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Hunting to herding on the Andean Altiplano: Zooarchaeological insights into Archaic Period subsistence in the Lake Titicaca Basin, Peru (9.0–3.5 ka)

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ABSTRACT

This study examines the subsistence strategies of Archaic Period inhabitants (9.0–3.5 cal. ka) of the Lake Titicaca Basin, located in the high Andes of South America. Faunal data from three Archaic Period sites in the Ilave region of Peru are used to explore the dietary habits of early foragers spanning over five millennia. Comparative analysis reveals heavy investment in camelids, with deer serving as a secondary meat. Small mammals, fish, and birds are virtually absent from the assemblages. We further observe increasing emphasis on camelids relative to deer over time, suggesting a shift from hunting to management during the period of investigation. We fail to find evidence of diet breadth expansion, risk averse foraging, or climate-induced subsistence changes. The observations align with previous studies that document a transition from camelid hunting to herding in other regions of the high Andes. The findings provide preliminary evidence of early camelid management in a suspected domestication center and contribute key insights into the economic strategies that facilitated the emergence of agropastoral economies and socioeconomic complexity in the Lake Titicaca Basin.

1. Introduction

The peopling of the South American high Andes was a crucial process in human population history (Aldenderfer, 2006, 1998; Capriles and Albarracin-Jordan, 2013; Haas et al., 2017; Núñez et al., 2001; Osorio et al., 2017b; Rademaker et al., 2014; Rick, 1980; Yacobaccio and Morales, 2005). At the center of the Andean highlands is the Altiplano, an expansive plateau ecosystem consisting predominantly of grasses and shrubs, and characterized by cold temperatures, low primary productivity, and a hypoxic atmosphere (Osorio et al., 2017b; Yacobaccio and Morales, 2005). The settlement of this region represents not only a remarkable feat of human adaptation to extreme conditions, but also the beginnings of a trajectory to endogenous agropastoral economies and the rise of one of the earliest Andean state-level societies, Tiwanaku, between 500 and 1100C.E. (Goldstein, 2013; Hastorf et al., 1999; Janusek, 2008; Stanish, 2003). The socioeconomic systems of the Archaic Period (11.7–3.5 cal. ka) clearly addressed the adaptive challenges of the region (Aldenderfer, 2009; Aldenderfer and Flores Blanco, 2011; Capriles and Albarracin-Jordan, 2013; Osorio et al., 2017b; Rademaker et al., 2014). Yet the adaptive mechanisms remain poorly understood. This study examines Archaic Period faunal assemblages from the Ilave region on the Peruvian side of the Titicaca Basin to advance our understanding of Archaic subsistence economies—how they changed over time and how they set the stage for Formative Period developments after 3.5 cal. ka.

During the Titicaca Basin Archaic periods, subsistence economies depended on foraged foods and other products (Aldenderfer, 1989; Aldenderfer and Flores Blanco, 2011; Klink and Aldenderfer, 2005). Numerous investigations have identified domestic campsites in the Lake Titicaca Basin, characterized by abundant lithic artifacts, faunal remains, and groundstone. Permanent structures and ceramics are absent, indicating a relatively mobile lifestyle (Craig, 2012; Haas and Viviano Llave 2015; Watson and Haas, 2017). The ubiquity of projectile points and large-mammal bone suggests heavy investment in hunting wild camelids and deer, the two large-mammal taxa endemic to the region during the Holocene (Chen et al., 2022; Haas et al., 2017; Kitchel et al., 2022). However, human bone chemistry, dental wear patterns, and paleoethnobotanical analyses reveal a high degree of investment in plant foraging, particularly tubers (Chen et al., 2024; Haas et al., 2017; Haas and Viviano Llave, 2015). Stable isotope chemistry of human bone

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shows that plant foods comprised the primary food resource (∼80 %) with mammals playing a secondary role (<20 %) and fish playing a negligible role (Chen et al., 2024). Isotope chemistry further reveals that, although populations were residentially mobile, their mobility patterns were restricted to the highlands with no evidence of appreciable vertical transhumance that included the lowlands (Haas et al., 2017).

Although these general patterns likely pertain to most of the Lake Titicaca Basin Archaic Period, pronounced socioeconomic shifts occurred during the Terminal Archaic Period, 5.0–3.5 cal. ka. The emergence of ceramics and gold jewelry points toward incipient sedentism and hierarchy (Aldenderfer et al., 2008; Craig, 2012, 2005). Decreasing projectile point size suggests the appearance of archery technology alongside atlatl technology, and increased use of obsidian suggests expanding exchange networks (Flores-Blanco et al., 2023). Groundstone and starch grain evidence indicates the cultivation of potatoes (Rumold and Aldenderfer, 2016).

Despite these remarkable advances in our understanding of early diets in the Titicaca Basin, considerable uncertainty remains regarding early hunting practices in the region. With stable isotope data indicating that approximately 80% of the diet consisted of plant resources, zooarchaeological evidence reveals a strong emphasis on hunting large mammals including camelids and deer. Thus, while plant foods constituted the main dietary source, hunting played an essential role in supplementing the diet with protein, fats, and other nutrients not provided by plant foods alone. Previous reporting on the faunal assemblages from Archaic Period sites is absent or limited to small samples (Haas et al., 2020; Haas and Viviano Llave, 2015). Here, we present the first complete examination of faunal assemblages from three Titicaca Basin Archaic sites—Wilamaya Patjxa (WMP: 9.0 cal. ka), Soro Mik'aya Patjxa (SMP: 8.0–6.0 cal. ka), and Jiskairumoko (JSK: 5.0–3.0 cal. ka)—all of which are open-air residential sites located in close proximity to one another in the Ilave sub-Basin of the Titicaca Basin (Fig. 1). Building on existing research, we confront these faunal data with four competing behavioral models of Archaic subsistence practices: Diet Breadth, Risk Mitigation, Climate, and Herd Management models (Table 1). We furthermore consider taphonomic effects in structuring the faunal assemblages. Specifically, we examine the extent to which these models anticipate patterns in taxonomic representation, age profiles, element representation, and fragmentation patterns. The goal is to identify the model or models that best account for faunal assemblage structure and change over time. Here, we outline the models under consideration and their predictions for faunal assemblages (Table 1).

1.1. Diet Breadth model

The diet breadth model (DBM) provides a framework for understanding human dietary practices across different ecological settings and over time. According to the DBM, optimally foraging hunter-gatherers initially prioritize the capture and consumption of high-yield prey (Bird and O'Connell, 2006; Broughton and Grayson, 1993; Hames and Vickers, 1982; Smith, 2015; Stiner and Munro, 2002). As high-yield resources become less abundant or more difficult to capture due to resource depletion, human population growth, or environmental shifts, foragers broaden their dietary spectrum to incorporate less-productive taxa, including small mammals, plants, aquatic resources, insects, and birds.

