by llama. It was hard work. Now, no. Now the harvest is carried by a car, including the buyer in their car. There [at the road] I sell and then bring the rest to my house so that we can eat it for the next six to seven months.

Buyers drive to town in big trucks to buy potatoes directly from the farmers next to their fields. This connection from the field to the city also allows farmer's children to easily and quickly return home for the harvest by way of the regional road.[17] It is too soon to make conclusions about how the asphalt will alter transportation capacities; however, people have commented on how the engineering has made the regional road less safe. The road has narrowed, and the smooth surface allows people to drive quickly around blind turns with no guardrails.

Figure 3.9 A Señora descends from a step shortcut to a path to the main valley from town that is also cut through by a road navigable by car, July 22, 2019 (photo by Alexander Menaker).

The local roads through town also allow Señora A to drive a tractor to some of her terrace treads: "We are still cultivating like our parents, but now, we can work with a tractor on land that is even with the road which is much faster. Less labor." According to Señora A, they take advantage of the work this technology saves, especially since there are fewer people to conduct *Ayni*, the reciprocal labor practices based on kinship. It decreases the number of days of work and is more powerful than a *yunta* (an animal-powered plow). It is my understanding that this is a community tractor; however, the road design and the stepped topography of the terraced landscape limits which terrace treads are accessible and which are not. The roads also allow people to bring materials and goods across the landscape. For example, while her fields are inaccessible for the tractor, Señora C uses a truck to bring dung to her fields, which are adjacent to, but below, the surface of the road. Señor G uses the roads to move among his many fields, scattered across the landscape: "Everywhere I have them [terraces]…I go there, I go over there…Just walking, just walking." This road eases travel for farmers like Señor G, especially when they can catch a ride. Both the local road and the regional road increased movement of people and things across the landscape and around the broader region.

Farmers are generally happy with the ease brought by both the regional and local roads, but there is discontent with the construction process of the local project and the results of the regional one. Terraces, under the authority of the *comunidad de campesinos* (community of farmers), were bulldozed or altered by the municipality, the representation of the state, causing tension between these two authorities. Additionally, eroding sediment from overland flow is visible on the steep dirt roads, potentially causing future issues with sediment in the river and landscape instability.

Farming Volcanic Lands: Soils and Water

The volcanic landscape, in combination with everyday practice, creates both benefits and issues for farmers on the landscape. According to the farmers, the main valley is composed of clayey and sandy soils, both of which lie over porous volcanic rocks, which differ from those in Paccareta and Soporo, but for different reasons. For example, farmers identify a heterogeneity in the topsoil texture and color across the main valley. Señor G points to the loose, black sand near where we were standing to demonstrate some of the soil properties in the main valley. Señora C explains that the soil where we were standing is loose and sandy while the soil further down in elevation was harder and clayey. Señor D also identifies his terrace soil as loose and sandy in contrast to his fields below in the *quebrada* (intermittent stream in a ravine). The unconsolidated sandy soil to which they refer is abundant across the landscape, especially on topographic lows of disused terraces.

In contrast, Señora A describes the soil in Soporo as not volcanic and generally possessing higher quality environmental characteristics for farming than in the main valley. According to Señora A, the main difference lies in the soils' capacity to hold water, evidenced by the need to irrigate only every 40 days in Soporo to ensure the appropriate soil moisture. The Señora considers Soporo's potatoes and *choclo* (large-kernelled maize) better overall than in the main valley due to the soil. Since I did not interview anyone from Soporo, this perception cannot be corroborated, but Soporo is lower in elevation and located in a side-valley overlying alluvial sediments (see figures 1.2 and 1.7). Similarly, farmers contrasted the soil between the main valley and Paccareta. Señor G, a farmer in the main valley, described the soil in Paccareta as firmer and clayier than in the main valley. He says that the difference stems from the soil in Paccareta being non-volcanic, or at least not like the black sandy soil present across the main valley. Señor H, a farmer in Paccareta, describes the differences even within a single terrace set, pointing to sandy volcanic soils in one terrace and a browner, more fertile soil in the terrace below. Señor H describes the main valley as more fertile than Paccareta due to its antiquity: the main valley is "volcanic land. The old land is clayey land. It is very fertile." While farmers have been using practices to maintain soil fertility in the main valley more continuously for a longer period, farmers in Paccareta had to entirely rehabilitate what they recall as a clayey surface missing a topsoil. The process of turning this clay into a workable soil included years of turning additions into the soil until they improved the texture and fertility. A road cut in Paccareta reveals the dark agricultural topsoil and the results of their labor (figure 3.10). It exposes a topsoil with a sharp lower boundary overlying a lighter, clay soil with a sharp lower boundary overlying an even lighter horizon overlying altering light and dark ash and tephra grading into larger (1 meter diameter) bombs. The different perceptions of each place are steeped within deep knowledge of their own fields and broader historical discourse about the landscape.

Figure 3.10 Soil profile of a terraced field from a roadcut in Paccareta, July 4, 2016 (photo by Author).

In addition to broad patterning of soil types, individual fields possess heterogeneity in soil characteristics including how water ponds or infiltrates the surfaces. To mitigate some perceived heterogeneity and issues related to these soil properties, farmers practice intercropping or multicropping, which refers to planting multiple crops in a field at a single time. Señor D intercrops maize and quinoa to mitigate plant sensitivities and to take advantage of the microtopographies and soil differences:

> These fields we always put quinoa in the borders. Maybe you have seen my fields recently. In the borders there is quinoa, maize, also fava beans according to where the water will reach. In the parts, for example, which are more inundated with water, I put fava beans because the fava beans are more demanding than maize with water…you will see fields that are not pure fava beans or pure maize…it is a mix.

The distribution, extent and patterning of crops are carefully considered at both the spatial and temporal scales, each considering a farmers' personal holdings as well as the crops' needs.

Figure 3.11 Hole in a broad field terrace in the main valley, July 24, 2019 (photo by Alexander Menaker).

In addition to soil type, farmers identify the underlying geology as one explanation as to the quick disappearance of water below the surface regardless of the topsoil texture. The volcanic subsurface enables water to quickly percolate through soil and into the underlying rocks. Señor G explains:

> They are volcanic lands. Why? Because when we irrigate, when we release the water, when we irrigate…it soaks [into] and percolates through the soil. The water disappears. The water leaves the soil. So, a characteristic of this land is that it is over lava...The water soaks in and the water disappears.

Señor G says that the disappearing water is evidence of the lava underlying the fields. Señor D, Señor F and Señora C also identify underlying lava and rocks as the reason for the disappearing water, in both the fields and the unlined canals. Señora A says that to produce a quality crop, the soils must be irrigated according to individual need and the characteristics of water movement through the soil:

> Here in the Valley of the Volcanoes, the soils are…it is volcanic land. It often quickly opens pipes, you know, under the land. So, irrigation is dependent. It could be every 15 days, 18 days. It does not maintain moisture because it is volcanic land.

It can take Señora A's fields only 8 days after irrigation to become dry, requiring her to irrigate at least twice a month. She additionally identifies calcic soils, which become dry after only five days. The water not only disappears, requiring more constant irrigation, but its percolation through the underlying lava fields creates holes in the terrace platforms (figure 3.11). Señora C blames the volcanic landscape for the development of these features: "It is volcanic, [the water] makes holes [in the surface]. The water passes through [it]. The water filters below." As the water filters quickly through the subsurface, it creates a hole in the surface of the soil. Señor G says that it is not useful to flood irrigate his soil because it will create a hole in the surface. Señora A identifies the physical impact as both surface erosion and holes in the surface of the terraces: "Holes open very quickly. Look, the holes…these are made by water." Señora A points to fine rills in the surface of her soil and further describes the velocity of the water as it enters her fields. The velocity, she says, is a result of the recent canal cementation. The 2016 cementation of the Canal Madre was completed using donated money from a mining company with the intention of increasing the irrigation water volume by preventing infiltration. Smaller feeder canals are slowly being cemented across the landscape, increasing the volume and velocity of the water.

The canal cementation was generally perceived as a positive technological change on the landscape, especially in relation to the perceived droughts and decreasing water availability. Señor H notes that the rainy season is both shortening and arriving later in the year. Señor F similarly notes shifts in the seasonality of the rains, which he attributes to climate change. He says that the rain used to arrive in November and December, but now they arrive in January and February. Señor G says that while that year had good rains, they were late. Generally, the rains start in November and last through March and April. Now, the rains start in February or March and last only a couple months. Other farmers, like Señor D, also note that the seasons used to be more defined, but now climate change has made them less predictable. This is altering when farmers, like Señor G, decide to begin preparations for planting. Farmers credit the cementation, and its ability to prevent infiltration of water through the canal bed, to the larger volume of water now available for irrigation. Señora C says "yes, there is enough water" and Señor D says that they continuing to cement the smaller canals to further improve the volume and decrease the amount lost to infiltration. Señor F remarks on the increase in the quantity and that the cementation makes logical sense in relation to the hydrological properties of the underlying volcanic soil and lava. He additionally remarks that the fields in which we were standing were only recently made usable due to the increased extent of irrigation water to this area. Previously, the water did not reach these lower-elevation fields, preventing him from farming them despite the other favorable environmental conditions.

Figure 3.12 Irrigation water exiting a canal at a water drop and leaking from stone-lined canal edge onto sloped tread, July 23, 2019 (photo by Author).

Paccareta has a separate canal that sources water from the Andagua River, which was constructed or reconstructed during the 1960 rehabilitation. Farmers in Paccareta are similarly experimenting with ways to decrease water infiltration in canals. Señor H points to a canal lined in black plastic traversing his brother's field and says he is considering trying this method on his canals to increase water volume. He says the cost of cement and sand is high and, although he perceives it as a better solution, the black plastic is the cheaper option. Either way, any solution to this problem of infiltrating water, Señor H says, will be fairer than the current situation: “I bought a membrane and this and I think that this is a good idea…It makes it a little more just.” While farmers remark on the benefits of cementation, several farmers also note issues related to the altered canal as well as the river water itself.

Generally, farmers spoke positively about the canal cementation; however, Señora A emphasizes that the water is now clearer, reaching the fields with little to no suspended sediments (figure 3.12). She is favorable of the increasing water volume, but is concerned that the canals no longer carry sand and other fine particles to the fields:

> The most important canals have already been channelized. They are channelized with cement. But it seems to me that while more water comes from the canal, it comes clearer and…it no longer brings the sand, the fine soil that comes with the water and tops the holes. And it no longer does this. The water comes much cleaner.

She explains that the water is flowing at a higher velocity, and while irrigating the volcanic soil would previously leave holes, she says that the water no longer carries or deposits sediments to help cover those holes. Farmers also are concerned about water contamination from the upriver mining activities, describing the milky color of the water as it enters the river from their processing plants. It is possible that the solutions to perceived issues with soil water retention and heterogeneity, climate uncertainty, and irrigation distribution may create new, complicated issues relating to reduced sediment deposition such as a decrease in fresh minerals and soil fertility.

Climate Change and Maize

Farmers’ descriptions of climate change and continuity most often use maize as the standard by which changes are measured. Farmers’ knowledge of an area’s capacity to cultivate crops, including maize, is acquired through generational communication and experimentation. This section explores the dynamism of local knowledge and how that flexibility interfaces with perceptions of climate change.

In contrast to other crops like hearty tubers, maize is vulnerable to adverse climatic conditions, requiring farmers to carefully consider its planting location. This consideration was present in peoples' minds when I asked them to describe the characteristics of various places in the valley. For example, Señor G highlights elevation and climate, and the capacity to grow maize, when describing the differences between Paccareta and the main valley:

> Each farm has its own climate and altitude. The ones in Paccareta do not grow maize. Why? Because it is very cold. In the valley below, maize does grow because the climate is much milder, it is warmer. This is a characteristic [of each area]. So, below in the fields [in the main valley] there are also areas that are cold and those that are warm. So, on warm days, we plant maize and on cold days we plant fava beans.

While it is unclear if the Señor is describing an on-the-day decision in this scenario, it is likely farmers decide based on other, long-term conditions such as seed or irrigation availability. Additionally, while he generalizes Paccareta as land unable to grow maize, he explains that the pattern of maize production is partially dependent on the microclimate of each field in addition to seasonal climate variability. When speaking about microclimates or climates, people are usually referring to temperature, wind and precipitation and soil moisture and temperature conditions at the scale of the field and soil column. Similarly, Señor H describes altitude and climate as important considerations when choosing planting locations. He says that each place has its own *microclima* (microclimate) that impacts how he distributes crops across his fields. Within the areas that can grow maize, there can be stark differences in the harvests. Señora A explains through a metaphor of maize soup: the heartier and more flavorful soup is made from maize grown at more favorable elevations with warmer temperatures. A maize soup made from higher elevations requires more maize for a similar heartiness but has less flavor. Additionally, the maize at a lower elevation grows more rapidly and results in a larger harvest.

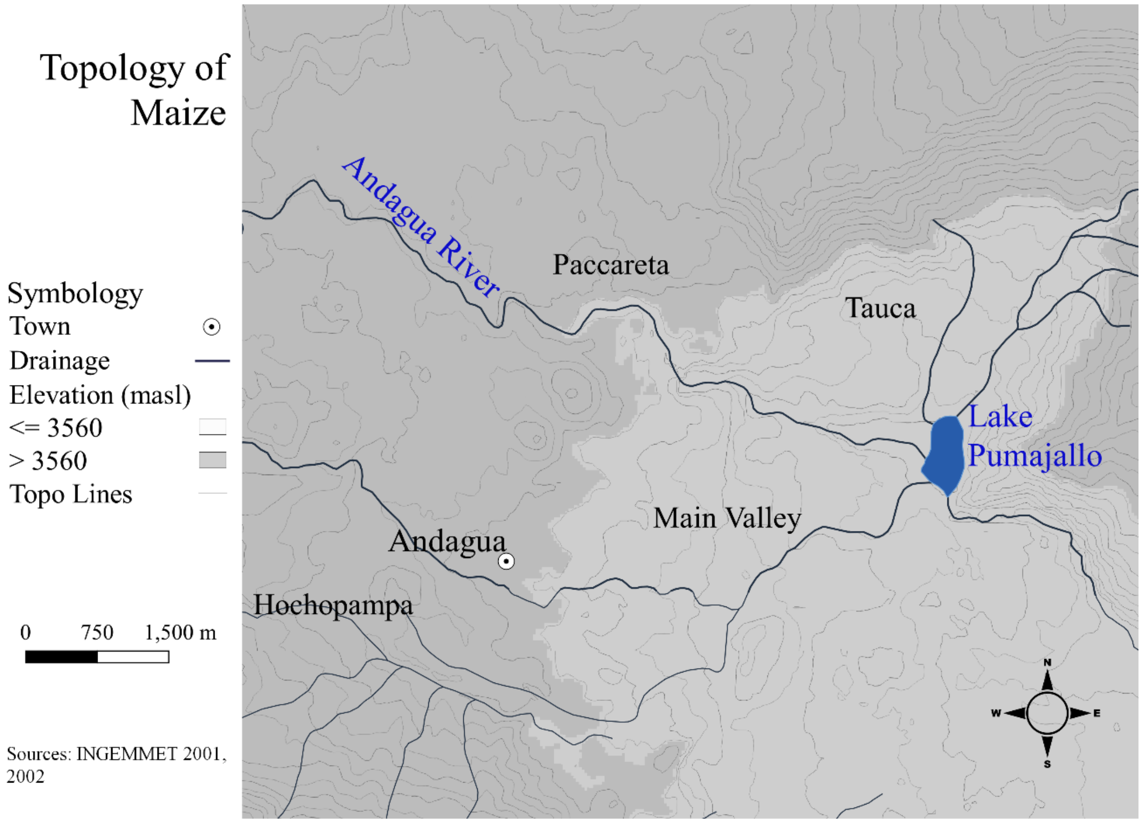


Figure 3.13 Areas around Andagua above and below the lowest elevation of the town of Andagua (3560 masl).

To possess a field that can grow maize has meaning and value beyond consumption. Señor D laments that his "best field" is not what is called a *maicero* (a field that grows maize), because it is a little too high in elevation. Señora E similarly uses this term to describe the differences among her fields. The field in which we spoke she described as a *maicero* as well as another field in an area called Sahuacata. However, a field that is a *maicero* is not just one with an appropriate microclimate, but one also with access to irrigation water. One farmer described his inability to farm a low-elevation field because the irrigation water from the Canal Madre had not reached that far in a while. In addition, farmers' discussions of their maize fields are often accompanied by a description of which fields do not support maize. These non-*maicero* terraces, at higher elevations and cooler temperatures, farmers grow heartier crops such as tubers, fava beans, onions, *ollucos*, and *ocas*. Farmers additionally mentioned alfalfa, wheat, oat, quinoa, and *kiwicha*, although they did not go into detail on where these crops were usually planted.

This maize standard is further exemplified when farmers were asked if they noticed any changes in the climate. Farmers are testing the perceived shifts in locations of potential *maicero* fields. Señora A, Señora C, Señor G and Señor H each use maize as an example when asked if they perceived any recent changes in the climate.[18] Several exclaim that maize is now growing in town, which is at an elevation of almost 3600 masl, higher than the typical upper reaches of maize cultivation in Andagua. Señora A says, "but now, with this significant change that is global warming of the earth, maize is in my house!" Señora A additionally describes the unseasonal increase in temperature, which is up to 20 and 21° Celsius in June at the time of the interview when normally she says it is around 14 or 15° Celsius. This difference, she says, directly suggests a changing climate and, specifically, global warming. She was the only farmer to use global warming as a description of the changes and expressed deep concern for both the perceived and documented changes in temperature and precipitation. Señor G, among several other farmers, similarly associates climate change with the expansion of maize cultivation: "It is already warming. It is notable because in the cultivation that we have, maize, for example, is for warm climates and the planting is only below in the valley. However, now, we have planted in town! In town we have already planted maize!" While Señor G described Paccareta as not normally maize producing because of its high elevation and cold climate, Señor H, a farmer in Paccareta, says that people with fields at lower elevations than his in Paccareta have begun to grow maize:

> Several meters there, down below, can produce maize. Maize does not grow well, but it grows…Yes, I noticed that. For this, I say, that before in Paccareta maize was not planted past the bridge. Maize was not planted. In places maize was not planted previously, now maize grows. As I say, it was not planted. The climate has changed. Yes, it has changed.

While the maize is not of high quality, he expresses that it is possible to grow at elevations that push the previous perceived boundaries of the crop. This perceived change is resulting in experimentation on the part of several of the interviewees and their relations. Señora A, interviewed in her terraces, explained that her and her father were knowledgeable of which fields would effectively grow which plants and which fields have never effectively grown maize. Yet, Señora A's husband decided to "casually" test maize in fields at higher elevations simply because he had a desire to try:

> I have lived here since I was a child. So, my father knew which land produces maize and which land does not…For pleasure [my husband] is testing the land. 'But I want to try to see if maize will grow,' said my husband. And he planted it, and maize grew where maize never, *never* had grown…It is not much, the maize is not growing much in the higher elevations…

While it was not a hearty yield, its successful growth indicates that the range of elevations suitable for maize is changing in Andagua. Similarly, Señora C is experimenting with the perceived changes in temperature using maize: "The maize is like this, small. I don't know, it is a test…I am testing the climate." She demonstrates using her thumb and forefinger that the maize is smaller than she would like and that some of the maize husks are empty; however, she explains that it was just an experiment to test the changes in climate. Although Señora C has few resources, she decided to spend energy, time, and money to conduct this test. Farmers are experimenting with the established boundaries of maize by expanding into areas that previously were suitable only for colder weather or heartier crops.

This demonstrates not only the flexibility of local knowledge and the importance of experimentation, but also the importance of maize as the measure.

It is revealing that farmers consistently use maize, a crop with cultural importance and narrow environmental requirements, as a barometer of both field microclimates and their change. A field either is or is not a *maicero*. However, as farmers define the use of a field through maize, they are communicating its microclimate and other biophysical factors. Understanding the human-environmental implications of farming a *maicero* is knowledge that is socially produced through generations, as Señora A attests, and is socially and climatically meaningful.

Looking Forward

Land tenure, management, and extent in Andagua today is mediated through past local, regional, and national social processes and forces stemming from the Inca, Spanish and Peruvian states in addition to environmental forces and landforms. In living memory in Andagua, farmers recount the *gamonal*, landowners whose power stemmed from Spanish colonial and post-colonial political circumstances, but not entirely equivalent to the *hacienda* system. Señora A was one of the few farmers who spoke to me about the local *gamonal*, a family who mainly raised cattle across the valley. She recounted several stories of violence, coercion, and control told to her by her grandparents and parents:

> My mother told me that they supposedly had a field over there. It was beautiful, they liked the field. Well, he told them, you know, sell me the land. The Señora says, I cannot because I have children, grandchildren. [he ordered] 'Sell it to me.' [she said] 'No.' Well, he had a bar in his house where you would be hung by the hand…Well, bones broke. [she said] 'I will give it to you.'

Señora A goes further to contemplate the suffering and hard work of previous generations, emphasizing that it was not done in vain. In several sentences, she speaks about the past, present and her own vision for the future:

> How much have Andagüeños suffered? How much do they suffer? How much have we suffered over the canals to bring water here? How much? Sometimes, my generation today, we don't know, Thank God…My father worked hard for this land. For this, too, I work for tourism with much love. Tourism will have its time now.

Señora A summarizes the suffering of the twentieth and twenty-first centuries related to the *gamonal* and water security, and then turns towards the future with a positive and hopeful determination, especially for tourism. Señora A is pivoting towards opportunities available through increased connectivity to non-local markets. Tourism in Andagua has increased in the twenty-fist centuries, especially through Peruvian city-dwelling tourists interested in the volcanoes. The recent designation of Andagua as part of the UNESCO Geopark is an exciting topic of discussion by locals. While drinking some chicha before heading to Paccareta with Señor H, he mentions that many people are leaving farming because it is hard work. Fields are "abandoned, without cultivation." However, he and other locals are hopeful that tourism will increase with the Geopark's creation. People are investing money in small hotels, restaurants, and other amenities, catering to the perceived influx of people and capital.

Other farmers are diversifying through the cultivation of organic produce for regional, national, and international consumption. One farmer and his son are experimenting with growing organic onions for export in the high elevations above town. They explain that the lack of bugs at so high an elevation enables them to grow without the use of pesticides, which is a significant advantage over coastal production. Additionally, they hope to contribute to the demand for organic produce in international markets. Another farmer in Tauca is growing a wide variety of crops, creating cheeses and raising bees for honey, all generated for the increasing market for local, organic produce within Peru. These different approaches to production for the market economy demonstrate the opportunities farmers and ranchers are creating for diversification within the changing social, physiographic, climatic, and economic environments.

DISCUSSION

The farmers I interviewed represented multiple genders, classes, lineages, and knowledges informing our interactions and how they perceived my questions. While this was heterogenous, the interviews revealed several broad themes connecting to historically and physically grounded local practice, perceptions, and ontologies. Farmers' direct and indirect discussions concerning change are narrated through real and metaphorical discussions over maize and potato production, for example. Change in practices and knowledge of those practices are also noted through shifting patterns of labor and migration, enabled through technologies such as paved roads and mechanical tractors. Technology is also providing more water, although farmers perceive that water to also be bringing contaminants and a smaller volume of suspended sediments. Finally, the means of measuring land and water is deeply social, embedded in history and knowledge of the landscape. This section will revisit these themes, exploring the social-physical meanings within broader contexts and their complicating heterogeneity.

Maiceros and Microclimates: Evidence of Climate Change

To define a field as a *maicero* in Andagua communicates its microclimate and generational knowledge of the area. It is possible that creating this binary–it is either a *maicero* or it is not–relates to its historical and contemporary significance in ritual and everyday life. Maize was cultivated and processed in the preceramic periods in southern Peru as early as 2500 BCE (Perry et al. 2006).[19] Additionally, fermenting maize into a low alcoholic beer, called *chicha* (maize beer), is important for local ritual and community activities, and connected to pre-Inca highland state production as early as 550-900 CE (Valdez 2006). As summarized by Covey (2006, 52), maize became central to agricultural production during the expansion of the Inca Empire; it was integral to ritual activities and for feeding and feasting those contributing labor to the state. The Inca increased obligations of maize in areas with appropriate climates, intentionally moving people downward in elevation from tuber-growing areas (D'Altroy in a comment to Guillet 1987) and enforcing the dedication of large swaths of areas for maize (Zimmerer 1996, 37). They additionally intensified existing and constructed new irrigated terraces to cultivate a surplus of maize in climates that could support its production, especially to produce chicha (Zimmerer 1993; Murra 2002, 47). Additional ritualized generosity of local highland lords included the distribution of *chicha*, among other products often not found locally, as part of the multi-layered ritual labor and goods exchanges (D'Altroy 2015, 315-316).

Maize was central to ritual in Andagua, such as when everyone dances and sings during harvest (*wank'ar*) around a maize stalk and when it is used in multiple forms, such as maize flour mixed with camelid fat and as popping maize, during offerings to Earth Mother. Maize can be seen drying in courtyards, gardens and on roofs in Andagua while cows feed on the remnant stalks after harvest. *Chicha* is also an important fixture in daily work, at festivals and parties, and is also shared among Andagüeños during harvest and planting activities. Maize's importance through time is reflected in its significance in Quechua myths, for example, when maize is identified as one of Earth Mother's daughters (Silverblatt 2005, 39-41; for other ritual surrounding these crops, see also Rowe 1946, 215-216). According to Silverblatt (2005, 38-39), Earth Mother had five daughters: maize, potato, coca, metal, and clay. Saramama was the name of the maize daughter who was an important representation of fertility. The male god of thunder, seen as the source of rain, was the male pairing to Earth Mother. According to local mytho-histories, Saramama is also the wife of the volcano Coropuna (Menaker, *pers. comm.*). These gendered relations to maize are also reflected in the creation of chicha, a household and ritual activity in the highlands historically reserved for women (Silverblatt 1987, 9).[20] As summarized by Murra (2002, 143-149), Spanish colonial chroniclers recounted extensive rituals relating to maize in the Andes including the singing, offerings and time afforded to its harvest and the use of it, as is or as a derivative product, in other ritual contexts. Market trading in early Spanish colonial Peru often involved maize as a means of exchange among, usually, women, as summarized by Mayer (2002, 58-59). Maize has long been incorporated into ritual and daily life in the central Andes, perhaps influencing its use as an important marker of climate, soil quality, irrigation capacity, and change.

Maize, then, is an important crop to daily and ritual life in Andagua and in the Andes, but Andagüeños expressed mixed emotions when describing its expanded cultivation range. It is established that boundaries of crop cultivation in the southern Peruvian Andes are patchy and socially and environmentally shaped (Zimmerer 1999); however, farmers demonstrated uncertainty when these fuzzy boundaries were significantly challenged, especially in context with other changing climate patterns. In Andagua, the town was perceived as a boundary, at or above which maize could not grow. Multiple farmers, including Señora A's husband, proceeded to experiment with maize and the new microclimates global climate change is producing. Gade (1967) also documented farmers testing boundaries of maize cultivation and investing in its success by building new infrastructure in other areas of southern Peru. The experiments in Andagua reveal that maize does grow at elevations of around 3600 masl in both Paccareta and in town, although not as well as lower elevations. Farmers were shocked that maize was growing at these elevations, a new piece of information building on their generationally produced, local knowledge of microclimates. Not only did farmers remark that the temperature was several degrees warmer than usual for that time of year, the precipitation amount and seasonality were also shifting.

Climate scientists expressed uncertainty when projecting the impacts of climate change on the heterogenous landscape of the Andes (Imfeld et al. 2020; Pabon-Caicedo et al. 2021), making farmers ideal informants about the local impacts of these global phenomena. However, not all farmers have the same depth of knowledge about the micro- and meso-climates of the valley. The only farmer who did not remark on the changing climate was the Señora that lives only part time in Andagua, commuting for planting and harvest from Arequipa, demonstrating the importance of daily experience and social relationships to environmental perceptions. Farmers are changing practices and experimenting with their evolving climate realities; however, we know that mountains are especially vulnerable to rapid changes from global climate change (Zimmer 2002). As such, it is necessary to provide locally flexible support for farmers to mitigate the impacts.

Labor and Class

While there are several crops specifically planted for the market, potatoes represent social and economic change, and practices related to them mark differences between locally and externally consumed products, the former being heritage crops and the latter typically being non-local varietals. The recently constructed local roads and newly improved regional roads alter the temporal and spatial patterns of movement through the landscape. Buyers travel to Andagua, drive their trucks through the terraced valley, and buy crops directly from farmers during harvest. This ease of engaging with the external markets correlates with an ease of acquiring high yield seed potatoes and the required pesticides. However, these non-local varietals are especially vulnerable to pests because they were developed elsewhere. All other crops, farmers were quick to tell me, were natural and grown with natural fertilizers such as animal dung.

The type of dung used seemed to be a personal preference perhaps in connection to affordability, accessibility, tradition, and class. Crop type is also important. For example, external seed potatoes require chemical inputs sourced through improved transportation systems. The INEI (2012) generally corroborates these numbers, documenting only 23 producers using chemical insecticides, 9 using non-chemical and non-biological insecticides, 26 using herbicides and 10 using fungicides, with a total of 43 using one or more of these to control pests. Alternatively, 287 producers report not using any of these. In interviews, farmers reported using little to no animal dung for heritage crops, on occasion, which may or may not be possible due to several factors: freshly weathered volcanic materials delivered by irrigation water or from soil; its cold and dry environment; enduring soil organic matter contents from previous input; growing cycles that include nitrogen-fixing plants; and dung from grazing domesticated animals. As summarized by Yamamoto (1985, 92) and Knapp (a comment in Guillet et al. 1987), potato cultivation, for example, requires additional inputs and the terrace productivity in the past was likely maintained through camelid dung.[21] Señor D described a practice of retrieving dung from the highlands, something that has become more accessible by road, although he almost laments the ease. Historic precedent for these relations between herding, maize and tuber areas are often organized by an *ayllu* or family kin group (D'Altroy 2015, 316). Older generations recall periods before the regional roads, when reliance on reciprocal labor and goods exchanges enabled access to materials and food from different altitudes. Pastoralists from up valley could exchange camelid wool and dung, *yareta* (*Azorella compaca*) and other goods from the *puna* with farmers for lowland crops.[22] It may be that people move away and these relationships, like those described by Señor D, may be weakening. Fewer people are participating in farming and reciprocal labor due to outmigration and a generational desire for capital. Permanent or temporary moves to the city accompany a reported decrease in local population, shifts in management patterns and trends away from the practice of *Ayni*. These linked shifts in demographics and practices may be leading to an increase in pesticide use, which, once engrained into everyday practices, will be difficult to disentangle and may ultimately have negative long-term impacts on farmers' health (e.g., Andersson and Isgren 2021). As such, like maize, potatoes were found to be a marker of change, although of a changing economy and transportation infrastructure, rather than climate.

During harvests conducted through this reciprocal practice in Andagua, I always perceived women to be in charge. The female host of the labor exchange was cooking and distributing food and pouring chicha. Women are the center of the household (Zimmerer 1996, 85; D'Altroy 2015) and having extensive kin for labor and goods exchange is comparable to capital wealth (Spalding 1984, 30). Murra (1968, 130) additionally equates the idea of investments with creating new reciprocal relationships as early as the sixteenth century. When helping with a potato harvest, it was women showing me and several archaeologists how to use a scythe-shaped mattock to scoop potatoes out of the ground. These exchanges were (and are) accompanied by ritual such as gendered singing, the creation of staff-like features and other practices connected to epistemology and myth. Women, in some Incaic traditions, are perceived as closer to maize, the daughter of Earth Mother, and the other figures and forms that are female and, as such, women handle the seeds while men break ground with foot plows (Silverblatt 2005, 42). Señor D recounted that women would specifically *wank'ar* when practicing *Ayni*. The women I spoke with differently represented labor and class tensions, some closer or further from these practices based on their social relations and personal histories. Of the women I spoke with, Señora

E was the most removed from these local practices and ways of thinking about the world. She used Quechua diminutive terms when speaking but was unsure of her irrigation source and was confident that *Ayni* was no longer practiced. She owned no animals but was able to afford hired labor for harvests and planting, as she had no family in town. Alternatively, Señora C also had few family members and was often unable to afford hired help without selling an animal or homemade clothing. Señora A, on the other hand, has ample family and capital and, as such, practices *Ayni* for harvest and for planting only where a tractor does not reach. Those participating in familial labor exchange during harvests were additionally supplemented with a portion of the crop, diversifying people's food.

Potatoes, whether for consumption or for sale, are also perceived by those with higher incomes as a lower-class crop, one that is only grown in need. The contemporary dichotomy between potatoes and maize is rooted in Spanish colonial and pre-colonial perceived prestige, and complicated by the market economy, local socio-political relations, and broader political process. The farmers who were not involved in production of potatoes for the market had extensive herds of prestige bulls, cows, and horses, or other forms of alternative income. While these ranchers and farmers grew crops like quinoa and maize for personal consumption, they did not grow potatoes or other crops that were perceived to be of a lower status. The source of these perceptions is tied to Inca, Spanish colonial and post-colonial perceptions of race and class. For example, while not as significant as maize to the Inca state for ritual purposes, surplus potatoes were important for food security and subsistence (Zimmerer 1993). During the Spanish colonial period, Zimmerer (1993) argues, non-Indigenous groups perceived subsistence crops like potatoes as inferior while Indigenous groups valued their importance for ritual and tradition. Murra (2002, 151) argues that the differential perceptions and practices between maize and tubers relates to where they were domesticated. Each valley has endemic tuber varietals, while was intensified by the state and has limited microclimates in which it grows (Murra 2002, 151). Murra (2002, 148) asserts that the focus on maize rituals, rather than tuber rituals, by Spanish chroniclers reflects their conceptualization of potatoes as lower-class subsistence crops–their perception was that only poor Andeans relied on tubers. Tubers did not require artificial irrigation, could grow in marginalized terraces in higher elevations and were not familiar to European tastes (Murra 1968, 132; Zimmerer 1999, 158; Murra 2002, 384). Alternatively, maize required elaborate practices to ensure its successful yield which, Murra (2002, 384) says, drew the attention of the Spanish over other less arduous crops. As argued by Markowitz (2019), the distinction between foods appropriate for elite, European consumption and Indigenous subsistence has endured through the transition towards twentieth- and twenty-first century export-oriented economies and urban food consumption. This is complicated by the changes following the agrarian reform in 1969, which encouraged farmers to pursue income-producing activities and resulted in a decrease in tuber and maize diversity, among other local plant varieties, centered on access to resources for their production and market demand (Zimmerer 1966, 68-85).

Ultimately, the decision to grow tubers or maize relies on a variety of factors not only including topographic position, but also history, culture, individual and community perceptions, resources and practices, and climate (Zimmerer 1999, 156-159). In Andagua, there is a perception by some ranchers with prestige animals that potatoes are a product reserved for lower-class and Indigenous farmers. It is possible that growing potatoes, unlike other crops, has acquired a stigma that relates to poorer farmers engaging in cultivation for the market due to capital needs. These ranchers also have complicated feelings about race and class, and their own backgrounds. Tensions stemming from colonialism and capitalism, like race and class, are impacting how, what and where people are planting and the animals they rear.

Infrastructure

The physical and social manifestations of empires, colonialism, and capitalism in Andagua are present not only in farmer and rancher decision-making, but also in infrastructure, social organization, community memory, and environmental composition and form. Local mytho-history and naming practices suggest Inca origins for the Canal Madre in town–it is also referred to as the Inca Canal–although that does not negate the possibility of its existence prior to Inca political rule in the area. Large-scale terraces and irrigation systems were in place elsewhere, like in the Colca Valley, prior to Inca influence. Regardless of local or Inca specialist engineering, the reorientation of terrace and canals towards excess production for the state likely occurred given the concentration of Inca material assemblages and settlements across the valley (see Menaker 2019b). Later, the Spanish forced resettlement into the centralized town, likely causing the broad disuse of terraces far from the settlement like those in Soporo, Tauca, and possibly Paccareta.

It is not clear if and how the *encomienda* system in Spanish-colonial Peru impacted Andagua; however, there is communal memory of violence and coercion under the local *gamonal* during the twentieth century. In contrast to the *encomendero*, the *gamonal* were embedded in local, Indigenous practices and ontologies (Poole 1987). They were present landlords, engaging in everyday activities and life, possessing extensive social power through expression of uniformity but also of dominance and violence (see Poole 1987 for historical anthropology of *gamonalismo* around Cuzco in the nineteenth and twentieth centuries). This dispossession of land and labor by the *gamonal* in Andagua remains in local memory, often through personal stories told by grandparents, the violence still painful in the retelling by their kin. By the 1960s, change through governmental policy and bottom-up social organization increased access to external markets, redistributed land to Indigenous farmers and extended the areas under cultivation. Señora A recalls the difficulties of the past and expresses gratitude for the hard work of her parents and ancestors ensuring the longevity of the soil, canals and terraces. The maintenance practices described by Señor G of building and rebuilding terraces every year after irrigation water and grazing animals knock them down are crucial to the longevity described by Señora A. Similarly, reciprocity and labor turns practiced at different social scale–the familial, irrigation sub-group, irrigation group and community–ensure the groups clean the canals, water is distributed, crops are harvested, and seeds are saved.

Although people practice reciprocal labor differently depending upon class, social relations and access to roads and tractors, among other factors, the practices have been altered by external and internal forces through time and challenged by increasing pressures from human-induced climate change and socio-economic and political agendas. While providing access to markets and centers of political control, roads are also a means of permanent or seasonal outmigration, decreasing the number of farmers and decision-makers on the landscape. Farmers either leave their land in disuse to potentially be commandeered by others, or they sell their land, concentrating the land into decreasing hands and increasing the workload to those that remain. Roads are also points of access within the valley, allowing famers access to tractors for plowing and cars for crop transportation. There is a significant difference between the types of plowing labor, even between foot plows and animal-powered plowing. For example, in Corporaque in the Colca Valley, plowing using a team of bulls can finish one *tupu* in one day while it would take fourteen people a whole day with foot plows to finish the same single *tupu* (Treacy 1989, 301). Both the local road and the regional road increased movement of people and things across the landscape and around the broader region. In the 2012 INEI, only seventeen producers reported using mechanical means (i.e., tractors) to work an agricultural unit, while the remainder use only animal (214 or 65%), only human (94 or 24%) or mechanical and animal (5 or 2%; INEI 2012). Since road construction occurred during and after the government census, these numbers likely changed with increased access to the tractor from road construction.

Since the roads enabled alteration of local practices, it is unclear how these will impact landscape stability and sediment connectivity to the river. As summarized by Tarolli and colleagues (2014), the introduction of machinery to terraced landscapes can lead to an increase in landslides and erosion. Additionally, terrace wall collapse can lead to increased erosion from this location, concentrating water flow (Brown et al. 2021). Terrace walls are also prone to instability due to the creation of preferential pathways in the subsurface that lead to pooling behind walls, leading to wall instability (Preti et al. 2018). While people did not speak much about slope stability or erosion on roads, they have remarked on the regional road's safety, especially how it has been made more dangerous through paving, which narrowed the road and enabled people to drive more quickly around blind turns on steep cliffs. The paving was in the process of being completed as I was beginning these interviews and, according to gossip from multiple sources including a truck driver, six trucks had already fallen off the road and down the steep cliffs since its recent re-opening. The local roads within the valley may additionally lead to increased erosion, although this needs to be tested by further study.

Other forms of "modernization" that has been disparaged include an NGO's reorganization of the irrigation system. According to farmers, the NGO decided it was inefficient to distribute by need, as farmers had been doing, and, instead, implemented a system that resulted in too little water, causing farmers to leave fields fallow where water no longer reached. Farmers perceive the water to be draining through the porous volcanic soil both in the canals and in fields. With decreasing water supply but similar demands, farmers are in the process of cementing all canals through the main valley, and some possibly in Paccareta. Water drainage in the canals and reservoirs is also reported in the Colca Valley, although, according to Guillet (1987), farmers report little water loss once it reaches the fields. By cementing the canals in Andagua, water is increasing in volume and enabling farmers to extend the fields in use. However, as Señora A pointed out, the water is clearer and no longer carries useful sediments. This may have broader implications in future generations, decreasing fresh minerals and causing declining yields. Several farmers also perceive the water as contaminated with mining tailings and are concerned about the impact on their fields and to themselves. While technology is also providing more water, farmers perceive that water to also be bringing contaminants and a smaller volume of crucial suspended sediments. Both issues will likely have long-term impacts on soil and human health, and terrace functioning.

Complaints of excessive water percolation in fields during flood irrigation is another issue that farmers blame on porous volcanic soil. It is possible that there are preferential pathways within the terrace tread or underlying geology. For example, earthquakes can create factures and microfractures in rocks, altering the subsurface hydrology and causing an increase in permeability (Wang and Chia 2008; Yamada et al. 2020). It may also be possible that feeder dikes corresponding to the Pleistocene-aged lava field (see Gałaś et al 2023, fig. 10), are channeling irrigation water quickly below. Underlying the overlapping Pleistocene-aged and Holocene-aged basalt and andesite in this area is Pleistocene alluvium, which overlies sedimentary rocks of Jurassic and Cretaceous age; however, the nature of the contact between the igneous rocks and the underlying surface is still uncertain (see Gałaś et al 2023, fig. 4). Additionally, there is evidence of collapsed lava fields from Holocene-aged events, which Gałaś and colleagues (2023) hypothesize are from the "smelting of evaporates" such as gypsum and anhydrites by magma. Given the presence of such landforms in the valley, it is possible that processes that created these features may also have created other features that contributed to the percolation described by farmers in Andagua. There are likely other explanations that can only be confirmed through further research. The geologic and tectonic features in Andagua have enabled resource extraction, both through agriculture and mining; however, external institutions have imposed top-down changes to social organization and ignored concerns about environmental safety and sustainability.

Tupu

Finally, the means of measuring land and water are deeply social, embedded in history and knowledge of the landscape. Through interviews, farmers would refer to their *andenes* (terraces) and *chacras* (fields) as being contained within a unit of management called a *tupu*. A *tupu* defined the boundaries of ownership and were marked by large walls, vegetation, and other partial barriers. These boundaries defined changes in management practices, soil properties, vegetation, and slope. These differing environmental and human forms impact processes–the distribution of sediment, ground and surface water exchange, lateral flow lines and slope stability. Additionally, the *tupu* and the irrigation management were intertwined. The irrigation system was organized through the *tupu*; farmers reported that one *tupu* will receive three hours of water regardless of the crop type and terrace sizes, each three-hour allotment referred to as a turn or *turno*. The previous irrigation system was based on need, where farmers would request irrigation water for each of their *tupus*, receiving that water regardless of where they were on the landscape. A similar system was described elsewhere in southern Peru called the *saya* system (Treacy 1989, 326; Gelles 2000, 69-74), which was organized by the two *saya* subsectors–the lower and the upper moieties–and then distributed according to requests (see Treacy 1989, 324, fig. 51). Local farmers in Andagua say that a Swiss NGO reorganized this system to its current iteration, although Treacy's (1989, 327-8, 333) summary of different irrigation types include the fact that the Peruvian Ministry of Agriculture attempted to alter irrigation systems across the region to improve their "efficiency" during the 1960s. The Ministry encouraged the *mita* system, which irrigates *tupus* in order from west to east and from top to bottom (see Treacy 1989, 324, fig. 51), which is like the Andagua turn system except that it is not timed in the Colca. One form of the turn system was dated to Spanish colonial periods around Cuzco (Villanueva and Sherbondy 1978, cited by Treacy 1989, 333). A switch to a different form of irrigation patterns was, according to Treacy (1989, 327-328), encouraged by the Ministry to reduce water loss to evaporation and infiltration while in transit in canals as well as to more effectively tax water use.

The *tupu* is not extensively covered in recent literature; however, Cook (1919) describes a *tupu* as a plot of land distributed to a head of house by the Inca. The total assigned land is considered sufficient to provide enough food to feed a family (Cook 1919). The family would receive another *tupu* with a baby son and a half a *tupu* with a baby daughter, which Cook (1919) speculates is because there are more feast days for boys. D'Altroy (2015, 311), drawing from Garcilaso's definition (1966, 245), describes an Inca *tupu* as a plot of land that is distributed to a newly married couple that can provide enough maize to feed them for a year. These units are relative and depend upon the environmental conditions of each place. Farrier (1967), analyzing different estimates given by "authorities" through time on the *tupu*, concludes that the Spanish had difficulty with the idea of having a fluid, non-standardized unit. The *tupu* in Andagua, also seems to refer to a relative term. The *tupu*, a socially and geomorphologically meaningful unit, will be explored in more depth in chapter five, including its changing meanings through time and how its relation to everyday human practice and history have impacted these landscapes, all of which have relational impacts.

CONCLUSION

This chapter set out to contribute to the documentation and communication of farmers' local knowledge of the terraced, mountain landscapes in southern Peru. The results reveal complicated relationships to the landscape that are tied to both real and perceived social and climate change. This chapter relates to shifting labor practices from largely kindship-based labor exchange to more reliance on paid labor, a difficulty especially for more financially or relationship impoverished farmers. Interviews highlighted the differences between soil fertility and crop management practices between subsistence and market-oriented products, the latter often relying on external inputs such as chemical fertilizers and non-local seeds. Additionally, farmers are noting perceived changes in precipitation seasonality, intensity, and amount, and shifting agricultural cycles, all of which are causing strain on water accessibility and the social relations managing its distribution. This is associated with increasingly warm winter temperatures and low river discharge, concerning farmers who live full-time in Andagua or the high Andes. They also detail local ways of categorizing, experimenting with, and measuring change, each of which are connected to history, culture, class, gender, and age, among other factors. *Maiceros* and *tupus* proved two revealing landscape analytics that not only describe physical characteristics, but also important historical, social relationships to people and the landscape. In terms of climate, farmers' experimentations with the geomorphic boundaries of maize, a crop with specific microclimate and irrigation needs, have revealed shifting temperature regimes in the Valley of the Volcanoes, potentially transforming higher-elevation fields into potential *maiceros*. Additionally, the *tupu* communicates land tenure units physically bounded by walls but is also a convertible unit of area.

This chapter found that perceived climate and social changes are impacting decision-making and those perceptions and actions are heterogeneous across race, gender, and class. These are mediated through memories of historical violence connected to the *gamonal*, contemporary frustrations with state inattention to economic and environmental need, perceptions of equality across water access, entrepreneurial focus towards external markets, and other factors. The next chapter exercises this local knowledge and experiments with local analytics to uncover meaningful land cover patterns visible in remotely sensed imagery and contextualize them through the twentieth and twenty-first centuries.

Chapter Four: Patterns on the Landscape

Local Landscape Analytics and Landscape Patterns

The complexity of human perception and practices revealed in the previous chapter is explored here within the context of terrace typologies of the Andes and bottom-up and top-down pattern changes on the landscape. Models of land use in the Andes typically have focused on the diverse ecological assemblages and the historical sociopolitical relationships among groups across a vertical gradient (see Moret et al. 2019; e.g., Murra 1968; Masuda et al. 1985; Zimmerer 1993; for a comment on vertical zonation, see Appendix A). There are additionally many terrace classification systems that focus on morphology, planform shape, topographic position, and the degree of change from the original slope (e.g., Donkin 1979; Brooks 1998; Wei et al. 2016; Brown et al. 2020). This chapter engages these conversations by creating locally informed terrace typologies to better understand the anthropogenic changes to the dominant geomorphic processes on the landscape. Mapping the patterns and morphology of human landforms such as terrace walls, roads, and paths, simultaneously complicates but also clarifies current, and suggests historical, patterns of land use through the twentieth and twenty-first century social, economic, and political change. In combination with interview data, these terrace and terrace feature classifications contribute to clarifying the sociopolitical and physical relationships people have to the landscape, complementing existing landscape models.

This chapter aims to better understand impacts of historical legacies and power relations on the integrated social-environmental landscape through time, disentangling the human and environmental forces behind the changing patterns of use of the terraced landscape in Andagua, Peru by asking:

1. What are the characteristics of internal terrace boundaries (i.e., terrace retaining walls) and terrace types in Paccareta and the main valley? And how do these change over time?
2. How do roads change over the twentieth and twenty-first centuries? How does the proximity of terraces to roads and paths change from 1977 to 2021? And does this impact terrace use?

To answer these questions, terraces, paths, and roads were mapped using object-oriented analysis of greyscale imagery from 1977 and fine-scale spatial resolution multispectral imagery from 2010 and 2021. Physical characteristics of internal and external boundaries were collected such as their condition, terrace type, land cover, and the pattern of the terrace unit in relation to surrounding units. Sampled terraces and fields were then classified as used and disused based on external and internal boundary characteristics, and then analyzed for patterns relating to mapped social and environmental characteristics. The proximity of roads and paths were additionally calculated and analyzed for change through time. Finally, variables were tested for their impact on terrace use across locations and over time. These contextualize the physical changes to the landscape described by farmers in the previous chapter, quantifying any discernable patterns of use and disuse on the landscape.

ANDAGUA: INTERNAL AND EXTERNAL SOCIAL AND ENVIRONMENTAL FORCES

Roads and Population: Increasing Roads and Decreasing People

Previous chapters have covered the history of settlement distribution and the physical and social impact of encounters with Inca and Spanish Empires in Andagua. This section will consider, in more detail, changing land use in relation to road construction and population change in the twentieth century drawing from the 2012 national agricultural census of Peru (IV Censo Nacional Agropecuario [INEI] 2012) and personal accounts by geologist and pilot Robert Shippee (1932a; 1932b; 1933; 1934), among other sources. This section demonstrates the rapid changes occurring in the late twentieth century associated with road construction and the increase in social and physical connectivity between the rural, agricultural town and other regional urban centers.

Despite its regional proximity to more highly trafficked areas of the southern Peruvian Andes, such as the Colca Valley, Andagua's high relief volcanic topography and its location in an intermontane *quechua* (the cultivable valley between high-elevation wetlands) made it difficult to access. Even by the 1930s it was apparently not documented on official Peruvian maps made available to explorers collaborating with the government (Shippee 1934, 129). Robert Shippee (1934, 129), geologist and pilot from the Shippee-Johnson Peruvian Expedition, recounted that the towns, scoria cones, and lava fields observed from their airplane were not documented on maps available to them. For this reason, the group decided to visit the valley on foot, after determining that there was no safe location to land a plane. They hiked over the Colca River near Cabanaconde in the Colca Valley on a fiber suspension bridge and then crossed over the *puna* at about 5180 masl before descending into the valley likely near Paccareta (figure 1.9; Shippee 1934, 129). After crossing the Andagua River canyon on a bridge, they passed the twin volcanoes they had seen from the air (1934, 129). Shippee (1932, 1934) described the higher elevation areas around Andagua as densely terraced and vegetated, and noted the large herds of cattle in these areas. Local sources described to Shippee occasionally herding the cows to the coast, possibly along what is now the regional road over Coropuna pass, a journey that required renting pastures from farmers at expensive rates (Shippee 1932; 1934).[1] At this time, there were few routes in and out of the valley, each of which required arduous travel over high mountain passes.

About 40 years later, the cattle trail over the Coropuna pass was described by the Peruvian government as a "carriage trail" covering 37 kilometers from Andagua to Machahuay, a town on the other side of the pass (figure 1.1; Oficina Nacional de Evaluación de Recursos Nacionales [ONERN] 1973, 430).[2] A bus route from Arequipa reached Andagua twice a week during this period, traveling over the pampa from the northeast and arriving into Andagua from the north after stopping in the mining town Orcopampa (ONERN 1973, 441, 450). Orcopampa then, like today, has silver and copper mines operated by Minas Buenaventura SA (ONERN 1973, 76-77), requiring transportation options for laborers to access its rural location. These roads were described as narrow with widths between 2.5 and 4 meters across and having sharp gradients and switchbacks (ONERN 1973, 415). Around this period, the local community of Andagua collaborated with other communities, such as Machaguay, over the Coropuna pass to construct a wider road to increase the ease of car access from the coastal highways to town (figure 1.1). Their successful construction of this regional road in the late twentieth century increased transportation connectivity but also correlated with a decrease in local population over that period.