Diet breadth expansion can be identified through faunal signatures in zooarchaeological assemblages. Assemblages from the earliest periods, representing the initial inhabitants of a location, are expected to display limited diversity with a predominance of large, high-ranked prey. In contrast, assemblages from later periods are anticipated to show greater faunal diversity, reflecting a growing reliance on lower-ranked prey (Grayson and Delpech, 1998; Stiner and Munro, 2002).

The DBM also anticipates secondary effects on faunal assemblages. A decline in large mammal populations would furthermore result in greater transport distances as foragers travel greater distance to procure increasingly rare large mammals. This dynamic anticipates more complete skeletal representations in early assemblages and more uneven representation, including increased hindquarter elements, in later assemblages (Faith and Gordon, 2007; Schoville and Otárola-Castillo, 2014). The impact of the decline in large mammal populations and increased transportation costs can also be seen in bone fragmentation patterns. As higher-ranked game becomes rarer, foragers are

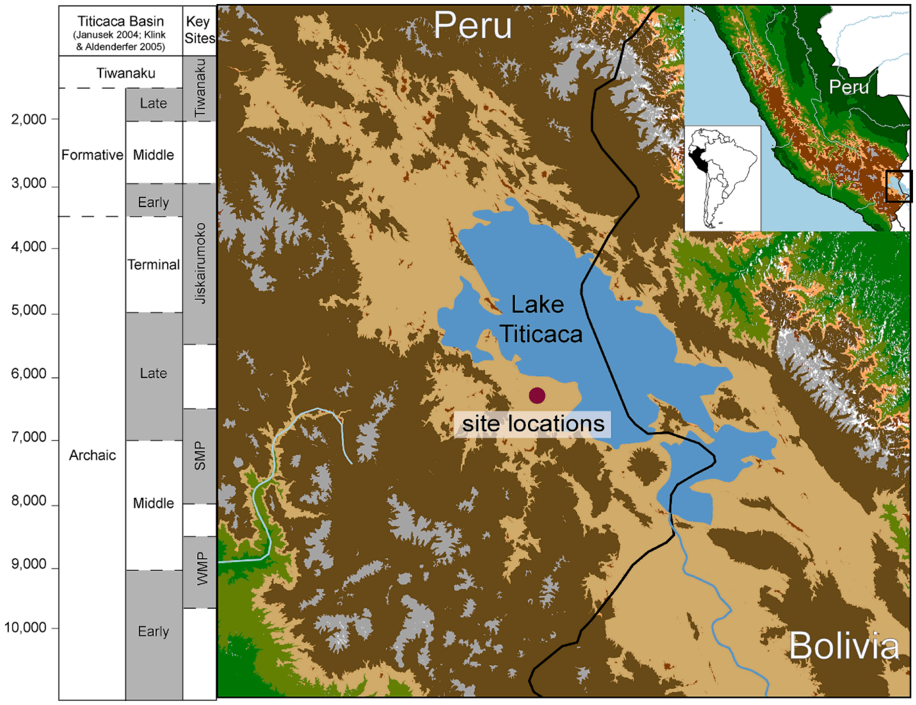

Fig. 1. Map showing the Titicaca Basin with the locations of the archaeological sites Jiskairumoko, Soro Mik'aya Patjxa, and Wilamaya Patjxa, accompanied by a temporal scale in years before present (BP) for site occupation periods.

Table 1
Formation models and predictions for zooarchaeological assemblages.

Model	Taxonomic profile	Age Profile	Body Part Representation	Bone Fragmentation	Skeletal Morphology
Diet Breadth	Diversification over time with early emphasis on large taxa	Adult inflated	Increasing differentiation over time	Increasing fragmentation through time	Constant
Risk Management	High diversity in all periods	Population profile	Complete carcass	Always high fragmentation	Constant
Climate Model	Large prey emphasized during favorable period, greater diversity during arid periods	Adult bias during favorable periods, increase in juvenile prey during arid periods	Complete carcass in favorable periods, increasing differentiation during arid periods	Less fragmentation in favorable periods, more in unfavorable	Constant
Herd Management	Large mammals consistently emphasized, domesticated species increase over time	Increase in juvenile camelids through time	Increasing completeness over time	Constant	Increase through time
Taphonomic process	Selection bias towards robust bones from large animals	Selection bias for older animals	Preservation favoring dense over porous bones	Fragmentation correlated with age	NA

Table 2
Faunal remains by taxa, number of identified specimens (NISP) and mass from WMP, SMP, and JSK.

Taxa	Common Name	JSK		SMP		WMP	
		NISP	mass (g)	NISP	mass (g)	NISP	mass (g)
Mammalia							
Camelidae	Camelid	576	1,152.13	54	127.88	27	21.81
	Camelid (c.f.)	21	69.23	16	52.32	12	3.72
Cervidae	Deer	38	30.31	17	44.86	3	8.89
	Deer (c.f.)	5	6.04	6	8.01	10	5.78
Artiodacyla	Artiodactyl	143	197.17	108	142.47	68	373
Carnivora	Carnivore	1	0.28	1	0.87	0	0
Rodentia	Rodent	0	0	4	0.41	0	0
Aves							
Anatidae	Duck	3	0.87	4	0.78	0	0
Total Identified		787	1,456.03	210	377.6	125	413.2
Undetermined							
Mammal Large		13,032	3,243.94	3198	725.06	462	115.86
Mammal Large/Medium		323	359.03	173	126.46	32	30.34
Mammal Medium		2	0.41	3	3.51	0	0
Mammal Small		67	6.65	22	2.21	1	0.11
Mammal Indeterminate		2,739	179.48	1166	155.84	889	61.51
Bird Indeterminate		9	1.11	16	0.99	1	0.14
Fish Indeterminate		3	0.11	3	0.29	0	0
Total Unidentified		16,175	3,790.73	4,581	1,014.36	1,385	207.96
Total		16,962	5,246.76	4,791	1,391.96	1,510	621.16

increasingly motivated to extract additional calories and nutrients from each harvested animal, leading to a greater degree of bone processing and fragmentation over time. Thus, early assemblages are expected to show low fragmentation of large mammalian bones, while later assemblages show high fragmentation rates (Stiner, 2002). Finally, the model anticipates a decline in the average age of large game animals over time as continued harvesting fundamentally reduces the average age of animals in the population (Smith, 2015; Stiner and Munro, 2002). In the broad artifact assemblage, tools related to animal procurement and processing will include hunting implements such as projectile points and scrapers (Aldenderfer, 2002; Craig, 2011).

1.2. Risk management

Risk management as a theoretical framework offers a viable lens for understanding subsistence strategies, particularly in diverse and unpredictable environments. In this framework, risk is conceptualized as the probability of securing sufficient resources, encompassing both their actual availability and the likelihood of successfully obtaining them (Bliege Bird and Bird 2008; Marston, 2011; Stirling, 2003; Winterhalder et al., 1999). Uncertainty, on the other hand, pertains to the limitations in an individual's knowledge about these probabilities (Clark, 2019; Winterhalder, 1986). This uncertainty is particularly pronounced in environments where resources are not only scarce but also unevenly distributed, both spatially and temporally.

To mitigate food insecurity and enhance resilience in marginal and unpredictable environments, human groups could have adopted a variety of risk-reduction strategies (Cashdan, 1985; Jochim, 1998; Kennett and Marwan, 2015; Winterhalder, 1986; Winterhalder et al., 1999). Diversifying food sources to avoid reliance on a single, potentially unreliable resource would have been a major approach. Such diversification could manifest in a broad spectrum of foraging and hunting practices, targeting a wide range of species and exploiting different ecological niches. In contrast to the DBM, which envisions gradual incorporation of low-ranked taxa, a risk mitigation model anticipates incorporation of diverse taxa across all time periods. The risk management model furthermore suggests that both adult and young mammals would have been harvested on encounter to ensure food security. With declining prey populations, a shift in carcass completeness is expected, characterized by an increase in hindlimb elements (Stahl, 1999). The model also predicts that the hindquarter bones would undergo more intensive processing to extract grease and marrow, leading to high rates of bone fragmentation at the sites (Alunni and Zangrando, 2024). In the broad artifact assemblage, animal-related tools will be limited to hunting implements (Aldenderfer, 2002; Craig, 2011).

1.3. Climate model

The climate model offers a framework for assessing changing subsistence strategies in relation to shifting environmental conditions

(Burke et al., 2017; Morgan, 2009; Rick et al., 2020). Subsistence patterns reflect the opportunities afforded by the prevailing climate, and as climate changes, subsistence strategies are expected to adjust accordingly, with faunal assemblages reflecting these changes (Hockett, 2015; Rindel et al., 2017; Yaworsky et al., 2023). A shift from productive to unproductive conditions will affect the availability of food resources and, consequently, general subsistence patterns. One particular version of this model envisions that the loss of predictable and stable resources has the most significant impact on subsistence strategies (Codding et al., 2024; Morgan, 2009). Changes in faunal assemblages can be compared to climate changes to evaluate these hypothesized relationships (Armsworth and Roughgarden, 2003; Goland, 1991).

During more productive periods, subsistence strategies likely focused on high-yield prey, resulting in faunal assemblages dominated by large mammals (Aldenderfer, 2006; Codding and Jones, 2013). In contrast, less productive and unpredictable climatic periods would reduce large-mammal populations, encouraging more diverse subsistence strategies and a broader spectrum of taxa (Morgan et al., 2017). Thus, a model that is climate-driven anticipates differences in faunal assemblages corresponding to more and less productive periods. To evaluate such effects, skeletal representation, age, and processing intensity of faunal remains can be correlated with climate proxy data (Byers and Broughton, 2004; Jones, 2015; Yacobaccio et al., 2017). During periods of abundance, the climate model predicts more complete skeletal representations of large, adult prey due to their greater availability and reduced transportation and processing needs. Conversely, during climatic downturns, increased transport distances and higher processing intensity would lead to more uneven skeletal representations, higher bone fragmentation rates, and greater presence of younger prey and more hindquarter elements (Byers and Broughton, 2004). Tools associated with animals identified in the broad artifact assemblage will be associated with hunting (Aldenderfer, 2002; Craig, 2011).

1.4. Herd management

The herd management model is a framework focused on the transition from hunting to the management of specific prey species (Brusgaard et al., 2022; Culley et al., 2021; Gasco and Marsh, 2015; Grant, 2017; López et al., 2017; Samec et al., 2018; Sasson, 2016). Evidence suggests that early hunters often employed sophisticated, specialized hunting strategies, maintaining a narrow diet breadth through the targeted hunting of specific animals (Horwitz et al., 1999; Mengoni Goñalons and Yacobaccio, 2006; Moore, 2016; Munro, 2004). However, prolonged and targeted exploitation posed a risk of diminishing prey numbers or triggering avoidance behaviors in ungulate species (Miller et al., 2006; Stankowich, 2008). To mitigate these effects and sustain herds, early hunter-gatherers may have adapted their subsistence strategies, including conserving and managing certain taxa (Larson and Fuller, 2014; Sapir-Hen et al., 2016).

The herd management model posits that as humans transitioned from hunting to the management of specific prey species, discernible shifts in faunal assemblage structure should become evident over time. The model anticipates an increase in the proportion of managed taxa relative to non-managed taxa, independent of the size or rank of the prey. The model also predicts changes in age demographic profiles, skeletal representation, and skeletal morphology of managed species. Faunal assemblages reflective of specialized hunting methods will tend to show elevated frequencies of large adult prey, while assemblages of managed animals will tend to show a more even demographic profile, including increased juvenile and neonatal representation. This shift indicates the systematic management and breeding of animal populations, as it reflects controlled breeding and culling practices to maintain and grow the herd (Cartajena et al., 2007; Goñalons, 2008; Mutundu, 2005; Zeder, 2006). Changes in skeletal morphology, such as size and shape, are also expected in managed species, reflecting adaptations linked to the initiation and intensification of herd management and selective breeding practices. Management practices impact skeletal size and shape of the target species due to selective pressures favoring traits that enhance manageability, productivity, and the overall health of the herd (Cucchi et al., 2021; Gasco and Marsh, 2015; Hernández et al., 2021; Le Neün et al., 2023; Manning et al., 2015; Meadow, 2014). An example of this is the documented changes in the size of the first phalanges of camelids, stemming from morphological adaptations linked to the initiation and intensification of herd management and targeted breeding practices (Le Neün et al., 2023). Additionally, in the entire artifact assemblage there will be a noticeable shift in the tools identified, from those associated with hunting, such as projectile points and scrapers, to those associated with herding such as weaving tools (Alaica and Bélisle, 2023; Chen et al., 2022; Flores-Blanco et al., 2023).

1.5. Taphonomic processes

While models discussed thus far emphasize systemic processes, it's crucial to consider how post-depositional processes can affect faunal assemblages (Schiffer, 1983). Specifically, it is vital to determine if faunal patterns are shaped by human activities or natural processes such as trampling or weathering because natural taphonomic processes can hinder reliable conclusions about historical human activities (Lyman, 1994, 1987; Mondini, 2002). Failure to consider taphonomic processes risks false-positive identification of behavioral signals or, conversely, can mask behavioral processes, leading to false negatives.