Livestock production throughout the twentieth and twenty-first centuries was an important activity in Andagua for bullfighting, breeding, beef production and, most widely, dairy production (ONERN 1973; INEI 2012; see Hartigan and Menaker 2022, 63). In the early 1930s, Shippee (1932; 1934) noted large herds of cattle grazing in the higher elevation areas surrounding the town. These large herds in the upper reaches were likely those of the *gamonal*, grazing on appropriated land gained through violence or threat of violence (Menaker 2019, 273). As mentioned in chapter Three, the *gamonal* was a local landowner presenting alternatively between indigeneity and non-indigeneity and benefiting from the vacuum of power in rural Peru that resulted from the state's attention towards international trade (Menaker 2019, 273; Thurner 1997). More commonly, farmers have smaller herds grazing on private, bounded terrace units. By 2012, there were 1223 reported parcels of land over 849.32 hectares in Andagua (INEI 2012). Of these, 70% of total land was currently in use and 62% of that was in use to grow animal feed (INEI 2012). Sometime after the introduction of cows to Andagua, ones who escaped and lived in the highlands without consistent human contact were designated as wild or native and periodically captured for their rich milk (see chapter 3; Hartigan and Menaker 2022, 65-6). It is not clear if the thirty-four landless livestock producers used communal land or they rented land, or a combination of that.

The above land use dynamics, in combination with those summarized in the previous chapter, have implications on the stability of the landscape. This next section will describe the data and methodology used in the object-oriented analysis, hypothesis testing and logistic regression to refine our understanding of the relationships between land use and terrace characteristics, geology, topography, distance to nearest roads, distance to nearest path and distance to town center from the 1970s to the present.

DATA CLASSIFICATION AND ANALYSIS

This chapter uses an object-oriented analysis of the human-modified landscape, focusing on agricultural terraces and associated infrastructure such as terraces and terrace unit walls, roads, and paths. Object-oriented mapping is a visual interpretation method that incorporates physical features visible in imagery to define boundaries around these features (Lillesand et al. 2015, 59-65). Imagery collected for use in analysis includes greyscale, oblique aerial imagery from the 1931 Shippee-Johnson Expedition, greyscale satellite imagery from the 1966 and 1977 United States (US) HEXAGON and CORONA intelligence missions, and multispectral satellite images from Maxar dating to 2010 and

2021 (all described below in more detail). Points were randomly sampled in Paccareta and the main valley (one hundred each) using QGIS random sampling function and the anthropogenic feature containing the point was selected for further analysis. Classifications and associated image keys were created for terrace type, internal and external boundary descriptions, and land cover to be applied to each point in each period, considering the spectral and spatial limitations of the imagery. Data of proximity to roads and paths were also analyzed for each year using parametric and nonparametric, as appropriate, hypothesis testing to determine if these significantly change over time. Data points were then classified as either in use or in disuse for logistic regression analysis to determine relationships between measured social and environmental characteristics and terrace use. This section will explain in more detail the methodology, classifications, and data characteristics.

Data

The images available for analysis contribute to better understanding the human-environment relations through the late twentieth and early twenty-first centuries in the southern Peruvian highlands when considered in context with social, economic, and physical forces and processes (figure 4.1). Each of the satellite images have pixel sizes of 1.1 meters or less except the 1966 imagery, which has an average pixel size of about 3.8 meters. These fine-scale resolution images enable object classification of terraces; however, the 1966 image is at too coarse of a spatial resolution to be confident in object boundary or land cover classification, so it was excluded from this chapter’s analysis. The 1931 images are used for qualitative analysis of land cover and terrace extent due to difficulty in geolocating the imagery.

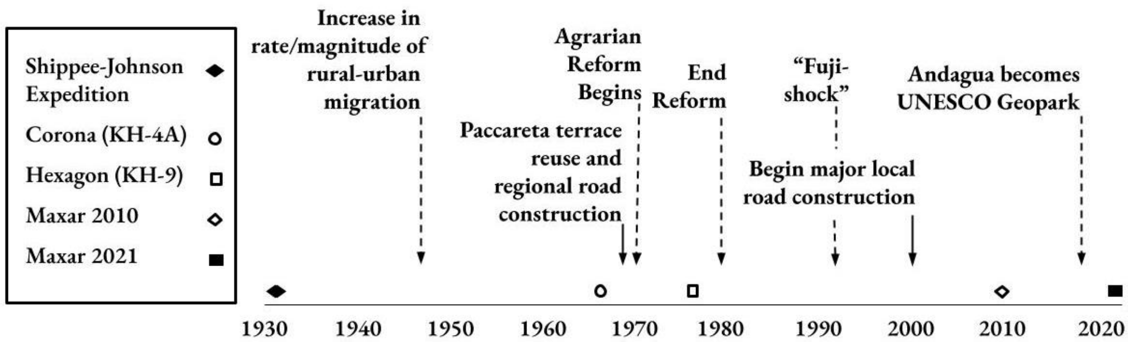


Figure 4.1 Timeline of major local and state events and processes in relation to images gathered for use in object-oriented analysis.

This section summarizes datasets used in this chapter, including their context, to better understand the production of knowledge and the power relations involved. These data include US declassified satellite imagery, aerial and ground imagery funded by the American Geographical Society and supported by the Peruvian government, and other remotely sensed imagery sourced from various international governmental and private sources. This section will discuss the Shippee-Johnson photographs and declassified satellite imagery and conclude with a description of data preparation and discuss analysis limitations.

Shippee-Johnson Peruvian Expedition

In 1931, US Navy Lieutenant and photographer George R. Johnson and US geologist and pilot Robert Shippee conducted aerial surveys of Peru funded by the American Geographical Society and Harvard Geological Society with the main goal of identifying and documenting archaeological features (Denevan 1993; New York Times [NYT] January 27, 1931; NYT August 31, 1931).[3] Johnson, having served in the Peruvian Navy as chief aerial photographer, knew of unmapped towns in the southern Peruvian Andes (NYT September 8, 1931). The goal of the 1931 project was to "map from the air and study and photograph on the ground the little-known agricultural communities on the floor of the deep gorge of the Colca River some seventy miles north of Arequipa," in addition to mapping areas in the north and east (*Science* 1930, 573).

The Shippee-Johnson Peruvian Expedition took oblique aerial photos of Andagua and the broader Valley of the Volcanos in southern Peru in mid to late June of 1931 and ground photos from later in the summer (Shippee 1932). Shippee, who did much of the communication with sources such as the *New York Times,* described the towns in the Colca Valley and that of Andagua as "lost" Inca villages (NYT July 29, 1931).[4] His perception of the town as absent on maps likely influenced his perception of the local population, in addition to his positionality as a US soldier and geologist, most interested in the scoria cones and lava fields. For example, he recounted that the Andagüeños spoke only Quechua, lived "under similar conditions as their Inca ancestors centuries prior to the landing of Pizarro" and learned from maps with mislocated cities (New York Times July 1931, paragraph 5). As a geologist, Shippee was particularly struck by the photographs taken of the volcanoes and volcanic flows in Andagua, noting their impact on the landscape hydrology (NYT September 7, 1931). They were additionally imbricated in the revolutionary activities occurring in Peru during this period, noting that they assisted both "rebels" and private companies in the conflicts (NYT September 7, 1931).

Of the over 3,000 photographs taken during the expedition, many are housed in the American Museum of Natural History Research Library in New York in addition to archives in Lima (NYT September 7, 1931). Aerial and ground photos of the expedition were selected that reveal information about the ecology and land use during that period (for photograph descriptions and information on their acquisition, see writeup and table B.2). No ground photographs at the library focused on terraced features, although the high spatial resolution of the aerial imagery allows for close inspection of the terraced landscapes in some locations in the valley. These photographs provide qualitative information on agricultural and settlement land use and extent during this period.

United States Declassified Satellite Imagery

In 1995, the US Department of the Interior (DOI) declassified high-resolution satellite imagery from intelligence missions named CORONA, ARGON and LANYARD that captured the Earth's surface between the years 1960 to 1972 (National Reconnaissance Office [NRO] 2022). The equipment in these earlier Keyhole (KH) missions improved over time, from a single panchromatic camera with a 12.2-meter resolution to two panchromatic cameras with a 1.8-meter resolution and stereoscopic capabilities (Dashora et al. 2007). These additionally used cameras oriented towards space to capture stars for the calculation of the vehicle's attitude (yaw, pitch, and roll) during acquisition (Dashora et al. 2007). These horizon photos are visible on either end of the films. The third round of declassified imagery from the intelligence program includes the high-resolution HEXAGON images that captured the Earth's surface between 1971 and 1986 (NRO 2011). These panchromatic images have a spatial resolution between 0.6 and 1.2 meters and a downward-looking terrain lens with stereoscopic capabilities (NRO 2011). HEXAGON satellites also used horizon photos, labeled Stellar cameras, to determine pitch, roll and yaw of the vehicle during image acquisition (NRO 1982, 2-5), although these data is often unavailable, making the creation of stereoscopic images more difficult without extensive corrections and mathematical calculations.

The available imagery for Andagua during these missions is from the CORONA (KH-4A) mission captured on June 30, 1966, and the HEXAGON (KH-9) mission captured on August 19, 1977. A full list of acquired files is in table B.3 in Appendix B including the satellite mission name and camera direction on the satellite. These were available either through free download or purchase order (at US$30 per scene) through the US Geological Survey (USGS) Earth Explorer application. These are also available through the National Archives and Record Administration (NARA), which is where the original negatives are stored (https://www.archives.gov/research/cartographic/aerial-photography/satellite-photography). The recurrence period of these data is highly dependent upon the US government's geopolitical agenda during this period, which was focused largely on a perceived threat of communism (Perry 2012, 10). While the US had interests in South America, there is no evidence of special interest in Andagua, in particular.

Georectification of Declassified Imagery

The US declassified satellite imagery from 1966 and 1977 lacked geolocation information and thus required georectification to assign latitudinal and longitudinal coordinates to each pixel. To do so, the declassified images were first cropped into general study areas to decrease the distortion introduced by georeferencing a broad extent. Georeferencing was produced by selecting ground control points (GCPs), such as corners of extant infrastructure or landscape features visible in both the declassified images and in higher spatial resolution geolocated remotely sensed imagery (GeoEye 2006). Georectification was completed using the *Georeferencer* GDAL extension in QGIS and high-resolution imagery (QGIS Development Team 2023).[5] A polynomial cubic lzw transformation created the least error, although some fine-scale distortion was unavoidable due to the high relief and geometry of the oblique images. The oblique angle of the 1931 Shippee-Johnson images disallowed them from being georeferenced. As such, their general extents and direction of viewing angle were created as shapefiles in QGIS to enable the quick identification of the best image for locating objects during analysis.

Classification Systems and Object-Oriented Mapping

The object-oriented analysis was conducted using image keys with photos and descriptions of each classification and subclassifications (see below). Object-oriented mapping is a visual interpretation method that incorporates some or all of the following: shape (and height), size, pattern (relationally to other objects), tone, texture (differences in tone), shadows, site location (both geographic and topographic), association, and spatial resolution (method after Lillesand et al. 2015, 59-65). Classification systems were made for terraces, boundary types and land cover in consideration of the social and physical history, and forces and processes described above. Image keys were created for land cover, terrace type, external and internal boundary characteristics, and feature patterns.

Random points (n = 200) were created in QGIS within boundaries of the visibly terraced areas of Paccareta and the main valley. The terrace within which the point was located was classified using the image keys, as noted above, for the years 1977, 2010 and 2021 (USGS 1977; Maxar 2010, 2021). Drainages, roads, and paths were digitized into shapefiles using QGIS for georectified 1977 declassified imagery and Google Earth Pro for Maxar imagery from 2010 and 2021. Drainages and geology were digitized from Peruvian topographic and geologic maps that were georectified into QGIS (INGEMMET 2001 [1994]; INGEMMET 2002 [1973]). Topographic derivatives of slope, aspect, profile curvature and plan curvature were created from the 30-meter topographic DEM in ArcGIS Pro. The curvature function in ArcGIS Pro creates a value for both planform or perpendicular to the downslope and profile or parallel to the slope (ArcGIS Pro 2023a).[6] The topographic derivatives of aspect, slope, profile curvature and plan curvature were calculated in QGIS from the SRTM DEM. This section will first discuss terrace classification systems drawing from research in Peru and elsewhere and then outline classifications for internal and external boundaries of terraces and terrace units and their condition. Lastly, it will briefly describe classifications and digitizing drainages, geology, roads, and paths.

Terrace Typology

The classification system for this dissertation considered the physical morphology of the terrace and its hydro-geomorphological impact. As defined by Brown and colleagues (2021, 2): "Fundamentally, a terrace is a modification of a slope form which steepens one part of the slope, the riser, in order to reduce another part of the slope, the tread." Terraces disrupt the prevailing dominant processes, such as slope continuity, erosion and soil production, and their construction can correlate with a higher occurrence of shallow mass failures in semi-arid environments when forces overcome the thresholds at either the wall or plane between the original surface and the overlying soil (Brown et al. 2021, 14; Tarolli et al. 2014). Mapping terrace form, in addition to the condition and patterns of retaining and bounding walls, provides clues as to the underlying forces on the terrace system in each place.

The following terrace classification scheme draws from multiple studies and reviews of terrace systems across the world (e.g., Field 1966; Donkin 1979; Brooks 1998; Wei et al. 2016; Brown et al. 2020), including only those terrace types observed during fieldwork in Andagua Valley.[7] Terrace types may correspond with historic socio-political relations, climate, or topography, although it is unlikely there is a direct correlation across place and over time. Terraced landscapes are a palimpsest of social efforts to construct and maintain these features; as such, multiple types can be found in one location (Brown et al. 2020). See table B.3 through B.5 in Appendix B for detailed physical characteristics of object-oriented analysis used in image keys.

Cross-Channel Terraces

Cross-channel terraces, also known as check dams or weir terraces (Treacy and Denevan 1994, 97; Brooks 1998, 129; Beach et al. 2002; Bocco 2022), are artificially leveled surfaces composed of naturally captured alluvium behind a wall or other obstruction perpendicular to water flow (Donkin 1979, 32-33, 131; figure 4.2; table 4.1) in low energy drainages (Treacy and Denevan 1994, 96). Cross-channel terraces likely originated as naturally occurring rocks, wood, or other barriers that capture sediments (as summarized by Doolittle 1990) and are possibly the earliest type that may have been transformed, in some cases, into more permanent features through berm construction over time (Donkin 1979, 32, 131; Brooks 1998, 17; Erickson 2019). Field (1966, 512) hypothesized that early forms of terracing may have been produced through stone clearance from fields and sediment accumulation behind the discarded stones. Cross-channel terraces are located across broad hillslopes or at the bottom of intermittent water drainages to take advantage of water flow and the accompanying fresh minerals and organic matter from high-energy storms and seasonal flow (as summarized by Doolittle 2010, 2-6). These sediments remain moist for longer periods and were likely the site of cultivation (Doolittle 1990). The obstruction also enabled soil production, decreasing the angle of the channel and, subsequently, the velocity and volume of water flow (Doolittle 1985, 298-299; Beach et al. 2002).

Cross-channel terraces are found in semi-arid, arid, and tropical environments including the Maya Lowlands, American southwest, Mexico, and the Andes (e.g., Doolittle 1980; Brooks 1998, 129-130; Beach et al. 2002; Doolittle 2010). In the American southwest, cross-channel terraces may have originated to control water; for example, Doolittle (1985) concludes that the distribution and topographic position of check dam features in a grassland-rich area of New Mexico indicates their function as protecting downstream fields from flood events and controlling water for irrigation (Doolittle 1985). In another example, check dams are documented in arroyos of the Sonora desert, Mexico, to create conditions appropriate for vegetation growth (Doolittle 1980). In both cases, the term check dam is used rather than cross-channel terrace because they were not necessarily used as an agricultural field. These are also found as agricultural surfaces on broad hillslopes and stream channels in the Maya Lowlands where the obstructions are composed of boulders and rubble placed on a gravel bed overlying bedrock (Beach et al. 2002, fig. 3). In Peru, cross-channel terracing is sometimes associated with ridgetop settlements dating to 0 - 800 CE (Donkin 1979, 131) and found at higher elevation cropping zones. For example, Brooks (1998, 128) notes that cross-channel terraces in the Colca Valley were largely found between 3750 and 4100 masl and in disuse at the time of research, while they were mostly in use at elevations between 25 and 4400 masl on the coast and in the sierras (as summarized by Brooks 1989, 126-129). People also construct berms across narrow valleys in the sloping upland *puna* (cold, highland grasslands) to create better pastureland for camelids (Nanavati et al. 2016).

Their location across intermittent streams and drainages in combination with the ephemeral construction materials can make them difficult to distinguish on satellite imagery, especially when no longer in use. They may appear in repeated patterns of parallel lines downstream or other drainage systems perpendicular to the flow (Doolittle 2010, 7). When in use, the land cover texture upstream of the obstructions is more like other agricultural fields than to the natural vegetation or land cover in the drainage, but their visibility is limited by the spatial resolution of the images. These are distinct from other terrace types because of their location in drainages and their ephemerality as well as the fact that they are not typically found in multiples (laterally) or often as a large group.

Figure 4.2 Used and disused cross-channel terraces in a quebrada, an intermittent drainage, in the hamlet of Tauca east of the town of Andagua. Left, August 4, 2016 (photo by Alexander Menaker). Right, May 2, 2006 (GeoEye 2006).

Table 4.1 Physical characteristics of cross-channel terraces for object-oriented analysis.

	Cross-Channel Terrace
Characteristic	Description
Shape	Generally rectangular in shape; walls usually less than 2 meters in height
Size	Dependent on slope and drainage
Pattern	In sequence down a drainage or across a convex hillslope
Tone	Contrasting with natural surroundings; depends upon vegetation and wall material
Texture	depends on vegetation and land use
Shadows	Possible wall shadows on terrace edges; possibly in shadow of channel walls, obscuring terrace
Site	Often in drainages and across convex slopes
Association	Can be found in groups or be isolated
Spatial Resolution	Depends on size of channel, local topography

Note: Nine characteristics of object-oriented analysis from Lillesand and colleagues (2015, 59-65). “Site” may refer to geomorphic setting.
Sources: Descriptions from Field (1966, 512), Donkin (1979, 23-33, 131), Doolittle (1990), Brooks (1998, 129-130), and Beach and colleagues (2002).

In Andagua, cross-channel terraces were documented in at least two *quebradas* (intermittent drainages) of moderate size in states of use and disuse. For example, figure

4.2 shows a series of cross-channel terraces east of the town of Andagua at an elevation below 3500 masl. This example has a series of three 0.5-meters tall dry-stacked stone barriers across the volcanic sand bed. The two upstream terraces were planted with what appeared to be rye and irrigated by water diverted into the quebrada from the valley floor canal, suggesting that there was an advantage to farming in this location despite the need to supplement rainfall and intermittent, seasonal streamflow with irrigation. The *quebrada* sides were steep and the north-facing wall was covered in natural shrubby vegetation and grasses.

Sloping Field Terraces

Sloping field terraces are composed of walls perpendicular to the slope, creating treads that are slightly less steep than the original surface that enable soil accumulation and production in the tread (Field 1966, 83; Treacy and Denevan 1994, 97; Brooks 1998, 16; table 4.2; figure 4.3). These walls may be more "rustic" than those found on bench terraces, for example (Denevan 1988, 20; figure 4.3). Previously in Peru, sloping field terraces were documented as strictly rainfed and, therefore, dependent on available precipitation or runoff (Denevan 1994, 97; e.g., Brooks 1998, 3); however, Field (1966, 477) documented sloping field terraces in Chile that appeared to be deliberately sloped and, he hypothesized shaped rhomboidally for irrigation distribution. In the Colca Valley, sloping field terraces are largely mapped as rainfed, located in the uplands above 3600 masl and occasionally used for farming quinoa or potatoes (Denevan 1988; Brooks 1989, 149). According to Treacy and Denevan (1994, 98), dry-field sloping field terraces are constructed in areas with sufficient precipitation to cultivate without irrigation, and both control erosion and enable soil production and deposition of eroded materials. Organic material from under a sloping field terrace wall in the Colca Valley dates to approximately 1570 BCE, which suggests an early date for the construction of these features (Malpass 1986, 163, as cited by Brooks 1998, 185). Brooks (1988, 17) additionally places these terraces in between early cross-channel terraces and unirrigated bench terraces in a sequence of technological development that did not necessarily indicate disuse of earlier types. Sloping field terraces can be segmented or continuous, in relation to other segmented field terraces (Denevan 1987).

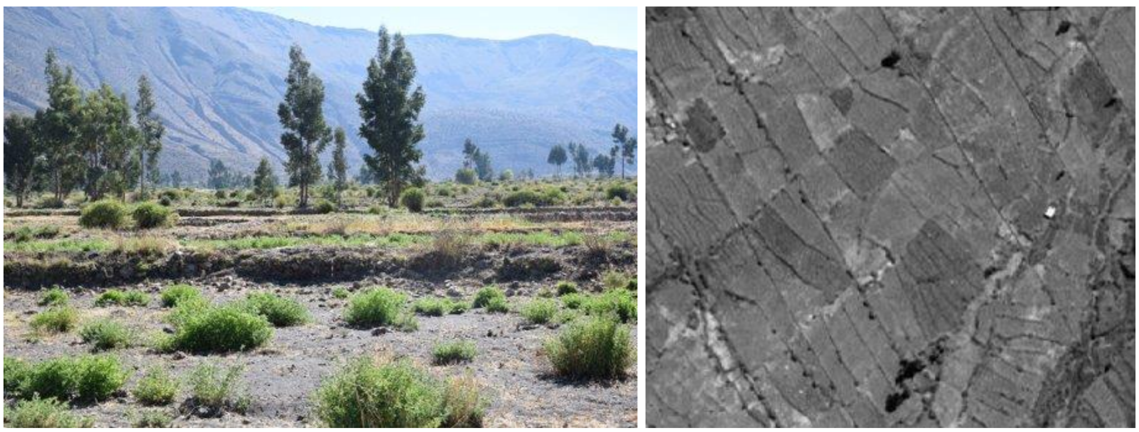


Figure 4.3 Sloping field terraces in Tauca. Left, August 4, 2016 (photo by Author). Right, May 2, 2006 (Orbview 3).

Sloping field terraces in the Colca Valley are abandoned in higher proportions than irrigated bench terraces (Denevan 1988; Brooks 1998, 149), which Field (1966, 486-487) hypothesizes can be attributed to the introduction of cattle to these areas and their penchant for knocking down terrace walls. In the southern Andes, the most-often abandoned terraces include the steeper sloping field terraces and the bench terracing with narrow downslope widths (Field 1966, 486-487). Alternatively, Brooks (1998, 3) hypothesizes climatic reasons for their abandonment due to their reliance on precipitation for cultivation for Colca Valley sloping-field terraces.

Table 4.2 Physical characteristics of sloping-field terraces for object-oriented analysis.

	Sloping-Field Terrace
Characteristic	Description
Shape	Generally, rectangular; occasionally rhomboidal
Size	Dependent on local aesthetics, perceptions of landscape needs, history, etc.
Pattern	In sets with walls perpendicular to the slope
Tone	Field is often in contrast with walls, but it depends upon vegetation and wall material
Texture	Depends on vegetation cover and land use
Shadows	Possible wall shadows on terrace edges
Site	On hillslopes
Association	Found in groups; may or may not be irrigated
Spatial Resolution	Often larger than other terraces, so may be more visible on imagery

Note: Nine characteristics of object-oriented analysis from Lillesand and colleagues (2015, 59-65). "Site" can refer to geomorphic setting.
Sources: Descriptions from Field (1966, 83), Denevan (1988, 20), and Treacy and Denevan (1994, 98).

In Andagua, sloping field terraces are located on alluvium in a valley east of town in the hamlet of Tauca at elevations spanning 3200 to 3500 masl at gradients between 8 and 10 percent (see figures 1.7 and 1.8). While these are similar in form to sloping-field terraces found in the Colca Valley, they are in distinct geographic positions on lower-elevation valley floors. The parent material is a mixture of andesitic aeolian sand and alluvium composed of shale and limestone sand and gravel (INGEMMET 2001). In 1977, the upper reaches of the alluvial valley were cultivated using irrigation water from a canal constructed by an engineer, which sources water from the Andagua River at the site of the waterfall that marks the beginning of Lake Pumajallo. The canal runs along the cliff edge and the valley slopes before descending into a series of lateral canals traversing the alluvial valley floor. There is evidence of a previous canal possibly dating to pre-Hispanic periods higher up the steep valley side, its water source being from higher elevation areas. Over time, farmers have rehabilitated more sloping field terraces, beginning with those overlying alluvium and gradually grading into the lower elevation terraces overlying aeolian sand. The irrigated terraces are organized in units downslope of a series of lateral canals, features not apparent in the lower elevation disused terraces (figure 4.4). In a sandy transition zone, farmers were rehabilitating some of these lower elevation terraces, digging ephemeral, sand-lined canals into the aeolian sand to bring irrigation water to their fields.

Bench Terraces

Bench terraces have retaining walls that follow the elevation contour line on a hillslope creating a relatively level tread that can be angled for effective water distribution from one terrace to the next (Field 1966, 475-77; Donkin 1979, 32; Brooks 1998, 127; Beach et al. 2002; figure 4.4; table 4.3). The wall height and plan size are partially dependent on the original slope angle and plan curvature, in addition to the amount of infill required to create the level surface (Donkin 1979, 32). They may have lateral retaining walls that are perpendicular or rounded relative to the retaining wall (Field 1966, 103, 110). Wall composition and form depended upon local availability of material and the engineering knowledge of the builder (Field 1966, 67; Donkin 1979, 131). Additional features such as steps in the form of a series of projecting stones on terrace walls or irrigation canals are noted on bench terraces in southern Peru such as those in the Colca Valley (Brooks 1998, 133-5).

This classification system further divides bench terraces into linear terraces and broad field terraces, largely differentiated by their plan view shape. Linear terraces are more evenly shaped and have a narrower downslope width, while broad field terraces are unevenly shaped and have a wider downslope width (Brooks 1998, 135; figures 4.4 and 4.5; tables 4.3 and 4.4). Broad field terraces are usually integrated with linear terraces and a single terraced unit may contain both (Denevan 1987; figure 4.5; table 4.4). Brooks (1998, 135) also has a “contour” terrace category; however, this dissertation considers all terrace morphology to be relational to the landform morphology and, therefore, excludes this category. Brooks (1998, 135) additionally includes valley floor terraces into the bench terracing category, but this dissertation places them in their own categories because of their unique topographic positions and different relationships to the surrounding landscape.

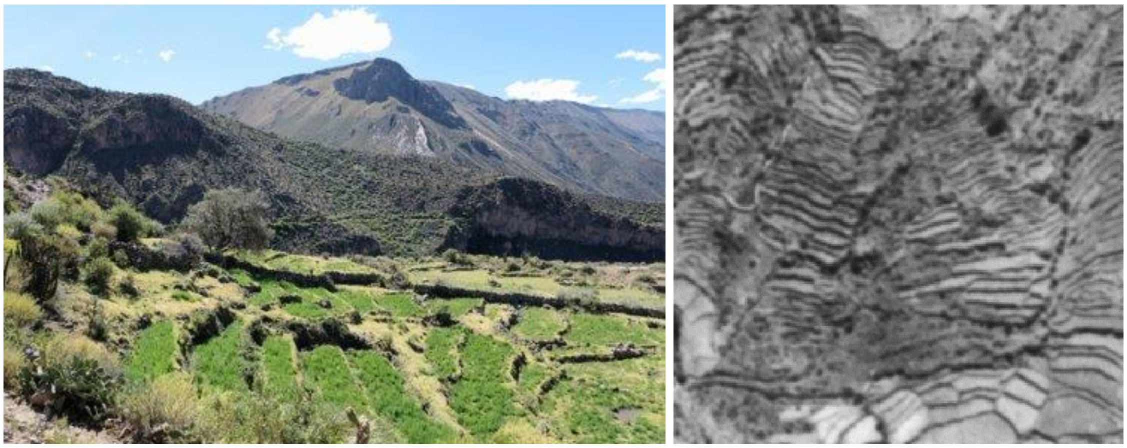


Figure 4.4 Linear bench terraces in the main valley. Left, July 3, 2016 (photo by Author). Right, declassified satellite image, August 19, 1977 (USGS 2021).

Bench terraces often occur in a vertical and lateral series, occasionally bounded into units by walls or irrigation systems (e.g., Field 1966, 103). Those that are found in sequences across a large area and appear similar in design and construction are often considered to have been created at the same time and by state-level or other systematic social organization (Field 1966, 203, 466). Sequential and uniform bench terraces at Inca administrative or residential sites exemplify large-scale terrace construction. For example, bench terracing at the site of Tipon near Cusco, Peru was engineered to manage water velocity and volume through the design and construction of ditches, channels, sluice gates, waterfalls, and other features (Ortloff 2019; Treacy and Denevan 1994, 99, fig. 5.3). This contrasts with those in smaller sequences or those that appear to be constructed as needed. These were most likely built through familial social organization using lightly worked rocks and appear in a variety of shapes and sizes (Donkin 1979, 33). For many types of bench terraces, irrigation is crucial for cultivation and irrigation features such as water drops may be incorporated into bench wall design (Treacy and Denevan 1994, 99).[8] In the semi-arid Andes, irrigation is important for farming especially during the dry season (Treacy and Denevan 1994, 98, 102).

Table 4.3 Physical characteristics of linear bench terraces for object-oriented analysis.

	Bench Terrace
Characteristic	Description
Shape	A function of the plan curvature and slope; length (longer edge) follows the same elevation contour line
Size	Height of walls and plan size dependent on original slope angle, local aesthetics, engineering knowledge and age
Pattern	Often in repetition with others of similar shape and size across and down slope
Tone	Walls generally darker in tone than fields; field tone depends on moisture content, crop cultivation or crop rotation or aspect
Texture	Field depends on vegetation and land use
Shadows	Liner shadows following walls
Site	Valley sides, ridgetop sites, interfluves, sloping valley floor
Association	Often in set bounded by larger walls indicating property lines; may be found near archaeological sites
Spatial Resolution	Some may approach pixel size, depending upon image

Note: Nine characteristics of object-oriented analysis from Lillesand and colleagues (2015, 59-65). “Site” may refer to geomorphic setting.
Sources: Descriptions from Field (1966, 475-77), Donkin (1979, 32), Denevan (1987), Brooks (1998, 127), and Beach and colleagues (2002).

Bench terraces are found throughout the main valley of Andagua, in Paccareta, on the hillslopes surrounding Inca sites, in the quebrada of Tauca, and on the hillslopes of the pre-Inca site of Paccareta. Linear terraces appear on both steep and moderate slopes. Broad field terraces are prevalent throughout the main valley and Paccareta, intergrading into linear terraces. Linear terraces, when found in a sequential pattern, are more likely to be on steeper slopes. The pattern of abandonment, disuse and use is patchy and, as such, vegetation patterns and wall and tread condition vary.

Figure 4.5 Broad field terraces in the main valley. Left, July 23, 2019 (photo by Alexander Menaker). Right, declassified satellite imagery, August 19, 1977 (USGS 2021).

Table 4.4 Physical characteristics of broad field terraces for object-oriented analysis.

Broad Field Terraces	
Characteristic	Description
Shape	Irregular shape, varying with topography
Size	Larger downslope width than the other terrace types
Pattern	In repetition with broad field terraces of different shapes and with linear terraces
Tone	Tread often in contrast with walls; depends upon vegetation and wall construction
Texture	Depends on vegetation and land use
Shadows	Possible wall shadows on upslope tread edges
Site	Areas of low relief
Association	Walls perpendicular to flow for irrigation often grading into lateral and sinkhole terraces as topography changes
Spatial Resolution	Depends on pixel size

Note: Nine characteristics of object-oriented analysis from Lillesand and colleagues (2015, 59-65). “Site” may refer to geomorphic position.
Sources: Descriptions from Brooks (1998, 135) and Denevan (1987).

Sinkhole/Depression Terraces

Sinkhole/depression terraces are a unique type of terracing located in depressions and, as such, have a distinct circular patterning and internal hydrology (figure 4.6; table

4.5). In the literature, sinkhole terraces are constructed within topographic lows that were created through dissolution of karstic landscapes (e.g., Earls and Cervantes 2015; Guengerich and Berquist 2020). While the terraces in Andagua are not overlying karst sinkholes, this terrace categorization system combines all terraces in geologic or geomorphic depressions into sinkhole/depression terraces. Further research may conclude that the depression terraces in Andagua do not fall under a sinkhole terrace designation.

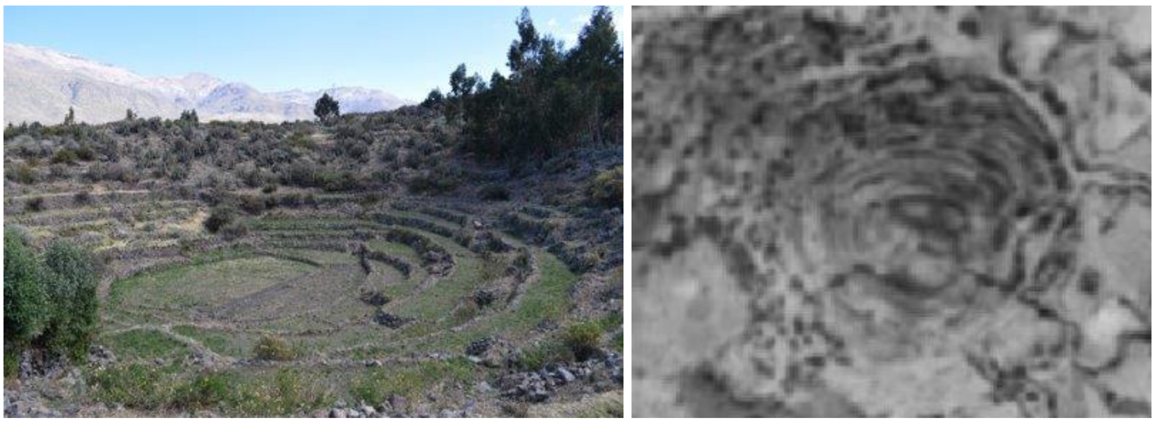


Figure 4.6 Sinkhole/depression terraces in the main valley of Andagua. Left, July 4, 2019 (photo by Alexander Menaker). Right, declassified satellite imagery, August 19, 1977 (USGS 2021).

Sinkhole terraces in Peru are found overlying karst landscapes throughout Peru. The most proximal documented sinkholes to Andagua are at Moray in Urubamba Valley (Wright et al. 2011; Earls and Cervantes 2015). In the Urubamba Valley, the sinkholes are locally known as *muyu* and were constructed by the Inca with stone walls and hydraulic details such as vertical waterfall channels, canals, and drains (Wright et al. 2011, 1-15, 45, 66). The size, quality of materials, precision of engineering, and labor required for the construction of the Moray terraces suggests to Earls and Cervantes (2015, 125-131) their use was largely for other, non-subsistence purposes relating to solar events such as the equinox and the solstices. Unlike terraces at Moray, the terraces in Chachapoyas in northeastern Peru were constructed with earthen berms and were as deep as twenty meters (Guengerich and Berquist 2020). In their hydrological model using high resolution DEMs, Guengerich and Berquist (2020, 165) noted that sinkholes drew water into them through "slight centripetal" forces, although they found their results pertaining to drainage of these features unclear, suggesting that they were serving as drainage points in some manner.

Table 4.5 Physical characteristics of sinkhole terraces for object-oriented analysis.

	Sinkhole Terraces
Characteristic	Description
Shape	Dependent on relief and size of topographic depression
Size	Radius dependent on relief and size of topographic depression
Pattern	Often singular; creates a radial pattern within itself
Tone	Tread often in contrast with walls; depends upon vegetation and wall construction
Texture	Depends on vegetation and land use
Shadows	Possible shading of the south-facing wall
Site	Topographic lows
Association	Often grading into lateral and broad field terraces; may be irrigated by canals
Spatial Resolution	Depends on pixel size

Note: Nine characteristics of object-oriented analysis from Lillesand and colleagues (2015, 59-65). "Site" may refer to geomorphic position.
Sources: Descriptions from Earls and Cervantes (2015) and Guengerich and Berquist (2020).

In the Maya lowlands, *rejolladas* (karst sinkholes with a soil-filled base) were used for ritual, cultivation, and gardening as early as 1500 - 900 BCE (Dedrick et al. 2020). *Rejollada* soils are moister and have a more neutral pH than the surrounding landscape (Dedrick et al. 2020) and have distinct microclimates that enable dense vegetation through the dry season (Munro-Stasiuk et al. 2014). They are as deep as twelve meters below the surface but remain above the water table (Munro-Stasiuk et al. 2014). While these karst sinkholes can be farmed, they are not necessarily terraced like those found in the Andes (see Munro-Stasiuk et al. 2014, fig. 15).

There are at least two depression terraces in Andagua grading into the surrounding broad field and linear bench terraces. Concentric and sequential, irrigated bench terracing lines the circular depressions. Walls are composed of local stones, like the other bench terracing in the area. Today, walls perpendicular to the slope divide the terraces into multiple land tenure units, their management by multiple individuals is further evident by different vegetation and states of maintenance. One depression terrace measures about 100 meters in diameter at its widest, although field measurements or higher resolution topographic data are needed to measure the depth and profile. There did not appear to be any evidence of ponding or salt accumulation on the bottom fields, indicating natural or engineered drainage features mitigating these potential issues. These depressions overlie high relief topography of a Pleistocene-aged lava and ash field (Gałaś et al. 2023). There is evidence elsewhere in the valley of depressions created from magma "smelting" gypsum and anhydrites from the Murco Formation, causing a non-volcanic crater to form (Gałaś et al. 2023). It is possible that a process similar to this formed the depressions that are now lined with agricultural terraces. Alternatively, there are slow-moving landslides triggered by earthquakes and groundwater that have created closed depressions in the Colca Valley (Lacroix et al. 2015) that are terraced (Jonathan Sandor, pers. comm, July 25, 2022). Most of these in the Colca Valley are on lacustrine or avalanche deposits lining rivers, indicating erosion, in addition to earthquakes, are one contributing factor to its velocity (Lacroix et al. 2015) in addition to precipitation and groundwater saturation (Bontemps et al. 2020). One of the slow-moving landslides are located on weathered andesitic lava (Lacroix et al. 2015), although unlike Andagua, it is situated on a drainage. Further fieldwork such as excavations and remote sensing investigations such as DEM comparisons over time would be needed to confirm their origins.

Other Terrace Types

Other more uncommon terrace types include valley floor terraces and box terraces. Valley floor terraces are larger than bench terraces and found on valley floor stream terraces and floodplains with low retaining walls perpendicular to the flow (Donkin 1979, 102; Treacy and Denevan 1994, 100-102; Beach et al. 2002). These terraces are bounded by earth or adobe walls 0.5 to 3.0 meters in height (Field 1966, 130-133; Donkin 1979, 111). Although Brooks (1998, 135) places valley floor terraces under bench terracing, this dissertation's classification system considers them as distinct due to their topographic position on a valley floor or river terrace, and their distinct soil profiles. In the southern Andes, these fields are locally referred to as *cuadros* (Field 1966, 130). Valley floor terraces are also found in the Maya Lowlands on foot-slopes above depressions to mitigate and use colluvium and eroded sediments to create cultivable areas (Beach et al. 2002). Box terraces are typically found in relation to settlement structures and were likely seedbeds or house gardens, as are seen in the Maya Lowlands (Beach et al. 2002).

Land Cover Classification

Each terraces' land cover was classified according to the type covering greater than 50% of the area. Categories include barren, shrub, and other vegetation (i.e., grasses, crops) cover. The single-band, greyscale declassified imagery made it difficult to be confident about distinguishing between crops and grasses, and therefore, they are combined. Subcategories listing a second-order cover, such as shrubs, helped to further clarify the land cover, when appropriate. Image keys were created to help with consistency in the classification and analysis of the landscape. This section will briefly outline the land cover classifications and subclassifications, and their distinguishing features on satellite imagery.

The barren or little to no vegetation cover category includes areas with thin or no soil or sand or exposed rock (Anderson et al. 1983, 18). There were many scenarios where it is unclear if the non-vegetation cover is natural or if it is human induced (Anderson et al. 1983, 19). This may include sandy dunes, volcanic rocks, disused fields without vegetation cover, recently tilled or turned fields, and corrals, among other anthropogenic or natural processes.

The vegetation cover category includes both crops and grasses, with fewer than 50% shrubs, cacti, or trees. As stated above, the panchromatic imagery makes it difficult to discern between grassy and crop vegetation cover as their tone can be similar. While crop cover is defined as land used for the "production of food and fiber" (Anderson et al. 1983, 13), local farmers leave land fallow and may deliberately seed grasses, making the context of being in a field not always reliable as an indicator of cover. As such, both will be considered non-shrub vegetation. If it is likely that the cover is crops, due to texture or pattern, then it may be noted. If the cover has between 20 and 50% shrubs, it will be considered shrubby.

Shrub cover refers to areas with greater than 50% shrubs, cacti, or other native vegetation. These may occasionally include long-abandoned terraces or slopes. They are distinguishable due to the stippled texture and often dark tone. They will be considered dense when there is greater than 70% shrubs.

Boundary Classification System

Mapping boundary condition, type and patterning gives clues about the hydrological and geomorphological processes, irrigation systems (see Brown et al. 2021, 3), and social relationships. This classification system was created with consideration for these patterns in the Andes. Firstly, the classification system distinguishes between external and internal boundaries, which typically correlate with walls and canals, although their exact composition and morphology can only be confirmed with ground-truthing (table B.4). Internal boundaries refer to the anthropogenic contiguous curvilinear or linear features that are parallel or perpendicular to the slope and contain no other permanent interior features of a similar description. They are the retaining walls for the accumulated sediments, emplaced or produced soils and drainage features. They are often less than three meters in width and encircle one land cover type. An exterior boundary will often contain multiple internal boundaries, can be greater in width than the interior boundaries and will be continuous in a circular, irregular, or rectangular pattern. If a point is in a field or terrace set that is not clearly bounded by an exterior feature, then that category is considered not available and only the interior boundary features are recorded. Features are further refined by a description of their contiguity: possessing many breaks, some breaks, or no breaks.

The conditions of boundary features are then categorized by its tonal and textured relationship to the land cover. They can either be “contrasting” or “ambiguous” in relation to the surrounding land cover. A contrasting boundary has a clear juxtaposition in tone between the tread, boundary feature and area outside the feature (figure 4.7). A subcategory is assigned to both interior and exterior features to describe the majority (greater than 50%) feature texture. Contrasting features may be coarse, soft, or fine. A fine contrasting feature appears delicate and thin with few noticeable protrusions. Coarse contrasting features appear with sharp and frequent protrusions from the line, which is often thicker in width. Soft contrasting features appear with softer and frequent protrusions from the line. An ambiguous boundary has similar tone or texture to the tread. It may have many soft or jagged protrusions up to double the feature width or larger and may have many to no breaks. Ambiguous subcategories include craggy, fluffy, or bristly boundaries. Craggy features appear irregular with a largely disrupted continuity leaving the tread and feature difficult to distinguish. The tone and texture may vary. Fluffy ambiguous features appear intact but are largely obscured or difficult to discern due to possessing a similar texture and/or tone as the tread or surrounding area. Bristly ambiguous features are largely discernable from the tread in tone and texture but can be obscured by many jagged or soft protrusions. The identification of these features is reliant on the relationship between the feature and pixel size; it is difficult to identify walls in coarser imagery when their width is less than the dimensions of the pixel.

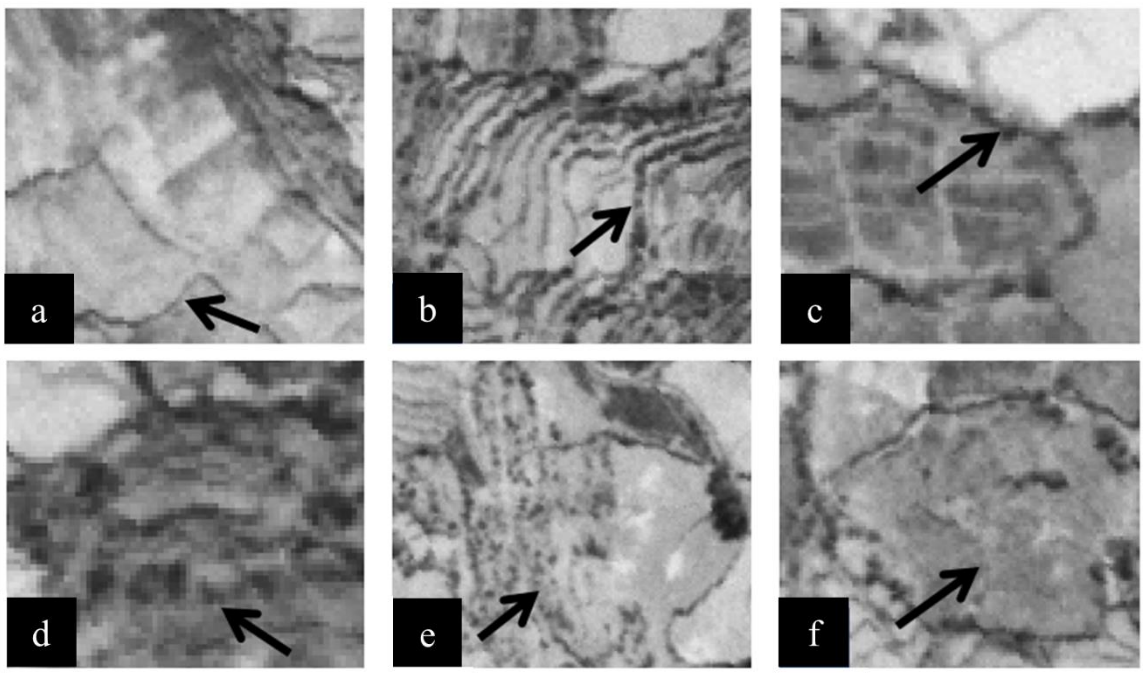


Figure 4.7 Examples of contrasting exterior boundary features of fine (a), coarse (b), and soft (c), and ambiguous boundary features of craggy (d), bristly (e), and fluffy (f).

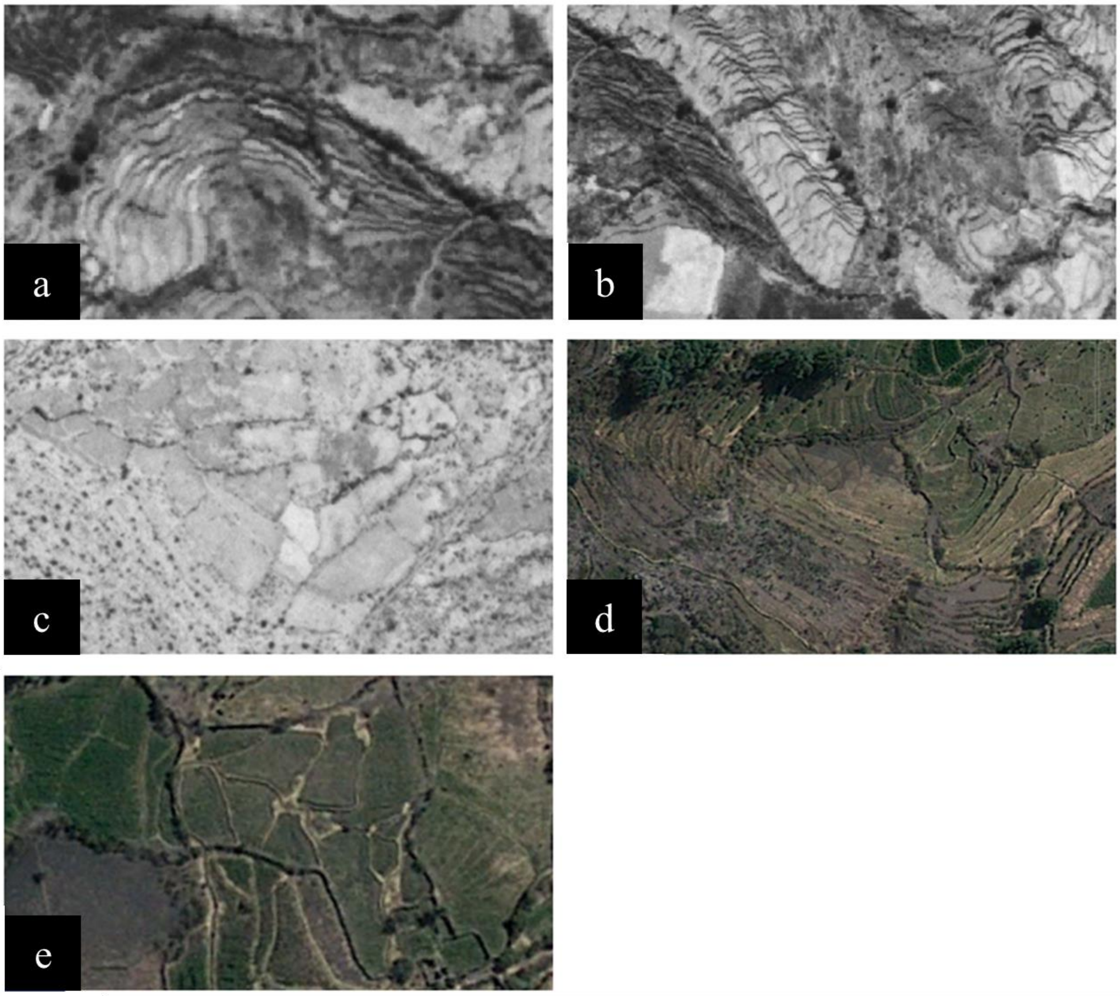


Figure 4.8 Examples of sequential horizontal (a), sequential vertical (b), segmented (c) and sequential horizontal and vertical (d) exterior feature patterns and segmented (e) and sequential (a, b & d) interior feature patterns (USGS 1977; Maxar 2010).

The planform patterning, both for external and internal boundary features, were also categorized to provide context for slope continuity (see Brown et al. 2021), land tenure, and land use. The planform patterning refers to the relationship of the mapped terrace feature to the surrounding terraces or terraced units (figure 4.8). Exterior boundaries are in segmented, sequential horizontal or sequential vertical patterns. Sequential horizontal patterns refer to a feature with more than one external boundary that follows the contour line (across a single elevation) along multiple similar terrace units. Sequential vertical refers to a terrace unit with more than one external boundary perpendicular to the contour line, which continues along the same trajectory on a separate terrace unit. A feature may be both sequential vertical and horizontal. Segmented refers to external boundaries that are not continuous along or perpendicular to the contour line across multiple terraced units, and the lengths are segmented by other linear features. Each of these continuous boundaries are likely also canals or paths. Interior feature patterns include segmented, sequential, and sequential extended. Segmented interior boundaries follow the contour line, but the majority do not touch more than one external boundary. Sequential internal boundaries describe boundaries that largely follow the contour line and extend from one external boundary to another often retaining a singular terrace tread. A sequential extended boundary is the same as above but much longer in length.

Mapping Drainages, Geology, Topography, Roads, and Paths

Roads and paths connect settlement features, fields, water sources and other places of ritual and everyday practice. Paths are established routes for walking, leading animals, and riding horses, for example, and are often rooted as deep as the Inca and pre-Inca periods. These often overlap with canals or field boundaries and may be difficult to distinguish when covered by vegetation or are multi-use. Pre-colonial paths have been mapped across the valley by Menaker (2019) and are generally three meters across or narrower. Features were classified as roads when the width was, on average, greater than about four meters across and the edges appear evenly constructed. Many roads were constructed as part of the gridded *reducción*, and others are more contemporary (late twentieth and early twenty-first century), constructed by the municipality to enable vehicle movement throughout the valley across agricultural fields as well as across settlements in the valley.