When assessing a faunal assemblage, considering the impact of taphonomy is particularly important in bone fragmentation analysis. Natural fragmentation processes can mimic cultural practices like marrow or grease extraction, common among foragers and predicted by the diet breadth, risk, and climate models (Outram, 2002, 2001). Taphonomic effects can also compromise our ability to interpret other observed patterns, such as changes in body-part representation or the prevalence of lower-ranked prey, as predicted by the diet breadth and risk management models (Orton, 2012; Speth, 2012). Similarly, within the climate model framework, misinterpreting taphonomic changes as human activities can skew interpretations of faunal diversity and resource availability, making it hard to distinguish between natural and human-induced alterations in the assemblage. For the herd management model, if taphonomic processes mainly shape the assemblage, patterns like larger mammal remains or changes in species composition and carcass completeness may not accurately reflect herd management practices.

The relationship between bone density and fragmentation rate can be assessed to determine whether taphonomic processes have influenced the preservation of an assemblage. Taphonomic fragmentation processes predict density-mediated attrition, where lower-density skeletal elements exhibit higher fragmentation rates. In contrast, human-induced bone fragmentation does not necessarily show this relationship. If taphonomy is not identified as the primary factor influencing the patterns observed in the faunal assemblages, these patterns can be reliably linked to past human behaviors and decision-making processes (Lyman, 1994, 1987; Mondini, 2002).

1.6. Synthesis

Each of the models considered here offers archaeologically testable predictions for faunal assemblages (see Table 1). These models range from examining shifts from high-yield prey to diverse diets due to environmental changes and caloric needs, to strategies for mitigating resource scarcity and adapting to climatic variations, including the transition from specialized hunting to systematic prey management and domestication. Consideration of taphonomic processes helps avoid spurious conclusions about subsistence practices. Confronting these models with archaeological data, we aim to identify the model or models that best explain the Titicaca Basin Archaic faunal data and thus offer the most likely explanation of subsistence strategies for each time period under investigation.

2. Materials and methods

In order to evaluate the competing models for Archaic subsistence practices on the Andean Altiplano, our analysis examines faunal assemblages from three open-air archaeological sites whose occupations span the Altiplano Archaic, encompassing the region's first archaeological population of nomadic hunter-gatherers to the last hunter-gatherers who transitioned to early agropastoralism. The sites include Wilamaya Patjxa (ca. 9.0 cal. ka), Soro Mik'aya Patjxa (8.0–6.5 cal. ka), and Jiskairumoko (5.0–3.5 cal. ka), all of which share a common ecological setting on an alluvial plain in the Ilave sub-Basin of the western Titicaca Basin. While Wilamaya Patjxa and Soro Mik'aya Patjxa were occupied by mobile hunter-gatherer communities, Jiskairumoko was, by the end of its occupation, inhabited by some of the earliest semi-sedentary horticulturalists in the region. Their congruent ecological context paired with their distinct settlement patterns make them well suited for a diachronic analysis of subsistence strategies throughout the Archaic.

The faunal materials were recovered via several methods. For each cultural feature, up to 40L of sediment was recovered and examined by flotation. All other feature sediment was passed through a 1 mm screen to recover faunal and other archaeological materials. In addition, sediment from plow zone contexts was passed through 4 mm screens. These efforts resulted in the recovery of thousands of faunal artifacts, providing a rich data set for our analysis. On the one hand, the use of plow zone artifacts augments sample sizes. On the other hand, there is a risk of including temporally intrusive samples. As we discuss below, a robust suite of radiocarbon assays shows relatively constrained dates, thus reducing mixing potential. Nonetheless, we remain alert to this potentially confounding factor. Here, we provide an overview of these sites before presenting the zooarchaeological approaches to examining their faunal assemblages.

2.1. *Wilamaya Patjxa (ca. 9.0 cal. ka)*

Located within the Ilave Basin, Wilamaya Patjxa was predominantly occupied during the Early and Middle Archaic periods, ca. 9.0 cal. ka, by mobile hunter-gatherers (Haas et al., 2020; Smallwood et al., 2023). The site is marked by a moderate density of surface artifacts diagnostic of Early to Middle Archaic periods. Excavations revealed numerous cultural pit features and artifacts, including lithics, groundstone, animal and human bone, and charcoal. Radiocarbon dates on two human burials place the occupation around 9.0 cal. ka. The artifact assemblage paired with stable isotope analyses from human remains indicates that this region was permanently utilized by the Early Archaic inhabitants (Chen et al., 2024). The artifacts, specifically the abundance of projectile points paired with animal processing tools, give insight into a comprehensive toolkit catering to an array of large-mammal hunting activities, from prey capture to hide processing. Although the artifact collection underscores a strong hunting tradition, isotope studies on the bones of two Early Archaic individuals—one female and one male—from Wilamaya Patjxa indicate a plant-based diet with meat playing an important but lesser role.

2.2. *Soro Mik'aya Patjxa (8.0–6.5 cal. ka)*

Soro Mik'aya Patjxa is situated in the Ilave Basin and was occupied by mobile hunter-gatherers during the Middle and Late Archaic Periods (8.0–6.5 cal. ka) (Haas et al., 2017; Haas and Viviano Llave, 2015). Covering approximately 0.28 ha, the site initially revealed itself through a surface scatter of Archaic artifacts. Excavations spanning 50 m^2 uncovered 16 cultural pit features and 80,000 artifacts, which included lithics, human remains, animal bone, and charcoal, signifying episodic yet recurrent habitation. Radiocarbon dates from 19 samples establish the occupation between 8.0 and 6.5 cal. ka. The absence of ceramics and permanent architecture corroborates the mobile lifestyle of its occupants. A significant portion of the unearthed artifacts consisted of lithics from the Middle and Late Archaic Periods, suggesting practices of large mammal hunting. Additionally, the site predominantly featured burial pits and non-specific pits, likely used for storage or cooking. Dental wear analyses suggest a diet rich in terrestrial plants, especially tubers, supplemented by wild animals (Watson and Haas, 2017). Isotopic examinations show a plant-based diet with lesser contributions from meat (Chen et al., 2024) and further establish that the inhabitants of Soro Mik'aya Patjxa remained primarily in the highlands, showing no evident signs of transhumance into lower elevations (Haas et al., 2017).

2.3. *Jiskairumoko (5.0–3.5 cal. ka)*

Situated on the northern edge of the Rio Ilave Basin, Jiskairumoko is an expansive open-air site occupied from the Terminal Archaic Period (5.0–3.5 cal. ka) and spans about 0.55 ha. Mobility decreased over time, becoming fully sedentary by the end of occupation (Craig, 2005; Rumold and Aldenderfer, 2016). In contrast to Wilamaya Patjxa and Soro Mik'aya Patjxa, Jiskairumoko contained not just a dense distribution of lithic remnants, animal bone, groundstone, ocher, and charcoal, but also few ceramics, pit-house structures, and even gold (Aldenderfer et al., 2008; Craig, 2012). Twenty-five radiocarbon dates establish the site's occupation between 5.0 and 3.5 cal. ka, spanning 1500 years (Craig, 2005). While the presence of projectile points indicates a continued focus on hunting, their reduced size is characteristic of the Terminal Archaic and Formative periods and suggests the introduction of archery technology (Flores-Blanco et al., 2023; Kitchel et al., 2022). Notably, the groundstone artifacts from Jiskairumoko offer evidence for the cultivation or domestication of potatoes (*Solanum tuberosum*), aligning with theories that suggest the advent of plant cultivation during the Terminal Archaic Period (Bruno, 2006; Rumold and Aldenderfer, 2016). This trend towards sedentism and food production at Jiskairumoko contrasts markedly with the patterns observed in the earlier Wilamaya Patjxa and Soro Mik'aya Patjxa assemblages.

2.4. *Paleoenvironmental Context*

Lake Titicaca is highly sensitive to climate variations on interannual to millennial timescales, with significant fluctuations in lake depth throughout the Holocene confirmed through multiple paleoenvironmental proxies (Abbott et al., 2003, 1997; Baker et al., 2005, 2001; Cross et al., 2001; Guédron et al., 2023). Climate reconstructions indicate that Early Holocene conditions oscillated between warm and dry (11,500–10,000 cal. BP) and cooler, wetter periods (10,000–8,500 cal. BP) due to increased precipitation and glacial runoff. These shifts resulted in heightened outflow from Lake Titicaca and a more productive landscape. During the Middle Holocene (7,000–4,000 cal. BP), the climate became warm and hyper-arid, leading to diminished precipitation and increased evaporation. Consequently, the inflow into Lake Titicaca ceased, causing the lake to shrink by up to 100 m below modern levels and reducing much of the lake to shallow pools. After 3,050 cal. BP, the Lake Titicaca Basin experienced a gradual increase in rainfall, resulting in rising lake levels. These wetter conditions facilitated stable temperatures, with modern climate conditions becoming established by 3,000 cal. BP.

In the Ilave valley within the Lake Titicaca Basin where the three sites considered in this study are located, this research aligns with the history of terrace formation andregional climatic events (Rigsby et al., 2003). The aggradation of compound terraces corresponds to high precipitation periods and rising Lake Titicaca water levels which continued until around 8,000 cal. BP. This was followed by episodes of rapid downcutting linked to decreased precipitation and lower lake levels, impacting the river system and local habitats. The infilling of terraces after 4,000 cal. BP occurred during times of rising lake levels and increased sedimentation (Rigsby et al., 2003).

2.5. Faunal Analysis

We identified and analyzed the faunal remains from Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko following standard zooarchaeological methods (Reitz and Wing, 2008) and utilized comparative collections in the Collasuyo Archaeology Research Institute (CARI) in Puno, Peru. We recorded the primary data classes including taxonomic identification, element portion, side, length, weight, fusion status, burning, and any indication of gnawing and butchery. The majority of the faunal remains consist of rib and long bone shaft fragments, as well as unidentifiable bone fragments (UID). We assigned these specimens to categories of "Large Terrestrial Mammal" or LTM (e.g., deer or camelid), "Medium Terrestrial Mammal" or MTM (e.g., fox or other carnivore), and "Small Terrestrial Mammal" or STM (e.g., cuy or rodent) categories.

We calculated measures of relative abundance, including the number of identified specimens (NISP), biomass derived from measures of weight, skeletal element abundance (MAU), and minimum number of elements (MNE). Calculated from measures of weight, biomass is an estimate for the amount of meat associated with a bone based on measures of the weight of a bone (Reitz et al., 1987; Reitz and Wing, 2008). MNE is calculated by determining whether fragments are from the same element by assessing whether two elements overlap and whether they are from the same side (i.e., right or left). If the bone fragments do not overlap, then they may be from the same element and the MNE is 1 (Lyman, 1994). MAU or percentage MAU value is calculated by dividing MNE by the number of times that element appears in a complete skeleton.

The effects of taphonomic processes, including weathering and trampling, density-mediated attrition was evaluated (Lyman, 1994; Stahl, 1999). Density-mediated attrition assesses the breakage of more porous, and thus fragile bones against denser bones that can better withstand the effects of weathering and trampling (Lyman, 1994). We determined skeletal portion survivorship by dividing MNE (Minimum Number of Elements) values by expected MNE values given 100 percent survivorship (Lyman, 1994). We then plotted percent survivorship against previously calculated cattle-specific bone mineral density (BMD) values (Stahl, 1999) where $p \leq 0.05$ was considered significant. To examine bone fragmentation, we used the index of NSP:NISP (Outram, 2001; Wolverton, 2002).

To quantify species diversity within the faunal assemblages, we utilized the Shannon index (H') and Simpson's index (D). These indices are commonly used in zooarchaeology to measure the richness and evenness of species distribution in assemblages. We computed both indices for each faunal assemblage to assess the diversity and to compare the relative contributions of different species across the three archaeological sites. The Shannon index (H') is calculated using the formula below where p_i is the proportion of individuals found in the i-th species. This index accounts for both the number of species (richness) and the relative abundance of each species (evenness), yielding higher values for assemblages with a more even distribution of species. An H' value close to 0 indicates low richness and uneven species distribution, while values approaching 2 or higher suggest greater richness and a more balanced representation of species. A Shannon index value between 0.5 and 1.5 indicates a dominance of camelids and deer, with minimal fish and bird presence; values nearer 1.5 suggest a more balanced species representation, while values closer to 0.5 indicate a strong focus on camelids.

$$H' = -\sum p_i \ln p_i$$

Simpson's index (D) is calculated using the formula below where p_i is the proportion of individuals found in the i-th species. Simpson's index measures the probability that two individuals randomly selected from a sample will belong to the same species. Lower values of Simpson's index indicate higher diversity. A D value close to 1 suggests low diversity (high dominance of a single species), whereas values approaching 0 indicate high diversity with more evenly distributed species. Therefore, values close to 1 (e.g., 0.8 to 0.9) will reflect low diversity with camelid dominance, whereas values near 0 (e.g., 0.3 to 0.5) suggest higher diversity with a mix of species like deer, fish, and birds. Overall, a temporal shift where the Shannon index decreases and the Simpson's index increases through time will reflect a shift from a broader subsistence strategy to a focus on camelids.

$$D = \sum p_i^2$$

We assessed the exploitation and utilization of artiodactyls, camelids, and deer through skeletal completeness. Camelid element frequency data were compiled along eight anatomical groupings: head (skull, mandible, teeth, atlas and axis vertebrae), axial (ribs and sternum, cervical, thoracic and lumbar vertebrae), forequarter (scapula, humerus, radius, and ulna), hindquarter (innominate, sacrum, femur, patella, and tibia), forefoot (carpal and metacarpals), hindfoot (tarsals and metatarsals), foot (metapodials, astragalus, calcaneus, sesamoids, and phalanges), and tail (caudal vertebrae).