ArcGIS Pro was used to calculate the distance to the nearest path, road, and drainage for each point for each year in addition to extracting the geologic information for each point for each year, resulting in geolocated data containing terrace type, boundary types and conditions, geology, elevation, plan and profile curvature, elevation, slope, and distance to nearest town and the nearest drainage, path, and road.

DATA ANALYSIS

Hypothesis Testing Over Time and Across Place

To answer the first set of questions on the differences between the terraces and associated terrace boundaries (i.e., retaining walls) in Paccareta and the main valley, the statistical difference between the data sets for each variable was tested using either a parametric or nonparametric hypothesis test, as appropriate (see below). Hypothesis testing was also used to answer the second set of questions relating to the presence of roads and paths and their proximity to terraces. Data were tested for change through time (1977, 2010 and 2021) collectively and for the individual areas of Paccareta and the main valley.

The null hypothesis states that the test statistics for each population are statistically the same (given the corresponding p-value of 0.05 and 95% confidence interval; Dunn and Smyth 2018, 53-56). Student's t-test was used for variables with normal distributions and statistically similar variances; Welch's t-test was used for variables with normal distributions but statistically different variances; and Wilcoxon rank sums test was used for variables with non-normal distributions. The Wilcoxon test is a nonparametric test, meaning that its null hypothesis states that there is no difference among the data using the median as the test statistic. The test hypotheses were two-tailed because the outcomes (lower or higher) were both important. If the variables were non-normal, different transformations were tested for normality before choosing the appropriate statistical test and transformation, if appropriate. All calculations were completed using RStudio.

Logistic Regression Data Preparation and Analysis

Logistic regression was used to address the question referring to the potential impact of the changing proximity of roads to terraces on use over time. This was approached in two ways (see Dunn and Smyth 2018, 248-9). The first was predictive logistic regression, which tests if the proximity to roads in combination with other environmental and social factors can predict terrace use. The second was effect-size logistic regression, which estimates the log-likelihood of terrace use given proximity to a road, adjusting for other related variables. While predictive logistic regression is concerned with incorporating variables to predict, the effect-size models are attempting to understand the impact of variables on the log-odds of the event. Each was conducted for Paccareta and the main valley separately and then all sampled terraces. The logistic regression models resulted in an equation producing the log-odds of the presence of a positive outcome given each scenario.

The data was first cleaned and formatted for predictive and effect-size logistic regression models. Each point was classified as a used or disused terrace or field, where used terraces were described as grass or crop vegetation with a contrasting interior boundary. Highly correlated variables were noted and discarded for predictive logistic regression. Other variables used to categorize terraces into the "use" category were also discarded. An important assumption for logistic regression is that the numeric variables have a linear relationship with the log-odds of use (Dunn and Smyth 2018, 340). As such, variables were also categorized or transformed, as appropriate, to satisfy this assumption.

For effect-size logistic regression, individual models were created for each variable. Each model was evaluated for fit using two pseudo R^2 indicators: McFadden's and McKelvey and Zavoina, the latter being the better estimation (Signorell 2022). They were also evaluated using the AIC (based on the Akaike's Information Criterion), residual deviance, standard error, p-values, and Analysis of Variance Chi-squared test (Dunn and Smyth 2018, 246-247, 270-271). The log-odds models the tested if they were significantly different from no model were then used to produce probabilities of use in different scenarios.

For predictive logistic regression, data was randomized and split into seven different sets of training (80%) and testing groups (20%) for each year. Repeating the randomization for each year multiple times reveals inconsistencies, patterns, or outlier variables. The models resulting from the training data were evaluated using the same criteria as above and the addition of calculating the predictability and area under the curve. New models were created by eliminating insignificant variables and retesting for model fit. These nested models were compared for best fit using likelihood ratio tests.

Limitations

There were several limitations to these analyses, including the inability to ground-truth land cover, wall condition, or use during any of these time periods. While the definition of use was created from field experience, the selection criteria does not include ambiguous boundary categories, which may be excluding some older, fallow or heavily vegetated terraces. Additionally, while the images from 1977 and 2010 are from the dry season, the 2021 imagery is from the rainy season, limiting some continuity. As such, the land cover description for use was inclusive.

RESULTS

Object-oriented analysis resulted in the classification of multiple anthropogenic features, including terraces, fields, corrals, archaeology sites, paths or roads, indistinguishable anthropogenic features and those that are not clearly identified as anthropogenic (table 4.6).[9] Points classified as terraces increased in both the main valley and Paccareta over time. Several points in both Paccareta and the main valley were located within what appeared to be corrals due to their oval shape and isolated locations. They were also surrounded by natural vegetation and there were no terrace features in the immediate vicinity. Terrace features that appear to be located within paths or roads in the main valley in 2010 are a result of the road construction widening paths and cutting across terraces. The remainder of the results section will exclude points that were not classified as terraces. This section will first describe results of the object-oriented analysis and outline statistical results from hypothesis tests, and then conclude with results from the predictive and effect-size logistic regression models.

Table 4.6 Count of sample points' anthropogenic classification for each year by location.

	Year	Terrace	Corral	Arch. Site	Path or Road	Other	NA
Main Valley	1977	68	2	1	0	4	24
	2010	78	3	1	2	2	14
	2021	78	2	1	1	2	16
Paccareta	1977	47	2	1	2	5	27
	2010	58	4	1	1	1	17
	2021	61	3	1	1	3	15

Note: "NA" refers to points with no anthropogenic features, "Other" refers to points that appear to be contained within an unidentifiable anthropogenic feature, and "Arch. Site" refers to points located inside archaeology sites.

Object-Oriented Analysis

Physiography

Of the sampled points, Paccareta is significantly less steep and higher in elevation than the main valley; although the highest sampled terraces were found in the main valley west of town (see tables 4.7 and 4.8). The lowest elevation terrace was also found in the main valley located in a drainage southeast from town. The aspects are significantly different between these two locations. The median and mean aspect of the main valley is east facing while the men and median of Paccareta is more southeast facing (see figure C.1). Plan and profile curvature were not significantly different, both being relatively flat (see also figures C.2 and C.3). This possibly reflects the coarser resolution of the topographic dataset or slope modifications made by terracing. The mean slope in Paccareta is gentler by several degrees than the main valley (see also figure C.4).

Table 4.7 Summary statistics for locational and topographic features for sample points classified as terraces.

	Main Valley					
n = 78	Minimum	First Quantile	Median	Mean	Third Quantile	Maximum
Y	8283797	8284630	8285282	8285395	8285792	8288177
X	780678	784048	784048	784532	785529	787448
Z (m)	3256	3431	3517	3515	3596	3826
Slope (°)	2.074	4.33	6.90	7.65	9.98	20.23
Aspect (°)	19.88	62.54	94.13	105.83	132.43	341.07
Profile Curvature	-0.0017	-0.0006	-0.0002	-0.0002	0.0001	0.0024
Plan Curvature	-0.0242	-0.0060	-0.0018	-0.0020	0.0022	0.02356

Table 4.7 cont.

			Paccareta			
n = 61	Minimum	First Quantile	Median	Mean	Third Quantile	Maximum
Y	8287387	8287919	8288146	8288104	8288391	8288658
X	783411	783682	783979	783957	784213	784565
Z (m)	3538	3616	3627	3621	3634	3643
Slope (°)	0.98	1.75	2.34	3.80	5.56	15.69
Aspect (°)	64.18	108.31	142.51	149.45	178.77	290.70
Profile Curvature	-0.0030	-0.0003	-0.00003	-0.00005	0.0001	0.0019
Plan Curvature	-0.0157	-0.0052	-0.0010	-0.0004	0.0016	0.0454
			Total			
n = 139	Minimum	First Quantile	Median	Mean	Third Quantile	Maximum
Y	8283797	8285155	8287118	8286584	8288087	8288658
X	780678	783731	784184	784280	784870	787448
Z (m)	3256	3507	3600	3561	3631	3826
Slope (°)	0.98	2.36	4.78	5.9578	8.14	20.23
Aspect (°)	19.88	82.78	116.89	124.97	156.20	156.20
Profile Curvature	-0.0030	-0.0005	-0.0001	-0.0001	0.0001	0.0024
Plan Curvature	-0.0242	-0.0056	-0.0017	-0.0013	0.0021	0.0454

Data: SRTM 2000.
Note: Data taken from 2021 samples.

Table 4.8 Results from hypothesis testing for statistical difference between Paccareta and the main valley for physiographic variables.

Variable	Statistical Significance from Hypothesis Test
Slope	***’
Aspect	***+
Plan Curvature	‘
Profile Curvature	‘
Elevation	***’
Distance to Town	***+
Distance to Nearest Drainage	**’

Data: SRTM 2000.
Note: * < 0.05, ** <0.01, *** <0.001; ^ if Student’s t-test was used, + if Welch’s t-test was used, ‘ if Wilcoxon rank sums test was used. H_o = the variable in Paccareta and the main valley are the same.

Object-oriented analysis revealed evidence of landslides and erosion impacting infrastructure. The sediment and stone canals, while beneficial for sediment distribution on terrace treads, are vulnerable to landslides and require regular maintenance, as mentioned by farmers in Andagua (see chapter 3). One example of this precarity, seen in 1977 imagery, is the collapse of the Canal Madre as it traversed the eastern twin volcano (figure 4.9). A landslide scar is visible beginning slightly above and traversing a discontinuous canal. Its importance to the main valley for irrigation implies that it was reconstructed relatively quickly after this event. There is a similar landslide scar proximal to this one visible as early as the 1931 imagery, indicating that such thresholds were overcome multiple times in the past.

Figure 4.9 Landslide disrupting the flow of the Canal Madre in 1977 (middle; USGS 1977), then seen as a scar in 2010 (right; Maxar 2010). Evidence of previous landslide scars in similar position as early as 1931 (left; Museum of Natural History Library, image no. ppcs551_l22).

There were also instances of infrastructure remaining in disrepair for decades. For example, there are retaining walls in both used and disused terrace units that appear to have collapsed sometime in the past but were left unrepaired. Terraces like this that are upslope of maintained terraces are potentially sources of eroded sediment for the downslope-maintained terraces. There are other examples of large expanses of terraces containing a mixture of both maintained and unmaintained terraces, sometimes within what appears to be a single land tenure unit. This includes one larger extent linear, sequential terraces below the reservoir and micro-hydroelectric plant near the eastern twin volcano in the main valley (figure 4.10). The patterns of disuse seen in 1930 and 1977 for these terraces remain in various states of disrepair through to 2021. Long, cultivated linear terrace treads extend into disused portions composed of sandy soils, shrub cover and fallen terrace walls. Similarly, disused terrace treads extend into a cultivated terrace set, evident by its stippled texture. What are likely cows are visible on both the maintained and unmaintained portions of this terraced hillslope, demonstrating that some “disused” terraces are used for grazing cattle while not cultivated or otherwise visibly maintained.

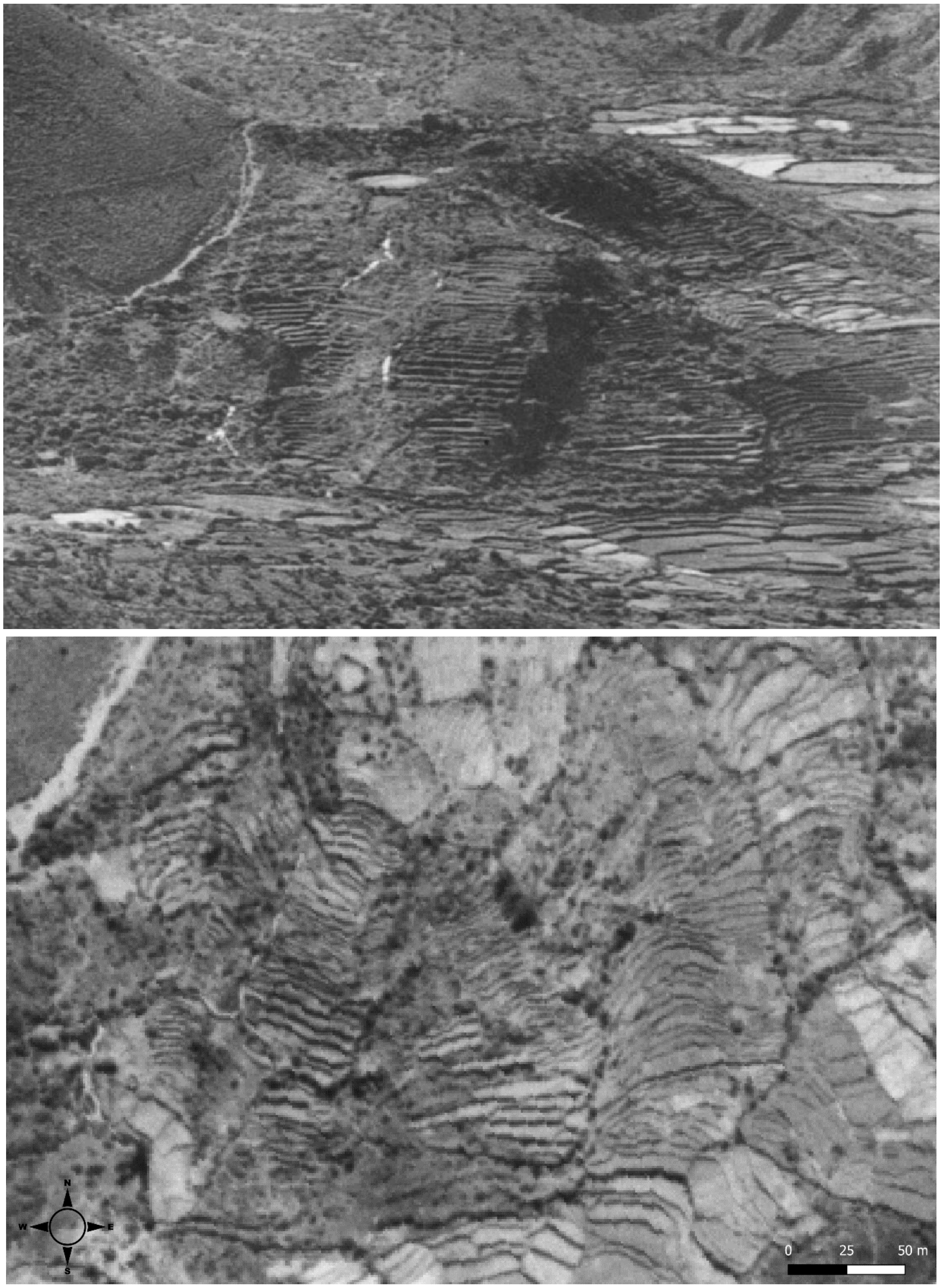


Figure 4.10 Terraced hillslope with patterning of used and disused terraces near the micro-hydroelectric plant in in 1930 (top; American Museum of Natural History 2016, image no. ppcs551_l22), 1977 (bottom; USGS 1977) and 2010 (next page; Maxar 2010).

Figure 4.10 cont.

Canals

In addition to terraces and fields, supporting infrastructure such as canals were and are constructed, maintained, abandoned, and altered over time in both Paccareta and the main valley in tandem with expansions, disuse, and reuse of cultivated land. For example, what are likely abandoned canals were incorporated into the degraded sequential terraces on the eastern and northern portion of the site of Paccareta, although neither are currently in use. The canal that is currently in use in Paccareta sources water from the river like the Canal Madre in the main valley (figure 4.11). Between 1977 and 2010 a concrete weir was constructed upriver from the canal intake, possibly to regulate the volume of water entering the canal system.[10] This *bocatoma* (intake) is several kilometers upriver of both Paccareta and the main valley to capture the water before the river incised into the lava fields covering the valley floor. The remainder of the Canal Madre was cemented in 2016, causing the interruption of the electricity in town, its source being a micro-hydroelectric plant supplied by the canal. The stone and soil feeder canals and diversion boxes are also gradually being cemented with concrete donated by mining companies and other local interests (see chapter 3).

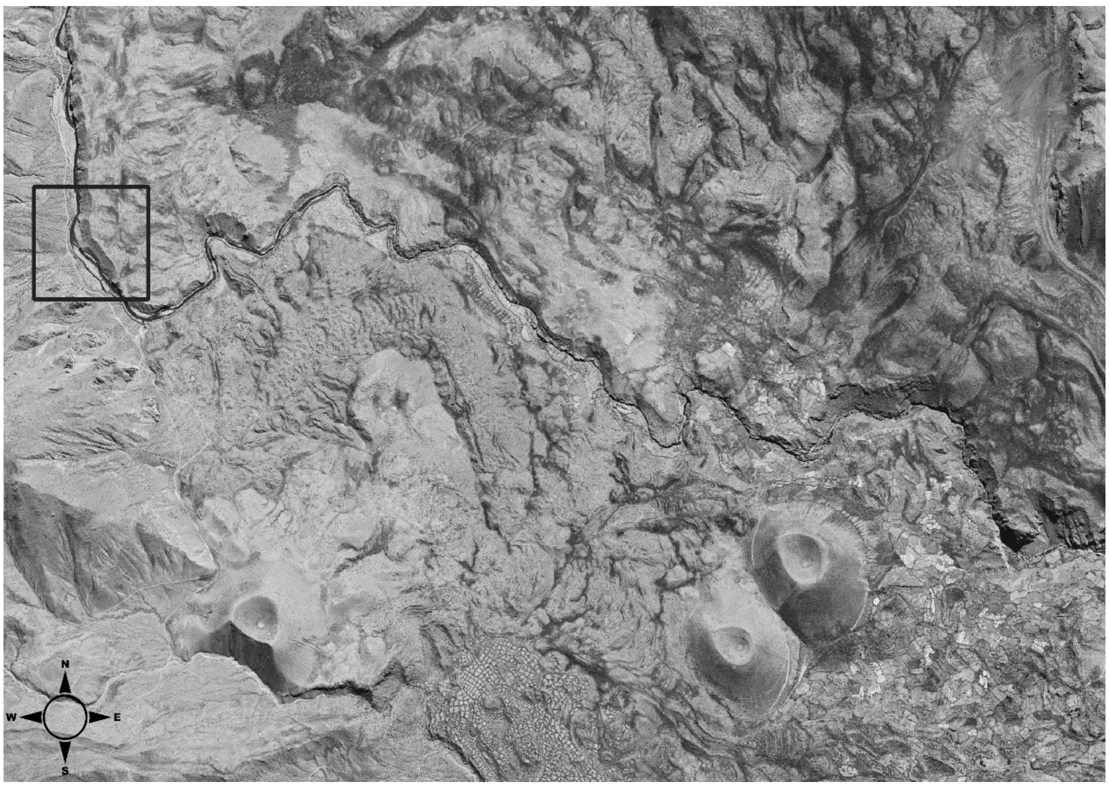


Figure 4.11 The canal intake for both the main valley's Canal Madre on the right bank of the river and the Paccareta canal on the left bank in 1977 (left on next page; USGS 1977) and 2021 (right on next page; Maxar 2021). Their location in relation to agricultural fields (above; USGS 1977).

Figure 4.11 cont.

Terraces and Internal Boundary Features

Sampled terraces included broad field and lateral terraces and those that possessed characteristics of both broad field and lateral categories (table 4.9). There was additionally one terrace overlying alluvial material that may have been a valley floor terrace, although a field visit is needed to clarify its relationship to channel boundaries and its position within the floodplain or location on a low stream terrace. A flooding event between 1977 and 2010 destroyed this possible valley floor terrace. There were a high number of broad field terraces in both Paccareta and the main valley, although a higher proportion of sampled terraces in use in Paccareta were broad field. The change to 2021 for both locations was marginal. Terraces in Paccareta slightly increased in that year while those in the main valley decreased. No sampled terraces were classified as sinkhole terraces, cross-channel terraces, or sloping-field terraces, although these are present in Andagua. There are further agricultural features that may or may not be terraces and, therefore, their terrace type is considered not applicable. This category also includes potential terraces with undetermined terrace types likely due to degradation.

Table 4.9 Number of sampled terraces of each terrace type through time in Paccareta and the main valley.

	1977		2010		2021	
Terrace Type	Pacc.	MV	Pacc.	MV	Pacc.	MV
Broad Field	25	21	37	27	41	24
Lateral	4	27	3	23	4	21
Lateral-Broad Field	8	11	11	14	10	16
NA	11	9	7	14	6	17

Note: "Pacc." refers to Paccareta and "MV" refers to the main valley; "NA" refers to undefined features that may be unterraced, but fieldwork is needed to confirm.

The increase in terrace units in Paccareta in 1977, 2010 and 2021 correlates with the rehabilitation of terraces and the formation of land tenure units beginning in the mid- to late-1960s. The 1977 imagery depicts rehabilitation beginning with the terraces in the southern portion of Paccareta, which is the area closest to town (figure 4.12). A larger portion of these terraces appear to overlie a lighter topsoil, rather than the black sand in the northern areas of Paccareta, and may have been periodically in use as evidenced by their ragged yet clearly distinguishable boundaries in Shippee-Johnson images from the 1930s. A wide path divides Paccareta into a northern and southern portion, running from the vegetation-covered bridge over the river canyon and ascending over the site of Paccareta towards the highlands (figure 4.13). In 1977, the area north of this path was covered by disused terraces, their walls remaining in relatively straight but fuzzy outlines of terraced fields. A steel and concrete bridge was constructed south of the colonial-era bridge between 2010 and 2021 that, in combination with new switchbacks up the steep escarpment, enabled trucks and cars to traverse the river canyon. This switchback's road cut reveals both the impacts of the farmers' soil rehabilitation and the past volcanic history, depicting an anthropogenic topsoil with a sharp lower horizon overlying a clayey subsoil, overlying pyroclastic lapilli and ash, overlying pyroclastic bombs (figure 4.14). The new bridge corresponds with expansion of terrace rehabilitation largely on the segmented, broad field terraces. This likely had to do with irrigation limitations, because the sequential, lateral terraces are largely located on steeper slopes and at higher elevations on the ridges of the pre-Inca archaeology site of Paccareta.

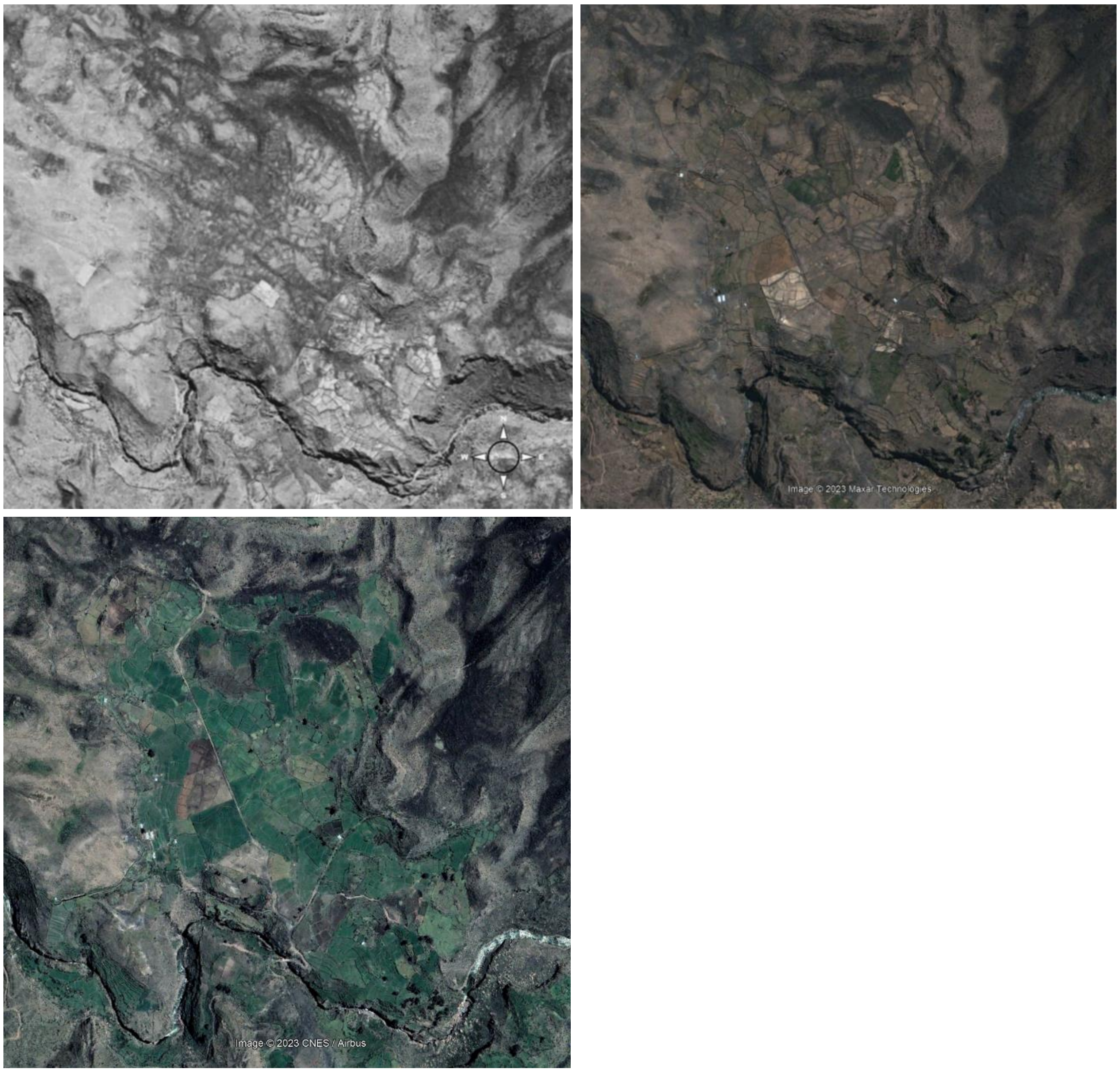


Figure 4.12 Paccareta extent in 1977 (top left; USGS 1977) depicting terrace rehabilitation concentrating in the southern portions near the river canyon and some northern portions, near intermittent water sources. The extent in use expanded in 2010 (top right; Maxar 2010) and 2021 (bottom; Maxar 2021).

Figure 4.13 Likely Spanish colonial-era bridge covered in layers of sediments and grass spanning the canyon of the Andagua River, with person in red shirt for scale. Photo taken from modern bridge, June 27, 2015 (photo by Author).

Figure 4.14 Soil profile revealed by the cutbank of the switchback ascending from the twenty-first century bridge towards Paccareta, July 4, 2016 (photo by Author).

As terraces are reconstructed and rehabilitated in Paccareta, the internal boundary characteristics shift from ambiguous to contrasting (table C.1). This sharp contrast of rehabilitated and abandoned terraces is especially apparent in the 1977 imagery (figure 4.15). In some cases, terraces appear abandoned or in disuse in 1977 and remain so through 2010 and 2021, distinguishable by sandy land cover and ambiguous internal and external boundaries. In 2010 and 2021, new, contrasting internal boundaries and paths were constructed overlying what were previously ambiguous internal boundaries. Of the sampled terrace internal boundaries, 80% were ambiguous in 1977 while only 19% are ambiguous by 2010. Other evidence of reconstruction includes the decrease in breaks in internal boundary features from 81% having few to many breaks in 1977 to 32% in 2010. By 2021, 21% of internal boundaries were ambiguous and 36% had few to many breaks.

Figure 4.15 Example of rehabilitated terrace features in Paccareta with boundaries constructed overlying previous boundaries in 1977 (left; USGS 1977), 2010 (middle; Maxar 2010), and 2021 (right; Maxar 2021).

In 1977, the sampled internal boundaries in the main valley were both sequential and segmented, each possessing similar average slopes at 8.7 and 7.4 °, respectively (table C.1; figure 4.16). All the sequential or segmented terraces were classified as having few to many internal boundary breaks, correlating with some terraces in disuse; however, this also likely corresponds with terraces with braided planform boundary patterning (see Brown et al. 2021, fig. 1). In other words, the discontinuity of many internal boundaries may be a planned water control feature. Over time, internal boundary conditions fluctuate from 40% contrasting in 1977 to 79% contrasting in 2010 and 49% contrasting in 2021 (figures C.1 to C.3). This pattern likely has to do with slightly different seasons in which the 2021 image was taken, while both the 1977 and 2010 images were taken in the same season. As such, the rainy season in 2021 may have impacted the distribution of internal boundary conditions. The majority of terraces with sequential patterning sampled in 1977 were either lateral or a combination of lateral and broad field terrace types, while the majority of segmented terraces were classified as broad field or a combination of broad field and lateral, demonstrating key features of each of these terrace pattern types.

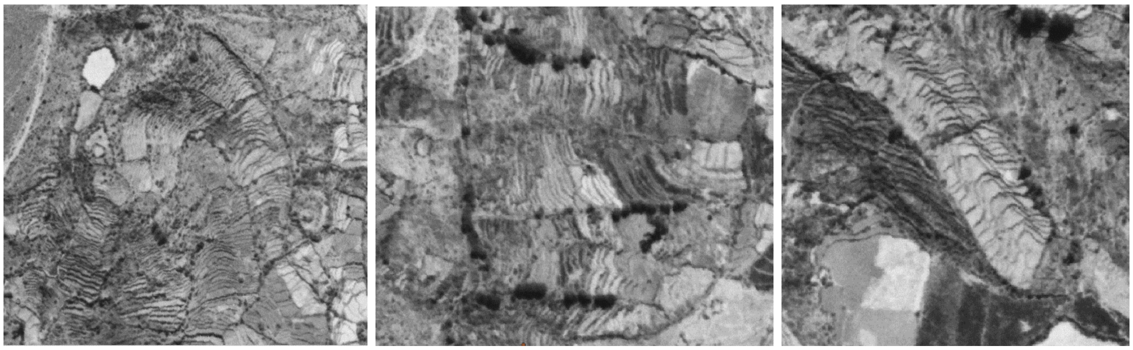


Figure 4.16 Examples of sequential terraces in the main valley with varying boundary characteristics located below the reservoir (left), near the lake (middle) and descending into the quebrada floodplain near Ninamama lava flow (right; USGS 1977).

Used and Disused Terraces

Although both document a marked increase in used terraces between 1977 and 2010, the proportion of terraces classified as used or disused changes more drastically for Paccareta than the main valley (table 4.10). In Paccareta, used terraces more than triple in number while the disused terraces decrease by half in that thirty-three-year period. The changes between 2010 and 2021 are less drastic for both the main valley and Paccareta, both areas' sampled terraces not dramatically changing in proportion.

Location in relation to Town and to Drainages

The Euclidean distance to the center of the main square and the distance to drainages changes each year; however, much of that difference lies with the shifts in sample points' classification from or to a terrace over time. Generally, Paccareta is statistically farther from town than the main valley, the latter location surrounding the Spanish-era town in all directions (table 4.11). The average distance to town in the main valley is over 1000 meters closer than Paccareta. This relationship changes over time as road expansion and transportation options enable driving automobiles to Paccareta. The median and average distance to town in Paccareta fluctuates over time, reflecting how terraces were rehabilitated and became more visible in imagery.

Table 4.10 Summary of the number of sample points classified as terraces in use and disuse in 1977, 2010 and 2021.

	1977		2010		2021	
Location	Use	Disuse	Use	Disuse	Use	Disuse
Main Valley	45	23	62	16	60	18
Paccareta	12	35	44	14	48	13

Note: A terrace in “use” was defined by a grassy land cover and a contrasting internal boundary classification.

Table 4.11 Summary statistics of distance to the town center from sampled terraces.

Location	Year	Min.	1st-Q	Med.	Mean	3rd-Q	Max.
MV	1977	346	1344	1999	2004	2628	3906
	2010	345	1247	1956	1916	2580	3857
	2021	345	1292	1956	1949	2575	3857
Pacc.	1977	2694	3170	3400	3380	3661	3917
	2010	2693	3213	3454	3402	3668	3915
	2021	2693	3181	3398	3380	3673	3910
Total	1977	346	1818	2744	2552	3381	3917
	2010	345	1744	2743	2541	3396	3915
	2021	345	1863	2784	2577	3406	3910

Note: “Pacc.” refers to Paccareta and “MV” refers to the main valley; distances are in meters.

The drainages do not change location in either the main valley or Paccareta, although the summary statistics do fluctuate with the addition and subtraction of terraces, as above (table 4.12). Most farmers in both the main valley and Paccareta source water from the Andagua River. Farmers in the main valley source drinking water from the spring called Misahuana that is also a mapped tributary of the Del Tambo River, which passes between the southern portion of the main valley and the lava fields. The Del Tambo River, beginning in the highland lakes and associated wetlands and glaciers below the Coropuna volcano, is also occasionally used for irrigation, although farmers note the current flow is not sufficient for irrigation purposes recently. The higher density of drainages in the main valley correlates with terraces being statistically closer to them than in Paccareta, although the Andagua River is incised into the valley floor as it passes both Paccareta and the main valley.

Table 4.12 Summary statistics of distance to the nearest drainage from sampled terraces.

Location	Year	Min.	1st-Q	Med.	Mean	3rd-Q	Max.
MV	1977	3	130	312	393	623	1196
	2010	3	151	346	417	631	1196
	2021	3	150	346	420	643	1196
Pacc.	1977	57	335	539	539	745	1077
	2010	57	334	558	549	752	1077
	2021	50	309	539	533	759	1036
Total	1977	3	171	428	451	695	1196
	2010	3	210	458	473	709	1196
	2021	3	207	456	470	710	1196

Note: "Pacc." refers to Paccareta and "MV" refers to the main valley; distances are in meters.

Distance to Roads and Paths

The mapped roads increase in number and density around the town of Andagua including through fields and towards neighboring valleys and towns from 1977 to 2021 (see figures 4.17, 4.19 and 4.20). In 1977, the main roads include unpaved roads within the gridded town, a byproduct of Spanish colonial urban planning, and those going up- and down-valley (figure 4.17). There is a wide path bisecting Paccareta starting at the Spanish colonial arched bridge traversing the Andagua River canyon, going through the pre-Inca site of Paccareta, and up towards the highlands. Although it is wider than six meters, it is not labeled as a road during this period because it is inaccessible by cars, a crucial distinction for this classification. This patterning was about a decade after the reconstruction and rehabilitation of terraces began, in addition to the bottom-up regional road construction over the Coropuna pass. During this period, distances to roads and paths are statistically different between the main valley and Paccareta (table 4.13). Considering the location of the major roads, sampled terraces were, on average, 1600 meters further from roads than those in the main valley (table 4.14). Additionally, sampled terraces were more than 150 meters further from paths than in the main valley.

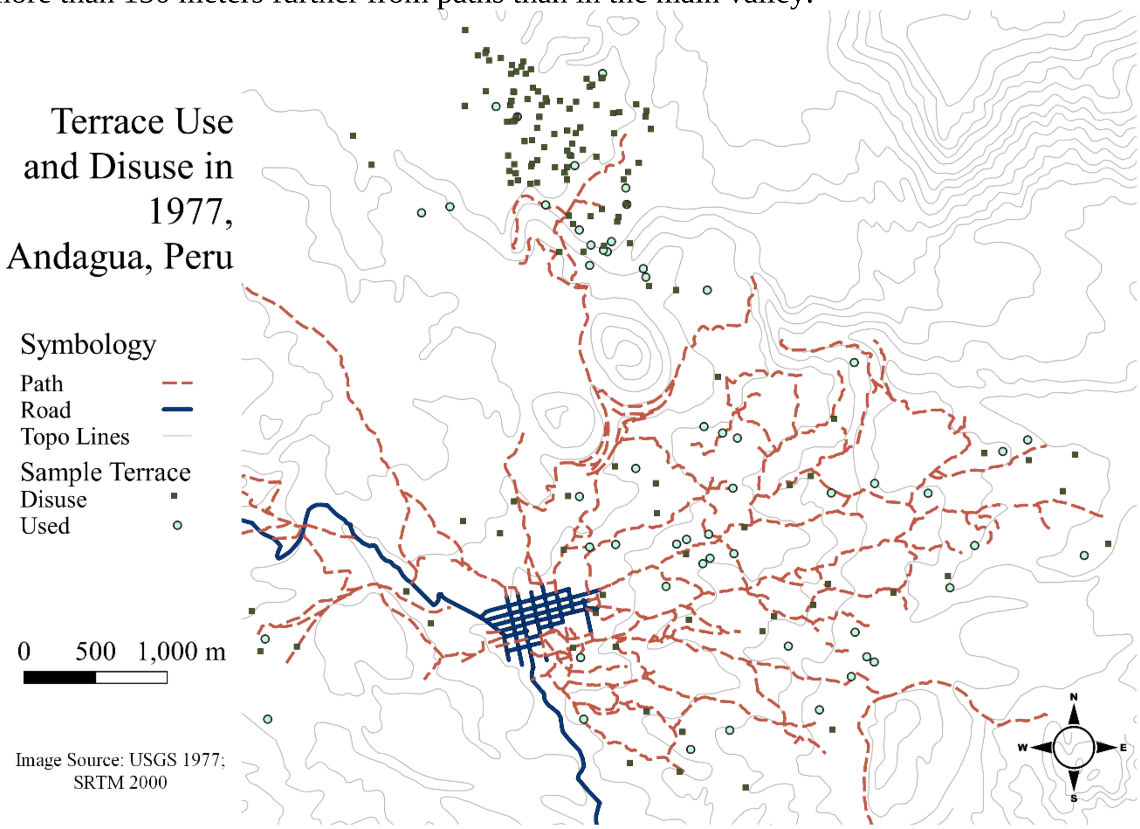


Figure 4.17 Map of roads and paths in relation to all sample points in Andagua Peru in 1977.

Table 4.13 Hypothesis testing results between distances in Paccareta and the main valley.

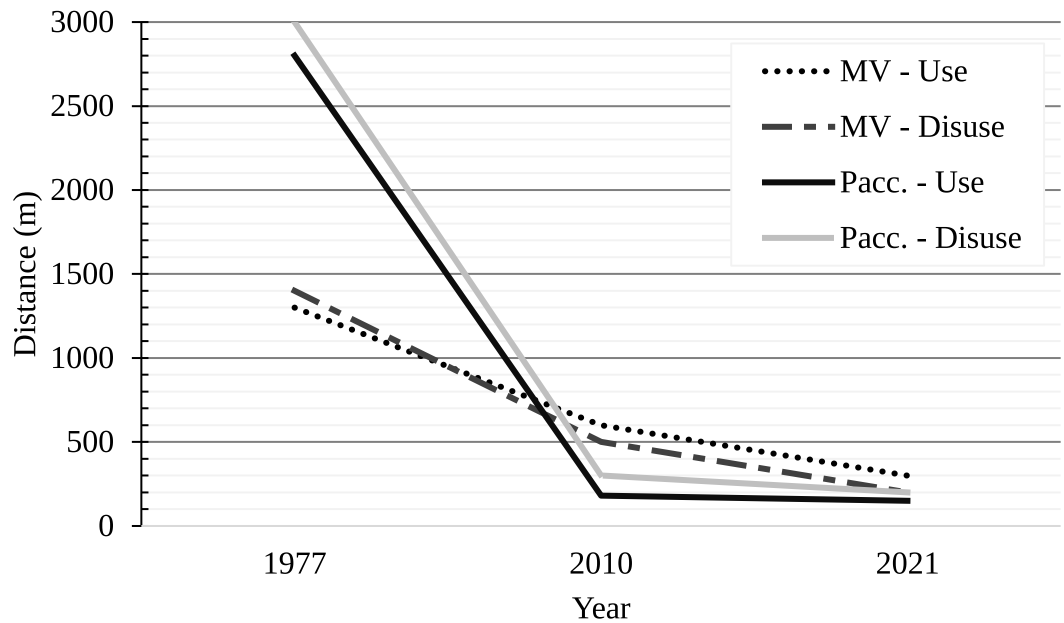
Variable	1977	2010	2021
Distance to Road	***+	*** ‘	^
Distance to Path	*** ‘	*** ‘	*** ‘

Note: * < 0.05, ** <0.01, *** <0.001, ^ if Student's t-test was used, + if Welch's t-test was used, ‘ if Wilcoxon rank sums test was used.

Table 4.14 Distance of terraces to roads and paths over time.

Distance to Road							
Place	Year	Min.	1st-Q	Med.	Mean	3rd-Q	Max.
MV	1977	67.01	686.02	1181.15	1375.73	2098.23	3399.65
	2010	29.55	188.17	464.76	588.27	794.48	2457.96
	2021	10.34	81.82	167.28	245.05	356.34	1024.52
Pacc.	1977	2361.00	2809.00	2920.00	2925.00	3066.00	3507.00
	2010	10.47	95.53	175.23	201.98	252.26	567.97
	2021	10.47	75.27	141.67	168.60	227.92	511.83
Total	1977	67.01	1023.01	2255.73	1992.62	2907.73	3506.99
	2010	10.47	140.73	246.07	425.91	524.79	2457.96
	2021	10.34	77.64	156.70	211.50	275.90	1024.52
Distance to Path							
Place	Year	Min.	1st-Q	Med.	Mean	3rd-Q	Max.
MV	1977	0.26	45.54	88.34	147.64	185.85	644.79
	2010	3.87	42.17	75.79	119.19	135.55	644.79
	2021	3.87	44.18	78.31	127.46	146.54	1202.64
Pacc.	1977	1.15	140.99	244.72	313.56	454.05	833.83
	2010	10.92	92.74	185.54	244.08	388.77	703.56
	2021	10.92	136.78	243.01	274.67	389.18	703.56
Total	1977	0.26	65.58	140.99	213.73	341.14	833.83
	2010	3.87	51.66	116.09	171.68	208.33	703.56
	2021	3.87	62.09	136.28	192.07	259.10	1202.64

Note: "Pacc." refers to Paccareta and "MV" refers to the main valley; all distances are in meters.



Note: "MV" refers to terraces in the main valley and "Pacc." refers to those in Paccareta.

Figure 4.18 Average distance to the nearest road for used and disused sampled terraces in 1977, 2010 and 2021.

Table 4.15 Summary statistics of mapped path and road segment widths.

	2010		2021	
Statistics	Path	Road	New Roads	New paths
Number of Segments	188	199	19	9
Mean	2.79	5.96	6.12	3.39
Standard Deviation	0.94	2.15	1.57	0.91
Maximum	5.5	15.8	9.2	5.4
Minimum	0.9	3	4.2	2.2
Mode	2.4	4.7	5	2.9
Median	2.8	5.3	5.8	2.9

Data: Mapped using Maxar imagery (2010, 2021).
Note: All width measurements are in meters.

By 2010 the main constructed roads include those going up valley towards the mining town of Orcopampa, up and through Paccareta, east towards the hamlet of Tauca, and south towards the hamlet of Soporo (figure 4.19). The roads going north and through Paccareta overlie existing paths. Another road brings tourists to a lookout point on top of a lava dome and two others follow ridges through the valley. Additional path segments include social trails shortcutting switchbacks in roads, although this did not significantly change the average distances to paths from sampled terraces (tables 4.13 and 4.14). The average distance to roads significantly changed from 1977 to 2010, decreasing by more than 900 meters in the main valley and more than 2700 meters in Paccareta. The difference between distances to roads and to paths for sampled terraces are still significantly different in this period (table 4.15). However, sampled terraces are now closer to roads in Paccareta than those in the main valley (figure 4.18). Additionally, new terraces and fields appear to be cultivated by 2010 near newly constructed roads. One example includes a lava flow north of town patterned with alternating lighter and darker soils with shrubs lining their interface. The darker areas were put into cultivation, possibly with the help of the community tractor accessed by the expanded road, and the lighter areas with shrubs were left uncultivated. These fields do not appear to have constructed internal boundaries but do have anthropogenic external boundaries.

While there were only one or two major changes in Paccareta between 1977 to 2010, it led to a steep decline in proximity to roads for sampled terraces during that period (figure 4.18; table 4.14). This is more dramatic than the main valley, although the decrease is still evident, especially in the maximum distances. Summary statistics show a decline in all categories for Paccareta from 1977 to 2010, corresponding with the continued reconstruction and rehabilitation of terraces (table 4.14). The proximity of terraces to the nearest path fluctuates from 1977 to 2010 for both the main valley and Paccareta, perhaps due to the replacement of some paths by roads, thus increasing the distance to the nearest path. New roads at the southern and northern margins of town were documented in 2010, as were new residential, commercial structures, and accompanying corral features (figure

4.20). Roads existing in 2010 were on average about 6.0 meters in width, while paths during this period were around 3.0 meters in width (table 4.15).

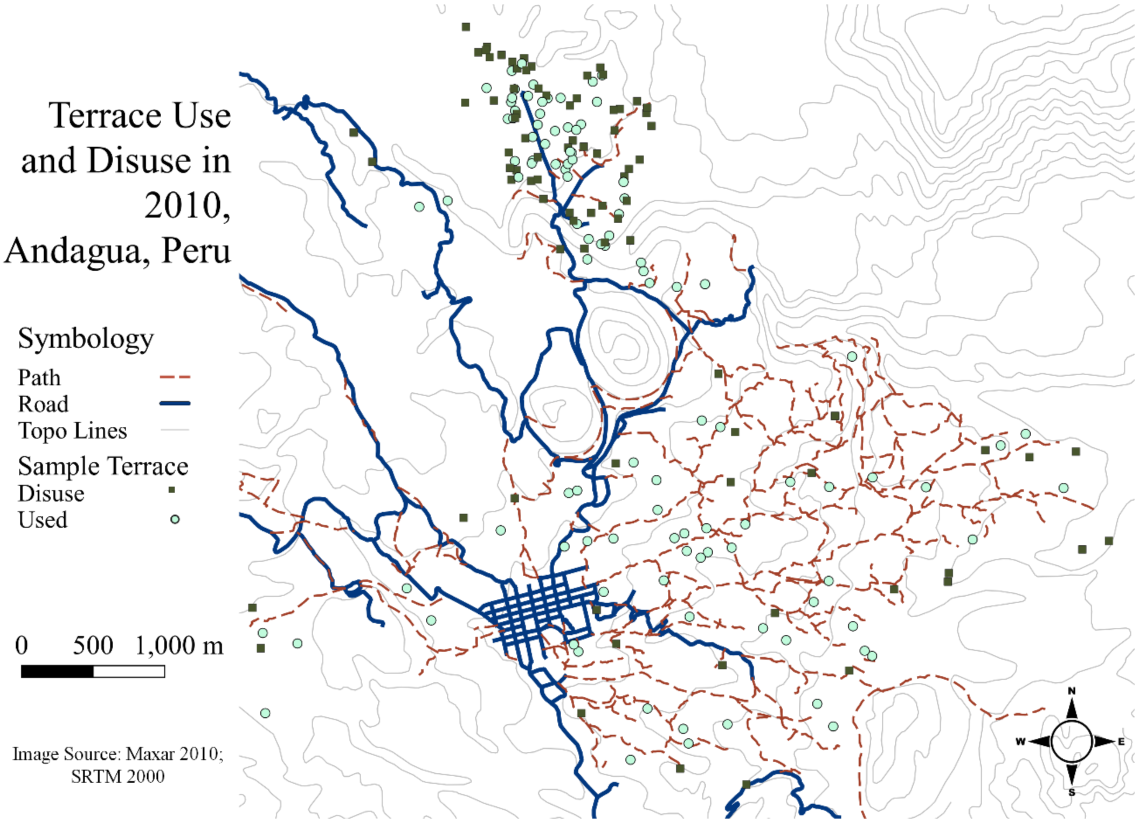


Figure 4.19 Map of roads and paths in relation to all sample points in Andagua Peru in 2010.

By 2021, many large paths beginning from a road in the gridded town descending into the valley were replaced with roads (figure 4.20). The municipality, having oversight of the town itself, began this expansive road construction project through the 2010s in the main valley correlating with a significant difference for distances to the nearest road from 2010. Roads were generally constructed along existing main paths in the valley, requiring bulldozing of terrace walls and fields to expand sufficiently for the passage of cars and trucks or for alternate routes through the valley. This required reconstruction of external terrace walls and occasionally split single terrace units into two (as seen in figure 4.21). Expansion of existing roads from 2010 in Paccareta did not make a significant difference to sampled terraces' distance to the nearest road. By 2021, the distances to the nearest road are no longer statistically different (table 4.13).

The roads in the valley are unpaved, although the main road out of town towards the Coropuna pass was paved in late 2018 and early 2019. New path and road segments in 2021 are both wider, on average, than in 2010, but not significantly so. The edges of these road segments constructed between 2010 and 2021 are uniform, reflecting that they were constructed recently and with heavy machinery. The use of a tractor revealed ancestor bones buried in terraces and walls, especially when the roads required grading on steep slopes (Alexander Menaker, *pers. comm.*). A school campus was also built south of town during this period as were new settlement compounds with structures, gardens, and external boundary walls. Several roads were constructed exiting the northern edge of town including through the Quisguarani archaeology site and through and around the twin volcanoes with branches towards Paccareta, Tauca and the canal intake for the Canal Madre (figure 4.20). A road was also constructed around the recently renovated bull ring and Spanish-era chapel on the east side of town.

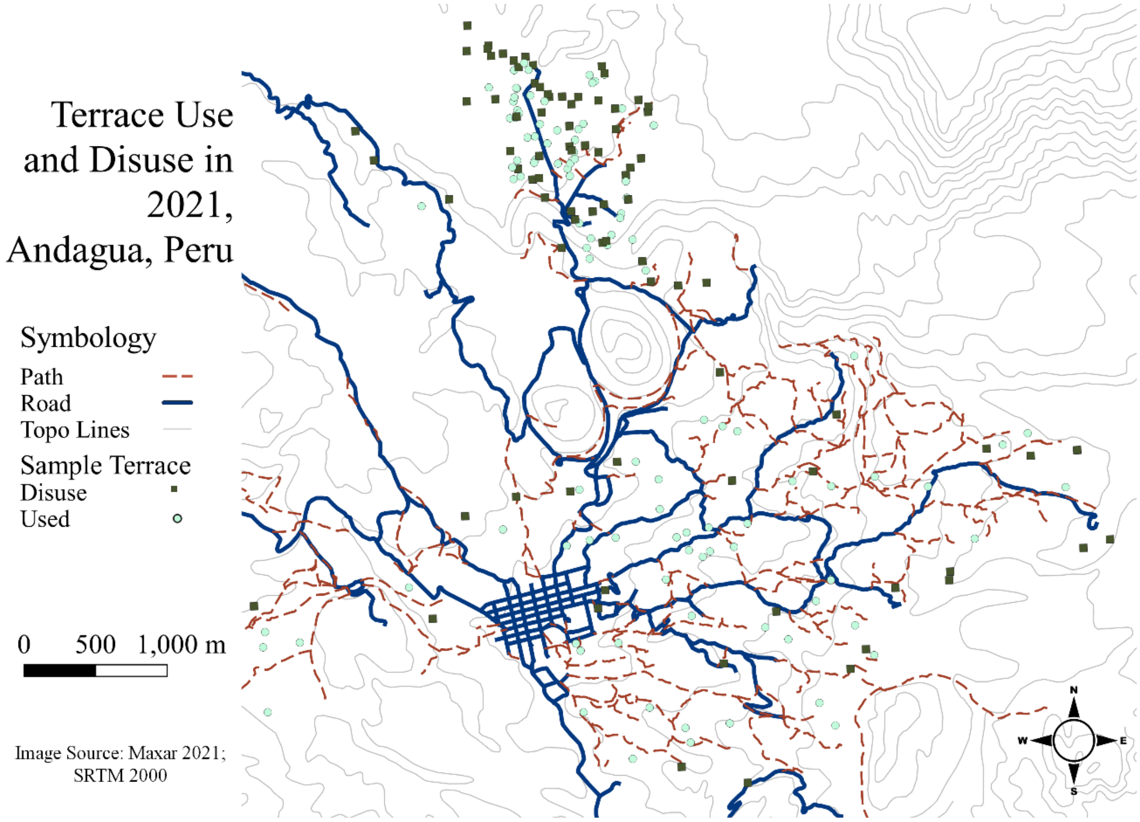


Figure 4.20 Map of roads and paths in relation to all sample points in Andagua Peru in 2021.

Figure 4.21 Terrace in the main valley divided by the construction of a road between 2010 (middle; Maxar 2010) and 2022 (right; Maxar 2022). Same terraces shown in 1977 (left; USGS 1977).