To compare the deer to camelid ratio in faunal analysis through time, we systematically quantified and recorded the relative abundance of deer and camelid remains from archaeological sites across different temporal contexts. In Archaic Andean sites, a temporal shift from a balanced deer:camelid ratio to one increasingly favoring camelids is interpreted as the growing importance and management of these animals (Cartajena et al., 2007; Diaz-Maroto et al., 2021; Moore, 2016). We then analyzed these data to identify trends and shifts in the proportions of these species, providing insights into changes in hunting strategies, such as a shift from hunting wild deer and camelids to the targeted exploitation of camelids, a pattern previously identified in the Andean Archaic Period.

We assessed mortality profiles for camelids from each of the three sites via analyses of post cranial epiphyseal fusion. We grouped camelid elements into three categories based on fusion states: early fusion of subadults (12–18 months), intermediate fusion for breeding age camelids (18–36 months), and late fusion of mature camelids (36–48 months) (Kaufmann and Lorena, 2009; Kent, 1982). We used the proportions of fused and unfused postcranial bones to infer the age of death of camelids, providing insights into hunting and potentially herding practices (Mondini and Muñoz, 2017).

To evaluate the transportation distance of large mammals, we analyzed carcass completeness by examining the presence of various skeletal parts. The identification of only hindquarter bones typically indicates longer transport distances, as hunters will prioritize the most calorically dense parts (Monahan, 1998; O'Connell et al., 1990). Conversely, a more complete skeletal representation often indicates a reduced need for extensive transportation, as the entire carcass, being heavier, is typically only transported over shorter distances.

We collected measurements with calipers on first phalanges from adult camelids. Elements exhibiting evidence of thermal alteration or significant weathering were not included to control for the impacts of taphonomic weathering. We compared the latero-medial width and anterior-posterior width of the proximal epiphyses of the first phalanges against reference measurements from domestic and wild South American camelid species (Costa and Barri, 2018; Gasco and Marsh, 2015; Izeta et al., 2009; Kent, 1982; Mondini and Muñoz, 2017). The replicability and comparability of these osteometric measurements facilitated the differentiation and classification of various camelid species (Kent, 1982; Moore, 1989). However, significant size variability existed within the four camelid species, largely attributable to their extensive geographic distributions (Mengoni Goñalons and Yacobaccio, 2006; Wheeler, 1995). Notably, morphological diversity was previously observed in South American camelids (SAC), with smaller specimens identified in Peru compared to larger ones in southern regions. This was further complicated by the considerable size variation within llama populations that spanned intermediate to large size groups (Le Neün et al., 2023). Distinguishing between wild and domestic forms within the same genus, and between alpacas and llamas, is particularly challenging in archaeological contexts where all four taxa might coexist.

3. Results

This analysis resulted in the examination of 23,263 faunal artifacts from the three sites (Table 2). In the following sections, we present a site-by-site summary of the findings, illustrating the taxonomic composition, the age profile of the fauna, the breakdown of skeletal elements, the extent of fragmentation, and the impact of taphonomic processes. We then present a comparative analysis of the assemblages, which aims to assess patterns in subsistence practices within and across these archaeological contexts.

3.1. Wilamaya Patjxa (9.0 cal. ka)

The Wilamaya Patjxa assemblage, comprising 1,510 specimens, displays a notable lack of diversity in species with only wild camelids (vicuña or guanaco) and deer (taruca) identified. No other taxa were identified. The assemblage has a low species evenness and richness with a Shannon index of 0.928 and a low diversity as reflected by Simpson's index of 0.562. Among the identified specimens, 27 bones are from camelids and can be attributed to at least two different individuals, and 10 deer bones correspond to at least two distinct individuals. This results in a camelid:deer ratio of approximately 73:27. In assessing artiodactyl bones (camelid and deer), few elements are identified, but they are evenly distributed throughout the carcass (Fig. 3). Osteometric measurements of camelid phalanges and assessments of epiphyseal fusion are valuable for detecting changes in size over time and differentiating between wild and domestic camelid subspecies (Le Neün et al., 2023; Wheeler, 1999). However, we were unable to complete these measurements due to a lack of these elements in the assemblage.

The assemblage consists primarily of fragmented remains (95 %), mainly ribs and long bone pieces from large mammals. The index of fragmentation (NSP:NISP = 4.95) indicates that the carcasses of large mammals were heavily fragmented. To determine whether taphonomic processes influence this fragmentation, a density-mediated attrition analysis is conducted (refer to Fig. 2). This analysis, however, reveals no significant correlation between bone density and the likelihood of bone fragmentation (correlation coefficient r = 0.25, p = 0.37), suggesting that factors like weathering or trampling do not appreciably influence fragmentation (Stahl, 1999). Modifications by heat are the most common included burning and calcination (n = 111), with the majority of the burned bone (87 %) displaying a dark brownish color, indicating heating at less than 400 °C (Shipman et al., 1984; Stiner et al., 1995). Due to weathering, few cut marks (n = 4) are identifiable on large mammalian rib and long bone fragments, most likely from camelid or deer. Gnaw-marks and digestion corrosion that characterize assemblages impacted by birds of prey and carnivores are also absent.

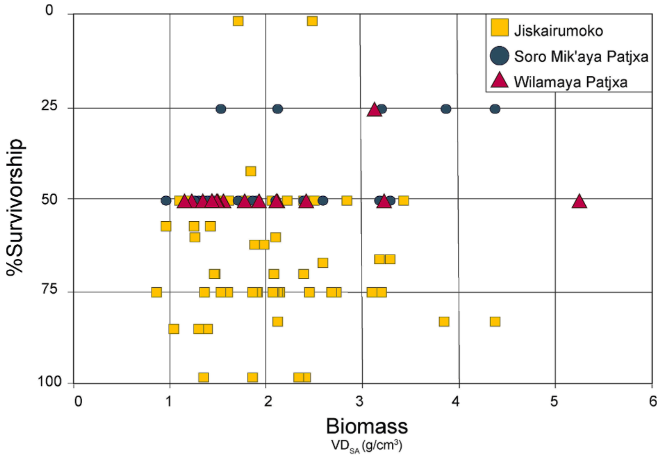

Fig. 2. Scatterplot depicting the correlation between biomass estimates and faunal remains' percentage survivorship at Jiskairumoko, Soro Mik'aya Patjxa, and Wilamaya Patjxa sites. The data show no relationship between bone mineral density and survivorship, indicating that taphonomic processes have had little effect on bone fragmentation. Rather, anthropogenic processes are more likely to have driven bone fragmentation at the three sites.

3.2. Soro Mik'aya Patjxa (8.0–6.0 cal. ka)

The Soro Mik'aya Patjxa site yields an assemblage of 4,791 specimens with a similarly limited diversity in species. The assemblage predominantly consists of large mammals including wild deer and camelids (n = 93), but also includes additional finds such as a carnivore element, a probable cuy (*Cavia* sp.) element, four duck elements (Family Anatidae), and three fish vertebrae. The Shannon index for this assemblage is 1.127 indicating a slightly higher species richness, and the Simpson's index is 0.612. Among the identified specimens, there are 54 camelid bones associated with four individuals and 17 deer bones linked to at least two individuals. This results in an increase in the camelid:deer ratio (76:24). Analysis shows elements distributed throughout the skeletons of both artiodactyls (camelid and deer) and camelids specifically (Fig. 4).

We completed osteometric analysis on only one camelid first phalanx with an anterior-posterior measurement of 14.4 mm and a latero-medial measurement of 18.8 mm (Table 3). The mortality profile, based on postcranial epiphyses fusion and isolated molars, indicates that the camelids consumed and discarded at the site are adults.

The assemblage is largely composed of fragmented large mammalian rib and long bones (67 %). The density-mediated attrition analysis conducted on this assemblage (refer to Fig. 2) does not show a significant correlation between bone density and survivorship (r = -0.19, p = 0.11), suggesting that, like Wilamaya Patjxa, factors other than taphonomic processes are structuring the assemblage (Stahl, 1999). The higher fragmentation index (NSP:NISP = 17.77) at this site indicates an even greater extent of carcass fragmentation compared to Wilamaya Patjxa.

The assemblage shows evidence of heat modification, with the majority of burned bone displaying signs of exposure to temperatures around 400–500 °C but lacks evidence of gnaw marks or digestion corrosion typically caused by birds of prey and carnivores (Shipman et al., 1984; Stiner et al., 1995). Cut and percussion marks are observed on 28 large mammalian elements. These observations suggest that the majority of fragmentation is related to systemic cultural processes with relatively little effect of natural fragmentation processes.

3.3. Jiskairumoko (5.0–3.5 cal. ka)

The assemblage from Jiskairumoko contains 16,962 specimens, primarily comprising large-bodied mammals, along with the identification of a carnivore bone, elements from three ducks (Family Anatidae), and three fish vertebrae. A notable aspect of this site is the scarcity of small mammalian elements, the few of which are too fragmented for identification, suggesting a minimal dietary contribution from small mammals such as cuy (*Cavia* sp.). The Shannon diversity index for Jiskairumoko is 0.708 and Simpson's index is 0.388, indicating low diversity among a limited species range. Of the identified specimens, the assemblage includes 576 camelid elements, representing 16 individuals, contrasted with 38 deer elements from 5 individuals. This results in an increase in camelid exploitation with a camelid:deer ratio of 94:6. Elements are again found to be distributed across the entire carcasses of large herbivores (deer and camelid), as illustrated in Fig. 5. Additionally, linear measurements are conducted on 11 camelid first phalanges

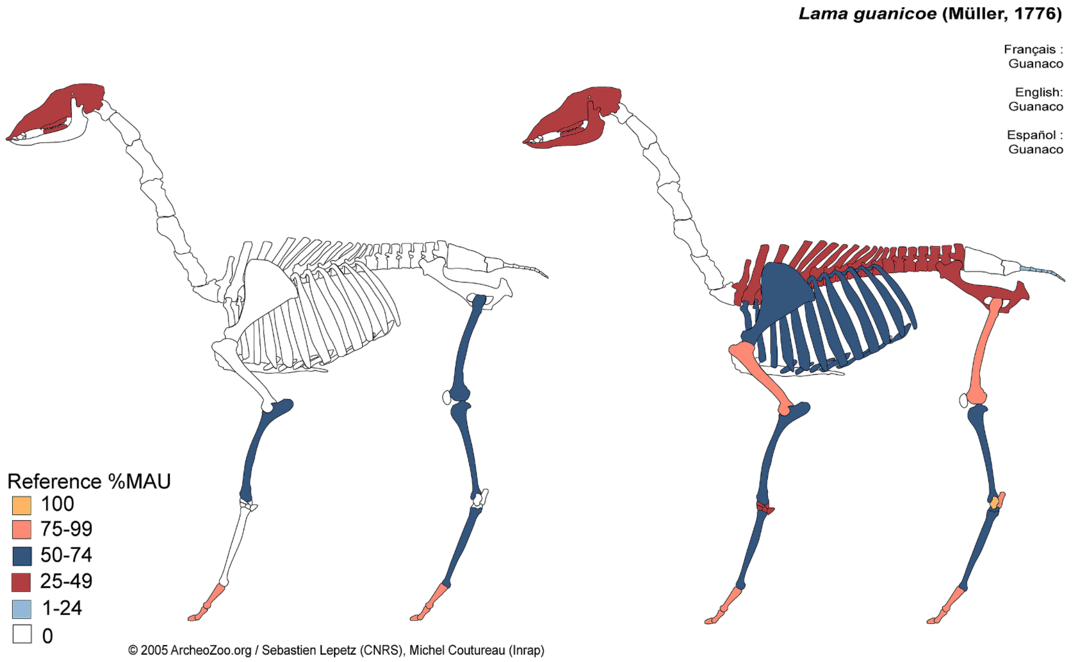

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Fig. 3. Color-coded diagram of guanaco (*Lama guanicoe*) skeletal part representation at Wilamaya Patjxa, based on the Minimum Animal Units (MAU) reference percentage, highlighting the most common skeletal parts found. Although only a small quantity of bones could be specifically identified as camelid (left illustration), the overall artiodactyl skeletal representation (right illustration), including camelid, deer, and unidentified large mammal bones, indicates high skeletal completeness. This suggests that entire carcasses of camelids and deer were transported to the site.