Effect-Size Models for Use and Disuse

Paccareta

Variables that significantly estimate the effect size of terrace use in Paccareta in 1977 include slope, elevation, longitude, latitude, distance to nearest road and distance to town (table C.7). The variable that was the best estimate, according to multiple evaluation indicators, was slope. According to the resulting formula from logistic regression, the probability of use during this time generally increased with increasing slope, although it was variable (figure 4.22). The highest probability was for those terraces with slopes higher than 4.8 degrees. These higher slopes are on the terraced hillslopes of the site of Paccareta and the terraced edge of the Andagua River canyon. Locational variables such as longitude, latitude, and elevation indicate terraces that are closer to town and closer to the canyon (i.e., in the eastern, southern, and lower elevation portion of Paccareta) have a higher probability of being in use (table C.7; figures 4.23 and 4.24). This corresponds with distance to town and nearest road formulas, both of which indicate that increasing distance correlates with decreasing probability of use. The formula for distance to nearest road produces a probability that decreases slowly for each unit increase in distance, likely a result of the nearest road being in town and far from Paccareta. A dichotomy present in the data at around 3200 meters from town resulted in this threshold being used for the formula. Terraces in use closer than the threshold had over 60% probability of being in use, while the probability of those being in use further from that threshold dropped to 11%.

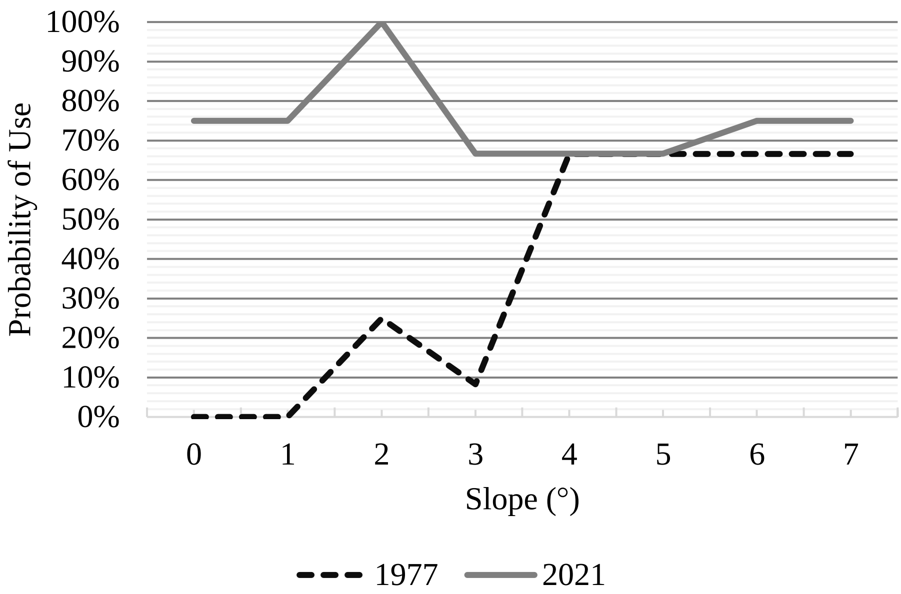


Figure 4.22 The probability of terrace use given terrace slope in Paccareta in 1977 and 2021 from effect-size logistic regression.

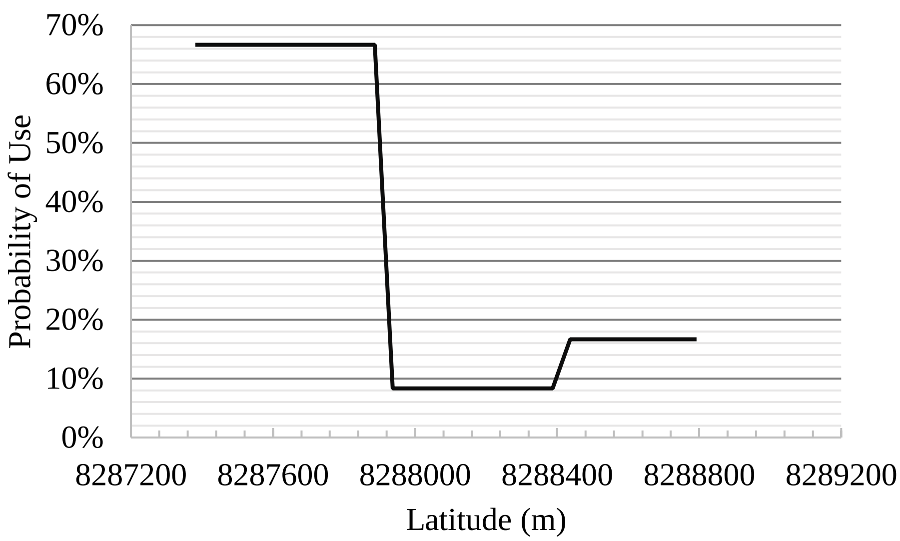


Figure 4.23 The probability of use given latitude in Paccareta in 1977 from effect-size logistic regression.

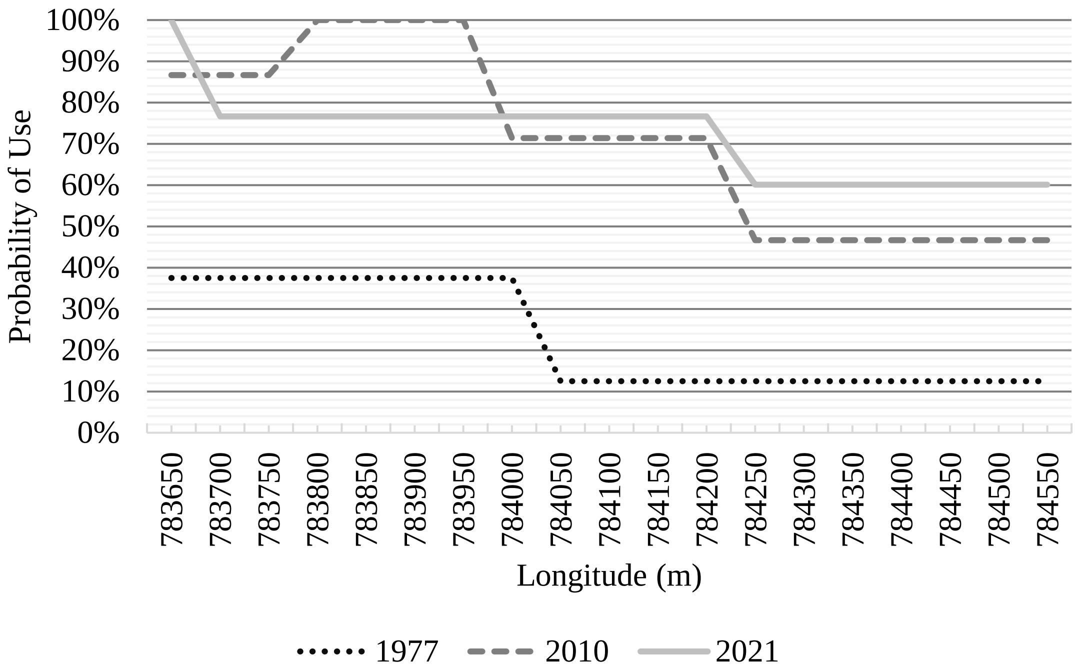


Figure 4.24 Probability of terrace use given longitude in Paccareta in 1977, 2010 and 2021 using effect-size logistic regression.

By 2010 in Paccareta, slope, latitude and distance to town are no longer significant, distance to road and longitude remain significant, and distance to nearest path becomes significant (table C.10). The variable that has the most impactful effect-size on use is distance to nearest road. As terraces are further from the nearest road, their probability of use decreases at a higher rate than in 1977 (figure 4.25; tables C.7 and C.10). The increasing probability of use per meter distance from the nearest path in 2010 likely reflects the replacement of paths by roads during this period.

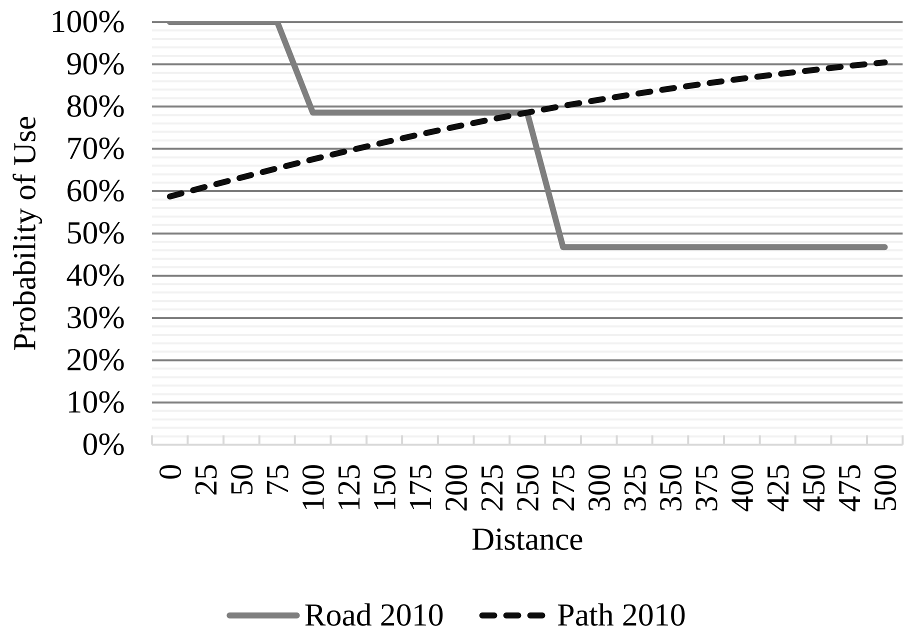


Figure 4.25 Probability of use given distance to road and path in Paccareta in 2010 using effect-size logistic regression.

In 2021, slope again has significant effect on use in Paccareta, the probability of which increases at gentler slopes to around 75% in contrast to that of 1977 (table C. 13; figure 4.22). The slight bump at 2° in both years may indicate an optimal slope may be due to the topography of Paccareta, in general. The probability in 2021 from 2010 changes slightly for longitude, reflecting the continued expansion of terraces put in use over time and the pattern of disuse (figure 4.24). Plan curvature is also significant in 2021 with the highest probability of use being for slight concavity in the downslope direction. The second highest probability of use is for terraces with slight convexity and the lowest probability are for those with little convexity or concavity.

Main Valley

In 1977, no variables significantly can produce an effect-size model for use in the main valley (table C.8). By 2010, slope, distance to town and the nearest path become significant (table C.11). Slope produces the best model of the three, indicating a decreasing probability with slopes over 4.5° (figure 4.26). Slope continues to be significant in 2021, the effect-size equation producing similar probabilities to the 2010 equation, although the probabilities of use for terraces less than 4.5° are around 20% lower (figure 4.26). Distance to town is also significant during this period and has a threshold of higher probability of use closer than 3450 meters than further away in 2010 (figure 4.27). This pattern continues into 2021, although the probability drops around 2000 meters closer than 2010. The distance to nearest path indicates highest probabilities of use for terraces between 41.2 and 136.0 meters around 90% and terraces closer than 41.2 meters around 80% probability of use (tables C.9 and C.11).

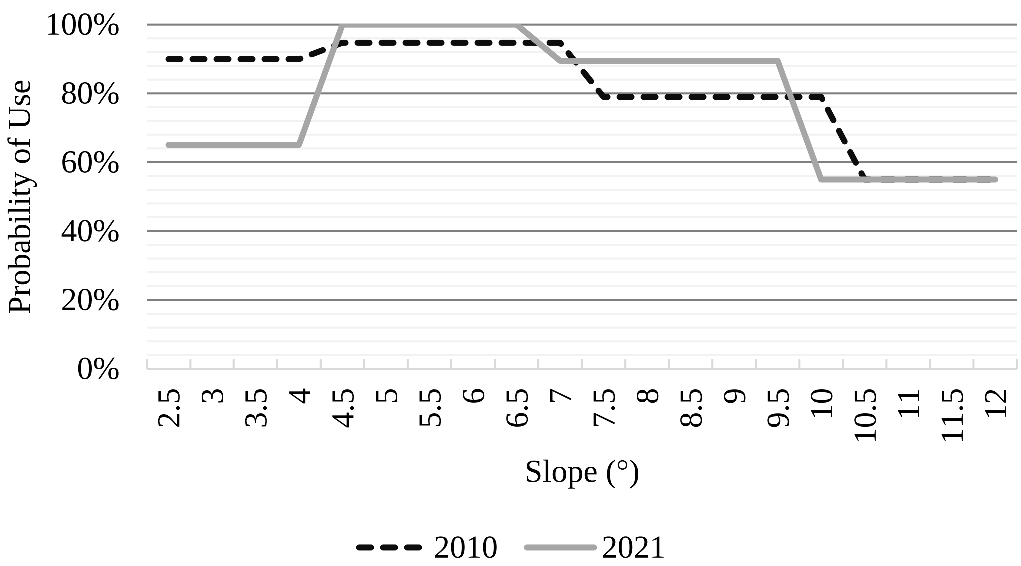


Figure 4.26 Probability of use given slope in the main valley in 2010 and 2021 using effect-size logistic regression.

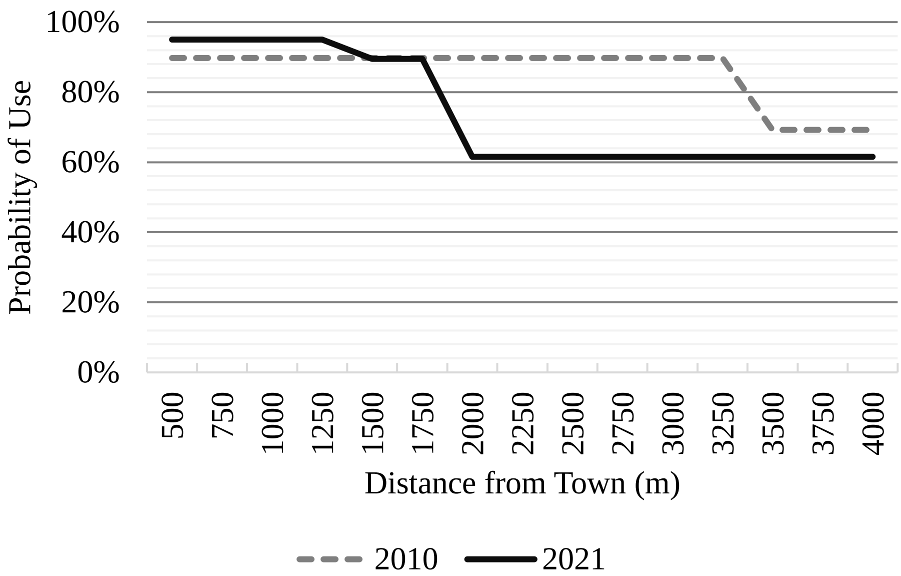
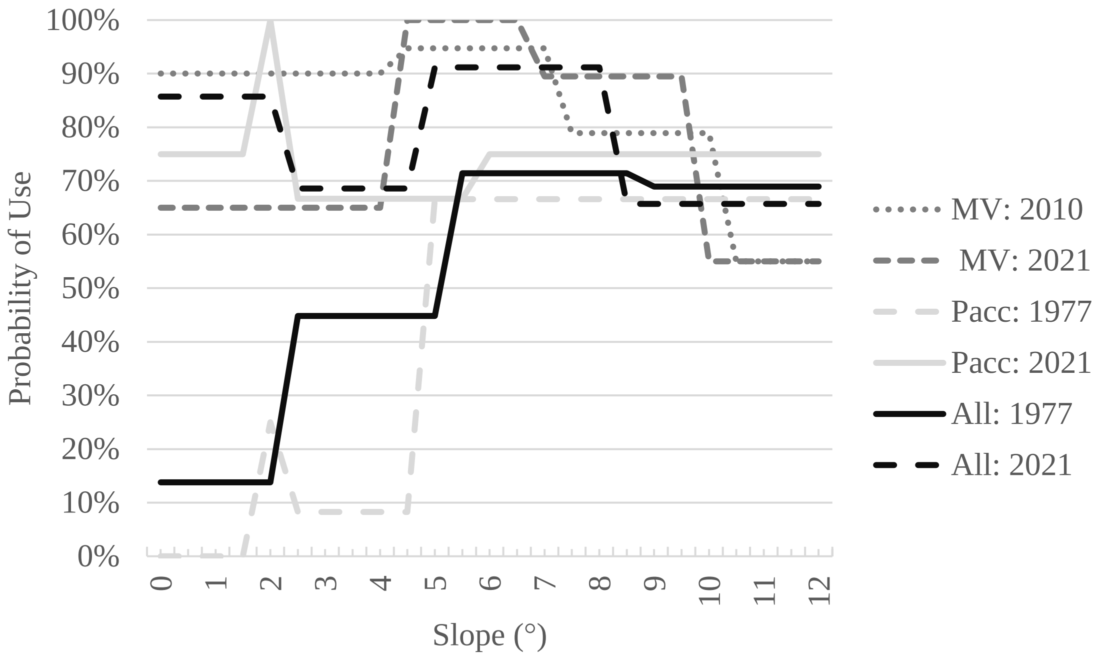


Figure 4.27 Probability of use given distance to town in the main valley in 2010 and 2021 using effect-size logistic regression.

Combined Paccareta and Main Valley

The decreasing number of variables able to significantly give probability of use after 1977 in effect-size logistic regression using all sampled terraces revealed the extent of the divergent patterns in Paccareta and the main valley through the late twentieth and early twenty-first centuries (tables C.15 to C.18). In 1977, slope, longitude, latitude, elevation, distance to nearest road and distance to town all significantly give probabilities of use (table C.16; figure 4.28). The different proportions of use and disuse in 1977 between the two farming locations created significance for these locational and topographic variables. Slope and latitude produce log-odds equations that best fit the data in this period. This changes by 2010 when only the distance to nearest road was significant and, in 2021 only slope and distance to town were significant (tables C.16 and C.17).



Note: "MV" refers to the main valley and "Pacc." refers to Paccareta.

Figure 4.28 Probability of use given slope using effect-size logistic regression.

Predictive Model for Use and Disuse

Predictive models tested if any variables from each year could predict use on the landscape using randomly selected training and testing data. The predictive regression resulted in highly variable and inconsistent results (tables C.19 to C.25). This suggested that there were points that heavily weighed the data or that there are more complex patterns in the data. Using all variables resulted in high areas under the curve and moderate pseudo R^2 values; however, the predictability and repeatability were both low. Reducing the models to fewer variables resulted in decreasing predictability. Distance to road was not consistently a predictor for any year.

Discussion: Historical Patterns and their Impact on Bottom-Up and Top-Down Landscape Changes

This chapter set out to better understand the relationship between terrace cultivation and the complex social, political, and environmental changes through the late twentieth and early twenty-first centuries, such as increasing agricultural and transportation infrastructure, shifting local and state power relations, concerns for soil and water health and climate change, among other topics. Results indicate that terrace type and condition are inexorably tied to pre-existing topography and changing dynamics of water management (Sandor and Eash 1995), a connection that is evident through the mapping and analysis of the anthropogenic landscape in Andagua.

While terracing in volcanic landscapes is not unique (e.g., Kuhlken 2002; Cicinelli et al. 2021), the unique Pleistocene-Holocene-aged andesitic lava field on which the terraces are constructed and maintained in Andagua create a graded pattern of broad field, lateral bench, and depression terracing. No depression terraces were sampled for this chapter, but their presence is noted and the manner of their drainage and origin of their landform shape should be a topic of further study. The sloping field terraces were also not sampled for this chapter, and it is possible that these are unique from those described elsewhere in the Andes. Those in Andagua are largely below 3600 masl and irrigated from a canal built in the twentieth century. There is evidence of a previous, possible pre-colonial, canal higher on the sedimentary rock escarpment. Additionally, the clear, contrasting retaining walls of Paccareta reflect their recent reconstruction, while the braided patterning of many terrace retaining walls in the main valley evidences its long history of use, the constant need to repair walls from the pressure of cattle and water, and potentially engineering design for irrigation distribution across the terrace treads and from one tread to the next.

The mitigation of water's power and the control of its distribution additionally underlie the politics, economics, everyday sociality, and practices of people at different spatial and temporal scales. In Andagua, this manifests within the politics of irrigation distribution, social practices around canal cleanings, the enabling of canal cementation, and the choice of crop based on water availability (see chapter 3). Such relationships, practices, perceptions, and decision-making are also connected to the forms of agricultural infrastructure. Terraces and canals are the physical manifestations of these efforts, and their conditions over time reflect forces acting on the landscape. The differences in the extent, distribution, and use of terrace types and internal boundary patterns between the main valley and Paccareta exemplify these relationships. While most terraces in both the main valley and Paccareta are linear terraces, there are a larger proportion of broad field terraces in Paccareta likely because of its broader extent of gentler slopes. These differences in gradient likely also play a role in the higher proportion of breaks in internal boundaries in the main valley. Terrace retaining walls disrupt the slope-length, and since the height of walls largely depends upon the angle of the original slope, terraces in the higher gradient main valley likely resist greater geomorphic forces making them more vulnerable to wall collapse. In addition to slope and environmental forces, social dynamics over a longer continuous time period such as fluctuating access to social networks for labor over the past 500 years, likely interacted with the terrace retaining walls and treads to produce the higher number of breaks in terraces seen today.

Additionally, the difference in breaks between the main valley and Paccareta may also be a product of intentional design differences and time, more generally. One interviewee's terraced unit is an excellent example of a vertical set of treads and walls that are interrupted by ramps and water drops that appear intentionally used for irrigation distribution (see figure 3.3). Alternatively, there are few breaks in the rehabilitated terraces across the moderate gradients of Paccareta. In 1977, the many breaks in the main valley correlate with broad disuse of terraces and, as these retaining walls were rebuilt, water drops were not a design feature. Additionally, the walls in Paccareta are new and, therefore, had not yet been knocked down by pore pressure or grazing cattle. The majority of Paccareta is also likely less vulnerable to large-scale slope-failure events, excluding the steep river channel edges that have evidence of terrace landslides.

Other evidence of the impacts of time includes the apparent stability of terraced slopes with intergrading used and disused terraces, which was surprising and may potentially have positive side effects from their disrepair. The example near the reservoir of such a mixed pattern of ambiguous and contrasting internal boundaries and land covers demonstrates that there is either a benefit or hindrance to not repairing these features, or perhaps that the owner of the unrepaired terrace treads is absent (see figure 4.10). Some of these barriers to reconstruction may be from a lack of labor available to fix such a large extent of terraces, as this can be an arduous activity (e.g., Guillet 1987). While farmers were concerned with lack of laborers and land degradation in the 2012 census, these accounted for only 11% and 7% of farmers (INEI 2012). Instead, lack of water (67%) and a lack of seeds (24%) were of a higher concern (INEI 2012). As many of these disused terraces and terrace treads in this example span almost 90 years in similar conditions, another hypothesis may be that the downslope terrace retaining walls capture the eroding material mobilized by irrigation and precipitation, providing the much-desired sediments to cover subsiding soils overlying the porous rocks, as described by Señora A. Another benefit, which farmers may or may not be directly working towards, includes the introduction of fresh minerals into the soil, contributing to its fertility. In this way, the terraces may be acting as a sink for upslope eroded materials, providing an interruption to the hydrological connectivity of the landscape, given the downslope walls are functioning properly (for examples of benefits of sediment capture at landscape scales see Lesschen et al. 2009 and Mongil-Manso et al. 2019). This advantage would be mediated by the ability to maintain the downslope wall, mediate effective water drainage, and mitigate potential hillslope failures. Additionally, since much of the abandonment dates to almost a century ago, there may be less sediment erosion than in other more recently disused areas of the valley (see Brandolini et al. 2018). While the cementation of the canals is reducing the suspended materials deposited into the terrace treads, terraces units with disused treads and terraces downslope of other disused terraces may be at an advantage in the future. This partially depends on the dominant land cover and its ability to stabilize the soil, as vegetated slopes are more effective at reducing sediment mobilization at the scale of a terraced unit (Lesschen et al. 2009). It also depends on local farmers' perceptions of the clearer and higher-velocity irrigation water. The canal gradients and internal terrace irrigation features were designed for water with a different velocity. If farmers can redesign some features of the canals and terraces to reduce velocity, this may mitigate some of these potential issues.

The enduring patterns of use and disuse of terraced landscapes are also connected to historical power dynamics, for example, the forced resettlement of local people into gridded Spanish towns, and the many shifts in relationships to the state and locally powerful authorities through the post-colonial periods resulting in land redistribution. Evidence of these shifts in how and where people focus their agricultural pursuits are firstly in the abandonment of Paccareta likely after the arrival of the Spanish. While the Shippee-Johnson expedition did not focus their ground photographs on their travels across Paccareta, a comparison between the main valley and Paccareta in their aerial photographs depicts sparsely vegetated land cover and degraded terrace walls. The increasing population over the twentieth century, the variable but plentiful precipitation leading up to and through the 1960s, and perhaps a mitigation strategy in the conflict between the *gamonal* and his desire for land, may have encouraged farmers to rehabilitate Paccareta. This expansion is clearly visible in the 1977, 2010 and 2021 images as are the increasing terraces mapped as used. Those closest to town had a higher probability of being in use in the earlier period and, over time, locations further from town at higher elevations and flatter topography were rehabilitated. However, the climate also changed, providing difficulties for farmers in Paccareta. While the annual precipitation for seven years of the 1960s was above 600 mm, there is an apparent threshold around 1982 where the ensuing average annual precipitation hovers around 350 mm (tables 1.3 and 1.4). These changes are not clearly visible on the landscape, although farmers express their concerns about the increasing temperatures and irrigation scarcity.

Other evidence of the impacts of power dynamics on the landscape include the longevity of terrace use in the main valley near the Spanish *reducción*. This site was previously an Inca settlement and the Inca focused their attention here and on multiple lower-elevation sites in the area (Menaker 2019b).The Spanish also concentrated their efforts in this location and required people to live in this new settlement rather than near their fields (for example of this in the Colca Valley, see Wernke 2013). Although this effort was not fully realized, as evidenced by field houses throughout the valley (Menaker 2019). It is possible that people also focused their attention on the fields more proximal to the town through the succeeding centuries. Logistic regression demonstrated that terraces further from town (over 3250 meters in 2010 and 2000 meters in 2021) had a lower probability of use. While this suggests a connection to settlement locations, these results may additionally correspond with the decreasing precipitation through the late twentieth and early twenty-first centuries and altered irrigation distribution methodologies introduced by the NGO. The canal enters the valley between the twin volcanos north of town and now distributes to terraces nearest the canal first and then proceeds down in elevation and through the smaller feeder canals. This has left farmers unable to plant terraces that are furthest from the canal during periods of low water availability. As such, the proximity to town variable may be correlating with other unmeasured patterns such as distance from the canal intake.

The introduction of European farm animals, especially cattle, also altered how people used the landscape and played a role in bottom-up regional road construction. The *gamonal* forcibly acquired land from Andagüeños before the Peruvian agrarian reform. Others also owned cattle, and both were forced to drive their herds over the Coropuna pass on a narrow "carriage trail" to get them to market (ONERN 1973, 14). The ranchers and farmers subsequently intervened through a bottom-up conversion of the trail into a passable road, in collaboration with those in the neighboring valley. The decrease in the population over the late 1960s and 1970s (ONERN 1973, 14) suggests that the road may have enabled out-migration and shifts in labor availability. Dairy processing plants opened over the next decades. Now, dairy, and dairy products, are a large part of the local economy. The 2012 census recorded farmers had 70% of agricultural land in use at the time and 62% of that land was used to grow animal feed (INEI 2012). As such, a large number of fields are dedicated to animal production. This is not expansively evident in satellite imagery, although cows are visible in Shippee-Johnson aerial imagery such as in the example of cultivated terrace units with a mix of collapsed and well-maintained walls.

After the local initiatives for land rehabilitation and road construction came the Peruvian agrarian reform and, with it, changes in the administrative oversight of the agricultural landscape and the town as well as the capacity for farmers to sue for the return of their stolen land (Menaker 2019b, 271, 274). Inherited land is important as it represents the past reciprocal relationships between Earth Mother and their ancestors (see chapter 3). While farmers do purchase land from others who are leaving for the city to supplement or entirely compose their land holdings, most possess land given to them by their family. An additional pattern is farmers' children leaving for the city and, while some do return for harvest and other events, there is an increasing generational disconnect. These experiences may shape how people make decisions in the future, which also may change as generations of decision-makers change.

The importance of inherited land and tradition, and the different gradients across Paccareta and Andagua, may explain why the distance to the nearest road was not consistently significant in giving the probability of terrace use, even as new roads were constructed through the main valley by the municipality. Despite the municipality not having authority over the agricultural land, they implemented a top-down construction of the terraced landscape. It is not clear what the nuances of the conversation were between the municipality and the community of farmers; however, there was disagreement over the indelicacy of the use of machinery to plow through terrace treads and reveal buried ancestors. So, while the decreasing distance to roads is not necessarily changing where people farm, it has changed how people farm, increasing access to tractors for some fields and altering the possibilities for the sale of goods to travelling merchants.

As of now, it is unclear how the construction of new roads will affect the soil, fertility, sediment connectivity, and other social variables such as decision-making at the personal, community and state level. The use of machinery is known to produce compacted soil and lead to surface erosion of land surfaces, including terracing (Tarolli et al. 2019; Tarolli and Straffelini 2020). The addition of new, wide roads throughout the terraced landscape will likely contribute to this potential erosion issue. While vegetated terrace surfaces may mitigate some of the erosion from rain splash, for example, the new roads have no such protection and likely will contribute to sediment connectivity in the catchment (Harden 2001). Future research will be needed to consider these and other socioenvironmental questions to better understand the broader impacts of these new infrastructural changes to Andagua's terraced landscape.

CONCLUSION

This chapter explored the patterns and morphology of agricultural terrace features and transportation infrastructure in Andagua, Peru in the context of local and non-local ways of acting on, thinking about, and defining the landscape. Classifications, research questions and analyses drew from interviews in the previous chapter, helping to better understand the socio-geomorphic relationships that are crucial to the continued stability of terraces as human landforms. Results indicate that historic relationships to the land are important to where and how people farm, including the gradient of the slope on which the terrace was constructed and the shifting demographics and settlement location of farmers during top-down political and economic forces.

The differences in top-down and bottom-up infrastructure projects differentially impact the use and disuse of the landscape for farming and ranching. For farmers in Andagua, one of the processes that appears most impactful includes the violence of rural peasant-*gamonal* relationships lasting until the Peruvian agrarian reform. The bottom-up reconstruction and rehabilitation of terraces in Paccareta leading up to the reforms is evident in the remote sensing imagery, expanding the land in use for agriculture and ranching to higher elevations and flatter topography, and creating new social groups to manage the land and water.

Additionally, the type, patterning, and distribution of terraces across Andagua reflect the distinctive topography that resulted from volcanic activity as recent as the sixteenth century. This includes the non-karst depression terraces that require further study to understand their internal drainage and general geomorphic setting. This research also documented irrigated sloping-field terraces below 3600 masl and intergrading bench, broad field and depression terraces in single terrace units and across entire slopes.

Future questions include the impacts of the increasing density of roads constructed by the municipality on the production of crops for the market (and the use of chemical additions), the increased mechanization on terrace treads, the sediment connectivity in the catchment, and other questions. This is all in the context of shifting populations and means of income during the Covid-19 pandemic, and entrepreneurship related to becoming a UNESCO Geological Site. The next chapter will look towards how these patterns and processes interact to produce land tenure boundaries.

Chapter Five: The Tupu: Social Measure of Land Tenure and Area

INTRODUCTION

Standing in a Peruvian farmer's impressive agricultural terraces bounded by dry-stacked stone walls, she gestures and says, "All of this is a *tupu*, from the top to the bottom." Others described farming *tupus* across microclimates and elevations, using diminutive versions or fractional descriptors for smaller units. The *tupu* was also central to the measurement and distribution of water; the local irrigation commission, in coordination with an NGO, reorganized the irrigation system to be distributed in three-hour allotments per *tupu*. Here, the *tupu* was being used interchangeably as a unit of land measure and a description of a land tenure, both seemingly relational to landscape characteristics. This chapter teases apart the multiple meanings and uses of the term *tupu* in the Andes to refine our understanding of colonial and post-colonial policies of privatization and the shifting socio-historical management of water that gradually cemented these formally flexible units in place. The goal of this chapter was to better understand the history of the *tupu* in Andagua, contextualizing it within regional and local history to tease apart its complexities on the landscape. To do so, this chapter asks:

1. How do land tenure units physically manifest on the landscape in Paccareta and the main valley through the twentieth and twenty-first centuries?
2. And, how do these land tenure units relate to the *tupu*?

This chapter first presents studies of the *tupu* in the Andes, including disagreements over the quantitative and qualitative meanings of the *tupu* through time and across the Andes. It then analyzes the differences between mapped external boundary features in the main valley and Paccareta in 1977, 2010 and 2021 using object-oriented analysis to test how land tenure and the *tupu* differs between these two locations with different environmental and social histories. The chapter then turns towards comparing changes in Paccareta between 1966 and 1977 to better understand the physical impact of reconstruction and land use during this period of rapid change for the valley. Declassified satellite imagery from 1966 and 1977 and multispectral satellite imagery from 2010 and 2021 will be used for object-oriented analysis. Aerial imagery from 1931 from the Shippee-Johnson Expedition will be used to qualitatively assess land use and land cover from earlier in the twentieth century.

The chapter concludes that the *tupu* today is used interchangeably as a unit of land measure and a description of a land tenure unit; it is both relational and cemented in space and time through social relationships, such as community and family, and shifting power dynamics at local, regional, state, and international levels.

TUPU

Defining the Tupu

Scholars' concern with the *tupu* (alternatively spelled topo) in the twentieth century took several turns including uncovering its areal extent (e.g., Rowe 1946) as well as challenging attempts at a standardized definition (e.g., Farrier 1967) drawing from Spanish colonial documents, ethnography, and other fieldwork. This concern is most often traced to researchers' investigations into the economic, political, and social organizations during pre-Hispanic and Spanish colonial contexts (Covey and Quave 2017; Murra 1968; Wernke 2013). This section introduces and analyzes these varying definitions of the *tupu* and situates them within a context of power relations through time.

In Quechua, the *tupu* refers to actions, objects and, possibly, individuals with the capacity or authority to measure as well as the objects being measured, themselves. Sixteenth and early seventeenth century Quechua dictionaries (e.g., Anonymous [1586]

2014, 172; Holguin [1608] 1989, 347; Tomás [1560] 2013; table 5.1) define the *tupu* as a general measurement, including distance, volume, and area, in addition to more relational measures that form a compound word when combined with an object. For example, Holguin ([1608] 1989, 347-348) lists the meaning of the *tupu* by itself, but also in many compound words or phrases such as "Allpa tupuk apu, o cequek apu" translating as a meter/gauge or the deliverer of land, "tupuni" meaning to "measure something with a *vara*, or a measure," "tupuyok" meaning "the finite measurable" and "mana tupuyok" or "tupunnak" translating as "the immense, or infinite" or that which cannot be measured. Other Indigenous media additionally use the term *tupu* in non-agricultural or agricultural-adjacent contexts, including twentieth century Quechua songs, oral histories, and Quechua dictionaries. In one example, anthropologist and linguist Regina Harrison (1989, 99) translated and interpreted many Quechua songs from oral traditions, one of which engages with concepts of royal lineages, seasonality, and agriculture. In this song, Harrison draws from sixteenth century Fray Santo Tomás to translate the word *tupu* as both a concrete and metaphorical "measure" or "example" that, in this context, refers to reaching a remote destination or a point that was already laid out in the past (Harrison 1989, 99; see table 5.1). In other words, this song describes identifying, measuring, and bounding signs in the sky to understand relational practices such as defining proper planting seasons and legitimizing Inca inheritance of the throne (Harrison 1989, 99). While many variations of the *tupu* exist in Quechua dictionaries and oral traditions, its dominant association is with land units (see table 5.1).

Table 5.1 Quantitative and qualitative definitions or uses of the *tupu*.

Definitions or Uses of Tupu	Source
"a measure of volume," a liquid measure," "a drafting compass" or "carpenters' triangle," "a model" or "sampler," "example," "an image of something," "a measure of anything," "to measure," "level of a building," "a sample," "to measure using a drawing compass," "to measure anything," and others*	Santo Tomás ([1560] 2013, 576-577, see reference for more definitions and synonyms)
"League," "measure of anything," and to "measure something with a (drafting) compass"*	Anonymous ([1586] 2014, 172)
"league" and "el topo con que prenden las indias la saya"	Holguin ([1608] 1989, 347)
1.5 Spanish *fanenga* [0.9639 hectares][1]	Garcialaso (1723, pt. 1, bk 5, ch. 3) cited by Rowe (1946, 324)
"60 by 50 paces" [0.526 hectares][2]	Cieza de León, *Crónica del Perú* (1880, 53, note D) cited by Rowe (1946, 324)
50 fathoms by 25 fathoms [300 feet by 150 feet; 0.324 hectares]	Cobo (1890-95, 14) cited by Rowe (1946, 324)
"the amount of land necessary to support a married couple without children, and hence varied with local conditions"	Baudin (1928, 90) cited by Rowe (1946, 324)
In Cuzco: "88 x 44 varas (44 by 22 fathoms or about 264 by 132 feet)" [0.324 hectares] In Arequipa: "somewhat larger but similarly measured area" [> 0.324 hectares][3]	Rowe (1946, 324)
"Inca land measure; measure of area, distance, and volume"	Steward (1946, 978)
"amount of land received by every taxpayer for himself and his wife" (citing Valera) and "amount of land allotted out of community lands for each agriculturist and his wife"	Moore (1958, 37, 176)
"quantity sufficient" for own support and dependents (plus for the state), "quantity given under certain conditions," and "a measure"	Farrier (1967, 456)
About 0.33 hectares	Farrington 1980b (15)
"amount of land needed by a household to subsist relative to the productivity of the land and capacity of the cultivators who had the rights to usufruct"	Masuda, Shimada, and Morris (1985, 537)
A unit of measure for agricultural areal extent and not necessarily constant or relative; its early colonial meaning is not tied to subsistence; 0.25 *tupu* is equivalent to 1 *andén*, 1 *pata* and 1 *pedazo**	Benavides (1987, 136)

Table 5.1 cont.

"Inca measure equivalent to a landholding capable of feeding a family for one year"	Silverblatt (1987, 230)
"measurement of distance" and "measurement"	Harrison (1989, 99, 232)
"a unit of measurement today close to half its colonial size is unknown" and "unit of measurement that in pre-Hispanic times was probably flexible and related to crop or ecological zone. The modern topo is approximately 0.33 ha."	Treacy (1989, 232, 456-7)
"league and a half" and "standard measure of ground ore, a fixed amount of which had to be delivered weekly by the *mortiri*" or an Indigenous person serving their *mita* in silver mines; for Peru, in general, is 0.349 hectares, Cuzco, Peru is 0.272 hectares, and Puna, Peru is 0.461 hectares	Long (1991, iv, T-5, M-7)
"agrarian measure of land that is approximately eight-eight by four-four yards"	Mamani and Humán (1996, 178)
"usufruct plots" owned by the Spanish Crown but under management by the Indigenous elites and communities	Thurner (1997, 21)
"Agrarian measure of land which is approximately eight-eight by four-four yards. There are approximately three *tupus* to one hectare" [0.324 hectares]	Gelles (2000, 205)
"energy required to work specific plots" and "unit of land area or distance based on effort exerted (e.g., for plowing or walking)"	Goodman-Elgar (2002, 90, 267)
"Measure (volume), measure of land"	Hornberger and Hornberger (2013, 115)
"During Inka and early colonial times, the actual surface area of a topo was not a fixed figure but varied relative to soil quality, elevation, topography, and other factors that affected agricultural productivity" and "a colonial topo can be roughly compared to its modern standardized equivalent of 3,496m^{2}" [0.324 hectares]	Wernke (2013, 253-4)
"the area [a newly married couple] needed to feed themselves for a year"	D'Altroy (2015, 311) citing Garcialaso (1966, 245)
"50 x 25 *brazas*, or about 90 x 45 m, which is about 0.4 ha"	D'Altroy (2015, note 4, 320) citing seventeenth century Jesuit priest, Bernabé Cobo
"Indigenous lands were typically measured as topos" in late seventeenth century *visitas* (census)*;* between 0.25 and 0.42 hectares; between 93 by 38 *varas* and 100 by 60 *varas*	Covey and Quave (2017)
1 *tupu* will result in < 6, 000 kiloliters organic potatoes, while 1 hectare will result in 15,000 kiloliters organic potatoes [~0.4 hectares]; 1 *tupu* receives 3 hours of water regardless of need	Señora A (chapter 3 of this dissertation)

Note: * translations using *Word Reference* (2023) when needed; original is in Spanish.

Early Spanish colonial use of the *tupu* in censuses to describe areal extent of land suggested to some scholars that its origins are pre-Hispanic and securely tied to land distribution and tenure (Julien 1985, 201; Murra 1968); however, it is difficult to disentangle these relations across this violent temporal divide. According to Spanish colonial documents, an Inca-era *tupu* was distributed by the community or Inca representative to a couple or household head, the amount of which was defined as "sufficient" to feed a couple for a year (Cook 1919; D'Altroy 2015, 311). The family would receive another *tupu* with a baby son and a half *tupu* with a baby daughter (Cook 1919).[4] According to Spanish colonial legal documents, this type of distributional relation to community-controlled usufruct land, or land held by an authority and managed by farmers, continued from pre-Hispanic periods, except the crown claimed ownership over the land (Thurner 1997, 21). Land could be distributed to expanding families and individuals who were eligible to pay tribute to the crown by the community, but colonial restrictions shifted the ultimate authority to the Spanish crown (Thurner 1997, 21). These early definitions suggest that land extent was a function of yield in relation to need, and that its use was managed through the social relationships between an individual or family unit and the locus of local and regional power. Goodman Elgar (2002, 90) interprets this through a lens of energetics, suggesting that the *tupu* is reliant on the time and "energy required to work specific plots." How this physically manifested through shifting socio-political and environmental conditions must be further teased out to understand its meaning more clearly over time and across place.

Researchers worked towards and argued about converting this social relationship to a physical description or areal unit. According to Rowe (1946, 323), the *tupu* was an Incan standardized measurement of both distance and area, with the former being marked on Inca roads in relatively even intervals of 1.5 Spanish leagues or 4.5 miles.[5] The Spanish, then, incorporated this measure into the census data for Indigenous land, reserving the Spanish *fanegada* or *fanega* for private property of people of Spanish or European descent (Covey and Quave 2017). Alternatively spelled *hanega* (Moore 1958, 36-37), Ferdinand V of Spain ordered the layout and distribution of a certain number of *fanegas* dependent upon the Spanish subjects' profession and social status in addition to other plots designated for specific purposes (Pozo 1946, 488). While Covey and Quave (2017) cite a *fanega* as about 2.7 hectares in size, Rowe (1946, 324) considers the colonial *fanega* as equivalent to 1.5 bushels of grain, which describes a volume that required an area that was relative to environmental conditions to produce. Regardless, the *fanega* was a unit in Spanish urban planning, its distribution and location ordered by Royal decree (Pozo 1946). Both the *fanega* and the *tupu* were measured using the Castilian rod, also called the *vara*, that was both a "staff of office" and a unit of measure, the distance of which was locationally relative (Covey and Quave 2017, note 13; Steward 1946, 978). As another explanation for the differences in the census data, some Indigenous farmers would decline to use Spanish units of measurement when reporting their land (D'Altroy 2014, 311) and would occasionally destroy land to make it appear untaxable (Benavides 1987, 140). The definitions of both the *fanega* and the *tupu* suggest that they were crucial to relations of power through this period and were possibly both standardized by at least a measure related to yield across different environmental and social contacts, rather than fixed areal extents.

Despite the relational colonial-era definitions of the *tupu*, Rowe (1946) posited that the *tupu* was standardized by the Inca into a measure that continued through the colonial period. He argued that the Spanish could not have standardized the *tupu* because the Spanish themselves did not use a standardized unit of land at the time (Rowe 1946). In fact, the Inca possibly created example *tupus* manifested as fields bounded by rocks, the areal extents of which were to be altered to local conditions (Farrier 1967, 456-457). Rowe's argument also conflicts with ample evidence of the Spanish implementing standardized urban aesthetics in the Americas while Spanish European towns retained their Medieval characteristics (Mumford 2012). While early inroads into the Andean highlands included little alteration of where most people lived, friars were beginning the important part of the Spanish colonial project–conversion–by constructing chapels in existing settlements (for an example in the Southern Andes, Wernke 2003, 158-213, chap. 5). The Church additionally began the standardization and use of Quechua in written religious documents for the purpose of conversion, transforming the language into a tool of colonialism (Durston 2007). Later, the Spanish dictated a series of laws outlining the functioning of colonial towns including the form of their municipalities, planned urban spaces and a focus on Christianity to assert control over the Indigenous peoples and their resources (Mumford 2012, 45). Part of this plan included the forced resettlement of Indigenous people into these newly created gridded towns, referred to as *reducciónes*, to enact this conversion of people into Christian Spanish subjects and impacting their access to fields and other resources (Mumford 2012, 49-50). While there were very few rectangular gridded towns in Spain at the time, grids came to symbolize Spanish power and institutions; the Spanish were to impose their views through the physical reorientation of space (Mumford 2012, 119, 121).[6] This reorientation also served to extract *tasas* (tribute) of wheat, maize and/or potatoes more easily (Covey and Quave 2017). Thus, regardless of Spanish standardization of their own land, it is likely they enforced or attempted to enforce a relatively standard measure of control over Indigenous resources such as land distribution, labor, and extent through documentation, taxation, and ownership of Indigenous land.

The actual implementation of this Spanish colonial plan was met with local power relations, existing settlement patterns and environmental conditions, resulting in a "negotiated" landscape (see Covey and Quave 2017; Wernke 2013). The extensive Inca administrative system encountered by the Spanish was also locally flexible and heavily influenced by local elite (as summarized by D'Altroy 2015, 352-3). It is likely that the *tupu* land units designated as "sufficient" in pre-Hispanic periods would have possessed figurative and transitive properties that were relational between speakers and mediated by place. In other words, the *tupu* was a product of the relational interaction of the broader processes of power and people at the local level. The colonial censuses recorded the unevenness of Spanish success in influencing their new colonial territories (Covey and Quave 2017). Both Spanish and Indigenous land analytics appear in the census data. In addition to *tupu* and *fanega*, these include *topo de chácra*, *chácra*, *andén*, *pata*, *pedazo* (Benavides 1987, 136), *papacanchas* and others (Covey and Quave 2017). These could be converted across terms, for example, in the Colca Valley, *andén*, *pata* and *pedazo* were equivalent to 0.25 *tupu* while *topo de chácra*, *topo* and *chácra* referred to similar extents with the addition of *chacra* indicating that it was under irrigation (Benavides 1987, 146). In the census data of the Colca Valley studied by Benavides (1987, 136), information listed for each plot, referred to as a *suerte*, was its location by toponym, its total area in units of *tupu*, and the dominant crop, although these were likely not monocropped. Quantitatively, the contemporary extent of terraced units and those listed in census data provide evidence of values ranging between 0.24 and 0.96 hectares, with most estimates around 0.3 hectares (table 5.1). Despite the appearance of standardization in the census document, the range of quantified conversions reveals its continued relativity by environmental and social conditions (see table 5.1; D'Altroy 2014, 311).

The quantitative and qualitative meaning of the *tupu* over time appears variable and steeped within relations of power. The clear socio-economic stratification of land ownership listed in Spanish census data (discussed in more detail below) suggests to Benavides (1987, 139) that the *tupu* was largely disassociated with the definition of “sufficient” land during the colonial period. However, Benavides (1987, 140) states that its pre-Hispanic definition persisted in rural locations where it was still being used to describe relative land units during the late twentieth century in the Colca Valley, suggesting that it retained some of its early-Spanish colonial and possibly pre-Hispanic meaning in locations further from urban centers of power. Farrier (1967) also noted that in addition to agricultural contexts, Andean women would use the term *tupu* to describe a unit of cloth without further need for explanation.[7] The transitive properties of the *tupu* in a modern context continue to refer to a quantity sufficient for multiple objects, including but not exclusive to farmland (Farrier 1967).[8] The need for the Inca to provide a physically bounded example of a *tupu* or for the Spanish to calculate conversions demonstrates that the *tupu* continued to be defined by “quantity sufficient.” However, the power of defining what is sufficient and for what purpose shifted from the local to the non-local.

In a more recent example, the USGS Center for Inter-American Mineral Resource Investigations (CIMRI) defines local and regional units of measure and names for geologic and geomorphic processes and landforms for the stated purpose of fostering improved international mining relations (Long 1991). In the CIMRI dictionary, the *tupu* is defined as unit of length, volume, and area, with different measures of area given for Peru, generally, and Cusco and Puna, specifically (Long 1991, iv, T-5; see table 5.1). The *tupu* additionally appears as a volume of metal, the conversion of which requires an understanding between the Indigenous laborer serving their *mita* (turn) and the mining manager (Long 1991, M-7). The continued use of the Inca word *mita* for an Indigenous miner in the twentieth century demonstrates the enduring inequalities in this relationship and suggests that how the volume of metal is decided upon is steeped in centuries of racial and class hierarchies. The *tupu* is, contradictorily, both a fixed and relational measure, often central to (uneven) reciprocal relations of extraction, taxation, and exploitation. This next section will explore the *tupu* through relations of power, looking towards local sources and litigious arguments in late-colonial and post-colonial periods to better understand its relationship to land tenure through time.

Land Tenure and the Tupu

The goal of this section is to tease out the role of the *tupu* in land tenure and how it changed from a largely usufruct relationship to an increasingly private one. At its center is the relationship between individuals, family units and their broader social relationships. In the Andes in pre- and non-Inca contexts, this was the *llaqta*, which describes both the human occupation and sociality of village units (see Marcus 2000; Menaker 2019a, 18-22; Salomon 1991). This shifted to emphasizing the *saya* ("sociopolitical subdivision"; D'Altroy 2015, 524) and the *ayllu* (local group engaging in reciprocal labor, often kin; Covey 2020, 521) during Inca period and possibly through to the present, then Spanish municipalities and then *communidades de campesinos*. Through time, this relationship became mediated through state and economic forces, impacting the power to distribute land and organize labor. This section will briefly touch on settlement distribution, verticality, and land tenure as they relate to the *tupu* through climate and social change.

The *tupu* as a social and physical unit is tied to local social organization across time periods. In pre-Inca and non-Inca contexts, *ayllus* had the power to distribute land and organize resources (D'Altroy 2015, 311). People settled on rocky outcrops, for defensive purposes in some cases, farming nearby terraces and fields (Arkush and Tung 2013). Terraces and irrigation infrastructure are located mostly on valley sides and fewer are in drainages and on floodplains (Donkin 1979, 32). In pre-colonial state contexts, the power shifted into the lands of local Inca lords and administrators, dictating where people should concentrate farming to satisfy the maize-centric reciprocal relationships with those in power, including the Inca State and local lords (Zimmerer 1993; Murra 2002, 47). For example, Holguin ([1608] 1989, 347) wrote in his seventeenth century dictionary: "el topo con que prenden las indias la saya" with the *saya* referring to the Inca duel social organizational and administrative system most often documented around Cuzco. This Inca system established provinces in a hierarchical series of dual groups following the decimal system, each of which was headed by a lord or local elite (as summarized by D'Altroy 2015, 353-356). The *saya* system and the local lords organized both local land tenure and water distribution. For larger, important tax-eligible projects, the Inca would mark their boundaries with "monuments" called *saywa*, which may have been simply a pile of rocks (Rowe 1946, 211). The term *saywa* also refers to other boundary features as small as rocks or as large as mountains, marking territories or agricultural fields (Covey 2006, 39, 244). It is not clear if these boundaries were similarly physically apparent for *tupu* plots or if they were more ephemeral to reflect the flexibility of land tenure at the time.

This shift from the pre- and non-Inca *llaqta* to the Inca *saya* system marks a change in who ultimately controls land tenure and use. According to Murra (1968, 128), under Inca control, the Aymara defined the *tupu* in relation to power dynamics between the elite. Local lords' wealth at the time consisted of the ability to control and receive the results of human labor on land and through herding camelids across a diversity of elevations. Their ability to marry multiple women likely gave them additional access to broader extents of land (D'Altroy 2015, 312). In general, lords were entitled to the results of greater than one percent of total *tupus* while the Inca were entitled to the results of an average of one percent of the total, not including those cultivated for children (Moore 1968, 36-7). Generally, a community would need a minimum of 1,000 *tupus* to be considered a *guaranga* (tributary unit) for the Inca (alternative spelling: *huaranga*, *waranqa*; Masuda et al. 1985, 535; Moore 1958, 36-37). This system was highly organized and locally flexible, indicating that those in power at different social scales were able to accommodate shifting familial and community needs through *tupu* distribution and redistribution. It was this system that the Spanish disrupted at their arrival in the Andes, albeit one impacted by internal warfare and disease (Covey 2020, 138-151).

The Spanish incorporated these existing power dynamics for their own goods and labor extraction. Land was appropriated from *ayllus*, and peoples' labor was used to produce goods for the Spanish, conflicting with local abilities to produce subsistence goods (Covey and Quave 2017). Different *ayllu* groups had varying success at mitigating colonial decrees and maintaining autonomy (Covey and Quave 2017). Ultimately, all the usufruct land was now transferred to the Spanish King, rather than held by the community (Thurner 1997), and the Laws of the Indies then dictated where and how people lived and farmed (Mumford 2012, 119-121). In Peru, this mandate was not strongly enforced until Viceroy Toledo's ambitious census and forced resettlement plan in the 1570s that included outlawing living outside the *reducción*, forcing people to reorient their daily practices and land use patterns to this new, gridded town (Mumford 2012, 97-98). The goal was to disentangle people from their existing social landscapes, including hierarchical politics and sacred spaces, as well as to more easily tax people and extract tribute such as wheat, maize, and potatoes (Covey and Quave 2017). Mayer (2005, 36) argues that the *reducción* was a "radical" alteration of the relationships between the household, community, and the state, especially later through the incorporation of the market economy. In some cases, land was redistributed among different groups, regardless of their previous landholdings, supposedly to make it fairer and to ensure that each social group had sufficient land for subsistence and tribute (Covey and Quave 2017). Using census data from sixteenth century Cuzco, Covey and Quave (2017) argue that the *reducciónes*, and other related colonial means of conversion and labor and goods extraction described in the censuses, seized local control away from Indigenous populations, turning them into "peasants." The colonial administrators required that people showed proof of individual ownership of land in addition to their boundaries, size, and the proper titles limiting who could and could not claim land (Covey and Quave 2017). Census data also documents dramatic decreases in population from the late sixteenth century to the early seventeenth century, causing the abandonment of terraces, usually those that were difficult to irrigate and far from the new settlements (Benavides 1987, 132). The decreasing rural populations through the eighteenth century further contributed to the alteration of land tenure patterns (Thurner 1997, 7), putting more *tupus* under the management of fewer families (Wernke 2013, 276).

Like with the Inca, local lords would ensure the Spanish would receive tribute from communities; however, the shifts towards private land led to local lords occasionally resorting to selling Indigenous land to meet tributes, which contributed to uneven land distribution (Thurner 1997, 7). Men aged 18-50 were considered eligible for tribute, with exceptions, and were reported to possess an average 1.5 *tupus* for maize and 2 *tupus* for wheat in Cuzco (Covey and Quave 2017) and about 1.5 to 1.7 total *tupus* in the potato and maize areas of the Colca Valley (Wernke 2013, 233-234). Other sizes and types of fields were also reported depending upon the environmental conditions, a persons' status and the number of dependents including children, women, the elderly, and others who were considered unfit for tribute (Covey and Quave 2017). For example, in the Colca Valley during the colonial period most families and individuals possessed sufficient land for subsistence, concurring with the largely agreed-upon Inca-era definition of a *tupu*; however, there are clear outliers with excessive or no lands, which likely reflects relations of power and status (Benavides 1987, 139). *Caciques* (local lords) likely owned or controlled more land as pasture for cattle or other herds (Benavides 1987, 139). These larger fields and pastures owned by lords or people of European descent were usually located on unterraced valley floors, a land tenure pattern that continued through to the twentieth century (Donkin 1979, 28; Farrington 1980, 28; Field 1966, 59-60). Covey and Quave (2017, 289) documented a "three-tiered allocation practice" that correlated higher status groups with higher quality lands often proximal to town and an average of ten more *tupus* than other tribute-age men. Quality of land additionally correlated with the desire for large extents of maize-producing fields and fields at diverse elevations and microclimates, as evidenced in the Colca Valley (Wernke 2013, 232-237). Men with a high number of dependents received the second highest number of *tupus* with an average of four *tupus* per tributary household and unmarried men, dependents and orphans received the least with one or fewer *tupus*. The "excess" fields were then auctioned to Spanish colonists and the Indigenous elite.

In addition to the differential distribution of *tupus* among tributes in a single town, there were also differences between those towns. Covey and Quave (2017) argue that wheat-growing areas received more and larger *tupus* because the land was less productive than maize-growing regions. Farrington (1980, 15, 24) additionally documented that farmers possessed about double the *tupu* size worth of higher elevation fields than maize fields. He notes that the fields in the higher-elevation tuber zone were rested for five to seven years in between cultivation, while fields in the maize zone are heavily manured, prepped by burning off brush, and rested less frequently (Farrington 1980, 21-22). Landscapes with complex topography also correlated with more complex patterns of land use and smaller *tupus* across a larger distribution of microclimates (Covey and Quave 2017).

Importantly, during this period, the Spanish Crown created distinct types of land entitlements based on a persons' identity as well as different land types. *Tierras de repartición* (repartition lands) were land officially owned by the Crown but given to communities to be distributed to community members eligible for tribute by a locally elected official (Thurner 1997, 49-50; Guillet 2005). This created a reciprocal relationship between the Crown and the tribute-paying Indigenous community members. Legally, this type of land that was owned by the Crown but able to be used by the community is referred to as usufruct land (Thurner 1997). The individual repartition lands could be inherited; however, their status as usufruct prohibited their sale (Thurner 1997, 29). In addition to titles, colonial administrators required marking land boundaries (Covey and Quave 2017). The second type of community land is referred to as *tierras de compositión* which is land that communities were able to claim using substantial oral histories that similarly were distributed to local community members; however, unlike plots in the repartition lands, plots in the composition lands could be sold (Thurner 1997, 49-51). Thus, the individual, usufruct *tupus* could be passed through generations, and potentially added to, or subtracted from, over time, when necessary. However, the requirements by the Spanish of land titles and other challenges to land tenure, began to cement their individual areal extents through generations.

Changes in the nineteenth century included the abolition of the tribute system shortly before Peruvian independence and the turn towards international trade, creating a vacuum in the relationships between rural peasants and the state (Thurner 1997, 21-29). In 1813, the Spanish parliament abolished the tribute system for the Indigenous populations and replaced it with the tax system already obligatory for those of Spanish descent (Thurner 1997, 21). This altered the reciprocal crown-tribute payer relation. The tribute system was reinstated a year later under the renamed *contribución* and would continue to be a point of contention through Peruvian independence (Thurner 1997, 21). Although these tribute-paying land recipients, and Indigenous elites in charge of the distribution, were most often men, there are examples of women in both positions as seen in court documents of the period (see next subsection, Thurner 1997, 24-26, 29). Identity claims by Indigenous people in court documents, Thurner (1997, 30) argues, were important and purposeful for the claims of land rights. For example, Silverblatt (1987, 119-121) describes the tensions between Spanish conceptions of married women as legal minors and existing Andean parallel lines of descent–meaning, men descend from their fathers and women descend from their mothers, giving them rights to inherit properties. In other words, the Spanish did not legally recognize women's rights to directly inherit property, altering the land tenure systems in place and women's independence (Silverblatt 1987, 131). Despite Spanish law disrupting the pre-colonial land tenure system, women were able to inherit land although they often had to subvert the colonial system to do so (Silverblatt 1987, 120, 131). At the local level, women attempted to control their own land, colonial officials found it easier to take lands from women than from men for colonial estates due to their tenuous land rights. There were several means of subverting the system found in historic documents including several cases where women indirectly inherited *tupus*, including a case where a women inherited 2.5 *tupus* from a woman who was likely her mother; however, this required that their husbands allocated to them what was rightfully theirs in Andean gender rights (Silverblatt 1987, 121). The land women did receive were smaller and fewer in number (Covey and Quave 2017). Additionally, age and class may have played a role. Almost all the women listed on the census were classified as elderly, receiving one *tupu*, while elderly men received 1.5 *tupus* (Silverblatt 1987). The remaining few women who received land were mostly relations of Inca lords, although a couple were widows of tributary men or wives of Spanish elite (Silverblatt 1987.). The ensuing centuries are variously documented and the nineteenth century, in particular, has less scholarly attention than previous centuries (Thurner 1997, 15). However, it does reveal the impacts of changing socio-political processes and policies on relationships among people and the landscape, and the role of gender, power, class, and race.

Land distribution and possession increasingly became privatized through Peruvian independence, and the prevailing uneven power dynamics across race and class contributed to land tenure being disproportionately in the hands of the elite. With Peruvian independence in the 1820s, the repartition lands were renamed the lands of the Republic or lands of the state, replacing local Indigenous elites as distributors of land with state administrators (Thurner 1997, 24). The creation of the new national civil code was an ongoing process during the nineteenth century (Guillet 2005, 98). It generally scorned Indigenous customary law in favor of a national legal code emphasizing a shared national identity and deemphasizing local difference (Guillet 2005, 35, 99). With this came the privatization of previously communal land, giving Indigenous contributors ownership titles to their land plots on the newly renamed state lands (Thurner 1997, 21). Official documentation and titles of land remained an important means of claiming ownership or rightful leasing of properties and, without them, it was difficult to retain their use through the courts (Thurner 1997, 28). This privatization required landowners to be literate in Spanish to complete the sale, placing further burdens on the Indigenous, rural population (Thurner 1997, 38). Other resources managed as common property such as wood from forests and water remained common; however, this was increasingly challenged by landowners such as *hacendados* and, later, *gamonales* as the state shifted its attention away from managing rural property disputes and towards international trade, Lima politics, and other national and international disputes (Thurner 1997, 45-48).

Guano extraction on coastal islands became important for capital accumulation for Lima elites, its success in international trade led to the dissolution of the Indigenous *contribución* in 1854 (Guillet 2005; Thurner 1997, 45-46). Similar to the 1813 dissolution of the state-tribute payer relationship, Thurner (1997, 46, 48) argues that the removal of the Indigenous contribution in 1854 irrevocably altered the peasant-state relationship, directly leading to the enclosures of common land by landlords and their acquisition of the labor of the resulting landless, often non-local peasants. Often called *foresteros*, these non-local, landless peasants had access to common land. With the state disinterested in local disputes and injustices, landlords continued to expand and build boundaries around their estates (Thurner 1997, 43). The end of the literacy clause led to sales of land from farmers in debt to *mestizos*, further alienating people from their land (Thurner 1997, 53). The ensuing local predatory reciprocal relationships and debt peonage between the large landowners and the Indigenous laborers were largely ignored by official laws and the state, enabling these practices to continue (Guillet 2005). An increasing population during this period compounded the problem of decreasing availability of usufruct repartition lands for distribution. This resulted in inter-family litigations which often involved children fighting over inheritable land (Thurner 1997, 32). This uneven reciprocal relationship between the peasants and local landowners continued through Peruvian independence and the twentieth century (see Menaker 2019, chap. 7).

The twentieth century *gamonales* and *hacendados* continued to center the *tupu* as a socially meaningful unit of land through their reciprocal relationships with local peasants. Testimonials from farmers, Mamani and Humán (1996), record the power imbued in the exchange between the *hacendado* and their families. In the glossary (Mamani and Humán (1996, 178), the *tupu* is defined by its areal extent; however, Humán's testimonials describe the *tupu* as deeply tied to social relationships, the power dynamics within them and the importance of the land for subsistence. Humán (1996, 110) tells of the *tupus* her family rented from the *hacienda* owner: three for corn and two for wheat, the latter of which they only planted during the rainy season every four years, leaving them fallow in between. The exchange between the *hacendado* and her family for the plots of land depended upon the type of field–the corn field required six days of unpaid work per month in addition to one month of "manor service" per year (Humán 1966, 110). Three days of work per month were required for each *tupu* of wheat in addition to one month of "manor service" per year cooking for the *hacienda's* dogs or doing various household tasks for the priests (Humán 1966, 110). The exchange of labor for the land was a transformation from the earlier reciprocal system, creating an uneven power dynamic that negatively impacted peoples' relationships to the landscape and their daily practices that shape that land and its environmental processes. While the *tupu* was defined in Euclidean units in the glossary, the testimonials reveal the unevenness across crop type and associated labor. This system, reminiscent of but more extractive and violent than the reciprocal relationships with Inca and local lords in the past, left farmers with little time to care for their own land and subsistence.

Colonial legacies of land tenure and land use endured through the twentieth century, their uneven dynamics unsuccessfully interrupted during the Peruvian agrarian reform. Farrington (1980, 28) notes that the Peruvian reforms, began in the 1960s, did unevenly alter land tenure in a valley near Cusco. The flatter, valley floor area continued to largely be controlled by the two *haciendas* in the area who previously required labor from peasants on local terraces (Farrington 1980, 28). By the late 1970s, the *hacendados* used the land largely for pasture, which Farrington (1980, 28) suggests is due to the broken canal and the agrarian reform. Although he does not explain further, it is possible that the *hacendados* no longer had the authority to compel Indigenous farmers to maintain the canal or lands. Some of the hacendado land was additionally transferred to former "peons" and unofficially farmed by others (Farrington 1980, 49-50). In addition to hacendado lands, farmers had *tupus* at various elevations depending upon where they lived and their familial relationships across the valley, exchanges conducted mostly by women provided families with goods produced in other elevations (Farrington 1980, 34). While it appears that farmers owned much of their land, Farrington (1980, 24-25) describes the land owned by community of Quesca as usufruct, where *tupus* were "reallocated" in the same manner of previous centuries. This possibly continuous and/or occasionally interrupted community-led practice appears to be only conducted for *maizales* or maize-growing fields in this area (Farrington 1980, 24-25).

Evidence from geographic, archaeological, and historical studies indicates that the *tupu* is both a social and physical unit, interchangeably meaning one or the other based on context. A similar example was noted in the southern Andes with the term *cuadro*. Field (1966, 151-152) noted that *cuadro* was used to describe an irregularly patterned, rectangular-shaped terrace type in addition to general land ownership and a unit of measurement. Like the *tupu*, it was divisible, but it is simultaneously a description of land tenure unit regardless of unit size (Field 1966, 151-152). Of this, Field (1966, 152) says:

> For most, the *cuadro* was a convenient but imprecise measure of unit ownership, no matter what its size, thus illustrating the degree to which a particular technique becomes the full identity of some activity.

In this case, the "activity" likely refers to the process of creating or farming river terrace fields bounded by earth or adobe walls (Field 1966, 130-133; Donkin 1979, 111). Despite Field's (1966) notation of its use in southern South America during this period, the USGS *A Partial Glossary of Spanish Geological Terms*, does not list *cuadro* as a unit in use in Chile or Argentina (Long 1991). However, it is listed as in use in modern Venezuela to describe units of land spanning 0.64 to 1.8 hectares in size and items of 60 kilograms in weight (Long 1991, viii). While it is not clear the origins of the *cuadro*, its multi-purpose meaning and use for general land tenure and unit measurement is strikingly similar to the *tupu*.

The power to define boundaries and restrict access to resources, including water, labor, and land, has shifted between various political and social institutions, both local and non-local. The increasing privatization, introduction of European grazing animals, the violent conversions of community or Indigenous-held land into private land for *hacendados* or *gamonales*, and the uneven return of land to communities and individuals through the agrarian reform and associated litigation all shaped the contemporary use of *tupu* as a land measure. Their physical manifestation appears to have also changed through time, from a socially flexible unit to one marked in place by walls and vegetation, related to grazing animals and privatizing land.

Irrigation: Cementing the Tupu in Place

Previous sections demonstrate the increasing impact of privatization and ranching on the *tupu*, cementing its extent in place. In Andagua, the *tupu* not only measured land tenure, but its boundary additionally acquired an irrigation limitation (see chapter 3). Interviewees described the *tupu* and the means of measuring land and water as deeply social, embedded in history and knowledge of the landscape. Farmers described their terraced units as *tupus*, bounded by large, tightly packed stone walls. These boundaries mark changes in management practices, soil properties, vegetation, water movement, and slope. In the early twenty-first century, these boundaries began to dictate irrigation management in Andagua, causing disputes over equality in terms of irrigation timing and volume. This section will briefly summarize findings from chapter three on irrigation practices and their relationship to *tupus*, both contextualized within *tupu*-irrigation practices described elsewhere in the southern Peruvian Andes.

In Andagua, the *tupu* and irrigation management have become increasingly intertwined as the system shifted from one based on need to one based on allotment. In the previous irrigation system, according to Señora A, farmers would request irrigation water for each of their *tupus*, receiving that water regardless of where they were in the landscape. The two *moieties* in the *saya*, the upper and the lower, were, and continue to be, in charge of organizing labor parties to maintain portions of the canals. A similar system in southern Peru, called the *saya* system (Gelles 2000, 69-74; Treacy 1989, 326), was organized by the two *saya* subsectors–the lower and the upper *moieties*–and then distributed according to requests (see Treacy 1989, 324, fig. 51). This shifted in Andagua when a Swiss NGO declared the need-based system as inefficient. Now, the community irrigation commission organizes water distribution in three-hour allotments per *tupu*, regardless of crop type, land unit size or environmental conditions. Each three-hour allotment is referred to as a turn or *turno*.[10] Elsewhere, Treacy (1989, 327-328, 333) describes similar alterations of irrigation systems in southern Peru by the Peruvian Ministry of Agriculture in the 1960s to improve their "efficiency" by reducing water loss to evaporation and infiltration, and to also more easily tax water use. The Ministry encouraged the *mita* system, which irrigates *tupus* in order from west to east and from top to bottom (see Treacy 1989, 324, fig. 51), which is similar to the Andagua turn system except Treacy does not note if the Colca Valley system is timed. The *tupu*, then, is steeped in historical process and social relations of power. This next section explores the *tupu* as a socially and geomorphologically meaningful unit in Andagua, briefly considering the environmental and social contexts of the main valley and Paccareta, in particular.

The Andagua River incised through the lava fields north of the twin volcanoes, separating the main valley from the area of Paccareta (figure 5.1). The river briefly runs underground and exits as waterfalls through several holes in the cliff face near the lake (figure B.2). As described in previous chapters, the area called Paccareta was largely in disuse at least since the 1930s. As seen in Shippee-Johnson aerial photos, largely disused broad field terraces cover the valley floor overlying volcanic flows and disused linear terraces cover the sides of the pre-Inca site of Paccareta that sits atop a topographic high. In response to the need for more land, and before the Peruvian agrarian reform would impose top-down redistribution of *gamonal* and *hacienda* land, a collective of farmers from Andagua rehabilitated terraces in the area of Paccareta, including constructing a new canal (for more detailed history of the *gamonal* in Andagua (see chapter 3; Menaker 2019b). Farmers reconstructed existing terraces and constructed new walls around individual units starting in the mid-1960s. Terrace retaining wall construction varies but are generally composed of smaller stacked volcanic rocks with grass-covered berms on the downslope end of the tread. External boundaries are composed of stacked stones of varying sizes but are generally larger than those in the terrace retaining walls (figure 5.2). External boundary walls occasionally are topped with pencil cacti, thorny shrubs, and tree limbs, possibly serving to keep animals in or out. A new canal was constructed (or perhaps reconstructed) during terrace rehabilitation that sources water from the Andagua River. In the main valley, the terraces and Canal Madre date to possibly the Inca period or earlier, although the retaining walls are regularly reconstructed after collapse from soil water pore pressure and the wear from cattle grazing. Like Paccareta, external boundary walls are dry-stacked stones lining roads and paths and between terraces belonging to different land units (figure 5.3). Similar thorny or sharp vegetation sometimes line external walls to keep grazing cattle in or out of terrace units.

Farmers in Andagua own between one and fifteen terraced units across the valley, the size of which fluctuates (table 5.2). According to the INEI (2012) 23% of producers with land own only one parcel, which is, on average, 2.24 hectares in area. These data are aggregated and, therefore, it is not possible to determine if this is because of outliers or if this figure reflects larger than average areas for those who own only one land unit. The average area of a parcel for those who own between two and fifteen units spans between 0.48 and 0.67 hectares. These figures fall within the span of numbers cited in the literature, the majority between 0.32 to 0.53 hectares with one outlier at 0.96 hectares (see table 5.1), so it may be that these contemporary units correspond to what is considered a *tupu*. However, the areas in Andagua fall on the higher end. Since these data also do not include elevation and location of the units across the valley, it is difficult to make any assumptions concerning these differences.

Figure 5.1 Paccareta with lava flows and the Puca Mauras volcano in the background and the canyon of the Andagua River in the foreground, July 1, 2016 (photo by Author).

Figure 5.2 Rehabilitated terrace unit in Paccareta with external boundaries of larger dry-stacked volcanic rock and terrace faces of smaller stacked volcanic rocks topped with grassy berm, October 17, 2015 (photo by Alexander Menaker).

Table 5.2 The number of producers owning one or more parcels of land, the total number of parcels owned by those producers, the total surface area covered by those parcels and the average surface area per parcel.

	Number of Parcels						
	1	2	3	4	5	6-10	11-15
Number of Agricultural Producers (count)	77	49	53	39	44	62	6
Agricultural Parcels (count)	77	98	159	156	220	439	74
Total Surface Area (hectares)	172.2	51.2	99.3	104.6	129	257.9	35.1
Average Surface Area Per Parcel (hectare/parcel)	2.24	0.52	0.63	0.67	0.59	0.59	0.48

Source: INEI (2012).
Note: The aggregation of farmers possessing between six and ten, and eleven and fifteen plots of land was done by the census.

Figure 5.3 Main valley terraces showing external boundary lining the road, July 2, 2016 (photo by Author).

It is also possible that the plots in Andagua are larger than what is considered a *tupu* elsewhere. Near Cuzco, Farrington (1980b) documented twentieth century use of the term *tupu* to describe area of farmer plots across different elevation zones; however, it does not seem that the term *tupu* was additionally used to describe the plot itself. According to Farrington (1980b), farmers would own a different number of plots depending upon the planting zone. For example, in the zone dominated by tubers, farmers would plant between four to five plots per year in different microclimates to spread risk on the landscape (Farrington 1980b, 15). This "field scattering" includes planting different fields during different seasons with different crops for both the market and for subsistence as one form of diversification that can contribute to spreading risk (Goland 1992). The four or five plots mentioned by Farrington (1980b) amounted to three *tupus*, which he converts to one hectare. They would typically rest each field in this zone for five to seven years before planting again (Farrington 1980b, 15). Farmers in the same valley in a lower tuber zone (at about 3200-3700 masl) would own between 1.5 to 3.0 *tupus* (0.5 to 1.0 hectares) of land and plant between 0.25 and 0.5 *tupus* of this land each year (Farrington 1980b, 17). In contrast, farms in the maize zone were larger irrigated and unirrigated plots of an average size of 0.5 to 1.5 *tupus*, where farmers would own one of each. The size of the units in use was a result of social organization and history, which also included the social organization of terrace and boundary construction. This twentieth century example in Cuzco suggests that the dominant crop type and the organization around them may impact the size of plots and demonstrates that the *tupu* did not necessarily additionally refer to a description of the plot itself in this place.

Physical Boundaries for Terrace Land Tenure Units

In addition to plot size, the physical boundaries and features of a plot may have also changed through time, across places, and within single valleys, the irrigation features, terrace design and ownership boundaries, among other factors, occasionally determining the extent. Terraces require a retaining wall made of stone, vegetation and/or soil to produce landscape modifications and, as such, additional boundary features are not always present nor are they always walls. For example, terraced units on sloping-field terraces in the Chilean Andes were in a sequential pattern and the retaining walls laterally bounded by either shrub-covered walls or "stone-lined water drop channels" (Field 1966, 91). In the Alto Salado in the Atacama Desert, terraces surrounding pre-Hispanic sites are ordered through networks of canals and their branches, and the authors hypothesized that the small size of each of the terrace units was a function of the low water volume from the canal

(Parcero-Oubiña et al. 2017). In other words, the narrow distance between canals, and the resulting narrow cross-slope terrace, helped to distribute water more efficiently across the terrace units in the dry landscape (Parcero-Oubiña et al. 2017). Also in Alto Salado, difference in construction form and material composition across terrace sections indicated different periods of construction and styles, some of which had irrigation ditches with walls dividing fields (Parcero-Oubiña et al. 2017). Elsewhere in the southern Andes, sloping-field terraces that appeared older lacked obvious unit boundaries, suggesting that unit boundaries are a newer feature in this location (Field 1966, 111). Terraced units may also be connected by the design of the irrigation features. The canal intake of irrigated terraces is typically located at the top of a terrace set, the water falling between each terrace within the unit and exiting through an outtake at the bottom of the set (Field 1966, 104). Dry-stacked stone walls dividing terraces may have also been multi-purposed as paths or boundaries, possibly specifically for containing cattle (Denevan 1987, 22). Others have noted that lateral walls were constructed to contain water for flood irrigation (Field 1966, 231).

There is little evidence of terrace land tenure walls before or perhaps during, the time of the Inca (Goodman-Elger 2002, 101). In some cases, high labor investments were made to create walls and structures ranging from basic stacked stone to high prestige masonry that followed an orderly aesthetic (Dean 2015, 75-76). Another type of lateral boundary on sloping-field terraces are thick walls called *sucwas*, created from small stones removed from the planting surface (Treacy 1987, 153). *Sucwas* may have been converted into taller walls to contain cattle in the sloping-field terraces on the uplands by building them up (Treacy 1987b, 153). Boundary walls are not a new feature and were found on abandoned terraces; however, there is evidence that they have been modified, added, or reconstructed to contain cattle on the terraced landscape.

METHODOLOGY

This chapter uses object-oriented analysis of satellite imagery drawing from the classification systems outlined in chapter four to address questions related to the manifestation and extent of land tenure units. The same sample points from chapter four were used to specifically document the external boundaries and conditions of terrace land tenure units in Paccareta and the main valley for 1977, 2010 and 2021 using declassified imagery (USGS 1977) and Google Earth imagery (Maxar 2010, 2021). Descriptive statistics describe the physical characteristics of sampled units through these periods. Sampled terrace units from 2021 were digitized from Google Earth imagery (Maxar 2021) and hypothesis testing determined the difference between the areal extents in Paccareta and the main valley. Finally, object-oriented analysis was conducted for the entirety of the terraced surface of Paccareta for 1966 and 1977 (USGS 1966, 1977) through the top-down rehabilitation and construction. The characteristics of terraced units in Paccareta in 1966 and 1977 were compared to refine how the terraced landscape changed during this period. All classification schemes for the comparisons of external boundaries across Paccareta and the main valley for 1977, 2010 and 2021 are found in chapter four. The remaining portion of this section outlines the altered classification schemes for the object-oriented analysis of Paccareta between 1966 and 1977 to account for the additional land covers and the coarser pixel size of the older 1966 imagery.

Boundary Classifications

The three-meter pixel size of the 1966 declassified imagery (USGS 1966) is coarser than many boundary wall widths, as such, the classification of the entirety of Paccareta in 1966 and 1977 used a simpler external boundary classification system. External boundaries are those linear features that contain multiple internal boundaries, likely retaining walls for terraces, and are continuous in a circular, irregular, or rectangular pattern. There are one or more land covers within an external boundary, depending on management practices and local environmental conditions, but are typically dominated by a singular land cover. The external boundary was considered absent when terraces or fields are not clearly bounded by such a linear feature. The classification then only distinguishes between contrasting and ambiguous boundary conditions, noting the presence or absence of breaks.

Land Cover Classifications

As in chapter four, land cover is defined as the type covering greater than 50% of the area. Categories include barren, shrubs, and other vegetation (i.e., grasses and crops), and subcategories were included of the second-order cover, when appropriate, such as shrubby grass or dense shrub. Image keys were created to help with consistency in the classification and analysis of the landscape. For the classification of Paccareta, additional categories were added to account for non-agricultural areas that do not fall under the above classifications. These include water and settlement and transportation infrastructure. The Open water and water channel category includes areas with standing water on the surface for most of the year as well ephemeral, intermittent, or continuous channels. This category can also include channelized rivers, canals, reservoirs, and other human-modified, fluvial systems. Reservoirs and canals can be distinguished from natural channels by their sharper external boundaries and lines. The settlements and transportation infrastructure category includes altered cover due to anthropogenic activities such as settlements, roads and trails, and other anthropogenic features associated with settlements and transportation. Contemporary settlement structures and features are sharper, more easily visible, and often found in clusters. Agricultural areas were first digitized according to dominant land cover and the presence, or possible presence, of an external boundary. The remaining areas were digitized according to the dominant land cover. Polygons were rasterized into a 10-meter resolution to account for error in the georectification process before conducting band math to measure change.

RESULTS

Terraced Unit Areas in Main Valley and Paccareta

Paccareta and the main valley’s different histories are connected through their social, political, and economic relationships to the contemporary town of Andagua. Their separate topography and land tenure areas correspond with these differences. The higher elevation and flatter topography of Paccareta, as discussed in the previous chapter, correlates with a higher mean and median terraced unit areas or terraces with external boundaries (table 5.3). The relationship between area and elevation, while weakly positive, explains slightly more variation in the main valley than in Paccareta (figure 5.4). Hypothesis testing confirmed the significant difference between the area of land tenure units in the main valley and Paccareta.[11] Paccareta’ s externally bounded terraced units are an average of 0.21 hectares larger than those in the main valley, at an average of 0.67 and 0.46 hectares, respectively. However, the largest terraced unit of 2.71 hectares is in the main valley in an area called Hochopampa, which is at a higher elevation and to the west of town and was more intensely farmed in 2010 than 1977 (see figure 1.2). This field is visible in the bottom left quadrant of figure 5.5, larger than the other surrounding sampled terrace units.

Table 5.3 Summary table for area of terraced units in the main valley, Paccareta and in both the main valley and Paccareta.

	Paccareta	Main Valley	Combined
Count	52	79	131
Minimum	0.073	0.079	0.073
Median	0.586	0.381	0.447
Mean	0.670	0.456	0.540
Maximum	0.876	2.709	2.709
Standard Deviation	0.454	0.350	0.406

Note: All measurements are in hectares.

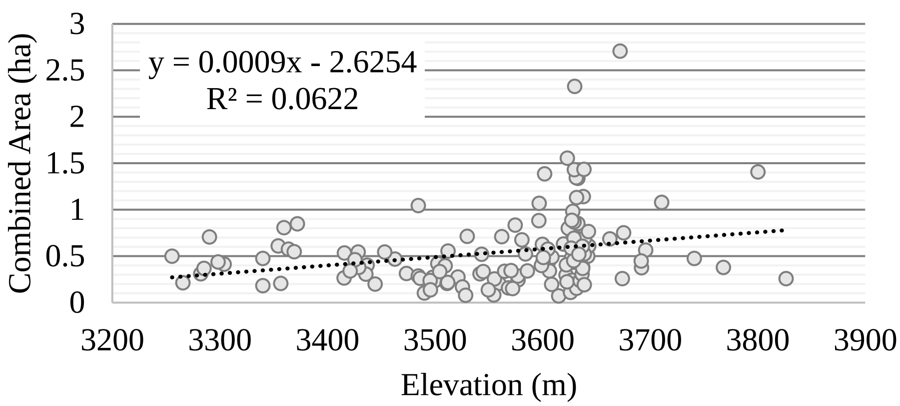


Figure 5.4 Terrace unit area by elevation of those terraces mapped with external boundaries in the twenty-first century in both Paccareta and the main valley (above), the main valley only (top, next page) and Paccareta only (bottom, next page).

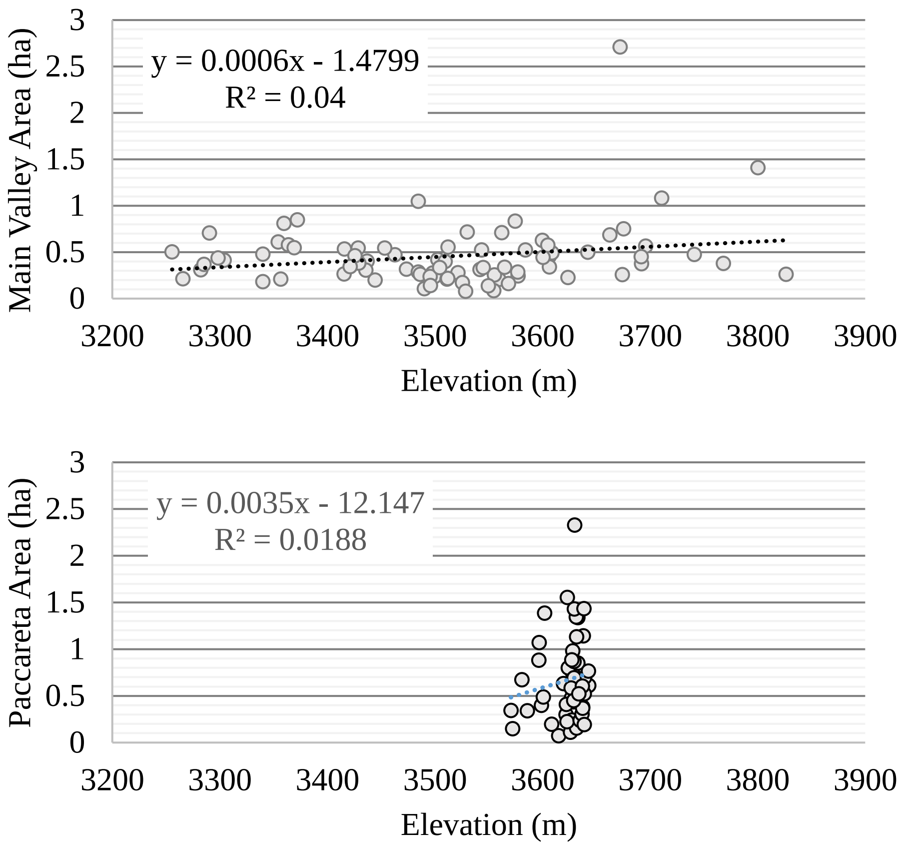


Figure 5.4 cont.

One limitation is the larger total farmed area in the main valley than in Paccareta, resulting in more randomly generated points being bounded by the same external feature, requiring them to be discarded from the analysis. This also resulted in terraced units being mapped proximally to other samples than in the main valley (figure 5.5). The main valley also spans a broader expanse of elevations, providing a higher lower boundary for terracing in Paccareta. This next section summarizes object-oriented analysis in Paccareta and the main valley, comparing the results across years.

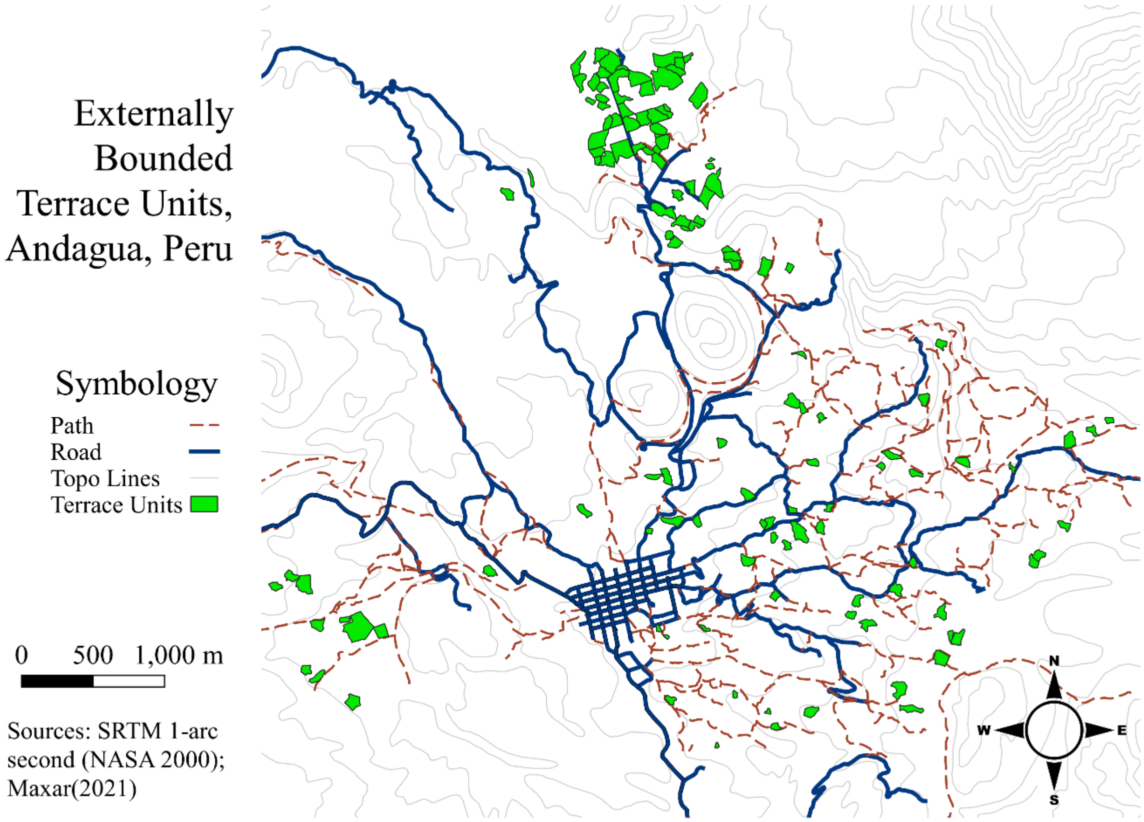


Figure 5.5 Sampled terrace units in Paccareta and Tauca.

External Boundaries 1977 to 2021

Paccareta

Results from object-oriented analysis focused on sampled terraces with mapped external boundary features, which indicated changes from 1977 to 2021 related to rehabilitation and road construction. The number of points classified as terraces that possessed external boundaries increased each year for Paccareta, from 81% with no external boundaries in 1977 to 33% in 2010 and 13% in 2021 (table C.26 to C.28). Shippee-Johnson images depict no clear external boundaries in Paccareta in 1931, and much of the landscape appears disused in this area (figure 5.6). Shrubby terrace walls and side walls containing grassy or sandy cover suggest long disuse in this arid and high-elevation location. The densely shrubby and rocky area at the bottom of the image is the site of Paccareta, the shrubs covering structures, terrace walls and fallen wall material. The right, upper hand side of the image depicts used terraces on the main valley side of the river, although it is unclear from this angle if they possess external boundaries. As such, external walls indicating land tenure boundaries were likely a late twentieth century addition to the pre-existing terraces. The land cover of these disused terraces in the Shippee-Johnson images appear to be soil, sand or gravel, shrubs, and possibly natural grassy vegetation. Over time, the newly constructed external boundaries were largely mapped as grass- or crop-covered and described as contrasting from the surrounding landscape (tables C.26 to C.28). In 1977, only nine terraces were classified as having an external boundary while the remaining 38 points classified as terraces had no discernable external boundary, the majority of both classified as either broad field or a combination of broad field and lateral terraces with craggy internal boundaries.

In 2010, the number of terraces without external boundaries in Paccareta drops to 33% of the total of the 82 terraced points (tables C.26 and C.27). The terraces that remained classified as without an external boundary were, on average, 4° steeper than those classified with an external boundary at this time, although they were not further from town. The number of terraced units in the segmented category increases from nine in 1977 to 52 in 2010, many of which were previously unmapped as terraces. Perhaps either they are newly constructed terraces or the degradation from long disuse made them difficult to discern from non-terraced land in aerial imagery. The linear features composing the external boundaries were 98% contrasting and 74% with no breaks, a possible result of their recent reconstruction. A similar pattern of contrasting features is found on the same terraces' internal boundaries, including 67% having no breaks, although possessing breaks on internal boundaries does not necessarily indicate a fallen wall or other degradation and may instead indicate a braided wall pattern that allows for irrigation water distribution. Most terraces were broad field or broad field-lateral, although the degraded state of much of the terraces without external boundaries made it difficult to classify them into terrace type.

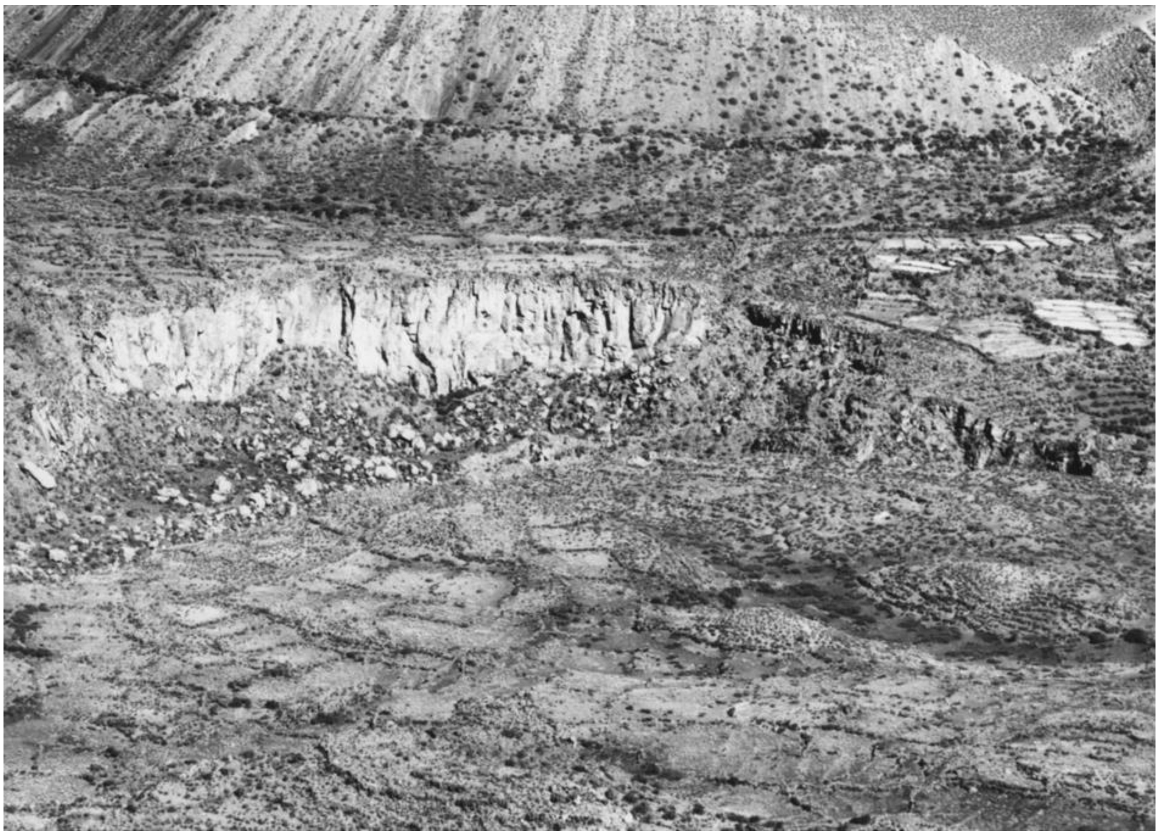


Figure 5.6 Likely disused or fallow broad field and lateral terraces in Paccareta depicted in the foreground of the image with the cliff face and colluvial material at its base of the canyon carved by the river. (American Museum of Natural History Library, Shippee-Johnson Collection, Image # ppcs551_l10).

By 2021, many of the terraces that were mapped as externally bounded remained so, while most of those that were mapped as terraced with no external boundaries were mapped as unterraced by 2021 (table C.28). This may be because the imagery in 2021 was taken during a wetter time of year and the unbounded terraces were not visible. Alternatively, they may never have been terraces or they were so degraded by 2021 they were no longer recognizable as terraces. The percentage of contrasting external boundaries remains high at 96% as does the external boundaries with no breaks at 68%.

Overall, since 1931 terrace conditions improved, shifting from largely ambiguous internal boundary features to contrasting boundary features in addition to the new construction of external boundary features. These new and altered features were in areas with flatter topography and facing east-southeast, while the condition of terrace features without external boundaries remained ambiguous and were facing south, on average. These differences coincide with terrace reuse and reconstruction, as described by farmers in Paccareta.

Main valley

In 1931, the main valley was extensively terraced, and it does appear that used terraced units possess external boundaries although there are exceptions. For example, figure 5.7 depicts terracing on the cliffs near where the Andagua River is dammed into a lake. Shrubs and shrubby-grass cover is patterned on terrace treads and along what are likely canals or abandoned treads among different cropping methods on lateral and broad field terraces (figure 5.7). Larger walls line paths and canals both of which are covered in shrubs and some trees. Most of the terrace units have walls between other units or paths but none on those that face the cliff. Terraced units vary in size and condition in 1931 (figure 5.7). Many external boundaries both perpendicular and parallel to the contour line appear to follow shrub-covered canals and paths, although not all. There are clear differences in crop cover and field practices between terrace units. Additionally, terrace retaining walls of farmed terraces appear grass-covered and well maintained in some places and shrub-covered in others.

Figure 5.7 An excerpt from a larger image depicting terraced cliff surrounding the Andagua River and waterfall near the lake in the main valley (American Museum of Natural History, Shippee-Johnson Collection, image ppcs551_k95).

Unlike Paccareta, the main valley appears to be cultivated throughout the period from 1930 to 2021 with few dramatic changes in external boundary features (table C.29 to C.31). Like Paccareta, most terraced units are mapped as segmented broad field or broad field-lateral terraces. In 1977, only 11% of terraces have no clear external boundary and, of those that did have external boundaries, 70% are mapped as contrasting and 49% have no breaks. The high percentage of external boundaries mapped in contrasting coarse conditions is likely explained by the practice of placing vegetation and allowing the growth of shrubs on boundary walls. These walls are also constructed with larger stones, making them wider and, therefore, appearing coarser. The breaks documented in these features may also be canal intakes, other designed openings or thick vegetation obscuring the walls. The distances to town, and the nearest road and path in this period are further for the samples documented as having no external boundary than most categories of those with external boundaries. By 2010, no sampled terraces are classified as lacking an external boundary in the main valley and most are classified as contrasting with few to no breaks. The aspect and slope remain generally the same as 1977, 8° and east-southeast facing. The distance to town and road for craggy ambiguous external boundaries is further than those in the contrasting categories. Terrace boundary patterns in 2021 are like 2010 although the number of terraces with contrasting external boundaries decreased to 74% and external boundaries with breaks also decreased to 47%. This decrease may be explained by the time of year of the image, the wet season, or may reflect other social patterns of land use.

Paccareta During Its Transformation

As mentioned previously, a collective of farmers in Andagua dramatically rehabilitated the soil and landscape in Paccareta during the 1960s and 1970s, including the reconstruction of terraces and the construction of new land tenure boundaries in the form of stacked stone dividing the landscape. While there was uncertainty in mapping the coarser 1966 imagery, comparing the main valley and Paccareta at the same scale reveals the clear differential patterns across these places (figures 5.8 and 5.9). The main valley has a quilted patchwork of different land covers evidenced by a range of contrasting tones and patterns bounded into irregularly rounded fields and land tenure units. In contrast, the range of land covers in Paccareta grade into one another, disrupted only by few patches of possible terrace or land tenure unit boundaries and slope changes from topographic variation. By 1977, the expansion of terrace unit boundaries is evident, and the visibility of the terraces are clearer at the same scale (figure 5.10). The finer pixel size of the later imagery contributes to this clarity, as does the rehabilitation and reconstruction of the terraces and the construction of new land tenure boundaries.

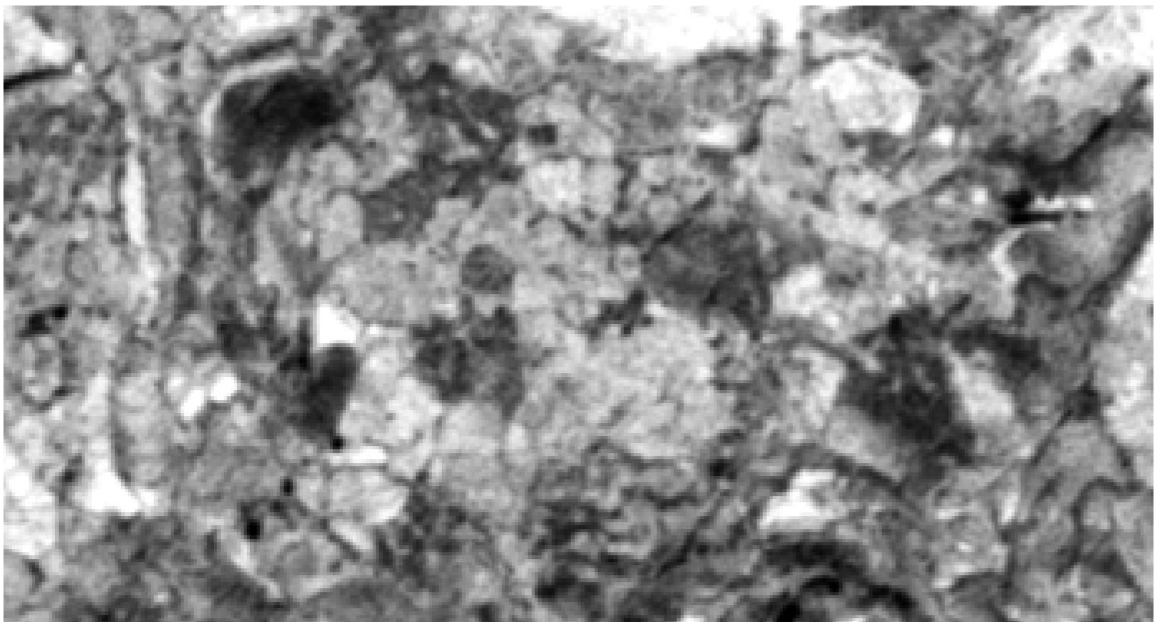


Figure 5.8 Image of the main valley from declassified aerial imagery from 1966 depicting terrace unit extents distinguishable by dominant land cover and with many bounded by a thicker, usually darker linear feature (1:2000 scale, north is up; USGS 1966).

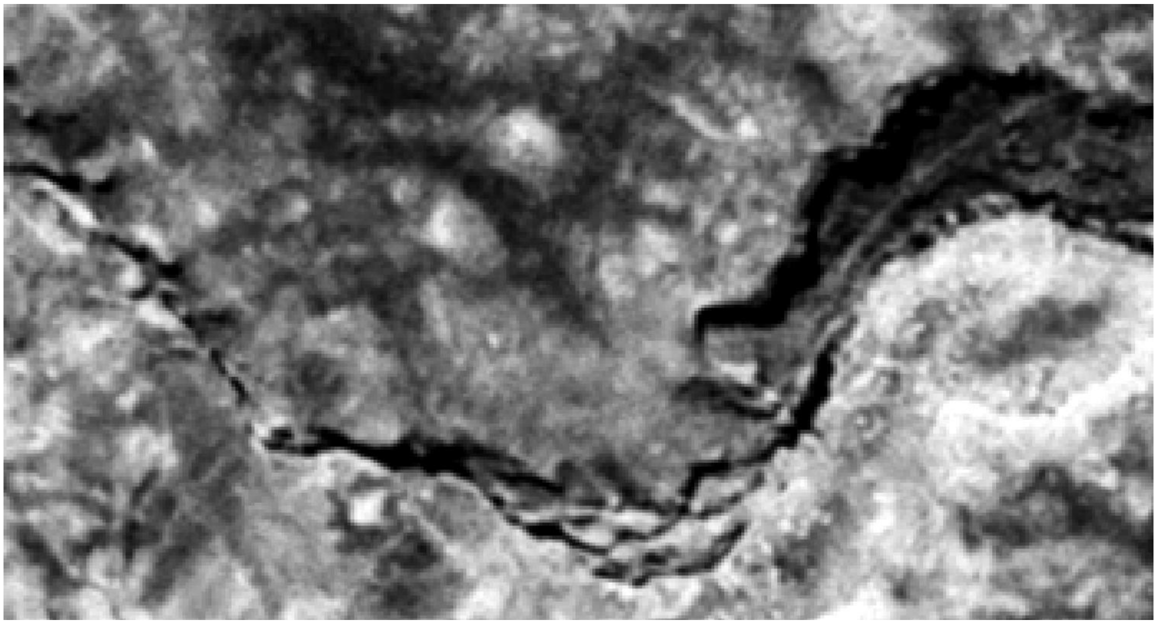


Figure 5.9 Image of Paccareta from declassified aerial imagery from 1966 demonstrating the differences in terrace cover and use at the same scale of the image above (1:2000 scale, north is up; USGS 1966).

Figures 5.11 and 5.12 are the pixelized results of mapping terrace cover in Paccareta in 1966 and 1977. The darkest color identifies terraced areas, the middle color identifies areas with possible terraces and the lightest color identifies areas with no identifiable terraces. The total extent of terraced land more than doubled from 38.67 hectares in 1966 to 101.1 hectares in 1977, while areas of potential terrace cover decreased dramatically from 62.11 hectares to 19.42 hectares (table 5.4). The decrease in areas mapped as lacking terraces in 1966 may indicate either new terrace construction or, more likely, that the areas were falsely marked as negative due to lower resolution and the low range of greyscale values captured in the imagery. Most areas mapped as without terraces in 1966 were mapped as having terraces in 1977 (table 5.5, figure 5.13). Only 1.16 hectares were mapped as transformed from terrace to no terrace, which may be explained by error stemming from the georectification process.

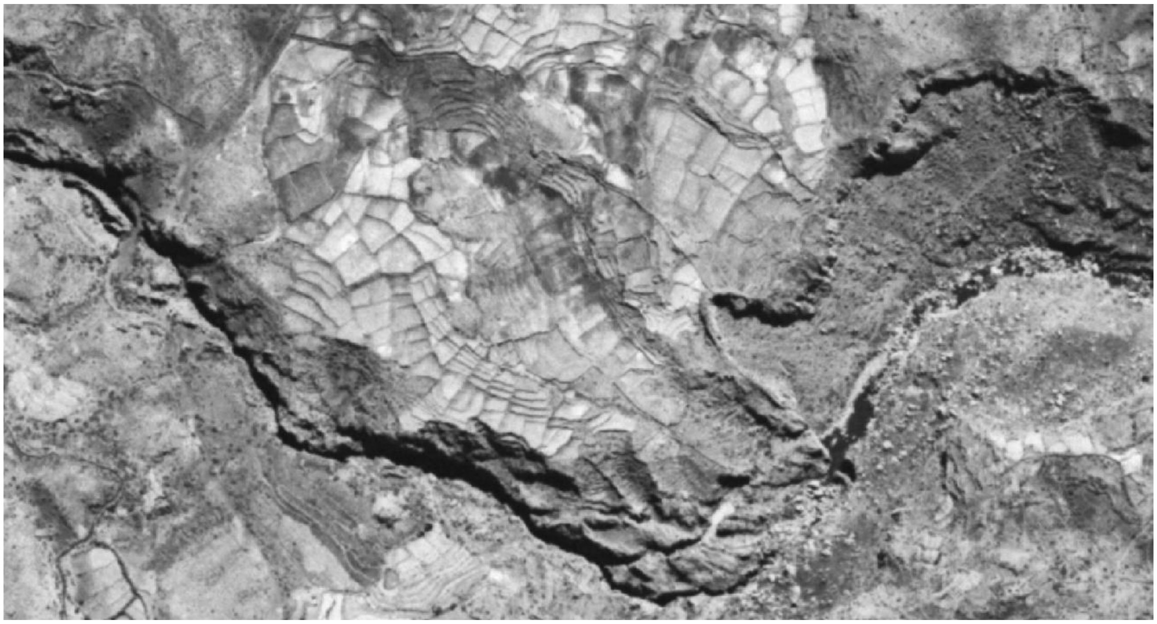


Figure 5.10 Image of Paccareta from declassified aerial imagery from 1977 demonstrating the difference in terrace cover and use at the same scale of the image above (1:2000 scale, north is up; USGS 1977).

Table 5.4 Mapped terrace areal extents in 1966 and 1977, and the total change from 1966 to 1977 in Paccareta.

	1966	1977	Total Change
Terrace	38.67	101.1	+62.43
Possible Terrace	62.11	19.42	-42.69
No Terrace	227.73	210.14	-17.59

Note: All measured areas are in hectares.

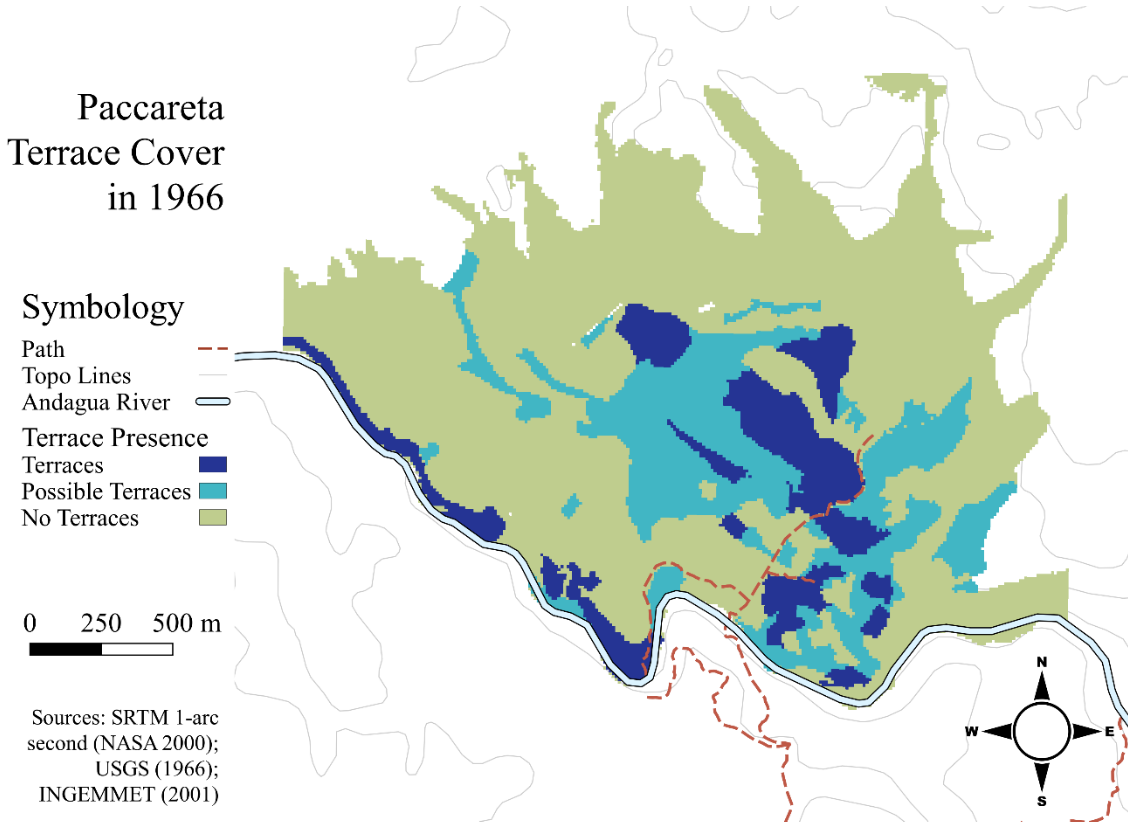


Figure 5.11 Visible terrace cover in 1966 in Paccareta.

Table 5.5 Changes in pixels' mapped terrace presence or absence from 1966 to 1977 converted into hectares.

Category	Areal Change from 1966 to 1977
Terrace to terrace	37.5
Terrace to no terrace	1.16
Possible terrace to terrace	41.96
Possible terrace to possible terrace	10.79
Possible terrace to no terrace	9.36
No terrace to terrace	21.64
No terrace to possible terrace	8.63
No terrace to no terrace	195.39

Notes: Pixel size was 10 meters by 10 meters; areal extent listed in hectares.

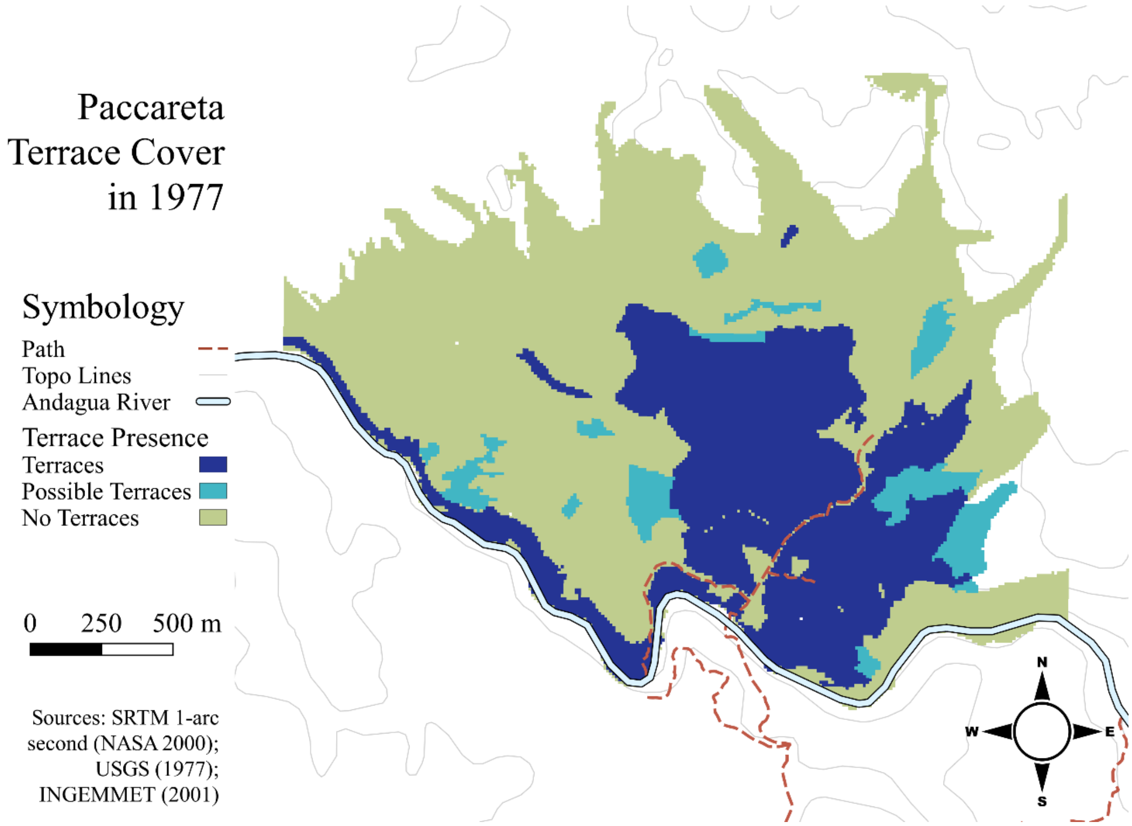


Figure 5.12 Visible terrace cover in 1977 in Paccareta.

Terraces are mapped in all land cover categories in 1966 and 1977, although most of the shrubby cover is along the south-facing canyon edges and within topographic lows in the valley floor. Soil, sand, or gravel covers wide expanses of the central portion of Paccareta, as it does today. Pale grasses cover the remaining areas in patches among the central part of Paccareta and in the northern uplands. The shrub cover in the topographic lows and in the northwest uplands expands by 1977, and the grass and shrub cover expand in the areas of terrace reconstruction. Both used and disused terraces are more clearly visible in the finer-resolution imagery from 1977. Areas both north and south of the main path in Paccareta are reconstructed and put back into use by 1977. Patches of unterraced areas remain in disuse for agriculture by 1977 throughout the terraced areas. External boundaries are also more visible by 1977, correlating with renewed land use and with the introduction of cattle into this area. Its high elevation, low relief, and possible vulnerability to frost and cold-air drainage are characteristics more suitable for cattle grazing and the production of heartier plants.

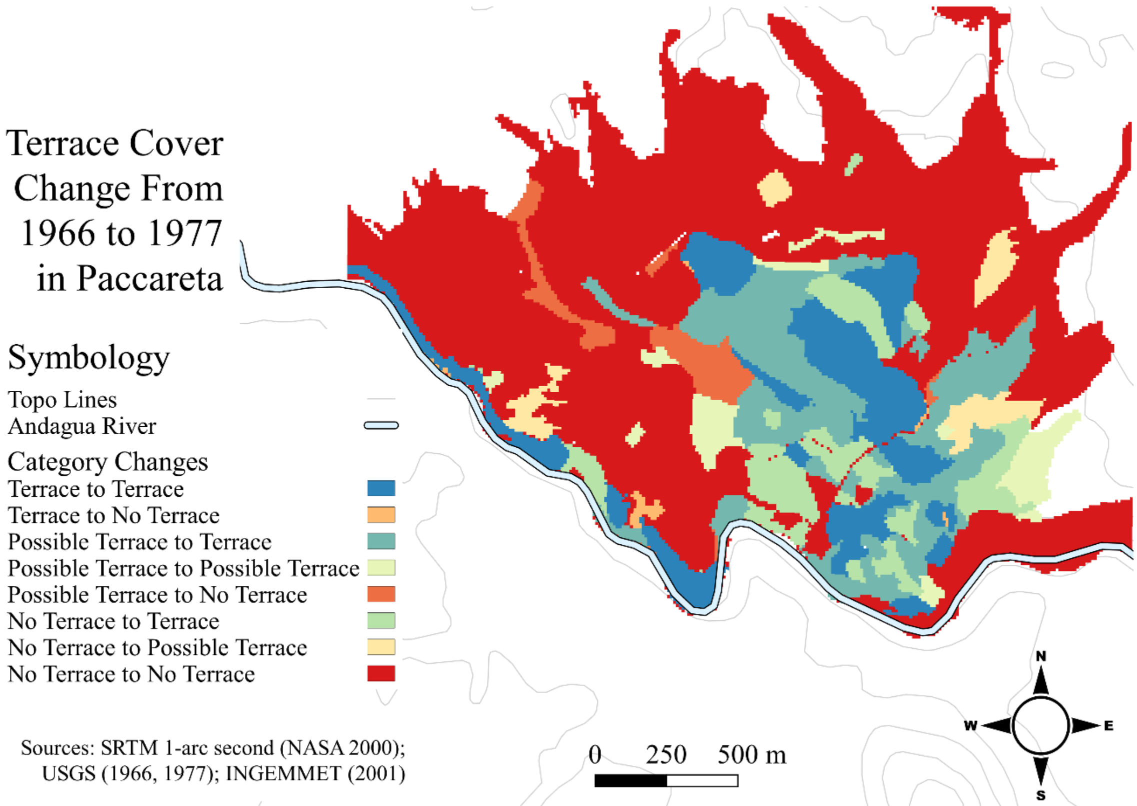
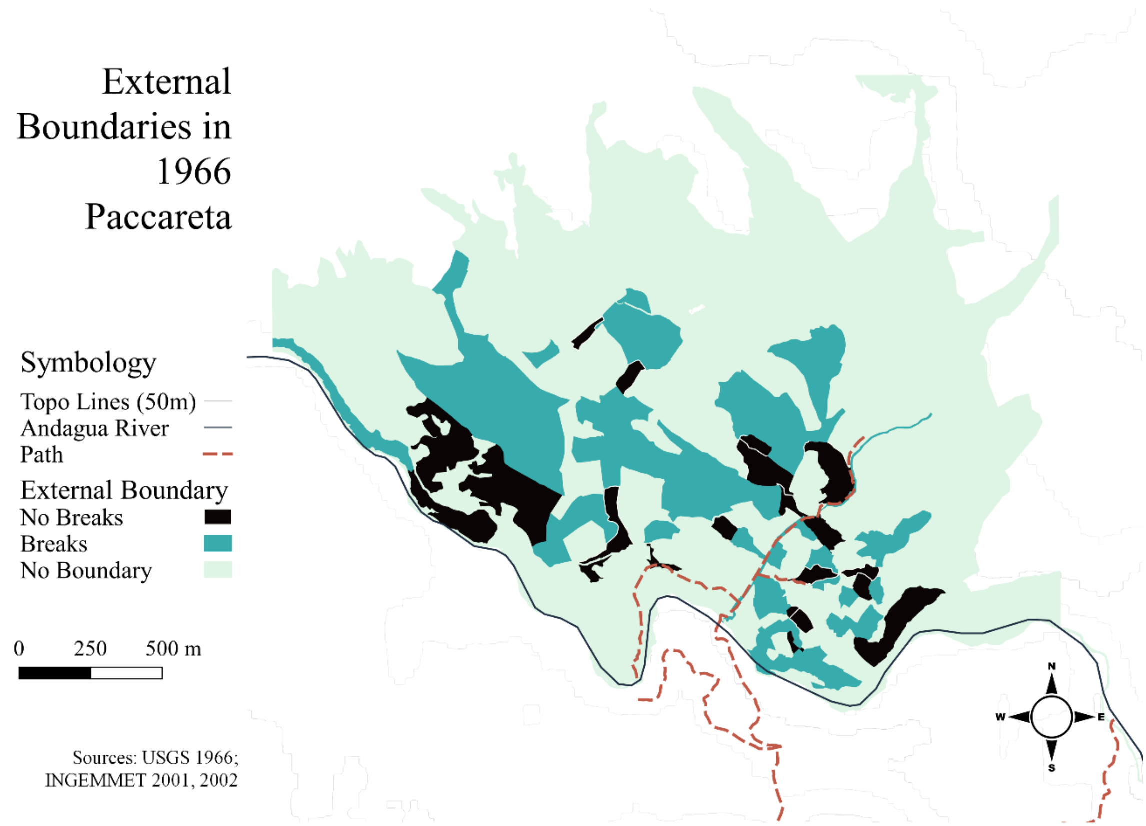


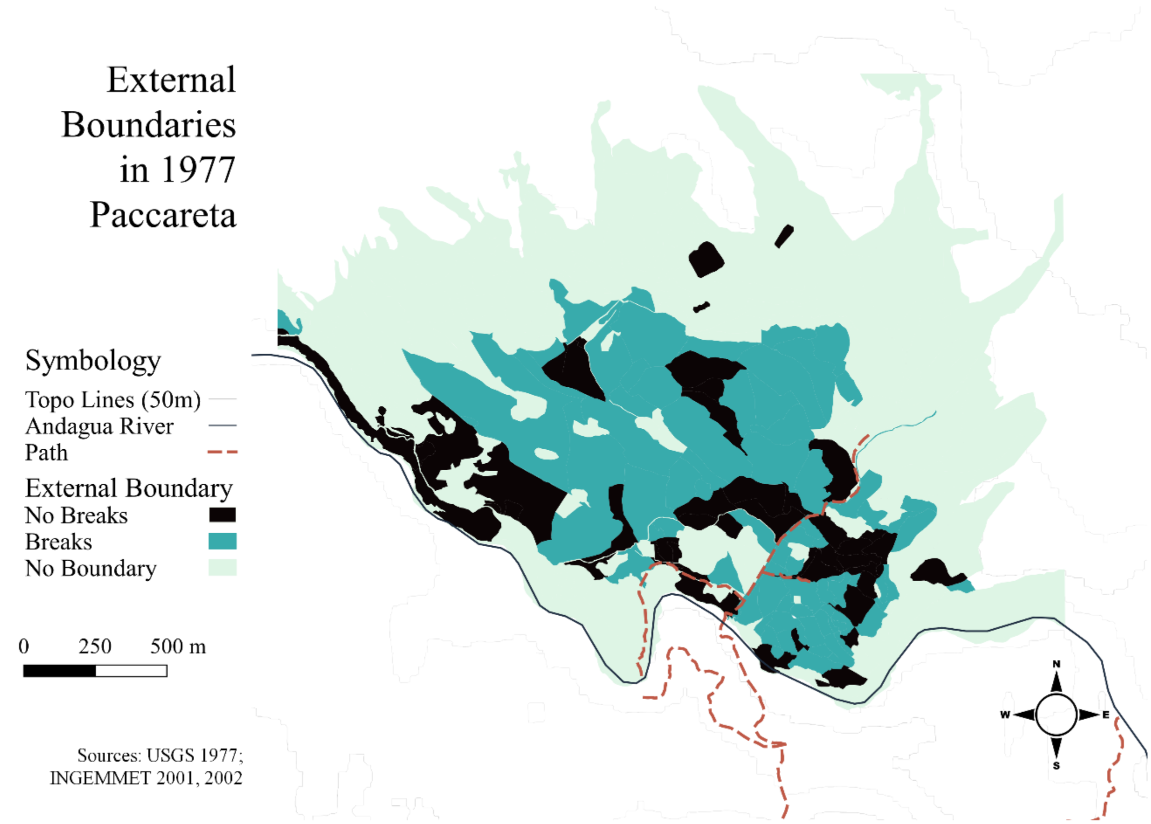
Figure 5.13 Change in visible terrace cover from 1966 to 1977 in Paccareta.

Figures 5.14 and 5.15 depict basic descriptions of external boundaries, notably their presence, absence, or partial presence around an area of terraces with the same dominant land cover. Not all external boundaries refer to walled boundaries and many are canals or paths, especially in the area north of the SSW-NNE path bisecting Paccareta in 1966. While the coarser resolution of the 1966 imagery made it difficult to be confident in the determination of an external boundary, Paccareta in 1966 appeared in widespread disuse except in some areas closer to the river canyon and to the town of Andagua, which are lower in elevation. Additionally, boundary walls were not yet visible in the well-maintained terraces, with a few exceptions. This was unlike the terraces near the main valley at this time, which were much more clearly divided into different management units on the satellite images.



Note: The "Breaks" category refers to areas with external boundaries that do not appear continuous.

Figure 5.14 Terrace external boundary presence or absence in 1966.



Note: The "Some Breaks" category refers to areas with external boundaries that do not appear continuous.

Figure 5.15 External boundary presence or absence in 1977.

Discussion

The transformation of the *tupu* from a relational, dynamic term to one largely cemented in place on the agricultural landscape mirrors the increasing pressure on Indigenous populations to conform to Inca, Spanish and Peruvian ideals. This uneven and incomplete incorporation of reciprocal relationships into local and state/imperial economics and politics is central to this and the need to control land, resources, and labor. While documented as Euclidian units by colonizers, local landowners, institutions, and the state, the *tupu* is unevenly but enduringly dynamic and relational at a local level. Its initial use was socially, environmentally, and physically flexible; however, the increasing need for control resulted in largely private units bounded by stacked stones, the areal extent of which are unevenly distributed across race, class, gender, and historical circumstances. While the likely post-colonial, dry-stacked stones marking those boundaries are not cemented in place, they signal differential patterns in management practices, soil properties, water availability, vegetation, and livestock. All these patterns reveal a tripartite relational dynamic that interlinks the *tupu* as a quantitative measure of the physical world and a qualitative measure of a metaphorical or social world, both mediated by institutions with the capacity or authority to dictate the meaning of these measures.

Those in local and state-level positions of power have the capacity to impose a particular human-environment relationship, which can be bottom-up, top-down or a negotiated combination of the two. For example, *tupus* are often central to (uneven) reciprocal relations of extraction, taxation, and exploitation through time, the extent of their physical boundaries both an illustration of privatization and European livestock ranching, but also representative of historic and contemporary human-environment relations in the Andes. The authority, whether given or taken, imposes requirements, such as taxes and restrictions on who can own land, which impacts how people perceive "quantity sufficient." Locally, the distribution and redistribution of usufruct land lies in the hands of the community, local officials, or local lords, depending on the state authority. During the Spanish colonial area, "quantity sufficient" would have included land to support the (male) head of household, his wife and children, and additional land to produce surplus for the state (Moore 1958, 37, 176; Farrier 1967, 456). In the literature, this areal extent is reported being around 0.33 hectares with those fields in Arequipa, as described by Rowe (1946, 324), being slightly larger. The main valley of Andagua is proximal to the Spanish *reducción* and was likely in use during this period (Menaker 2019). The average extent of fields sampled in this area was 0.46 hectares with a median extent of 0.38 hectares, corresponding with the range of extents reported in the literature and the expectation for larger areas nearer to Arequipa (see table 5.1). Additionally, the smallest units in the main valley, described by farmers in Andagua as *medio tupus* or *tupitus*, correspond with a quarter *tupu* at around 0.08 hectares, which were described as *andénes*, *patas* and *pedazos* in the Colca Valley (Benavides 1987, 136). The physical creation of walls around these units likely occurred during the Spanish colonial era, when cattle were introduced into the Andes, suggesting the physical bounding of these extents are a product of this period.

Alternatively, the physical walls in Paccareta were the product of a bottom-up project, their extent a result of conversations among the original group of farmers on the appropriate distribution of land. The succeeding decades of construction and expansion were a similar outcome of these relationships. The average size of a unit in Paccareta is 0.67 hectares and the median is 0.59 hectares, both of which are at least 0.2 hectares larger than the those in the main valley. In interviews, Señora A's mathematical description of a *tupu* was at 0.4 hectares, equivalent to the median values of terraced units in the main valley, which is where her fields are located. However, the largest unit in Paccareta is closer to the size of a Spanish colonial *fanega*, according to the number quoted by Covey and Quave (2017), rather than a *tupu*. There is a lack of evidence of colonial-era use of the high-elevation area (see Menaker 2019), and the similarity is likely a coincidence. Shippee did note the grazing of large herds in higher elevation areas (Shippee 1932), which, he did not discuss, possibly required boundaries for their containment. If he saw these herds along his routes in or out of the valley, then, according to a sketch published in Shippee's 1932 article in the *Geographical Review* and to his description in the 1934 article in the *National Geographic*, they may have been in Paccareta or higher.[12] Alternatively, they may have seen these large herds on their way over the pass at Coropuna, leaving the valley. If it is assumed that the large herds required physical boundaries to keep them in place, it is unclear where these were located. Additionally, farmers in Paccareta describe the pre-rehabilitated area as terraces without external boundaries. As such, the larger terraced units are more likely a result of negotiations in the 1960s than Spanish colonial or post-colonial herding.

While it is important to acknowledge who has the capacity to bound the landscape and in what form, it is also critical to focus on the quantification of the qualitative definitions of land tenure units and their ties to environmental and social conditions at different spatial and social levels. The state may dictate the need for taxes; however, the capacity of the land to procure these surpluses is known only to those with knowledge of the landscape. For example, Paccareta is largely above the maize cropping zone and thus was likely not a priority for Inca crop production. At a higher elevation, these may require longer fallow periods and, therefore, were constructed larger in size. It is possible that some areas of Paccareta may have continued to be cultivated during this period for subsistence while other areas were occupied by maize at the instruction of the Inca, as described in the Colca Valley by Shea (1987, 82). Large-scale rectilinear features in a basin near the site of Paccareta suggests state organization and Late Horizon (Inca) artifacts are present in the site; however, radiocarbon dates are yet to be tested for confirmation of feature dates (Menaker, pers. comm. March 19, 2023). As such, if following patterns elsewhere and considering the location of Inca sites in the valley, terrace intensification was likely at lower elevations in the main valley. Other areas that were central to Inca presence in the valley were the side valleys of Tauca and Soporo, a quebrada in the southern half of the contemporary town of Andagua (also known as Andagua Antiguo or Ancient Andagua) and the massive, gridded project in Quisguarani (Menaker 2019, 203, 206, fig. 5.2). The Spanish additionally directed social, political, and agricultural organization away from Paccareta. The contemporary town of Andagua, a Spanish *reducción*, is lower in elevation.

Like other areas of the Andes, the Spanish colonial officials physically and socially reoriented local people to this town and away from other areas of the valley (Menaker 2019, 250-251). Like elsewhere, this likely followed widespread population reductions due to disease, further altering land use patterns (Wernke 2010). As such, it is likely the elevation difference and the desire for specific products by first the Inca and then the Spanish impacted how and where people farmed in the Andagua Valley, shaping peoples' relationships to the land over the following centuries.

The physical manifestations of the land tenure boundary walls are also socially and environmentally contingent. The existence of external boundary walls on terraces may have originally stemmed from a practical need to contain irrigation water or sediment, a byproduct of terrace construction and maintenance, as part of engineering aesthetics, or as markers of land tenure for Inca or Spanish colonial administration (Thurner 1997; Dean 2010; 75; Covey and Quave 2017). In Andagua, for example, the land tenure walls often are lined with feeder canals and paths, demonstrating that the boundary serves multiple purposes. Additionally, the sampled terraces in the main valley have a mix of external boundary patterns, with a majority mapped as segmented. These segmented patterns suggest that each terrace unit was constructed piece-meal by a small but organized group, rather than a large-scale, state-directed project. So, while these terraces and their associated canals and walking paths may have originally been a part of the land tenure design, their cementation in place likely did not occur until the introduction of cattle. As mentioned above, the introduction of European animals, such as cattle, required farmers to alter existing terrace features such as creating lateral stone-stacked walls or by making existing walls higher (Denevan 1979, 22; Treacy 1987b, 153). Cattle herding for subsistence and milk production are widely important activities in Andagua today and in the past (see chapter 3). Cattle breeding for bull fighting and meat production are also high prestige activities deeply connected to class and land availability. The farmer interviewed from Paccareta lamented his inability to produce maize in his fields, but also spoke about his success with high quality beef production. The almost gridded pattern to the external boundaries in Paccareta, in contrast to the rounded, segmented broad field terrace patterns, reveals the disjuncture between their constructions. Additionally, the local *gamonales* violently appropriated land within living memory of interviewed Andagüeños mostly for cattle ranching, altering land use towards this practice and its physical requirements. In addition to contributing to the creation of boundaries, cattle themselves degrade internal terrace walls by knocking them over as they graze, according to farmers in Andagua. This is a further issue that may lead to higher proportions of eroded material if left unrepaired and if cattle are allowed to graze on abandoned terraces (Lasanta et al. 2001).

The cementation of land tenure and the reduction in community-owned usufruct land occurred simultaneously with the alteration of the meaning of the *tupu* from one indicating measurement – and the power to measure – to a multi-use and socially relational term indicating land tenure boundaries and area, thus dictating the social organization of water. Considering the many disruptions of land use and land tenure, it is difficult to locate the period in which the land tenure boundaries cemented in space. Available Spanish colonial census data in Andagua was not detailed like that of the Colca Valley, so an analysis of land tenure and toponyms, like that of Wernke (2010) was not possible at this time. Future research into historical documentation would be necessary to disentangle the complexities of the cementation of land boundaries in place. The largely segmented patterns of terrace construction across Andagua suggests that many of the terraces were constructed piece-meal using kin or community labor, with exceptions for the large-scale, sequential terraces found on steeper slopes. Many of the modern external boundaries correlate possibly with the extents of these terrace units constructed at the same time. In other words, these segmented terrace units may also be a *tupu*–or an area that produces enough maize to sustain a couple for a year, the extent of which varies by microclimate. While terrace unit size did increase with elevation, more than 75% of the variation from the regression line could not be explained. The average terrace unit size of Paccareta was larger than the main valley; however, the tenure unit walls were the result of twentieth-century construction. Thus, it is possible that the median value of 0.38 hectares in the main valley may possibly relate to the socially ascribed boundary size to create a *tupu* in Andagua. The microclimate associated with the broad terraces overlying the high-relief volcanic material may combine to require more land for the socially appropriate yield size in the past. A larger survey of terrace land tenure boundaries of long-abandoned and used terraces in the southern Andes in relation to topographic characteristics and microclimate would test these hypotheses.

CONCLUSION

This chapter's goal was to uncover the physical manifestation of land tenure units in Paccareta and the main valley through the twentieth and twenty-first century, and how these may or may not relate to the *tupu*. Results suggest that the physical boundaries of terraced land tenure units today are the product of the three-way relationship manifesting the *tupu* including its quantitative measures, its qualitative measures, and the authority to bound that measure in physical space. The forces and results of these relationships change through time, uniquely manifesting in Paccareta and the main valley, the external unit boundaries of the former being a product late twentieth-century local sociality rather than post-colonial negotiation. Additionally, the ability of a *tupu* to be both concrete and metaphorical (Harrison 1989) simultaneously enables the same unit to be described both in units of *tupu* and as the physical feature of a *tupu*, demonstrating the multiple meanings ascribed to the term today. Future interviews, historical and archival research and fieldwork will contribute to confirming the use, meaning and history of local analytics, land tenure and changes to the terraced landscape through time.

Conclusion: The Interconnection of the Terraced Landscape

The Valley of the Volcanoes is a uniquely terraced landscape created and transformed over centuries through complex and dynamic socio-geomorphic relationships. Farmers sustain these relationships among different social groups and the important figures on the landscape, including Earth Mother and local *wank'a*, to ensure the continued material benefits of terraces, shifting practices and relationships through social and environmental change. Such change over the twentieth and twenty-first centuries includes: the highly variable and generally decreasing interannual precipitation patterns; shifts and shortening of the rainy season; increasing temperatures; increasing connectivity to urban and coastal markets, employment and education; introduction of new agricultural methods such as mechanization and chemical additions to agricultural fields; uneven social, economic, political, and environmental support from outside institutions such as the state, NGOs and others; and, more efficient transportation routes; among many other factors. Each of these impacts farmers' decision-making about their use of the terraced landscape, the results of which may or may not support the continued functioning of the unstable geomorphic system.

The goal of this dissertation was to better understand the socio-geomorphic relationship through local knowledges as they apply to the farmers' and ranchers' terraced *herencias* or inheritance from their ancestors in Andagua, Peru. Interviews with farmers revealed practices, relationships, and ways of thinking about the landscape that were both contradictory and heterogenous, reflecting the diversity across individuals, gender, class, family, and other markers of social difference. The same heterogeneity was visible in aerial and satellite imagery in terrace retaining wall condition, pattern and form, terrace type, and road density and patterns, each of which echoes the separate and historically grounded practices and forces that contributed to the form of the twentieth-century reconstruction of Paccareta and the continuously used main valley. Results contribute possibly new terrace types and patterns unique to the Valley of the Volcanoes; draw attention to the continued use of a Quechua term–the *tupu*–to describe and bound the physical (and social) landscape in both transformed and enduring ways; clarify the impacts of human-induced climate change in this fragile mountain region; document bottom-up terrace reconstruction before and through a period of socio-economic and political reorganization in twentieth century Peru; and, reveal the importance of historic social relationships to the patterning of use across the landscape.

This dissertation approached these anthropogenic landforms, and accompanying practices, through a lens that enabled the incorporation and iterative conversation between both the human and non-human aspects of terracing. This crucially meant approaching these through a relational lens that considers history, social relationships among people and the landscape, individual perspectives and practices, and human and non-human landform features to be connected to and mutually impacting each other. This dissertation used local knowledge from interviews to identify, classify and give meaning to the physical patterns seen on the landscape during fieldwork and through the analysis of remotely sensed imagery.

Scales of Socio-Geomorphic Units: Landscape, Tupu, and Terrace

Using the terrace and the terraced landscape as the starting point of the study led the research project towards additional meaningful anthropogenic units deeply intwined with history, power, and culture. A heterogeneous view of boundary-making and classification led to the conceptual intertwining of the social and the geomorphic. In the case of Andagua, the interrogation uncovered not only the terrace as a socio-geomorphic unit, but also the *tupu* as a feature with quantitative and qualitative, context-specific boundaries including those of land tenure and area. At finer scales, this also directed the project to the mapping of terrace treads, retaining walls, paths, and roads, each of which are connected to social practices and processes that impede, enable, or take advantage of geomorphic process. Addressing each of these socio-geomorphic levels in environmental and social context and in conversation with each other strengthens our understanding of each individually and their inexorable, yet continuously changing, relationality.

The *tupu* is an especially illustrative example of an anthropogenic landform and landform unit that is relational to and revealing of historical circumstances. The physical manifestation of its dry-stacked stone walls surrounding terrace treads and retaining walls are a result of the tripartite relationship between its quantitative measures, qualitative measures, and the authority to assign those measures over time and across locations. This explanation of their differences is exemplified in the juxtaposition of Paccareta and the main valley. The main valley has been farmed since the pre-Hispanic periods and, as such, was under the authority of succeeding states since the Inca (Menaker 2019b). Historically, the extent of the *tupu* was guided by local environmental conditions and conceptions of what was "sufficient" (e.g., Farrier 1967, 456). The land itself, in southern Peru considered usufruct and its distribution organized by the local communities (Thurner 1997, 49-51), was flexible in its boundaries. Units were distributed as needed to expanding or retracting families. With the Inca and then Spanish, what was sufficient began to include surplus for the state through the introduction of new, uneven farmer-state reciprocal relationships (Farrier 1967, 456; Benavides 1987, 136). The usufruct land was gradually privatized (Thurner 1997, 21), and the boundaries cemented in place. In the main valley of Andagua, those boundaries were further cemented by contemporary irrigation distribution systems, standardizing the volume of water per *tupu* despite changing and dynamic environmental conditions. In contrast, Paccareta was largely abandoned since the colonial era, marking the 1960 top-down terrace rehabilitation and new boundary creation a product of contemporary negotiations among the farmers and their perceptions of what was "sufficient" given their local knowledge and needs. The different boundary sizes, then, are historical products and evidence of past colonial and post-colonial power dynamics and economics and environmental histories at the time of each *tupu*s' hardening on the landscape.

Classifying terrace morphology, patterning and condition also required a reflection on both the physical landscape and the social at different scales. The conditions of labor required to construct, maintain, and farm terraces, the relationships for organizing irrigation and canal management, and other forces and factors, impact decision-making about wall reconstruction, land use, and the capacity to plant, plow, and harvest at the individual terrace unit and at broader locations. Large areas of terraces were in disuse because of urban planning policies related to Spanish colonialism, for example, and shifts in irrigation distribution policy following an NGO study, in another example. This inquiry found that slope, related to the varied and unique volcanic topography, was a crucial element to the management of water and terrace use in Andagua. The terrace typologies common in the southern Andes were insufficient to explain terrace patterns in Andagua. For example, the depression terraces in Andagua were unique in geomorphic setting from other sinkhole terraces and unterraced agricultural fields found in the karst landscapes of the Americas (e.g., Dedrick et al. 2020; Guengerich and Berquist 2020; Lacroix et al. 2015). Their manner of form and drainage are unclear, and further investigations will be needed to clarify their functioning and landform origins. The volcanic lava fields on which terraces were constructed additionally results in unique grading between bench terrace types, causing the potential to have broad field, lateral and depression terraces within a single terrace unit.

The Pleistocene- and Holocene-aged andesitic and andesitic-basaltic rocks underlie and are proximal to the agricultural terraces and canals, likely supplying fresh minerals through aeolian processes, canal irrigation, and/or erosion. This may have historically contributed to some farmers reporting needing to add little to no chemical or natural additions in some years to their fields. For example, in combination with aridity, the rocks may create conditions in which leaving terrace treads in disuse and allowing erosion may be beneficial to downslope soil fertility. Examples of long-term terrace disuse within a single terrace tread and patterned throughout a hillslope likely reflect long-term abandonment of certain terrace features for agriculture or a lack of labor to reconstruct such an expanse of retaining walls. Before the canals were cemented, they also brought sediments that deposited in terrace fields, likely also creating opportunities for increased fertility. The decrease in these sediment deposits may diminish the ability for farmers to farm without chemical or natural fertilizers, as reported. Future research will need to be conducted to test if terrace use will require increasing inputs over time with decreasing deposits from flood irrigation.

The varied topography of the Andes at regional scales additionally causes difficulties in extrapolating the impacts of ENSO events and human-induced climate change at a fine scale (Pabón-Caicedo et al. 2021). This dissertation research reveals farmers' perceptions of increasing winter temperatures, decreasing summer precipitation, lower resulting summer river discharge, and a shortened rainy season in Andagua. These boundaries were tested and communicated through maize, a delicate and environmentally vulnerable crop. Farmers communicated the potentiality of yield, microclimate, and social management of water through their identification of a terraced field as a *maicero* or not and indicated that the expansion of *maiceros* correlated with farmers attempting to test the perceived change in temperature. This is only one example of the application of experimentation in the formation of local knowledge, a crucial aspect to understanding the socio-geomorphic landscape in Andagua.

Tupus, *maiceros*, and depression terraces are only a few examples of complex physical, humanized features on the landscape, and there are unanswered questions as to their functioning, meaning and use through time. Future research is required to investigate these at different scales, including at the surface and subsurface of the terrace tread and the soil pedon, for example, or the terrace extent at the entirety of the Valley of the Volcanoes. Continuing to include these new avenues of research within a socio-geomorphic perspective and through a reflective lens will create a more holistic understanding of these complex landscapes.

THE PEOPLE OF THE VALLEY OF THE VOLCANOES

Farmers and ranchers in Andagua express both concern and hope for the future, envisioning tourism, organic farming, and other opportunities in the face of concerns for water safety and volume, altered seasonality and the continuation of their *herencia* for their children and grandchildren. This dissertation has worked to highlight the importance of amplifying the complexities of local human-environment relationships and teasing out the factors and forces contributing to the formation and stability of the anthropogenic landscape and landforms. While I could never fully translate the meanings of local ways of classifying and being in the world in their entire historicity and contexts (De La Cadena 2015, 3), this dissertation makes the first steps at disentangling local analytics of the physical world to encourage bottom-up, heterogenous and multiple visions of the future that reflect the equally complicated knowledges, perspectives, practices, and ways of thinking about the world across the individuals, communities and groups that make up Andagua.

Appendices

APPENDIX A: BACKGROUND

Social and Ecological Models in the Andes

Alexander Von Humboldt is cited as one of the first scientists from the Global North to document elevation as a major factor in the diverse and layered ecological assemblages of the Andes, imparting a perspective of vertical zonation that has been studied and challenged for over two centuries (see Moret et al. 2019). According to anthropologist John V. Murra (1968), the goal of Andean social groups at different scales are (and were) to control multiple micro-climates across the environmentally diverse steep mountain landscape for product variety over time. This vertical conception of the landscape extended across spatial scales, from the individual terrace to the cross-section of the Andes, the sociality of which was differently managed over time and across social groups (Murra 1968, 121). The Spanish colonial censuses list geographic information that gives clues to these organizational methods, including the role of kin groups traveling to different ecological zones for access, creating an "archipelago" (for information on *mitmaq* in Lake Titicaca, see Murra 1968, 123) as well as other forms of "ecological complementarity" in Inca, pre-Inca, and non-Inca contexts (Murra 1985a, 4-5). The base for this complementarity is reciprocity among kin groups, broader processes of power and various environmental factors (Murra 1985b, 15-17; Mayer 1985, 46), none of which are independent from each other. Andean states employed these relationships in their extractive practices, requiring locals to engage in reciprocal relationships with those in power in addition to their kin groups (Mayer 1985, 46). Summarizing ethnographic details written by sixteenth century *encomendero* Polo Ondegardo, Mumford (2012, 37-38) describes Polo as an advocate for the Spanish to enable and exploit the systems of vertical landscape control previously employed by the Inca. The potential profitability of this system of reciprocity across the mountains was, to Polo and the Spanish, an appealing way to manage the new land (see also Pease 1985, 141-60). Pease (1985, 141-3) tempers Murra's original conceptualization of the vertical archipelago, arguing that these vertical organizations likely differed across ethnic groups and over time, citing discrepancies between Spanish definitions of territory and local ideas of control that resulted in misunderstandings in colonial records. As summarized by Mayer (1985, 49-50), there are multiple models of ecological zones in the Andes, each drawing from different ways of thinking about the world, including an Andean relational conception of environments that applies across spatial scales as small as two individual plant fruits. Mayer (1985, 50-51) then contrasts these models with the "real production zones" or the everyday practices and "resources" of local farmers that work towards crop growth. These practices differ across communities, including field type, social organization, irrigation systems, and boundaries (Mayer 1985, 50-51). Mayer's (1985, 52-60, see Figure 4.1) descriptions and diagrams depict relatively strict boundaries between these zones, each of which cultivate different assemblages of crops and are overseen by a series of hierarchical authorities; however, he also acknowledges the role of experimentation in introducing new crop species to different zones as well as many complicating rules and stipulations involved.

Zimmerer (1999) challenged the compartmentalized zone model, blurring the boundaries of twentieth-century farming of the vertical landscapes by suggesting the model of "overlapping patchworks," which considers the physical impacts of farmers incorporating multiple (and at times contrasting) landscape models. Zimmerer's (1999, 147) thorough study of land cropping spatial and temporal patterns near Cuzco, Peru concluded that the division between tuber and maize zones is fuzzier than previously thought, demonstrating vertical overlap in paired crop ranges and multiple decision-making factors for crop planting unrelated to environmental variables. Farmers replied that their decision-making was based on several factors, the two out of five relating to yield (with the top reason being a "good yield" and the third highest rationale was "maximum yield") while the second highest was the potential market returns and third being tradition (Zimmerer 1999, 148). Zimmerer also summarizes local analytics of topographic space, explaining that the relational understanding of the different topographic "zones" result in mostly fuzzy boundaries relating to social change, agriculturally relevant environmental factors, colonial legacies, and culture. This is not particularly unlike boundaries for topographic features in geomorphology such as the beginning or end of a hill. The resulting landscape model, defined as "overlapping patchworks," results from the interaction of social and environmental factors, including perceptions of land characteristics and the highly variable interannual climate patterns and resulting geomorphic processes (Zimmerer 1999, 156-159). Highly adaptable crops such as tubers, then, can be planted in a range of locations, enabled by the microclimates and patterns of local social and broader economic processes and forces (Zimmerer 1999, 158). Zimmerer (1999, 158) refers to this as the "adaptive dynamics" of the crops and their ability to have good yields in a variety of environmental conditions. The patterns of each of these forces on the landscape impact the resulting patterns of land cover distribution. Zimmerer (1999, 158) perceived development agendas and access to external markets as one of the major factors involved in these patterns, suggesting that simpler models (i.e., dual models or zonal models) may correspond with more rural locations. It is also unclear if these external forces would apply to pre-Hispanic periods, and if "overlapping patchworks" can be applied as an historic landscape model.

APPENDIX B: DATA AND METHODOLOGY

Interview Classification Categories

Table B.1 Coding categories for interview transcriptions.

Category and Subcategories	Subcategory
Human Landforms	
	Terrace
	Canal
	Road
	Topo
Natural Landforms	
	Mountain
	Volcano
	Rocks
	Soil
Natural Processes	
	Climate
	Hydrology
	Tectonics
	Degradation
Social Processes	
	Economy
	Politics
	Migration
	Religion
Human Practices	
	Social Relations
	Irrigation
	Plowing/Planting
	Harvest
Ecology	
	Pasture
	Natural Plants
	Crops

Imagery Acquisition

The author acquired 30 Shippee-Johnson photos depicting Andagua and the Valley of the Volcanoes in March 2017 from the Shippee-Johnson Expedition Special Collections of the Research Library at the American Museum of Natural History in New York, a trip funded by the William M. Denevan Master's field study award from the Conference of Latin American Geographers specialty group of the American Association of Geographers and the Laurence C. Herold Fund for student research from the Department of Geography and the Environment at the University of Denver.

Shippee (1932) recounts that they also took vertical aerial photos of Andagua (depicted on what was likely an inset into the magazine because no pages are listed), but these did not appear to be in the collection at the American Museum of Natural History in New York. The quality of the scans, and perhaps the printed mosaic itself, is not high–the pixels have a coarse resolution and the spectral range is low–and therefore is difficult to use at a local landform scale. These photographs depict areal extents of land use in Paccareta, the main valley of Andagua in addition to the side-valley hamlets and towns of Soporo, Tauca and Chachas. They additionally depict the group's journey by horseback into the valley and in the town center, both of which includes images of the people, vegetation, landforms, and architecture of Andagua. Shippee published the results of these in several formats including in the *National Geographic Magazine* (Shippee 1933, 1934) and in the journal *Geographical Review* (Shippee 1932a; 1932b).

Table B.2 List of images from the Shippee-Johnson Expedition acquired from the American Museum of Natural History in New York.

Name of Image	Photo Format	Description
ppcs551_aa223	Ground	Bunch grasses and cacti with agricultural terraces, volcanos and mountains possibly taken from the western valley.
ppcs551_aa231	Ground	Camp with donkeys and people in a cacti-filled volcano.
ppcs551_aa377	Ground	Volcano and lava fields in foreground with lake in middle distance and mountains in the background.
ppcs551_aa378	Ground	View of the north side of the unpaved town square, structures, and the church; sleeping dogs.
ppcs551_aa379	Ground	Striped chapel on east side of town.
ppcs551_aa380	Ground	Cacti with twin volcanoes in the distance.
ppcs551_aa381	Ground	Cacti with a volcano and mountain in distance.
ppcs551_aa383	Ground	Lava fields and volcanos.
ppcs551_aa386	Ground	View of the north side of the unpaved town square and the thatch-roof church.
ppcs551_aa387	Ground	View of thatch-roof chapel on the unpaved town square with people sitting along wall.
ppcs551_k18	Aerial	Agricultural terraces, volcanoes, Andagua, Quisguarani, and Paccareta; view northeast.
ppcs551_k30	Aerial	Agricultural terraces and town of Chachas around the lake draining the Andagua River; view southwest.
ppcs551_k33	Aerial	Twin volcanoes and main valley agricultural terraces, town of Andagua, Paccareta and lava fields; view southwest.
ppcs551_k42	Aerial	Twin Volcanoes, Tauca, Andagua Lake, Quisguarani, town of Andagua, agricultural terraces, and lava fields; view east.
ppcs551_k50	Aerial	Soporo, lava fields and cones, Chachas, agricultural terraces, and lakes; view east.
ppcs551_k91	Aerial	Ninamama lava field, other lava fields, agricultural terraces, and drainage; view southwest.
ppcs551_k95	Aerial	Andagua river and waterfall, agricultural terraces, and river crossing; view north.
ppcs551_k96	Aerial	Andagua town square with thatch-roofed church, thatch-roofed structures, roofless structures, metal-roofed *gamonal* complex, agricultural fields and terraces; view south.

Table B.2 cont.

Name of Image	Photo Format	Description
ppcs551_k97	Aerial	Andagua town square with thatch-roofed church, thatch-roofed structures, roofless structures, metal-roofed *gamonal* complex, agricultural fields and terraces; view northeast.
ppcs551_l10	Aerial	View of agricultural terraces and fields in Paccareta, agricultural terraces in main valley, twin volcanoes, river canyon, unpaved roads, landslides, canals, and mountains; view southwest.
ppcs551_l18	Aerial	Paccareta, twin volcanoes, agricultural terraces, mountains, and river canyon; view northeast.
ppcs551_l22	Aerial	Town of Andagua, agricultural terraces, Quisguarani, lava fields, twin volcanoes, Puca Mauras Volcano, roads, and canals; view northeast.
ppcs551_l37	Aerial	Chachas and Chachas Lake, lava fields, volcanic cones, agricultural terraces, roads, Andagua River, and town of Chachas.
ppcs551_l47	Aerial	Quisguarani, town of Andagua, twin volcanoes, reservoirs, agricultural terraces, Paccareta, Tauca and rivers; view east.
ppcs551_l71	Aerial	Agricultural terraces, lava fields, lava cone and drainage.
ppcs551_l78	Aerial	Soporo, agricultural terraces, lava fields, paths, sedimentary rock exposure and volcanic cones; view west.
ppcs551_l92	Aerial	Coropuna peaks, roads up to pass, twin volcanoes, other volcanic cones, lava fields, agricultural terraces, town of Andagua, and Andagua River; view west.
ppcs551_l94	Aerial	Andagua River, Lake Andagua, lava fields, volcanic cones, drainages, agricultural terraces, Tauca, and Soporo; view west.
ppcs551_l95	Aerial	Similar to above but no view of Tauca.
ppcs551_l96	Aerial	Andagua River, canals, reservoir, twin volcanos, lava fields, volcanic cones, drainages, agricultural terraces, Tauca, and Soporo; view west.

Note: Image name refers to catalog number from the American Museum of Natural History Shippee-Johnson archives.

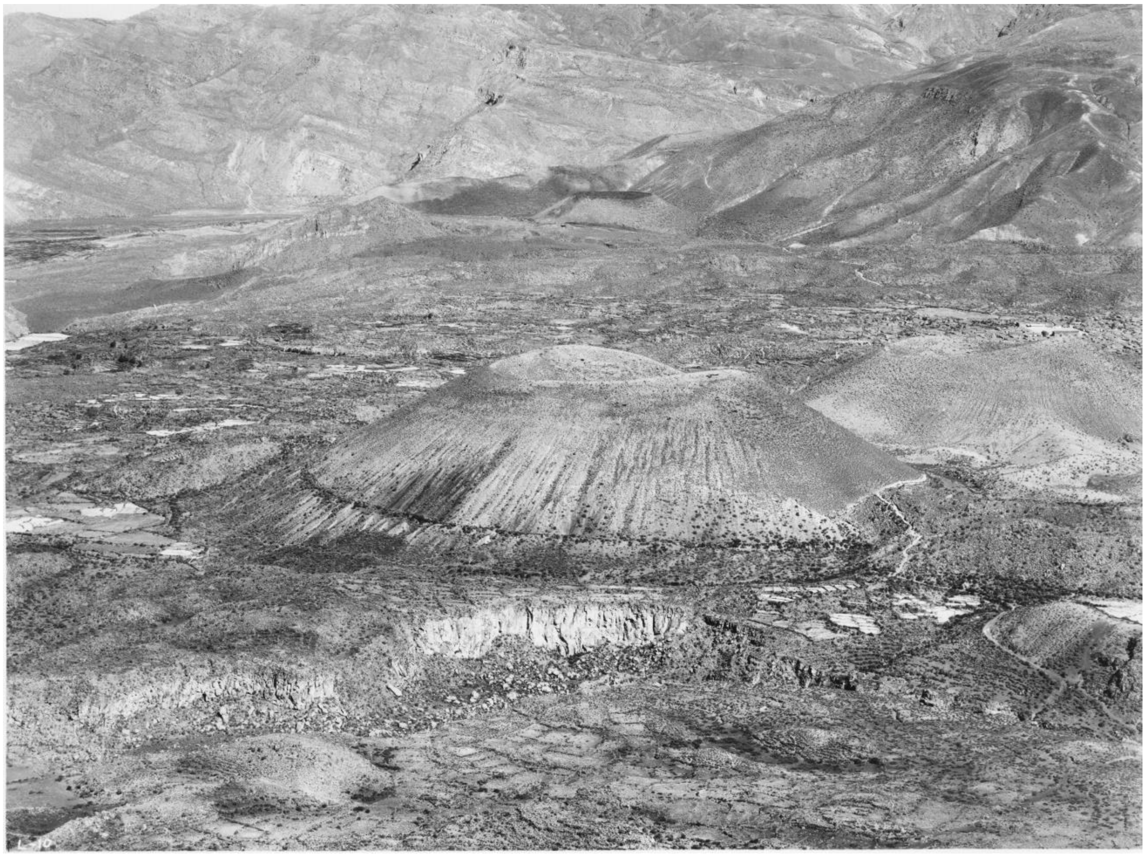


Figure B.1 An image used in analysis depicting abandoned agricultural terraces in Paccareta in the foreground and the main valley in the middle ground behind the volcano (Museum of Natural History Library, Image # ppcs551_l10).

Figure B.2 An image used in analysis depicting used agricultural terraces in the main valley on cliffs above the waterfalls of the Andagua River (American Museum of Natural History Library, Image # ppcs551_k95).

Table B.3 List of declassified images acquired for this project (USGS Earth Explorer 2021).

Satellite Mission Name (KH Designation)	Imagery Acquisition Date	File Name	Frame Number	Camera Direction	Download/ Purchase Date
CORONA (KH-4A)	6/30/1966	DS1034-2141DA035	35	Aft	4/1/2021^
---	---	DS1034-2141DA036	36	Aft	4/1/21^
---	---	DS1034-2141DA037	37	Aft	4/1/21^
---	---	DS1034-2141DA038	38	Aft	4/1/21^
---	---	DS1034-2141DF032	32	Forward	4/1/21^
---	---	DS1034-2141DF033	33	Forward	4/22/21*
---	---	DS1034-2141DF034	34	Forward	4/22/21*
HEXAGON (KH-9)	8/19/1977	D3C1213-200305A012	12	Aft	4/22/21*
---	---	D3C1213-200305A013	13	Aft	4/22/21*
---	---	D3C1213-200305F011	11	Forward	4/22/21*
---	---	D3C1213-200305F012	12	Forward	4/22/21*

Note: * refers to purchased images and ^ refers to downloaded images.

Classification Categories

Table B.4 Interior and exterior boundary descriptions for object-oriented analysis.

Characteristic	Interior Boundary Description	Exterior Boundary Description
Shape	Contiguous curvilinear or linear features parallel and perpendicular to the slope.	Contiguous curvilinear or linear features parallel and perpendicular to the slope.
Size	Typically, less than 3 meters in width and smaller in relation to external boundaries; length varies; possible shadow indicating height.	Typically, less than 3 meters in width, but larger in relation to internal boundaries; length varies; possible shadow indicating height.
Pattern	Dependent on terrace type; often in sequential parallel rows following the elevation profile with some perpendicular to the slope.	Dependent on land tenure, history, and terrace type; often in parallel rows perpendicular to and following elevation profile.
Tone	Depending on construction material, possible vegetation cover and the surrounding land cover.	Depending on construction material, possible vegetation cover and the surrounding land cover.
Texture	Same as above.	Same as above.
Shadows	Linear or curvilinear shadow on lower tread following wall in relation to sun aspect.	Linear or curvilinear shadow on lower tread following wall in relation to sun aspect.
Site	Hillslope, depression, valley floor, and drainage channel.	Hillslope, depression, valley floor, and drainage channel.
Association	Retaining wall of artificially leveled cropping or grazing surface.	Surrounding multiple artificially levelled cropping or grazing surfaces; possibly correlating with land tenure, irrigation canals, or paths.
Spatial Resolution	May be difficult to see if pixel size is greater than 3 meters.	May be difficult to see if pixel size is greater than 3 meters.

Note: Nine characteristics of object-oriented analysis from Lillesand and colleagues (2015, 59-65).

APPENDIX C: RESULTS

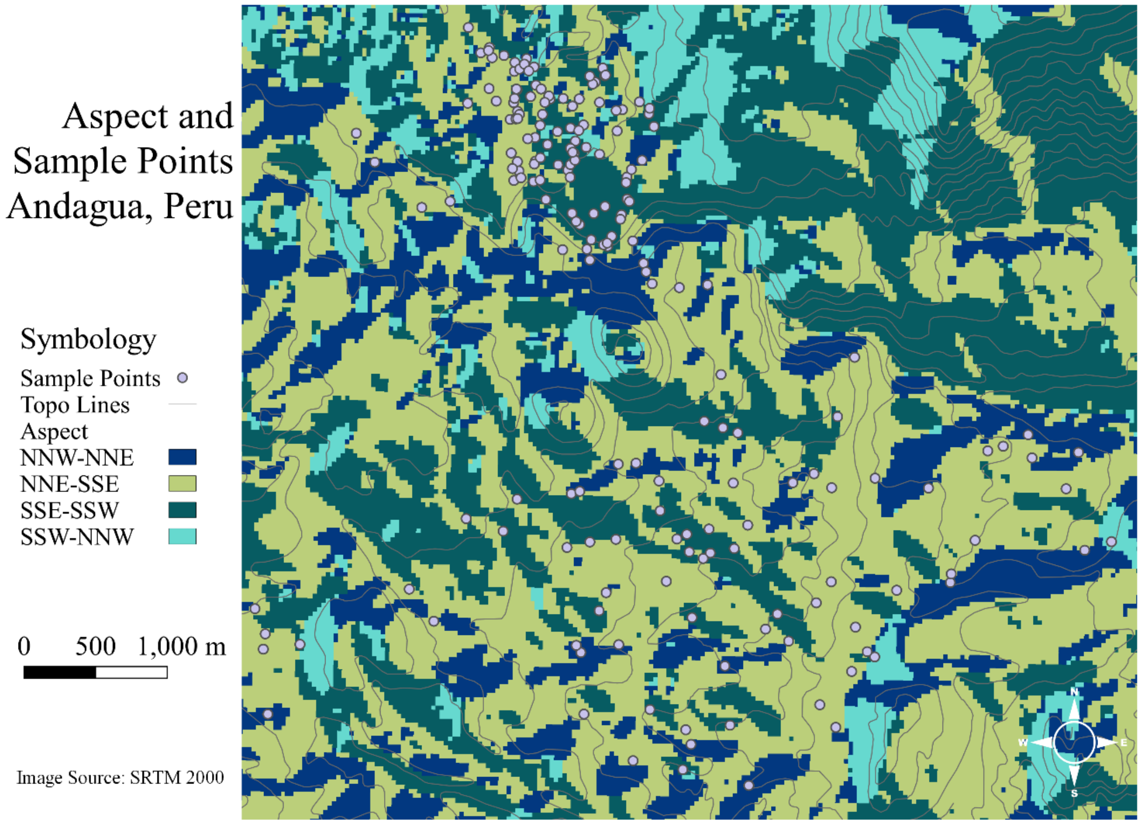
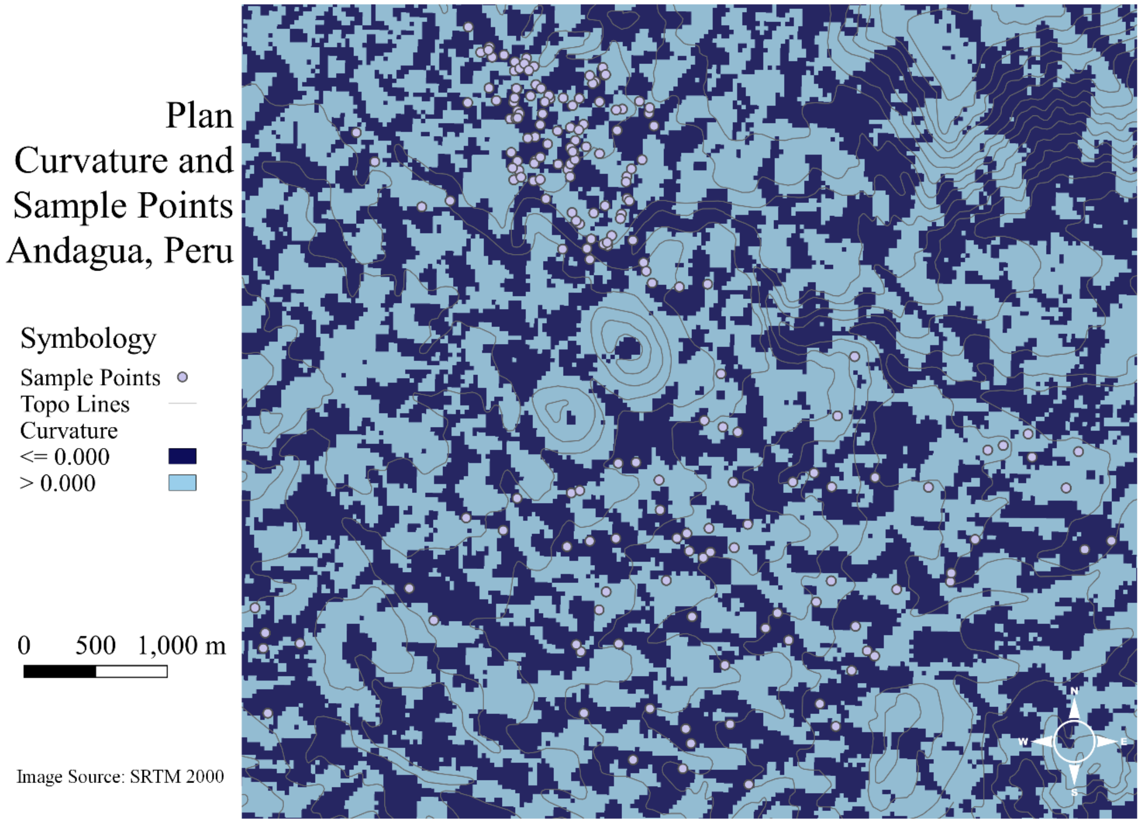
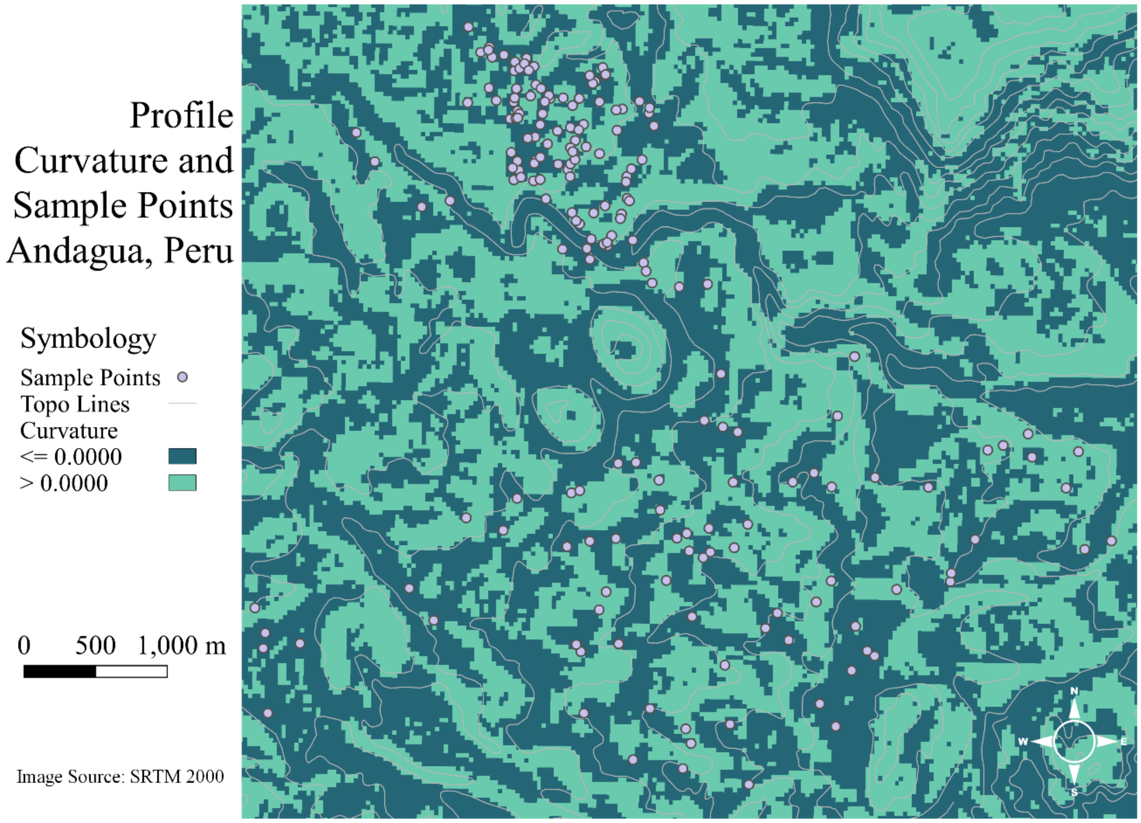


Figure C.1 Aspect of Andagua.



Note: A positive value is convex and negative value is concave.

Figure C.2 Plan curvature of Andagua.



Note: A positive value is concave and a negative value is convex.

Figure C.3 Profile curvature of Andagua.

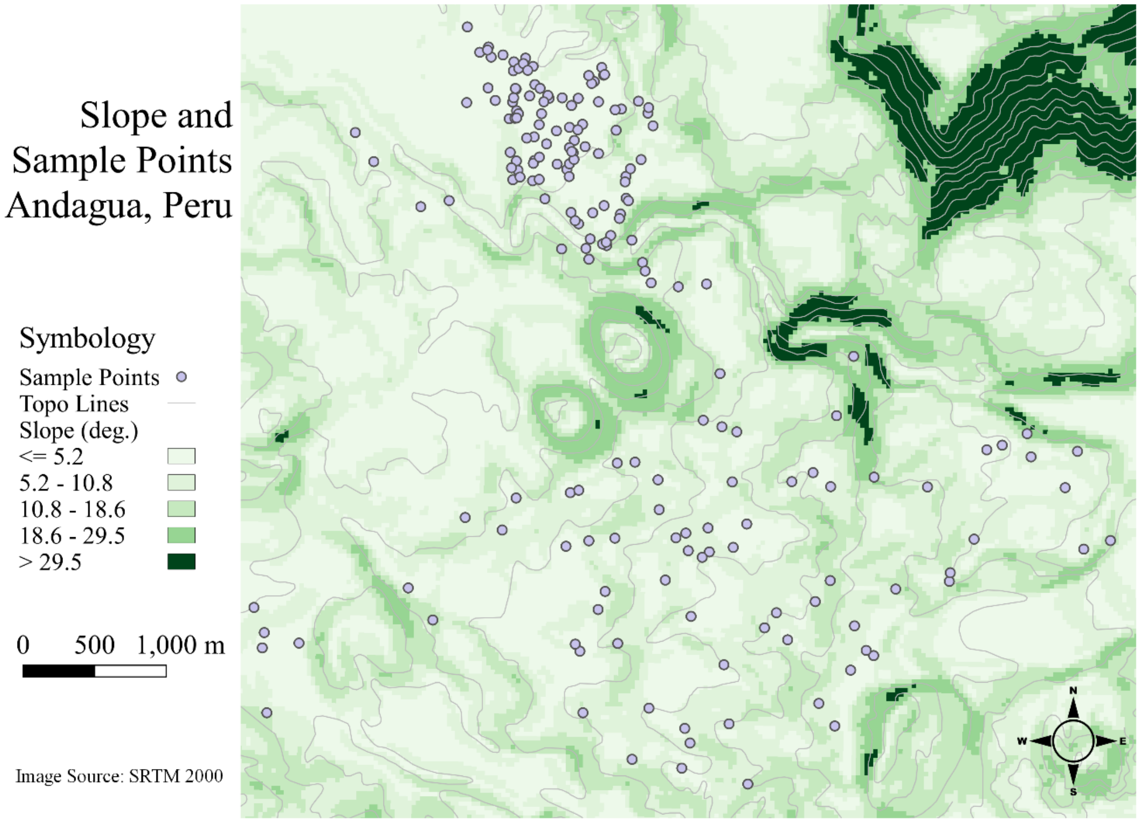


Figure C.4 Slope of Andagua.

Table C.1 Relation between internal boundary classification, breaks, internal patterns, slope, and terrace type for Paccareta and the main valley in 1977.

	Paccareta			Main Valley		
	Sequential	Segmented	NA	Sequential	Segmented	NA
Count	11	33	3	36	28	6
Internal Categories						
C, Coarse	4	5	0	8	8	0
C, Fine	0	0	0	3	1	0
C, Soft	0	0	0	3	3	0
A, Craggy	6	25	1	2	1	1
A, Fluffy	1	3	0	15	9	1
A, Bristly	0	0	0	5	6	0
NA	0	0	2	0	0	4
Breaks						
Breaks	5	25	1	21	15	1
Many Breaks	3	3	0	15	13	1
No Breaks	3	5	0	0	0	4
NA	0	0	2	0	0	0
Slope (°)						
Maximum	15.6	11.3	5.6	20.2	20.2	11.1
Mean	6.3	3.0	3.9	8.7	7.4	6.2
Minimum	1.0	0.9	1.3	2.4	2.1	3.5
SD	4.7	2.4	2.3	4.1	5.0	2.6
Terrace Type						
Broadfield	1	24	0	5	17	0
Lateral	4	0	0	22	4	2
Broadfield-Lat	6	2	0	8	3	0
NA	0	7	3	1	4	4

Note: "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "SD" refers to standard deviation; "NA" is not applicable.

Table C.2 Relation between internal boundary classification, breaks, internal patterns, slope, and terrace type for Paccareta and the main valley in 2010.

	Paccareta			Main Valley		
	Sequential	Segmented	NA	Sequential	Segmented	NA
Count	14	42	1	33	47	0
			Internal Categories			
C, Coarse	4	21	0	14	28	0
C, Fine	3	14	0	8	12	0
C, Soft	1	2	0	0	1	0
A, Craggy	5	2	0	5	2	0
A, Fluffy	0	0	0	4	2	0
A, Bristly	1	2	0	2	3	0
NA	1	1	0	0	0	0
			Breaks			
Breaks	7	8	0	11	15	0
Many Breaks	1	2	0	2	0	0
No Breaks	6	32	0	20	32	0
NA	0	0	1	0	0	0
			Slope (°)			
Maximum	15.6	8.4	4.8	20.2	20.2	0
Mean	6.1	2.9	4.8	8.1	7.7	0
Minimum	1.0	0.9	4.8	2.1	2.1	0
SD	4.3	2.0	Na	4.2	4.6	0
			Terrace Type			
Broadfield	3	34	0	3	25	0
Lateral	3	0	0	23	1	0
Broadfield-Lat	8	3	0	6	8	0
NA	0	5	1	1	13	0

Note: "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "SD" refers to standard deviation; "NA" is not applicable.

Table C.3 Relation between internal boundary classification, breaks, internal patterns, slope, and terrace type for Paccareta and the main valley in 2021.

	Paccareta			Main Valley		
	Sequential	Segmented	NA	Sequential	Segmented	NA
Count	15	46	0	32	46	0
Internal Categories						
C, Coarse	4	24	0	7	15	0
C, Fine	2	7	0	5	6	0
C, Soft	0	8	0	4	1	0
A, Craggy	5	2	0	3	5	0
A, Fluffy	3	2	0	9	15	0
A, Bristly	1	3	0	4	4	0
NA	0	0	0	0	0	0
Breaks						
Breaks	5	15	0	7	24	0
Many Breaks	2	2	0	2	0	0
No Breaks	8	28	0	23	21	0
NA	0	1	0	0	1	0
Slope (°)						
Maximum	10.3	15.6	0	20.2	20.2	0
Mean	5.2	3.3	0	8.3	7.2	0
Minimum	1.1	1.0	0	2.2	2.1	0
SD	3.1	2.9	0	4.7	4.0	0
Terrace Type						
Broadfield	5	36	0	3	21	0
Lateral	4	0	0	19	2	0
Broadfield-Lat	5	5	0	9	7	0
NA	1	5	0	1	16	0

Note: “C” internal boundary characteristic refers to contrasting features and “A” internal boundary characteristic refers to ambiguous features; “SD” refers to standard deviation; “NA” is not applicable.

Table C.4 Internal boundary and terrace characteristics for Paccareta and the main valley by year.

	Paccareta			Main Valley		
Year	1977 N=47	2010 N=57	2021 N=61	1977 N=70	2010 N=80	2021 N=78
Internal Boundary						
C, Coarse	9	25	28	16	42	22
C, Fine	0	17	9	4	20	11
C, Soft	0	3	8	6	1	5
A, Craggy	32	7	7	4	7	8
A, Fluffy	4	0	5	25	6	24
A, Bristly	0	3	4	11	3	8
NA	2	2	0	4	1	0
Breaks						
Breaks	31	15	20	37	26	31
Many Breaks	6	3	4	0	2	2
No Breaks	8	38	36	29	52	44
NA	2	1	1	4	0	1
Internal Pattern						
Sequential	11	14	15	35	33	32
Segmented	33	42	46	29	47	46
NA	3	1	0	6	0	0
Other Features						
Landslide	2	1	2	7	11	4
Path	0	1	3	2	1	1
Canal	5	8	4	4	4	4
Road	0	0	3	0	0	1
Structure	0	2	2	0	7	8
Archaeology Site	5	6	5	0	1	0
Other	5	14	17	12	15	17
NA	0	25	0	45	40	43
Land Cover						
Barren	14	6	7	0	2	3
Rock	1	1	1	0	0	0
Vegetation	31	45	48	45	56	54
Shrubby Vegetation	1	4	5	2	16	16
Shrubs	0	1	1	0	5	3
Dense Shrubs	0	0	0	0	1	2

Note: "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Table C.5 Relation between internal boundary classification, breaks, and internal patterns.

Internal Categories	Breaks Category: Breaks	Many Breaks	No Breaks	NA	Internal Patterns: Sequential	Segmented	NA
Paccareta, 1977							
C, Coarse	3	0	6	0	4	5	0
C, Fine	0	0	0	0	0	0	0
C, Soft	0	0	0	0	0	0	0
A, Craggy	25	5	2	0	6	25	1
A, Fluffy	3	1	0	0	1	3	0
A, Bristly	0	0	0	0	0	0	0
NA	0	0	0	2	0	0	2
Main valley, 1977							
C, Coarse	10	6	0	0	8	8	0
C, Fine	2	2	0	0	3	1	0
C, Soft	1	5	0	0	3	3	0
A, Craggy	4	0	0	0	2	1	1
A, Fluffy	10	15	0	0	15	9	1
A, Bristly	10	1	0	0	5	6	0
NA	0	0	4	0	0	0	4
Paccareta, 2010							
C, Coarse	5	0	20	0	4	21	0
C, Fine	4	0	13	0	3	14	0
C, Soft	0	0	3	0	1	2	0
A, Craggy	5	2	0	0	5	2	0
A, Fluffy	0	0	0	0	0	0	0
A, Bristly	1	1	1	0	1	2	0
NA	0	0	0	1	1	1	0
Main valley, 2010							
C, Coarse	13	0	29	0	14	28	0
C, Fine	2	0	18	0	8	12	0
C, Soft	0	0	1	0	0	1	0
A, Craggy	6	1	0	0	5	2	0
A, Fluffy	2	1	3	0	4	2	0
A, Bristly	3	0	1	0	2	3	0
NA	0	0	0	0	0	0	0
Paccareta, 2021							
C, Coarse	9	0	18	1	4	24	0
C, Fine	2	0	7	0	2	7	0
C, Soft	0	0	8	0	0	8	0
A, Craggy	4	3	0	0	5	2	0

Table C.5 cont.

Internal Categories	Breaks Category				Internal Patterns		
	Breaks	Many Breaks	No Breaks	NA	Sequential	Segmented	NA
Paccareta, 2021							
A, Fluffy	2	0	3	0	3	2	0
A, Bristly	3	1	0	0	1	3	0
NA	0	0	0	0	0	0	0
Main valley, 2021							
C, Coarse	10	1	11	0	7	15	0
C, Fine	1	0	10	0	5	6	0
C, Soft	1	0	4	0	4	1	0
A, Craggy	7	1	0	0	3	5	0
A, Fluffy	7	0	16	1	9	15	0
A, Bristly	4	0	3	0	4	4	0
NA	0	0	0	0	0	0	0

Note: “C” internal boundary characteristic refers to contrasting features and “A” internal boundary characteristic refers to ambiguous features; “NA” is not applicable.

Table C.6 Transformations to ensure linearity of log-odds of variables for effect-size logistic regression for 1977.

Variable	Paccareta	Main Valley
Slope (°)	Q1: < 1.81	Q1: < 4.707652
	Q2: >= 1.81 & < 2.30	Q2: >= 4.707652 & < 6.795790
	Q3: >= 2.30 & < 4.81	Q3: >= 6.795790 & < 10.126275
	Q4: >= 4.81	Q4: >= 10.126275
Aspect (°)	C1: X = 0 if <= 157 & > 189	Q1: < 56.63267
	C2: X = 1 if >157 & <= 189	Q2: >= 56.63267 & < 97.09770
		Q3: >= 97.09770 & < 128.21950
		Q4: >= 128.21950
Elevation (m)	C1: X = 0 if >= 3607.987	Q1: < 3419.792
	C2: X = 1 if < 3607.987	Q2: >= 3419.792 & < 3507.002
		Q3: >= 3507.002 & < 3570.961
		Q4: >= 3570.961
Longitude (m)	C1: x = 0 if >= 784009.5	Q1: < 784116.4
	C2: x = 1 if < 784009.5	Q2: >= 784116.4 & < 784913.1
		Q3: >= 784913.1 & < 785745.6
		Q4: >= 785745.6

Table C.6 cont.

Variable	Paccareta	Main Valley
Latitude (m)	C1: < 8287906 C2: >= 8287986 & < 8288394 C3: >= 8288394	Q1: < 8284626 Q2: >= 8284626 & < 8285260 Q3: >= 8285260 & < 8285754 Q4: >= 8285754
Plan Curvature	C1: x = 0 if >= 0 C2: x=1 if < 0	C1: < -0.00522790 C2: >= -0.00522790 & < 0.00305895 C3: >= 0.00305895
Profile Curvature	Q1: x = 0 if <= 0 Q2: x = 1 if > 0	C1: < -0.000662775 C2: >= -0.000662775 & < 0.000189525 C3: >= 0.000189525
Distance to Nearest Road (m)	None	Q1: < 665.96 Q2: >= 665.96 & < 1177.34 Q3: >= 1177.34 & < 2042 Q3: >= 2042
Distance to Nearest Path (m)	Q1: < 141.33 Q2: >= 141.33 & < 253.37 Q3: >= 253.37 & < 467.25 Q4: >= 467.25	C1: < 85.61 C2: >= 85.61 & < 180.0 C3: >= 180.0
Distance to Town (m)	C1: x = 0 if >= 3176.4 C2: x = 1 if < 3176.4	Q1: < 1334.3402 Q2: >= 1334.3402 & < 1984.4350 Q3: >= 1984.4350 & < 2596.2207 Q4: >= 2596.2207

Note: Q transformation categories refers to quantiles and C transformation categories refers to non-quantile transformations that relate to other patterns in the data.

Table C.7 Results from effect-size logistic regression modelling for sampled terraces in Paccareta in 1977.

Variable	Coeffecients	Pseudo R^2 (McF/ VZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = -18.57 2Q = 17.47 3Q = 16.17 4Q = 19.26	0.34/ 0.95	43.66	35.66	Yes ***
Aspect	Intercept = -1.46* C2 = 1.27 `	0.05/ 0.08	55.05	51.05	No `
Longitude	Intercept = -0.5108 C2 = -1.4351 `	0.08/ 0.14	53.84	49.84	Yes*
Latitude	Intercept = 0.6931 C2 = -3.0910** C3 = -2.3026 *	0.26/ 0.33	45.86	39.86	Yes ***
Elevation	Intercept = -1.8245 *** C2 = 2.1610 **	0.16/ 0.21	49.31	45.31	Yes **
Profile Curvature	Intercept = 1.204 ** C2 = 0.223	0.002/ 0.004	57.87	53.87	No
Plan Curvature	Intercept = -0.452 C2 = -1.158 `	0.05/ 0.09	55.09	51.09	No `
Distance to Nearest Road	Intercept = 14.56 ** Distance = -0.006 **	0.26/ 0.30	44.17	40.17	Yes ***
Distance to Nearest Path	Intercept = -1.609 * Q2 = 1.609 ` Q3 = -1.249e-15 Q4 = -2.919e-15	0.09/ 0.13	57.08	49.08	No
Distance to Town	Intercept = -2.0794 *** C2 = 2.7726 ***	0.25/ 0.42	44.39	40.39	Yes ***

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 53.98 on 47 degrees of freedom and residual deviance is the null deviance degrees of freedom minus the number of equations coeffecients (not including the intercept. "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.8 Results from effect-size logistic regression modelling for sampled terraces in the main valley in 1977.

Variable	Coeffecients	Pseudo R^2 (McF/ VZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = 0.1178 Q2 = 0.9808 Q3 = 0.8377 Q4 = 0.4884	0.03/ 0.04	92.85	84.85	No
Aspect	Intercept = 0.8755 Q2 = -0.7577 Q3 = -0.2693 Q4 = 0.3032	0.03/ 0.06	92.73	84.73	No
Longitude	Intercept = 0.69315 Q2 = -0.44183 Q3 = -0.08701 Q4 = 0.48551	0.02/ 0.03	93.47	85.47	No
Latitude	Intercept = 0.88 Q2 = 1.23 ` Q3 = -1.12 e-16 Q4 = 0.67	0.08/ 0.13	88.07	80.07	No `
Elevation	Intercept = 1.18 * Q2 = -1.0609 Q3 = -0.3032 Q4 = -0.5725	0.03/ 0.04	92.73	84.73	No
Profile Curvature	Intercept = 0.3567 C2 = 0.5188 C3 = 0.2495	0.008/ 0.01	92.30	86.30	No
Plan Curvature	Intercept = 0.3567 C2 = 0.2495 C3 = 0.8220	0.01/ 0.03	91.73	85.73	No
Distance to Nearest Road	Intercept = 0.1178 Q2 = 0.7577 Q3 = 0.4884 Q4 = 1.0609	0.03/ 0.04	92.73	84.73	No
Distance to Nearest Path	Intercept = 0.3567 C2 = 0.8220 C3 = 0.5188	0.02/ 0.04	91.22	85.22	No

Table C.8 cont.

Variable	Coeffecients	Pseudo R^2 (McF/ VZ)	AIC	Residual Deviance	Sig Different from No Model?
Distance to Town	Intercept = 0.12 Q2 = 1.061 Q3 = -1.723e-15 Q4 = 1.423`	0.06/ 0.11	89.41	81.41	No

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of of 87.021 on 67 degrees of freedom and residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.9 Transformations to ensure linearity of log-odds of variables for 2010.

Variable	Paccareta	Main Valley
Slope (°)	C1: x = 0 if >= 5.406925 C2: x = 1 if < 5.406925	Q1: < 4.453137 Q2: >= 4.453137 & < 7.163870 Q3: >= 7.163870 & < 10.253625 Q4: >= 10.253625
Aspect (°)	C1: x=0 if <= 113.9263 & > 147.4505 C2: x = 1 if > 113.9263 & <= 147.4505	C1: x = 0 if <= 113.9263 or > 147.4505 C2: x = 1 if > 113.9263 & < 147.4505
Elevation (m)	Q1: < 3615.923 Q2: >= 3615.923 & < 3627.292 Q3: >= 3627.292 & < 3570.96 Q4: >= 3631.759	C1: < 3430.779 C2: >= 3430.779 & < 3516.790 C3: >= 3582.378
Longitude (m)	Q1: < 783729.3 Q2: >= 783729.3 & < 783980.5 Q3: >= 783980.5 & < 784211.1 Q4: >= 784211.1	C1: < 783729.3 C2: >= 783729.3 & < 783980.5 C3: >= 783980.5
Latitude (m)	Q1: < 8287931 Q2: >= 8287931 & < 8288190 Q3: >= 8288190 & < 8288391 Q4: >= 8288391	Q1: < 8284645 Q2: >= 8284645 & < 8285266 Q3: >= 8285266 & < 8285764 Q4: >= 8285764

Table C.9 cont.

Variable	Paccareta	Main Valley
Plan Curvature	Q1: < -0.005941550 Q2: >= -0.005941550 & < -0.000877300 Q3: >= -0.000877300 & < 0.002160275l Q4: >= 0.002160275	C1: < -0.001669750 C2: >= -0.001669750 & < 0.002283050 C3: >= 0.002283050
Profile Curvature	C1: < -0.000243475 C2: >= -0.000243475 & < 0.000200825 C3: >= 0.000200825	Q1: < -0.000630825 Q2: >= -0.000630825 & < -0.000191100 Q3: >= -0.000191100 & < 0.000162350 Q4: >= 0.000162350
Distance to Nearest Road (m)	C1: < 95.53470 C2: >= 95.53470 & < 252.25646 C3: >= 252.25646	C1: < 95.53470 C2: >= 95.53470 & < 252.25646 C3: >= 252.25646
Distance to Nearest Path (m)	No transformations	C1: < 41.175539 C2: >= 41.175539 & < 136.033664 C3: >= 136.033664
Distance to Town (m)	C1: < 3213.454 C2: >= 3213.454 & < 3667.763 C3: > 3667.763	C1: x = 0 if >= 3454.341 C2: x = 1 if < 3454.341

Note: Q transformation categories refers to quantiles and C transformation categories refers to non-quantile transformations that relate to other patterns in the data.

Table C.10 Results from effect-size logistic regression modelling for sampled terraces in the Paccareta in 2010.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = 0.4055 C2 = 1.0704	0.04/ 0.06	65.51	61.51	No
Aspect	Intercept = 0.8690 ** C2 = 1.6959	0.05/ 0.11	64.62	60.62	No`
Longitude	Intercept = 1.8718 * Q2 = 16.6943 Q3 = -0.9555 Q4 = -2.0053 *	0.23/ 0.39	57.26	49.26	Yes **
Latitude	Intercept = 1.0116 ` Q2 = 0.2877 Q3 = -0.2007 Q4 = 0.4547	0.01/ 0.92	71.44	63.44	No
Elevation	Intercept = 0.1335 Q2 = 2.4314 * Q3 = 0.7828 Q4 = 1.7383	0.12/ 0.22	64.46	56.46	No`
Profile Curvature	Intercept = 2.639 * C2 = -1.723 C3 = -1.946 `	0.06/ 0.13	65.95	59.95	No
Plan Curvature	Intercept = 1.3863 Q2 = 1.1787 Q3 = -0.4700 Q4 = -0.9808	0.08/ 0.15	67.16	59.16	No
Distance to Nearest Road	Intercept = 18.57 C2 = -17.27 C3 = -18.70	0.22/ 0.38	55.82	49.82	Yes ***
Distance to Nearest Path	Intercept = 0.352812 Distance = 0.003791 `	0.06/ 0.13	64.02	60.02	Yes *
Distance to Town	Intercept = 1.386 * C2 = -0.47 C3 = 8.108e-16	0.01/ 0.02	69.53	63.53	No

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 64.109 on 57 degrees of freedom and residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.11 Results from effect-size logistic regression modelling for sampled terraces in the main valley in 2010.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Devianc e	Sig Different from No Model?
Slope	Intercept = 2.1972 ** Q2 = 0.6931 Q3 = -0.8755 Q4 = -1.9966 *	0.14/ 0.24	75.92	67.92	Yes*
Aspect	Intercept = 1.2528 *** C2 = 0.6190	0.008/ 0.02	82.52	78.52	No
Longitude	Intercept = 1.0986 * C2 = 0.5754 C3 = 0.2559	0.006/ 0.01	84.65	78.65	No
Latitude	Intercept = 1.3863 * Q2 = -0.6131 Q3 = 1.5041 Q4 = -0.2877	0.07/ 0.16	82.04	74.04	No
Elevation	Intercept = 1.3863 * C2 = 0.2877 C3 = -0.1823	0.005/ 0.01	84.73	78.73	No
Profile Curvature	Intercept = 1.0986 * Q2 = -0.3254 Q3 = 0.5754 Q4 = 1.0986	0.04/ 0.08	83.77	75.77	No
Plan Curvature	Intercept = 1.0647 ** C2 = 0.2570 C3 = 1.1325	0.03/ 0.06	82.96	76.96	No
Distance to Nearest Road	Intercept = 1.7346 * C2 = -0.4128 C3 = -0.6360	0.008/ 0.02	84.52	78.52	No
Distance to Nearest Path	Intercept = 1.3863 * C2 = 0.7538 C3 = -0.9808	0.08/ 0.13	78.51	72.51	Yes*
Distance to Town	Intercept = 0.8109 * Q2 = 1.3581 *	0.07/ 0.12	77.94	73.94	Yes*

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 79.159 on 77 degrees of freedom and residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.12 Transformations to ensure linearity of log-odds of variables for 2021.

Variable	Paccareta	Main Valley
Slope (°)	Q1: < 1.752640 Q2: >= 1.752640 & < 2.343100 Q3: >= 2.343100 & < 5.556290 Q4: >= 5.556290	Q1: < 4.33121 Q2: >= 4.33121 & < 6.90155 Q3: >= 6.90155 & < 9.97520 Q4: >= 9.97520
Aspect (°)	Q1: < 108.3080 Q2: >= 108.3080 & < 142.5080 Q3: >= 142.5080 & < 178.7720 Q4: >= 178.7720	Q1: < 62.53532 Q2: >= 62.53532 & < 94.12795 Q3: >= 94.12795 & < 132.43300 Q4: >= 132.43300
Elevation (m)	Q1: < 3615.602 C2: >= 3615.602 & < 3627.409 Q3: >= 3582.378 & < 3633.847 Q4: >= 3633.847	Q1: < 3430.779 Q2: >= 3430.779 & < 3516.790 Q3: >= 3516.790 & < 3595.931 Q4: >= 3595.931
Longitude (m)	C1: < 783681.7 C2: >= 783681.7 & <7 84212.6 C3: >= 784212.6	Q1: < 784047.6 Q2: >= 784047.6 & < 784791.0 Q3: >= 784791.0 & < 785528.6 Q4: >= 785528.6
Latitude (m)	Q1: < 8288146 Q2: >= 8288146 & < 8288391 Q3: >= 8288391	Q1: < 8284630 Q2: >= 8284630 & < 8285282 Q3: >= 8285282 & < 8285792 Q4: >= 8285792
Plan Curvature	C1: < -0.0010421 C2: >= -0.0010421 & < 0.0015941 C3: >= 0.0015941	Q1: < -0.00599922 Q2: >= -0.005999225 & < -0.001815350 Q3: >= -0.001815350 & < 0.00218365 Q4: >= 0.002183650
Profile Curvature	Q1: < -0.0002750 Q2: >= -0.0002750 & < -0.0000322 Q3: >= -0.0000322 & < 0.0001381 Q4: >= 0.0001381	Q1: < -0.000630825 Q2: >= -0.000630825 & < -0.000208850 Q3: >= -0.000208850 & < 0.000112825 Q4: >= 0.000112825
Distance to Nearest Road (m)	C1: < 75.27474 C2: >= 75.27474 & < 141.67080 C3: >= 141.67080	C1: x = 0 if >= 167.27671 C2: x = 1 if < 167.27671

Table C.12 cont.

Variable	Paccareta	Main Valley
Distance to Nearest Path (m)	C1: < 136.77613 C2: >= 136.77613 & < 389.17762 C3: >= 389.17762	Q1: < 44.182360 Q2: >= 44.182360 & < 78.311069 Q3: >= 78.311069 & < 146.539859 Q4: >= 146.539859
Distance to Town (m)	C1: x = 0 if >= 3673.122 C2: x = 1 if < 3673.122	C1:< 35.94479 C2: >= 35.94479 & < 44.23002 C3: >= 44.23002

Note: Q transformation categories refers to quantiles and C transformation categories refers to non-quantile transformations that relate to other patterns in the data.

Table C.13 Results from effect-size logistic regression modelling for sampled terraces in the Paccareta in 2021.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = 1.099 ` Q2 = 17.47 Q3 = -0.4055 Q4 = -1.813e-15	0.13/ 0.94	63.09	55.09	Yes *
Aspect	Intercept = 1.9459 * Q2 = -1.2528 Q3 = 0.6190 Q4 = -1.1575	0.08/ 0.16	66.23	58.23	No
Longitude	Intercept = 18.57 C2 = -17.38 C3 = -18.16	0.16/ 0.95	58.79	52.79	Yes **
Latitude	Intercept = 1.38629 ** C2 = -0.37469 C3 = 0.08004	0.005/ 0.009	68.86	62.86	No
Elevation	Intercept = 0.5108 Q2 = 1.2809 Q3 = 0.5878 Q4 = 2.1282 `	0.08/ 0.16	66.00	58.00	No
Profile Curvature	Intercept =2.773 ** Q2 = -1.473 Q3 = -2.079 ` Q4 = -1.761	.07/ 0.17	66.65	58.65	No

Table C.13 cont.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Plan Curvature	Intercept = 2.6741 *** C2 = -2.2687 * C3 = -1.9810 *	0.14/ 0.26	60.12	54.12	Yes *
Distance to Nearest Road	Intercept = 1.3863 * C2 = 1.2528 C3 = -0.4925	0.06/ 0.13	65.71	59.71	No
Distance to Nearest Path	Intercept = 0.7885 C2 = 0.5553 C3 =1.1575	0.03/ 0.05	67.50	61.50	No
Distance to Town	Intercept =1.0116 ` C2 = 0.4021	0.005/ 0.009	66.87	62.87	No

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 63.203 on 60 degrees of freedom and residual deviance degrees of freedom is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.14 Results from effect-size logistic regression modelling for sampled terraces in the main valley in 2021.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = 0.6190 Q2 = 17.9470 Q3 = 1.5210 ` Q4 = -0.4184	0.21/ 0.95	74.21	66.21	Yes ***
Aspect	Intercept = 1.3863 * Q2 = -0.6131 Q3 = -0.3567 Q4 = 0.3483	0.02/ 0.04	90.52	82.52	No
Longitude	Intercept = 0.8473 ` Q2 = 0.8267 Q3 = 0.4745 Q4 = 0.2513	0.01/ 0.03	91.06	83.06	No

Table C.14 cont.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Latitude	Intercept = 2.19722 ** Q2 = -1.16761 Q3 = -0.05716 Q4 = -1.99655 *	0.11/ 0.18	83.22	75.22	Yes *
Elevation	Intercept = 1.0986 * Q2 = 1.0415 Q3 = 0.2231 Q4 = -0.4796	0.04/ 0.08	88.74	80.74	No
Profile Curvature	Intercept = 1.3863 * Q2 = 0.2877 Q3 = -0.6131 Q4 = -0.2877	0.02/ 0.03	90.78	82.78	No
Plan Curvature	Intercept = 1.7346 ** Q2 = -0.4128 Q3 = -0.9614 Q4 = -0.6360	0.02/ 0.04	90.66	82.66	No
Distance to Nearest Road	Intercept = 1.0647 ** C2 = 0.2898	0.003/ 0.006	87.98	83.98	No
Distance to Nearest Path	Intercept = 1.73460 ** Q2 = -0.70498 Q3 = -0.06062 Q4 = -1.11556	0.04/ 0.06	89.28	81.28	No
Distance to Town	Intercept = 2.9444 ** C2 = -0.8044 C3 = -2.4744 *	0.14/ 0.26	78.70	72.70	Yes **

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 84.272 on 77 degrees of freedom and residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.15 Transformations to ensure linearity of log-odds of variables for 2021.

Variable	1977	2010	2021
Slope (°)	Q1: < 2.380170 Q2: >= 2.380170 & < 5.151890 Q3: >= 5.151890 & < 8.991590 Q4: >= 8.991590	Q1: < 2.308570 Q2: >=2.308570 & < 5.133230 Q3: >= 5.133230 & < 8.254535 Q4: >=8.254535	Q1: < 2.361150 Q2: >= 2.361150 & > 4.780400 Q3: >= 4.780400 & < 8.142010 Q4: >= 8.142010
Aspect (°)	C1: < 122.3070 C2: >= 122.3070 & < 164.3400 C3: >= 64.3400	Q1: < 80.5101 Q2: >= 80.5101 & < 118.8540 Q3: >= 118.8540 & < 159.9442 Q4: > 159.9442	Q1: < 82.77995 Q2: >= 82.77995 & < 116.88700 Q3: >= 116.88700 & < 156.20400 Q4: >= 156.20400
Elevation (m)	C1: < 3492.845 C2: >= 3492.845 & < 3590.107 C3: >= 3590.107	C1: < 3600.583 C2: >= 3600.583 & < 3629.299 C3: >= 3629.299	Q1: < 3507.002 Q2: >= 3507.002 & < 3600.413 Q3: >= 3600.413 & < 3630.561 Q4: >= 3630.561
Longitude (m)	C1: < 784240.3 C2: >= 784240.3 & < 785040.5 C3: >= 785040.5	Q1: < 783781.5 Q2: >= 783781.5 & < 784216.3 Q3: >= 784216.3 & < 784911.2 Q4: >= 784911.2	Q1: < 783730.8 Q2: <= 783730.8 & < 784183.9 Q3: >= 784183.9 & < 784870.2 Q4: >= 784870.2
Latitude (m)	Q1: < 8285045 Q2: >= 8285045 & < 8286121 Q3: >= 8286121 & < 8288009 Q4: >= 8288009	C1: < 8285049 C2: >= 8285049 & < 8288052 C3: >= 8288052	Q1: < 8285155 Q2: <= 8285155 & < 8287118 Q3: >= 8287118 & < 8288087 Q4: >= 8288087
Plan Curvature	Q1: < -0.00050265 Q2: >= -0.00050265 & < -0.00010690 Q3: >= -0.00010690 & < 0.00018220 Q4: >= 0.00018220	C1: < -0.006043775 C2: >= -0.006043775 & < -0.001330650 C3: >= -0.001330650	Q1: < -00051640 Q2: >= -00051640 & < -0.00012010 Q3: >= -0.00012010 & < 0.00012975 Q4: >= 0.00012975

Table C.15 cont.

Variable	1977	2010	2021
Profile Curvature	Q1: < -0.0051749 Q2: >= -0.0051749 & < -0.0016551 Q3: >= -0.0016551 & < 0.0024715 Q4: >= 0.0024715	Q1: < -0.000509625 Q2: >= -0.000509625 & < -0.000119000 Q3: >= -0.000119000 & < 0.000189525 Q4: >= 0.000189525	Q1: < -0.0055845 Q2: >= -0.0055845 & < -0.0016551 Q3: >= -0.0016551 & < 0.0021126 Q4: < 0.0021126
Distance to Nearest Road (m)	C1: <2263.60539 C2: >= 2263.60539 & < 2913.23307 C3: >= 2913.23307	C1: > 139.06030 C2: < 139.06030	Q1: < 77.64112 Q2: >= 77.64112 & < 156.69604 Q3: >= 156.69604 & < 275.89882 Q4: >= 275.89882
Distance to Nearest Path (m)	Q1: < 65.5847370 Q2: >=65.5847370 & < 141.6708028 Q3: >= 141.6708028 & < 345.5752782 Q4: >= 345.5752782	Q1: < 51.370381 Q2: >= 51.370381 & < 116.088565 Q3: >= 116.088565 & < 208.660692 Q4: >= 208.660692	C1: < 62.088731 C2: >= 62.088731
Distance to Town (m)	Q1: < 1832.7672 Q2: >= 1832.7672 & < 2769.1806 Q3: >= 2769.1806 & < 3394.9670 Q4: >= 3394.9670	Q1: < 1723.4187 Q2: >= 1723.4187 & < 2742.8299 Q3: >= 2742.8299 & < 3402.2992 Q4: >= 3402.2992	C1: < 1862.7168 C2: >= 1862.7168

Note: Q transformation categories refers to quantiles and C transformation categories refers to non-quantile transformations that relate to other patterns in the data.

Table C.16 Results from effect-size logistic regression modelling for all sampled terraces in 1977.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = -1.8326 *** Q2 = 1.6249 * Q3 = 2.7489 *** Q4 = 2.6311 ***	0.17/ 0.27	140.59	132.59	Yes ***
Aspect	Intercept = 0.1382 C2 = -0.4258 C3 = -0.2071	0.005/ 9.009	164.54	158.54	No
Longitude	Intercept = -0.6152 * C2 =0.9635 * C3 = 1.4137 **	0.06/ 0.10	155.13	149.13	Yes **
Latitude	Intercept = 0.2076 Q2 = 0.7574 Q3 = 0.2277 Q4 = -2.3671 ***	0.18/ 0.31	138.86	130.86	Yes ***
Elevation	Intercept = 0.8557 ** C2 = -1.8207 *** C3 = -1.6542 ***	0.12/ 0.19	145.55	139.55	Yes ***
Distance to Nearest Road	Intercept = 0.6419 * C2 = -0.6419 C3 = -2.2105 ***	0.12/ 0.20	146.20	140.20	Yes ***
Distance to Nearest Path	Intercept = 0.06899 Q2 = 0.57286 Q3 = -0.35667 Q4 = -0.56147	0.03/ 0.05	162.27	154.27	No
Profile Curvature	Intercept = 0.6419 * Q2 = -1.1343 Q3 = -0.9295 Q4 = -0.5729	0.03/ 0.05	162.27	154.27	No
Plan Curvature	Intercept = -0.6419 Q2 = 0.8495 Q3 = 0.4988 Q4 = 1.1343 *	0.03/ 0.05	162.42	154.42	No

Table C.16 cont.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Distance to Town	Intercept = 0.3483 Q2 = 0.6168 Q3 = -0.4914 Q4 = -1.6920 **	0.11/ 0.18	149.74	141.74	Yes ***

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 159.42 on 114 degrees of freedom residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). “McF” refers to McFadden’s Pseudo R^2, and “MZ” refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.17 Results from effect-size logistic regression modelling for all sampled terraces in 2010.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = 2.0149 *** Q2 = -0.4745 Q3 = -0.9933 Q4 = -1.2773	0.04/ 0.08	146.42	138.42	No
Aspect	Intercept = 1.0217 ** Q2 = 0.1570 Q3 = 0.7362 Q4 = 0.1570	0.01/ 0.02	149.89	141.89	No
Longitude	Intercept = 1.3499 ** Q2 = 0.1905 Q3 = -0.3283 Q4 = -0.1713	0.006/ 0.01	150.66	142.66	No
Latitude	Intercept = 1.02165 ** C2 = 0.51879 C3 = -0.04082	0.01/ 0.02	147.35	141.35	No
Elevation	Intercept = 1.5404 *** C2 = -0.3618 C3 = -0.6650	0.01/ 0.02	147.67	141.67	No
Distance to Nearest Road	Intercept = 0.9232 *** C2 = 2.5733 *	0.09/ 0.27	134.81	130.81	Yes***

Table C.17 cont.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Distance to Nearest Path	Intercept = 1.0217 ** Q2 = 0.5188 Q3 = 0.3283 Q4 = 0.1570	0.006/ 0.01	150.66	142.66	No
Profile Curvature	Intercept = 1.1787 ** Q2 = 0.3618 Q3 = -0.3032 Q4 = 0.3618	0.01/ 0.02	149.67	141.67	No
Plan Curvature	Intercept = 1.179 ** C2 = 0.3618 C3 = -1.869e-15	0.004/ 0.007	148.99	142.99	No
Distance to Town	Intercept = 2.3354 *** Q2 = -1.1567 Q3 = -1.5978 * Q4 = -1.1567	0.04/ 0.10	145.3	137.30	No

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 143.52 on 135 degrees of freedom residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.18 Results from effect-size logistic regression modelling for all sampled terraces in 2021.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Slope	Intercept = 1.7918 *** Q2 = -1.0116 ` Q3 = 0.5436 Q4 = -1.1412 `	0.07/ 0.13	145.58	137.58	Yes *
Aspect	Intercept = 0.9163 * Q2 = 0.4336 Q3 = 0.8755 Q4 = 0.1446	0.02/ 0.03	153.06	145.06	No

Table C.18 cont.

Variable	Coeffecients	Pseudo R^2 (McF/ MZ)	AIC	Residual Deviance	Sig Different from No Model?
Longitude	Intercept = 1.7918 *** Q2 = -0.2513 Q3 = -1.0116 ` Q4 = -0.7309	0.02/ 0.05	151.87	143.87	No
Latitude	Intercept = 1.3863 ** Q2 = 0.1542 Q3 = -0.4700 Q4 = -0.1699	0.01/ 0.02	154.22	146.22	No
Elevation	Intercept = 1.3863 * Q2 = 0.1542 Q3 = -0.4700 Q4 = -0.1699	0.01/02	154.22	146.22	No
Distance to Nearest Road	Intercept = 1.5755 *** Q2 = 0.4394 Q3 = -0.6592 Q4 = -0.7954	0.04/ 0.07	150.15	142.15	No
Distance to Nearest Path	Intercept = 1.3157 *** C2 = -0.2548	0.002/ 0.004	151.23	147.23	No
Profile Curvature	Intercept = 1.5755 *** Q2 = 0.2162 Q3 = -0.8379 Q4 = -0.5147	0.03/ 0.05	151.49	143.49	No
Plan Curvature	Intercept = 151.49 *** Q2 = -0.4722 Q3 = -1.3101 * Q4 = -1.1314 `	0.04/ 0.08	149.63	141.63	No
Distance to Town	Intercept = 0.9985 *** Q2 = 1.3686 *	0.04/ 0.10	145.63	141.63	Yes *

Note: ` = <0.1, * = <0.05, ** = <0.01, *** = <0001 p-value. All formulas have a null deviance of 147.54 on 138 degrees of freedom residual deviance is the null deviance degrees of freedom minus the number of equation coeffecients (not including the intercept). "McF" refers to McFadden's Pseudo R^2, and "MZ" refers to the McKelvey and Zavoina Pseudo R^2 (Signorell 2022). The significant difference from no model has a confidence interval of 95%.

Table C.19 Results for model iterations with all variables for predictive logistic regression for whole valley in 1977 showing only significant coefficients.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Significant Coefficients	Slope 19.33* Aspect 1.66* PlX 17.23 * DT 0.077 * DP 401-600 34.41* DP 601-800 40.18*	Z -0.023 *	Y 0.005* Z -0.01* Slope 14.96** Aspect 1.24* DT 0.40* DP 51-100 6.91 DP 101-200 11.65* DP 410-600 18.71* DP601-800 12.69*	Slope 8.39* DP401-600 7.61* DP601-800 8.59*	Slope 8.02* DT 0.33** DP401-600 12.25* DP601-800 13.56*	IPQ 4.26* PrSCC 8.13* DT 0.24* DP51-100 5.99* DP101-200 12.12* DP201-400 8.66* DP401-600 14.45* DP601-800 14.44*	Slope 5.34* DT 0.14*
Null Deviance	120.32	120.04	120.32	120.32	120.32	120.50	119.68
Residual Deviance	40.93	33.69	52.90	58.946	57.04	55.61	64.81
AIC	110.93	103.69	122.9	128.95	127.04	125.61	132.81
FSI	17	17	16	17	16	17	16

Table C.19 cont.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Mean Fitted Results	0.52	0.52	0.55	0.55	0.52	0.52	0.64
Predictability	0.48	0.478	0.45	0.45	0.48	0.48	0.36
Area Under the Curve	0.97	0.98	0.93	0.93	0.93	0.93	0.88

Note: ** refers to p-values less than 0.001 and * refers to a p-value less than 0.05; “DP” refers to the distance to nearest path categories; “DT” refers to the distance to nearest town categories; “FSI” refers to the Fischer Scoring Iterations; “IPQ” refers to the sequential internal pattern category; “PlX” refers to the convex plan curvature category; “PrSC” refers to the slight concave profile curvature category. The null deviance is on 86 degrees of freedom and the residual deviance is on 52 degrees of freedom.

Table C.20 Results for model iterations with all variables for predictive logistic regression for whole valley in 2010 showing only significant coefficients.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Significant Coefficients	IPQ -2.27*	IPQ -3.45*	IPQ -5.66**	IPQ -2.88**	IPQ -1.98*	IPQ -3.38**	NA
	PlCSC 4.82*	Slope -9.70*	Slope -0.17*	PlVSC 3.49*	PlSC 3.55*	PrSX 6.69*	
	PlCVSC 5.16*	PlSC 7.04**	PrVSX -6.99*		PlVSC 3.44*	PlSC 4.53*	
		PlVSC 6.16**	PrVSC -6.56*			PlVSC 6.35**	
		PlVSX 5.87*	PlSC 13.07*			PlSX 15.23*	
			PlVSC 11.36*				
			PlVSX 11.24*				

Table C.20 cont.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Null Deviance	97.66	108.38	100.52	113.04	105.88	108.38	110.76
Residual Deviance	48.66	56.45	41.04	67.52	62.83	50.29	30.32
AIC	120.66	128.45	113.04	139.52	134.83	122.29	102.32
FSI	18	19	20	19	18	18	21
McFadden R^2	0.50	0.48	0.59	0.40	0.41	0.54	0.73
Mean Fitted Results	0.89	0.789	0.799	0.86	0.83	0.78	0.79
Predictability	0.12	0.22	0.21	0.14	0.17	0.22	0.21
Area Under the Curve	0.90	0.93	0.98	0.90	0.88	0.93	0.97

Note: ** refers to p-values less than 0.001 and * refers to a p-value less than 0.05; "FSI" refers to the Fischer Scoring Iterations; "IPQ" refers to the sequential internal pattern category; "PlSC" refers to the slight concave plan curvature category; "PlCVSC" refers to the very slight concave plan curvature category; "PlVSX" refers to the very slight convex plan curvature category; "PrSC" refers to the slight concave profile curvature category; "PrSX" refers to the slight convex profile curvature category; "PrVSC" refer to the very slight concave profile curvature category. The null deviance is on 100 degrees of freedom and the residual deviance is on 65 degrees of freedom.

Table C.21 Results for model iterations with all variables for predictive logistic regression for whole valley in 2021 showing only significant coefficients.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Significant Coefficients	Pl-Hol 7.32*	IPQ -3.35**	Aspect 5.89*	Aspect 4.16* DRd401-600 -4.04*	X -0.01* Y -0.08* Pl-Hol 6.52* PrSC 5.08* DRd401-600 -4.73*	DRd51-100 -3.67* DRd401-600 -5.55*	X -0.01* Y 0.002* Aspect 0.44*
Null Deviance	12.33	114.92	114.92	117.39	117.40	112.33	109.64
Residual Deviance	62.20	64.62	53.15	65.30	65.56	62.25	57.75
AIC	134.2	136.62	125.15	137.3	135.56	134.24	127.75
FSI	18	19	19	18	18	18	18
McFadden R^2	0.45	0.44	0.54	0.44	0.44	0.45	0.47
Mean Fitted Results	0.82	0.81	0.76	0.85	0.81	0.86	0.81
Predictability	0.18	0.19	0.24	0.15	0.19	0.14	0.19
Area Under the Curve	0.94	0.95	0.99	0.94	0.87	0.85	0.93

Note: ** refers to p-values less than 0.001 and * refers to a p-value less than 0.05; “DRd” refers to distance to road categories; “FSI” refers to the Fischer Scoring Iterations; “IPQ” refers to sequential internal pattern category; “Pl-Hol” refers to the Pleistocene-Holocene underlying geology category; “PrSC” refers to the profile curvature slight concave category. The null deviance is on 108 degrees of freedom and the residual deviance is on 73 degrees of freedom.

Table C.22 Transformed variables to include in reduced predictive logistic regression models for the whole valley.

	1977	2010	2021
Variables	Slope	Internal Pattern	Aspect
	Distance to Path	Planform Curvature	Longitude
	Distance to Town	Profile Curvature	Latitude
	Aspect	Elevation	Distance to Road

Note: Variables were chosen based on their significance in previous predictive logistic regression models for the whole valley.

Table C.23 Results for model iterations with the reduced number of variables for predictive logistic regression for whole valley in 1977 showing only significant coefficients.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Significant Coefficients	Slope 3.53** DP101-200 1.79* DP401-600 2.34* DP601-800 2.84*	Slope 2.35*	Slope 3.40**	Slope 3.51**	Slope 3.39**	Slope 2.87**	Slope 3.58**
Null Deviance	120.60	120.04	119.66	119.68	120.60	120.60	120.32
Residual Deviance	92.93	102.35	92.14	96.82	94.03	100.22	91.43
AIC	112.93	120.35	112.14	114.82	113.03	120.22	111.43
FSI	14	4	14	4	14	14	14
McFadden R^2	0.23	0.15	0.23	0.19	0.22	0.17	0.24
Mean Fitted Results	0.45	0.66	0.66	0.66	0.54	0.60	0.66
Predictability	0.55	0.34	0.34	0.34	0.46	0.40	0.34
Area Under the Curve	0.83	0.73	0.81	0.71	0.79	0.76	0.79

Note: ** refers to p-values less than 0.001 and * refers to a p-value less than 0.05; "FSI" refers to the Fischer Scoring Iterations; "DP" refers to categories of distance to nearest path. The models' null deviance is on 86 degrees of freedom and residual deviance on 77 degrees of freedom.

Table C.24 Results for model iterations with the reduced number of variables for predictive logistic regression for whole valley in 2010 showing only significant coefficients.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Significant Coefficients	NA	IPQ -1.24*	IPQ -1.69**	IPQ -1.23*	IPQ -1.28*	NA	IPQ -1.18*
Null Deviance	110.76	103.26	110.76	100.52	105.88	110.76	115.21
Residual Deviance	98.19	88.09	90.05	84.77	83.25	96.23	100.73
AIC	124.19	114.09	116.05	110.77	109.25	122.23	126.73
FSI	16	17	17	17	18	17	16
McFadden R^2	0.11	0.15	0.19	0.16	0.21	0.13	0.13
Mean Fitted Results	0.96	0.95	0.86	0.92	0.91	0.92	0.95
Predictability	0.04	0.05	0.14	0.08	0.09	0.08	0.05
Area Under the Curve	0.73	0.75	0.78	0.77	0.85	0.75	0.66

Note: * refers to a p-value less than 0.05; "FSI" refers to the Fischer Scoring Iterations; "IPQ" refers to sequential internal pattern category. Models' null deviance is on 100 degrees of freedom and residual deviance on 98.19 degrees of freedom.

Table C.25 Results for model iterations with the reduced number of variables for predictive logistic regression for whole valley in 2021 showing only significant coefficients.

	Model Iterations						
	R1	R2	R3	R4	R5	R6	R7
Significant Coefficients	NA	NA	NA	NA	NA	NA	NA
Null Deviance	109.64	114.92	109.64	114.92	112.33	103.91	117.39
Residual Deviance	102.86	110.79	102/05	104.78	104.71	98.82	110.23
AIC	122.86	130.79	122.05	124.78	122.71	117.82	130.23
FSI	16	15	15	16	15	15	15
McFadden R^2	0.06	0.04	0.07	0.09	0.07	0.06	0.06
Mean Fitted Results	1.00	1.00	0.95	0.97	0.99	1.0	0.99
Predictability	0.00	0.00	0.05	0.03	0.01	0.00	0.01
Area Under the Curve	0.70	0.64	0.63	0.67	0.68	0.57	0.69

Note: "FSI" refers to the Fischer Scoring Iterations. Models' null deviance are on 108 degrees of freedom and residual deviance are on 99 degrees of freedom.

Stone Feature: Possibly a Walkway or Infrastructure to Control Water

Other interesting features identified in satellite imagery include an approximately two-meter-high stone and mortar feature in Paccareta is visible in satellite imagery (figures C.5 and C.6). The feature crosses a topographic low covered in black aeolian, volcanic sand, connecting the site of Paccareata to the west to a topographic high to the east that leads towards large unirrigated terraces at a higher elevation. It may be an elevated walking path or canal, or it may serve as an obstruction to either capture water on the upslope side or to mitigate issues stemming from strong winds impacting the gridded fields on the downslope side of the feature. It is may also be a defense feature although it is much smaller compared to other defensive features in the wall, although this is a possibility. The site of

Pumajallo near the contemporary area of Tauca has large perimeter and foundation walls (see Menaker 2019a, 164 and Figure 4.29). It appears connected to a linear feature that ascents onto the slope of the site of Paccareta to the south and continues north, although these features are not visible on the satellite imagery from 1977. Regardless, these features require further study to test these hypotheses.

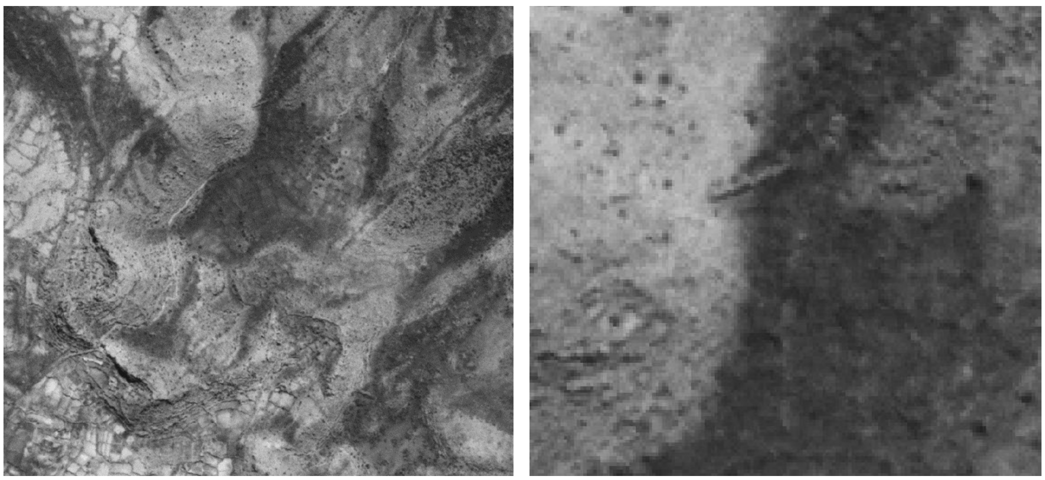


Figure C.5 Stone infrastructural feature connecting the site of Paccareta to a neighboring topographic high that leads to cross-channel terraces. Top left image shows the features location north of the site of Paccareta and the top right image is zoomed into the feature (USGS 1977).

Figure C.6 Feature with the Author for scale, left, July 4, 2016 (Photo by Alexander Menaker). Archaeologist in red shirt standing on the feature, right, June 27, 2015 (Photo by Author).

Table C.26 External boundary classifications of sampled terraces in Paccareta in 1977.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
TOTAL	2	1	1	4	0	1	39
Land Cover							
Soil, Sand, Gravel	0	1	0	1	0	0	13
Rock	0	0	0	0	0	0	1
Grass	2	0	1	3	0	1	24
Shrubby Grass	0	0	0	0	0	0	1
Shrubs	0	0	0	0	0	0	0
Dense Shrubs	0	0	0	0	0	0	0
Terrace Type							
Broad Field	1	0	1	3	0	0	20
Lateral	0	0	0	1	0	0	3
Lateral and Broad Filed	0	0	0	0	0	0	8
NA	1	0	0	0	0	1	8
External Patterns							
Segmented	2	1	0	4	0	1	1
Horizontal	0	0	0	0	0	0	0
Vertical	0	0	0	0	0	0	0
Horizontal and Vertical	0	0	0	0	0	0	0
NA	0	0	0	0	0	0	38
Internal Boundary Categories							
C, Coarse	0	0	0	0	0	0	8
C, Fine	0	0	0	0	0	0	0
C, Soft	0	0	0	0	0	0	0
A, Craggy	0	0	1	1	0	0	27
A, Bristly	0	0	0	0	0	0	0
A, Fluffy	1	0	0	0	0	0	2
NA	1	0	0	3	0	1	2
Internal Breaks							
Many Breaks	0	0	0	1	0	0	3
Breaks	1	0	1	0	0	0	27
No Breaks	0	0	0	0	0	0	7
NA	1	0	0	3	0	1	2

Table C.26 cont.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
External Breaks							
Many Breaks	0	0	0	1	0	1	0
Breaks	1	0	1	3	0	0	0
No Breaks	1	0	0	0	0	0	0
NA	0	0	0	0	0	0	39
Internal Pattern							
Segmented	1	0	1	0	0	0	26
Sequential	0	0	0	1	0	0	10
NA	1	0	0	3	0	1	3
Topography (Mean)							
Slope (°)	2.4	NA	2.3	2.9	NA	2.3	4.0
Aspect (°)	188.4	NA	191.7	124.6	NA	89.8	162.7
Profile Curvature	CC	NA	CC	CV	NA	CV	CV
Plan Curvature	CV	NA	CC	CC	NA	CV	CC
Location							
Mean Distance to Town (meters)	3586.7	NA	3303.3	3657.7	NA	3663.0	3336.0
Mean Distance to Road (meters)	749.5	NA	459.9	776.2	NA	674.8	502.5
Mean Distance to Path (meters)	293.6	NA	181.2	426.8	NA	653.2	297.7

Note: All plan and profile curvature values were largely between -0.001 and 0.001, which is within the "moderate relief" categories spanning -0.5 to 0.5 in QGIS. "CV" refers to convex curvatures and "CC" refers to concave curvatures. "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Table C.27 External boundary classifications of sampled terraces in Paccareta in 2010.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
TOTAL	16	33	0	0	0	0	9
Land Cover							
Soil, Sand, Gravel	2	0	0	0	0	0	4
Rock	0	0	0	0	0	0	1
Grass	13	32	0	0	0	0	1
Shrubby Grass	1	1	0	0	0	0	2
Shrubs	0	0	0	0	0	0	1
Dense Shrubs	0	0	0	0	0	0	0
Terrace Type							
Broad Field	10	26	0	0	0	0	1
Lateral	0	0	0	0	0	0	3
Lateral and Broad Filed	6	4	0	0	0	0	1
NA	0	3	0	0	0	0	4
External Patterns							
Segmented	16	32	0	0	0	0	0
Horizontal	0	1	0	0	0	0	0
Vertical	0	0	0	0	0	0	0
Horizontal and Vertical	0	0	0	0	0	0	0
NA	0	0	0	0	0	0	9
Internal Boundary Categories							
C, Coarse	10	14	0	0	0	0	1
C, Fine	2	14	0	0	0	0	0
C, Soft	1	2	0	0	0	0	0
A, Craggy	1	0	0	0	0	0	6
A, Bristly	1	1	0	0	0	0	1
A, Fluffy	0	0	0	0	0	0	0
NA	1	2	0	0	0	0	1
Internal Breaks							
Many Breaks	0	0	0	0	0	0	3
Breaks	5	4	0	0	0	0	5
No Breaks	11	26	0	0	0	0	0
NA	0	3	0	0	0	0	1

Table C.27 cont.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
Internal Pattern							
Segmented	11	26	0	0	0	0	3
Sequential	3	4	0	0	0	0	5
Segmented and Sequential	1	1	0	0	0	0	0
NA	1	2	0	0	0	0	1
External Breaks							
Many Breaks	5	1	0	0	0	0	0
Breaks	5	3	0	0	0	0	0
No Breaks	9	28	0	0	0	0	0
NA	0	1	0	0	0	0	9
Topography (Mean)							
Slope (°)	3.6	2.8	NA	NA	NA	NA	7.2
Aspect (°)	135.5	149.9	NA	NA	NA	NA	181.1
Profile Curvature	CC	CV	NA	NA	NA	NA	CV
Plan Curvature	CC	CC	NA	NA	NA	NA	CC
Location							
Mean Distance to Town (meters)	3352.9	3437.7	NA	NA	NA	NA	3361.7
Mean Distance to Road (meters)	199.0	177.7	NA	NA	NA	NA	296.2
Mean Distance to Path (meters)	262.8	274.8	NA	NA	NA	NA	98.3

Note: All plan and profile curvature values were largely between -0.001 and 0.001, which is within the "moderate relief" categories spanning -0.5 to 0.5, and a value of 0 indicates a negative surface in QGIS. "CV" refers to convex curvatures and "CC" refers to concave curvatures. "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Table C.28 External boundary classifications of sampled terraces in Paccareta in 2021.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
TOTAL	22	28	0	1	2	0	4
Land Cover							
Soil, Sand, Gravel	0	0	0	1	0	0	1
Rock	0	0	0	0	0	0	1
Grass	21	26	0	0	0	0	0
Shrubby Grass	1	2	0	0	1	0	1
Shrubs	0	0	0	0	1	0	1
Dense Shrubs	0	0	0	0	0	0	0
Terrace Type							
Broad Field	17	23	0	0	0	0	1
Lateral	1	0	0	1	0	0	2
Lateral and Broad Filed	4	5	0	0	1	0	0
NA	0	0	0	0	0	0	1
External Patterns							
Segmented	22	28	0	1	1	0	0
Horizontal	0	0	0	0	0	0	0
Vertical	0	0	0	0	0	0	0
Horizontal and Vertical	0	0	0	0	0	0	0
NA	0	0	0	0	0	0	4
Internal Boundary Categories							
C, Coarse	16	12	0	0	0	0	0
C, Fine	1	7	0	0	0	0	0
C, Soft	1	7	0	0	0	0	0
A, Craggy	1	0	0	0	0	0	0
A, Bristly	0	1	0	1	1	0	0
A, Fluffy	3	1	0	0	0	0	0
NA	0	0	0	0	1	0	0
Internal Breaks							
Many Breaks	0	0	0	0	0	0	1
Breaks	7	6	0	1	1	0	2
No Breaks	14	22	0	0	0	0	0
NA	1	0	0	0	0	0	1

Table C.28 cont.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
Internal Pattern							
Segmented	14	26	0	0	1	0	0
Sequential	7	2	0	1	0	0	3
Segmented and Sequential	1	0	0	0	0	0	0
NA	0	0	0	0	0	0	1
External Breaks							
Many Breaks	1	0	0	0	0	0	0
Breaks	8	4	0	1	1	0	0
No Breaks	12	24	0	0	0	0	0
NA	1	0	0	0	0	0	4
Topography (Mean)							
Slope (°)	4.3	3.6	NA	4.4	3.6	NA	5.0
Aspect (°)	146.2	144.5	NA	159.8	134.9	NA	203.9
Profile Curvature	CV	CV	NA	CC	CV	NA	CC
Plan Curvature	CV	CC	NA	CV	CV	NA	CV
Location							
Mean Distance to Town (meters)	3342.9	3387.4	NA	2963.3	2901.1	NA	3407.6
Mean Distance to Road (meters)	219.6	110.0	NA	13.7	80.0	NA	282.2
Mean Distance to Path (meters)	271.0	301.4	NA	238.0	247.9	NA	78.7

Note: All plan and profile curvature values were largely between -0.001 and 0.001, which is within the "moderate relief" categories spanning -0.5 to 0.5 in QGIS. "CV" refers to convex curvatures and "CC" refers to concave curvatures. "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Table C.29 External boundary classifications of sampled terraces in main valley in 1977.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
TOTAL	39	5	0	5	7	4	11
Land Cover							
Soil, Sand, Gravel	1	0	0	1	0	0	1
Grass	34	5	0	2	6	4	8
Shrubby Grass	3	0	0	1	1	0	0
Shrubs	1	0	0	1	0	0	1
Dense Shrubs	0	0	0	0	0	0	1
Terrace Type							
Broad Field	14	2	0	0	3	2	1
Lateral	17	2	0	1	2	1	6
Lateral and Broad Filed	5	0	0	1	2	1	2
NA	3	1	0	3	0	0	2
External Patterns							
Segmented	26	4	0	2	3	4	4
Horizontal	3	0	0	1	0	0	0
Vertical	3	0	0	1	3	0	0
Horizontal and Vertical	7	1	0	0	1	0	0
NA	0	0	0	1	0	0	7
Internal Boundary Categories							
C, Coarse	8	1	0	1	2	1	1
C, Fine	2	0	0	0	0	0	0
C, Soft	5	0	0	0	0	1	0
A, Craggy	1	0	0	1	0	0	0
A, Bristly	4	2	0	0	4	1	0
A, Fluffy	16	0	0	0	1	2	7
NA	3	2	0	2	0	0	3
Internal Breaks							
Breaks	15	3	0	3	6	0	5
No Breaks	20	0	0	0	1	4	3
NA	4	2	0	2	0	0	3

Table C.29 cont.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
Internal Pattern							
Segmented	13	1	0	1	4	3	2
Sequential	20	2	0	2	3	1	6
Sequential and Segmented	1	0	0	0	0	0	0
NA	4	2	0	2	0	0	3
External Breaks							
Many Breaks	0	1	0	0	1	0	0
Breaks	18	1	0	5	5	3	0
No Breaks	20	3	0	0	1	1	0
NA	1	0	0	0	0	0	11
Topography (Mean)							
Slope (°)	7.6	19.6	0	6.8	8.4	0	6.9
Aspect (°)	96.1	161.8	0	118.8	106.0	0	143.8
Profile Curvature	CV	CC	NA	CV	CV	CC	CC
Plan Curvature	CV	CC	NA	CV	CV	CV	CC
Location							
Mean Distance to Town (meters)	1760.5	1995.5	0	1845.7	1952.7	2884.7	2655.8
Mean Distance to Road (meters)	1087.4	1247.2	0	1081.5	1451.5	2373.3	2179.2
Mean Distance to Path (meters)	140.1	200.7	0	107.8	67.6	153.7	217.1

Note: All plan and profile curvature values were largely between -0.001 and 0.001, which is within the "moderate relief" categories spanning -0.5 to 0.5 in QGIS. "CV" refers to convex curvatures and "CC" refers to concave curvatures "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Table C.30 External boundary classifications of sampled terraces in main valley in 2010.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
TOTAL	56	16	0	2	4	2	0
Land Cover							
Soil, Sand, Gravel	2	0	0	0	0	0	0
Grass	40	11	0	0	3	2	0
Shrubby Grass	11	4	0	1	0	0	0
Shrubs	3	1	0	1	0	0	0
Dense Shrubs	0	0	0	0	1	0	0
Terrace Type							
Broad Field	20	6	0	0	2	0	0
Lateral	17	4	0	2	1	0	0
Lateral and Broad Filed	13	1	0	0	0	0	0
NA	5	5	0	0	1	2	0
External Patterns							
Segmented	41	14	0	2	3	2	0
Horizontal	4	0	0	0	1	0	0
Vertical	2	0	1	0	0	0	0
Horizontal and Vertical	8	0	0	1	0	0	0
NA	1	0	0	0	0	0	0
Internal Boundary Categories							
C, Coarse	33	4	0	0	2	0	0
C, Fine	9	0	0	9	1	1	0
C, Soft	1	0	0	0	0	0	0
A, Craggy	2	2	0	2	1	0	0
A, Bristly	3	1	0	0	0	0	0
A, Fluffy	5	0	0	0	0	0	0
NA	3	0	0	0	0	0	0
Internal Breaks							
Many Breaks	2	0	0	0	0	0	0
Breaks	14	5	0	2	1	0	0
No Breaks	37	11	0	0	4	1	0
NA							

Table C.30 cont.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
Internal Pattern							
Segmented	28	10	0	0	3	1	0
Sequential	25	4	0	2	1	0	0
NA	3	2	0	0	0	1	0
External Breaks							
Many Breaks	0	0	0	0	0	0	0
Breaks	26	1	0	2	2	1	0
No Breaks	30	15	0	0	2	1	0
NA	0	0	0	0	0	0	0
Topography (Mean)							
Slope (°)	8.1	6.9	NA	10.4	8.3	5.9	NA
Aspect (°)	110.6	110.3	NA	48.9	95.5	69.6	NA
Profile Curvature	CV	CV	NA	CC	CC	CC	NA
Plan Curvature	CC	CC	NA	CV	CC	CV	NA
Location							
Mean Distance to Town (meters)	1886.8	1991.8	NA	2329.8	2043.7	1476.8	NA
Mean Distance to Road (meters)	574.4	568.6	NA	1213.9	655.0	375.5	NA
Mean Distance to Path (meters)	91.1	231.5	NA	42.4	117.2	89.0	NA

Note: All plan and profile curvature values were largely between -0.001 and 0.001, which is within the "moderate relief" categories spanning -0.5 to 0.5 in QGIS. "CV" refers to convex curvatures and "CC" refers to concave curvatures. "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Table C.31 External boundary classifications of sampled terraces in main valley in 2021.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
TOTAL	43	8	1	6	4	9	6
Land Cover							
Soil, Sand, Gravel	2	2	0	0	0	0	4
Grass	32	5	1	1	4	9	2
Shrubby Grass	7	1	0	2	0	0	0
Shrubs	2	0	0	1	0	0	0
Dense Shrubs	0	0	0	2	0	0	0
Terrace Type							
Broad Field	15	2	0	1	3	3	0
Lateral	1	0	0	1	0	0	0
Lateral and Broad Filed	1	1	1	0	1	1	0
NA	8	4	0	2	1	1	6
External Patterns							
Segmented	36	7	1	4	7	4	0
Horizontal	1	0	0	2	0	1	0
Vertical	3	0	0	0	1	3	0
Horizontal and Vertical	3	1	0	0	1	1	0
NA	0	0	0	0	1	0	6
Internal Boundary Categories							
C, Coarse	15	1	0	0	2	1	2
C, Fine	5	4	0	0	0	0	1
C, Soft	2	0	0	0	1	2	0
A, Craggy	1	0	0	3	2	0	2
A, Bristly	4	0	0	1	2	0	1
A, Fluffy	15	1	1	0	0	5	0
NA	1	2	2	1	0	0	5
Internal Breaks							
Many Breaks	1	1	0	0	0	0	2
Breaks	14	1	1	3	5	0	4
No Breaks	3	2	2	0	2	1	1
NA	3	2	0	2	1	1	0

Table C.31 cont.

	Contrasting			Ambiguous			
	Coarse	Fine	Soft	Craggy	Bristly	Fluffy	NA
Internal Pattern							
Segmented	25	4	0	2	3	4	6
Sequential	16	2	1	2	6	4	0
NA	2	2	0	2	1	1	0
External Breaks							
Many Breaks	1	0	0	0	0	0	0
Breaks	18	2	1	6	8	1	0
No Breaks	24	6	0	0	2	5	0
NA	0	0	0	0	0	0	6
Topography (Mean)							
Slope (°)	7.0	5.0	8.2	6.9	10.6	9.1	4.4
Aspect (°)	102.5	133.9	69.9	111.3	108.1	93.7	142.9
Profile Curvature	CV	CV	CC	CC	CC	CV	CC
Plan Curvature	CC	CC	CC	CC	CC	CC	CV
Location							
Mean Distance to Town (meters)	1820.5	2683.0	1185.6	2186.4	2257.3	1818.2	2884.5
Mean Distance to Road (meters)	252.4	315.6	198.1	234.9	277.7	211.9	98.9
Mean Distance to Path (meters)	118.7	136.0	85.5	94.2	154.3	85.4	389.9

Note: All plan and profile curvature values were largely between -0.001 and 0.001, which is within the "moderate relief" categories spanning -0.5 to 0.5 in QGIS. "CV" refers to convex curvatures and "CC" refers to concave curvatures. "C" internal boundary characteristic refers to contrasting features and "A" internal boundary characteristic refers to ambiguous features; "NA" is not applicable.

Notes

Chapter 1

1. As argued by Brown and colleagues (2020), terraces have been understudied through the twentieth century because they do not possess charismatic structural or artifactual elements.

2. Wei and colleagues (2016) mistakenly conclude that terracing in the Andes have "suffered from total abandonment" after the colonial period, citing Posthumus and Stroosnijder's (2010) study of newly constructed bench terraces in southern Peru.

3. Sediment profiles in Maya terraces and other depositional features indicate grasses such as Zea mays (maize) compose a significant portion of organic matter in soils during the Late Classic period (Beach et al. 2010).

4. Donkin notes that this impermeable subsoil clay and coarse particle surface, called tierra arcillosa, is found under Inca terrace topsoils throughout the Andes, which he suspects, citing Field (1966), was purposefully created (1979, 33). Duripans or Argillic horizons are found underneath the mostly hand-filled terraces and excavated for wall emplacement in the Colca Valley (Sandor and Eash 1995). Natural soils in the Colca Valley contained these layers of silicate clay or other mineral accumulation in the subsoil, which is unusual for such high elevation soils (Sandor and Eash 1995; Eash and Sandor 1995). Their presence is explained as enabled through landform stability for some surfaces back through the middle Pleistocene below elevations of 4000 masl., as well as the high daytime temperatures in andesitic colluvial parent material that easily chemically weathers (Eash and Sandor 1995). These may also enable perching of water if not drained effectively, potentially waterlogging the soil.

5. Imfeld and colleagues (2020) additionally hypothesize that seasonal cloud cover in relation to solar radiation controls precipitation, diurnal temperature and frost, an effect that is particularly impacted by high elevations and noticeable by seasonal temperature differences.

6. Ice and snow melt on glaciers in the Peruvian Andes are documented to be driven by wet season precipitation impacting albedo and net shortwave radiation, rather than air temperature, although temperature still controls precipitation type and the threshold at which the ice turns directly into a gas state becomes a higher precent of glacier loss than melt (Fyffe et al. 2021).

7. The Central Volcanic Zone (CVZ) has more than 600 Quaternary volcanic centers (Clapperton 1993; Gonzalez and Pfiffner 2012).

8. The Andagua River also goes by other names in different sections through the Andagua Valley. It is mapped as the Andagua (or Andahua) River around the confluence of the Orcopampa River and the Chillcaimarca River after the town of Orcopampa, upriver from the town of Andagua, and changes names to the Challahuire after it drains from the lake near town, mapped as Lake Pumajallo (INGEMMET 2001, 2002) but also referred to as the Lake Andagua by others. I will refer to it throughout the dissertation as the Andagua River and Lake Pumajallo for consistency.

9. Ancojahua glacier covers an area of 0.370 square kilometers at an elevation of 5249 masl in the province of Condesuyos (ANA 2015a, 40). The glaciers on Coropuna Volcano cover an area of 39,980 square kilometers at a maximum elevation of 6398 masl and a minimum elevation of 4906 masl in the Castilla province (ANA 2015a, 40).

10. The INEI (2012) reports that the Andagua Irrigation Commission irrigates 848.14 hectares. The discrepancy may be a difference in definition. While the ANA reports the area that could be irrigated by this canal, the INEI reports the total agricultural area currently owned by local producers in the area.

11. Quechua is a language indigenous to South America and is spoken in Andagua. Of the reported heads of household in the 2012 Peruvian National Agricultural Census (INEI 2012), 18 reported first learning Quechua before Spanish as a child.

12. A separate rehabilitation process occurred in the 1950s in the town of Coporaque in the Colca Valley where farmers repaired and redistributed disused terraces among community members to stop non-local people from legally claiming the abandoned land (Treacy 1987). This legality was not explained as part of the discourse in the rehabilitation of the terraces in Andagua; rather, they expressed a desire for more land. The difference may be the proximity of the Colca and a road that enabled easier access to the land by outsiders.

13. The towns in the side valleys (i.e., Tauca and Soporo, see Figure 1.2) near Andagua, Shippee (1934, 130) hypothesizes, were recently abandoned. He speculates that the estimated population of 1,200 in the 1930s is lower than in the past due to the large extent of now abandoned terraces.

14. The bull fighting ring was also constructed during the 1970s correlating with the increasing attention to breeding for *media casta* bulls (Hartigan and Menaker 2022). According to the local breeders, bulls for bullfighting came from Cusco about 80 to 100 years ago and those that cross-bred with wild cows created the *media casta* bulls. These offspring would "play" in the Plaza before the construction of the bullring.

Chapter 2

1. While I use "process" to describe movements of energy or mass in a geomorphic system, such as sediment redistributing downslope, or the reproduction of hegemonies, such as enforcing the capitalist market economy across the globe, the word "practice" is used to refer to the everyday movements and activities of people in a place.

2. For other human-environment approaches in ecology, see Zimmerer (2020, 151-153) and their summary Table 11.1 for a list of terms and explanations for methodological approaches and Table 11.2 for examples of their application.

3. Interestingly, Goudie's (1994) *Encyclopedic Dictionary of Physical Geography* has no entries for "landscape," "landform" or "form" although these terms are referred to consistently throughout the book.

Chapter 3

1. One exception to this pattern is the terrace soil in the upper Ica Valley, which has low organic matter and Phosphorus (Nanavati et al. 2016). The authors of the study suggested that this is an anomaly within the findings of other terrace studies in the southern Peruvian Andes (Nanavati et al. 2016).

2. An alternative spelling of the foot plow by Murra (2002, 382) is *taklya*. In pre-colonial periods, farmers used the foot plow to disentangle and disrupt the topsoil (Donkin 1979, 10-11). The foot plow was about 1.8 meters in height with a handle, a hard endpoint, and a footrest (Rowe 1946, 211). Men would loosen the earth with the foot plow and women would follow to turn the clod and plant the seeds, if appropriate (Donkin 1979, 11-13; Murra 2002, 382). It may also be used as a planting stick for maize and for planting and harvesting potatoes (Rowe 1946, 211).

3. For example, Ochoa-Tocachi and colleagues (2019) describe and test water harvesting tactics in the Central Andes including the diversion of water during the wet season to highland slopes for infiltration and subsequent recharging of springs. Using a dye tracer, they tested the connectivity of water diverted using an upslope canal during the wet season and downslope springs, which showed the increased water availability of downslope springs during the dry season (Ochoa-Tocachi 2019).

4. A starchy maize developed by the Instituto Nacional de Innovación Agraria (INIA) on behalf of the MINAGRI that is resistant to a rot caused by the *Helicoverpa zea* insect and to a fungus and has increased yields (MINAGRI 2020).

5. Mayer (2002, 2) also found fields to be places of importance for farmers and where they were comfortable sharing.

6. According to the INEI (2012), 171 of the 243 producers that own cattle possess them for the purpose of either selling the milk or for personal consumption.

7. This is the one instance in which I met up with an interviewee at their home rather than in the field. It is early in the morning, and he must have already left for the morning and not yet returned. His mother invites us in and insists we drink some warm, fresh *chicha* (maize beer) for breakfast, explaining that she made it the other day and likes to drink it before it ferments too long. She also kindly insists we eat spaghetti with a red meat sauce in their public room, which is lined with posters of bulls, bullfights, and sporting event calendars. There are also images of religious figures, idols, *keros* (wooden drinking vessels), ceramic pots and paraphernalia from local organizations.

8. According to the INEI (2012), 15 landed producers possess 78 heads of cattle, and 241 landless producers possess 2,830 heads of cattle. In addition, 2 landed producers possess 2 pigs, 141 landless producers possess 250 pigs, 23 landed producers possess 359 sheep, and 110 landless producers possess 649 sheep.

9. According to an article in the Peruvian newspaper *El Comercio,* one fire was set near Tauca, east of the main valley, that transformed into a wildfire. It burned 90 hectares of grass and shrubland a month after my interviews.

10. *Ichu* (a common name for local bunch grasses) is also used for brooms, braided ropes, and ceremonial activities (Rowe 1946, 216).

11. A *cuy* (guinea pig) is also spelled *quwi* in contemporary Quechua (Horberger and Hornberger 2013, 86). Likely, this structure is a place that holds both *cuy* and seeds and is made with *ichu*. According to the INEI (2012), 126 producers possess a total of 1,736 guinea pigs. Producers also report possessing birds and only one producer reports having rabbits.

12. In the INEI, 51 producers report using *abono organico* (organic fertilizer). Only 3 farmers in the INEI (2012) report having organic certification over a combined 16.53 hectares.

13. According to the INEI (2012), 32 landed producers own 892 alpaca, and 34 landed producers own 2,872 llamas, while 8 landless producers own 204 alpaca, and 7 landless producers own 610 llamas.

14. The INEI (2012) documents 23 producers using chemical insecticides, 9 using non-chemical and non-biological insecticides, 26 using herbicides and 10 using

fungicides, with a total of 43 using one or more of these to control pests. Alternatively, 287 producers report not using any of these.

15. It is unclear if these are oxen–it is unusual for bulls to be used for plowing because they are dangerous and often aggressive. However, farmers in Andagua express the docility of many of their bulls. For more on bulls and bullfighting in Andagua, see Hartigan and Menaker (2019).

16. Alternatively spelled *topo* (see Farrier 1767). This is not to be confused with a type of metal fastening pin called a *tupu* (or *topo*) that was used to hold a garment on the body of women (Phipps 2018).

17. The quickness is relative. It is a 13-hour bus ride from Arequipa to Andagua along a narrow, winding road that has been made more dangerous by its paving. The engineering of its paving and drainage has left it even more narrow in addition to allowing for higher driving speeds.

18. Senor H's fields on which we spoke were about 3630 masl and are generally north facing. Senora A's fields on which we spoke are at 3508 masl and are generally east-northeast facing. Senora C's fields where we spoke are at 3491 masl and are south facing. I do not have the elevation and aspect of Señor G's fields.

19. Excavations and analysis of microfossil remains on grinding stones and in soil samples from a preceramic house in the Cotahuasi Valley, one valley north of the Andagua valley, evidence maize cultivation and processing as early as 2500 BCE; the study recovered abundant grains in these excavations and correlated the continued occupation of this area with its access to water and its elevation of about 3600 masl as ideal for accessing land for tuber and maize cultivation (Perry et al. 2006). There is additional evidence of maize and chili peppers (Capsicum) often occurring together as early as the preceramic periods throughout the Andes, indicating them as important components of food production and consumption (Perry et al. 2007).

20. According to Silverblatt (1987, 14), the pre-colonial household was a space where men and women were seen as equally contributing to its sustenance. While both men and women worked in the fields, weaving and chicha production were associated with women's labor while plowing and war were associated with men's labor (Silverblatt 1987, 14).

21. According to Knapp (as a comment in Guillet et al. 1987), while irrigation water brings fresh minerals to fields, early unirrigated terraces likely required additional agricultural inputs in the form of camelid dung or *guano* (bird dung). Knapp links the distribution of camelid herds with the distribution of terraces across the Andes.

22. *Yareta* is a cushion plant that grows between 3800 and 5200 masl, can reach about six meters in diameter and more than 3000 years in age (Pugnaire et al. 2020). People selectively harvest them for fires–possibly restricted to specific ritual events as I have only seen them burned during ceremonial offerings, although this cannot be confirmed. They have a distinct smell when they burn, and they burn very slowly.

Chapter 4

1. The Shippee-Johnson Expedition then hiked out of the valley over the pass at Coropuna volcano to the Andamayo Valley and the town of Viraco (Shippee 1934, 131), following the route of the current paved road and possibly the cattle trail. From the town of Aplao, they were able to catch a car to the Pan Americana on the coast to return to Arequipa (Shippee 1934, 131).

2. The US government partially funded the ONERN project through the Agency for International Development (AID).

3. Other individuals listed as accompanying Shippee and Johnson on the trip include historian Irving May (alternatively reported as Irving O'Hay), civil engineer Valentine Van Keuren, mechanic Max Distel, cameraman W. O. Runcie, and Peruvian military escort Major Roberto Ragus (NYT August 31, 1931; NYT July 27, 1931). The American Geographical Society during this period was dedicated to gathering data and producing works useful for both national and international interests, first led by Isaiah Bowman and later, during the period of the expedition, John Finley, which much of the funding for projects sourced from regular members, board members and foundations such as the Rockefeller Foundation and the Social Science Research Council (Wright 1952). The wife of the secretary of the Peruvian Embassy named the two Bellanca monoplanes planes Washington and Lima, and the Peruvian Ambassador Manuel de Freyre y Santander and representatives of the State, War and Navy departments were present during their takeoff from the US (NYT November 24, 1930).

4. Shippee also reported that locals informed him of a "plague, possibly black fever of some kind" that considerably decreased the population of the Colca Valley in 1854 and that the abandonment of agricultural terraces was also attributed to a lack of water or water contamination (NYT, June 29, 1931, para. 6).

5. The *GCPs: Image to Image* georectification process in ENVI software was first used; but it proved only useful for broader scale georectification (Exelis Visual Information Solutions, Boulder, Colorado). While the Polynomial transformation introduced the least error, it coarsened the resolution to the geo-located source imagery, which was often coarser than the images. Additionally, the triangulation transformation

cropped the image to the source image, removing Pumajallo from the declassified images.

6. A negative value in the profile output indicates a convex value, a positive value indicates concave and a value of 0 indicates a flat surface. A negative value in the plan output indicates concave, a positive value indicates convex and a 0 indicates a flat surface. Moderate relief spans between -0.5 to 0.5 while higher relief can reach up to -4.0 and 4.0 (See figures C.2 and C.3).

7. Terraces are refined into a variety of categories (e.g., Wei et al. 2016; Brown et al. 2020) and classified largely by morphology and topographic position. For example, Wei and colleagues (2016), distinguish terraces by wall material, climate, embankment presence, history, function, and topographic position. Brown and colleagues (2020) classify terraces according to their plan and profile morphologies in consideration of slope continuity, fill, hydrology, and landslide risk.

8. Archaeologists have also found representations of agricultural terraces and irrigation infrastructure carved into stones in the Colca and elsewhere, that are "hydraulically functional" miniatures of the terrace system found nearby (Wernke 2013, 154).

9. One interesting feature in the Shippee-Johnson imagery includes the clear distinction between one of the *gamonal's* house complexes on the main square and the surrounding structures in town. The metal roof of the structures in the complex contrast with the *itchu* roofs visible throughout town. See Chapter 4 for a discussion on the importance of *itchu* and the transition from *itchu* roofs to metal during the twentieth century and an outline of the impact of the *gamonal* in the southern Peruvian highlands.

10. The weir was constructed by an Andagüeño who studied engineering and helped to build it (Menaker, *pers. comm*., March 3, 2023).

Chapter 5

1. Conversion using Long (1991, iii).

2. If Cieza is using an Inca pace, 1.3 meters (from Farrier 1967), then it is 78 by 65 meters or 1.3 acres.

3. Rowe (1946, 324; Table 5.1) compares definitions of the tupu from the Inca periods with those of the late nineteenth and early twentieth-century Peru. For example, he (Rowe 1946) reports twentieth century tupus in Arequipa, Peru as a "somewhat larger but similarly measured area" to Cuzco, which he says is around 0.8 acres and comparable

to Spanish colonial officials' measurements and Cobo's definition (324; Table 5.1). Rowe's (1946) own quantitative and qualitative examples reflect differences across several places and, if he had reported the environmental conditions of each, perhaps their relationality to the landscape would be clear.

4. Cook (1919) speculates that a family received more land for a baby boy because of the higher requirements attached to more feast days.

5. A linear distance of 30 *tupu* may have been referred to as a *wamani*, both apparently relatively standardized units under the Inca (Rowe 1946, 324).

6. For example, Philip II of Spain enacted the Laws of the Indies in 1573 mandating rules about where and how officials were to lay out towns and distribute land, including constructing gridded streets radiating from a rectangular plaza, a layout that colonial officials had already informally implemented throughout the Americas (Mumford 2012, 47, 87). It also described the locations, layouts, and topographic positions necessary for the religious and government buildings on the plaza as well as the distribution of residential and farming land (Mumford 2012, 119-121).

7. An historian, Farrier (1967) also was interested in determining the meaning of the *tupu*, grappling with what he perceived as a disjuncture between his contemporaries' quantification of what he perceived to be relative in colonial documents. During his travels, he came across Shipibo fisherman using the word *tuponti*, a similar-sounding word to *tupu*. The Shipibo fisherman explained that *tuponti* is used to describe measurement, a system given to them by the Inca that was still in use (for more detail, see note 5 in Farrier 1967, 452). The fisherman said that "when the amount is understood between both parties, the word *tuponti* may be used to represent ANY quantity" including a measure of cloth, land, or distance (emphasis by Farrier; Farrier 1967, 453). In other words, the word for "a measurement" or *tuponti*, in this case, could be used without further descriptors if both people in the conversation were aware of what was being measured. This definition is strikingly similar to the Quechua definitions given of *tupu*, leading Farrier to conclude that *tuponti* was equivalent to the *tupu*.

8. A transitive verb is defined in Webster's Dictionary (1988, 438) as "expressing an action carried from the subject to the object and requiring a direct object to complete the meaning."

9. Another relative term used in the Colca for a unit of land is a *yuntada* which refers to "the amount of land which a team of oxen (*yunta*) can plow in a day" (comment 10 in Guillet 1987).

10. A form of the turn system dates to the colonial periods around Cuzco (Villanueva and Sherbondy 1978; as cited by Treacy 1989, 333).

11. The t-statistic from Welch's two-sample t-test was 2.68 with a p-value of 0.008 and a confidence interval of 0.08 to 0.58. The Welch's two-sample t-test was conducted on the log of data for each of Paccareta and the main valley, a transformation that resulted in normally distributed data; however, their different variances required Welch's t-test rather than Student t-test.

12. The sketch in Shippee's 1932 *Geographical Review* article depicts their route into Andagua as passing over the river canyon west of the Spanish-era stone bridge, which he describes in the same article as the only way to cross the river. While it appears that the sketch was completed overlying the aerial imagery due to the accuracy of the canyon topography, the bridge, if it is the stone bridge, is depicted too far west. However, they did note in the 1934 *National Geographic* article that they used a wooden bridge. There are two hypotheses to explain these discrepancies. One is that Shippee mislabeled their route and misspoke about the material of the bridge. Or it could be that there was also a wooden bridge located to the west of the stone bridge during this time. The more likely conclusion is the former. Either way, they crossed the river near Paccareta.

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