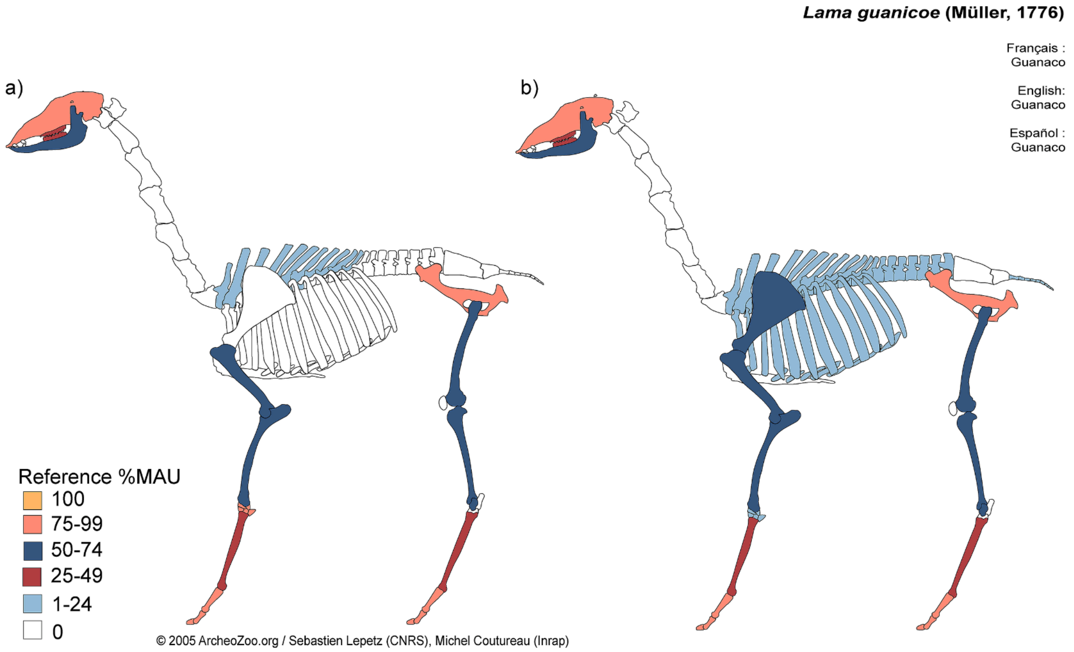

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Fig. 4. Color-coded diagram of guanaco (*Lama guanicoe*) skeletal part representation at Soro Mik'aya Patjxa, based on the Minimum Animal Units (MAU) reference percentage, highlighting the most common skeletal parts found. Camelid bones are identified throughout the skeleton (left illustration), and the overall artiodactyl skeletal representation (right illustration), including camelid, deer, and unidentified large mammal bones, indicates high skeletal completeness. This suggests that entire carcasses of camelids and deer were transported to the site.

with anterior-posterior measurements ranging from 16.9 mm to 21.0 mm and latero-medial measurements ranging from 16.8 mm to 17.7 mm (Table 3). Mortality profiles for camelids, based on postcranial fusions, predominantly reveal adult specimens, with an absence of newborns but the presence of juvenile elements. This indicates that the camelid population was mainly composed of adults, with juveniles also present.

The majority of this collection comprises fragmented large mammalian long bones (72 %). Additionally, elements are identified throughout the carcass, suggesting minimal transportation costs. Despite signs of natural effects such as gnawing by rodents and carnivores, and some weathering, a density-mediated attrition analysis (see Fig. 2) indicates no significant correlation between survivorship and bone density (r = 0.10, p = 0.43), suggesting minimal impact from taphonomic processes on the preservation of fauna. The fragmentation

Table 3
Comparative Measurements of anterior-posterior and latero-medial Breadths at Soro Mik'aya Patjxa and Jiskairumoko.

Site	Anterior-Posterior	Latero-Medial	Site	Anterior-Posterior	Latero-Medial
Soro Mik'aya Patjxa	14.4	16.8	Jiskairumoko	18.8	17.4
Jiskairumoko	16.9	16.8	Jiskairumoko	19.3	17.1
Jiskairumoko	17.9	16.8	Jiskairumoko	19.7	16.5
Jiskairumoko	18.1	17.2	Jiskairumoko	20.2	16.6
Jiskairumoko	18.3	16.7	Jiskairumoko	20.9	17.5
Jiskairumoko	18.4	15.8	Jiskairumoko	21.0	17.7

index (NSP:NISP = 18.06) underscores the extensive fragmentation of large mammal carcasses.

Evidence of human processing is seen from the 139 cut marks found on camelid, deer, and unidentified mammalian long bones. These marks, varying in size, shape, and location, offer insights into butchering practices, with marks on long-bone epiphyses and irregular bones like vertebrae, astragali, and scapulae suggesting meat separation and carcass dismemberment. About a third of the assemblage (32 %) shows signs of burning, ranging from light brown to white or calcined bones, indicative of varying exposure temperatures. Most of the lightly burnt unidentified fragments suggest possible boiling, with a smaller proportion of thermally altered camelid specimens, primarily at the epiphyses.

3.4. *Comparisons through time*

The Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko Archaic sites exhibit uniformly low species diversity, mainly featuring large-bodied herbivores (Fig. 6). This lack of diversity precludes models of dietary breadth expansion and risk aversion. Wilamaya Patjxa contains the highest evenness (0.845) among its limited species range, despite a low Shannon index (0.928) and a Simpson's index (0.562). In contrast, the Soro Mik'aya Patjxa assemblage yields a slightly higher diversity (Shannon index 1.127, Simpson index 0.612) but with less evenness (0.629). Jiskairumoko records the lowest diversity (Shannon index 0.708, Simpson index 0.388) and uneven species distribution.

Moving beyond initial assessments of species diversity, an analysis of animal exploitation through the camelid:deer ratio highlights shifting patterns in animal use over time (Fig. 7). The data indicate a progressive increase in the preference for camelids relative to deer over time. At Wilamaya Patjxa (9.0 cal. ka), 73 % of the deer and camelid remains were camelids, increasing to 76 % at Soro Mik'aya Patjxa (8.0–6.5 cal. ka), and reaching 94 % at Jiskairumoko (5.0–3.5 cal. ka). The logistic regression analysis using NISP data supports this trend, indicating a statistically significant increase in camelid remains relative to deer remains with each temporally successive site (coefficient = 0.70 ± 0.21, $p < 0.01$). However, it is important to note that the use of NISP (Number of Identified Specimens) data could potentially create a false positive result, as it does not account for potential biases such as differential preservation or recovery rates. Conversely, the logistic regression on MNI data reveals some uncertainty (coefficient = -0.56 ± 0.53, $p = 0.29$), but this may be due to the small sample sizes, which limits our ability to detect a statistically significant trend. While the high p-value does not rule out the possibility of a trend, it suggests that further data recovery would help clarify the pattern. The faunal data thus reveal a likely trend of increasing reliance on camelids, highlighting a transformation in hunting and herding practices over the millennia.

In the study of artiodactyl bones, including both camelids and deer from the Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko sites, elements were found distributed across the carcass (Figs. 3-5) with no evidence for an abundance of hindquarter bones. This pattern suggests that hunters transported carcasses over relatively short distances. It is noteworthy, however, that the limited number of camelid bones from Wilamaya Patjxa and Soro Mik'aya Patjxa restricts our understanding of transportation costs at these sites. In contrast, the presence of bones from various parts of the camelid carcass at Jiskairumoko indicates short transportation distances. Additionally, the overall completeness of large mammal skeletons, when considering all large artiodactyl bones,

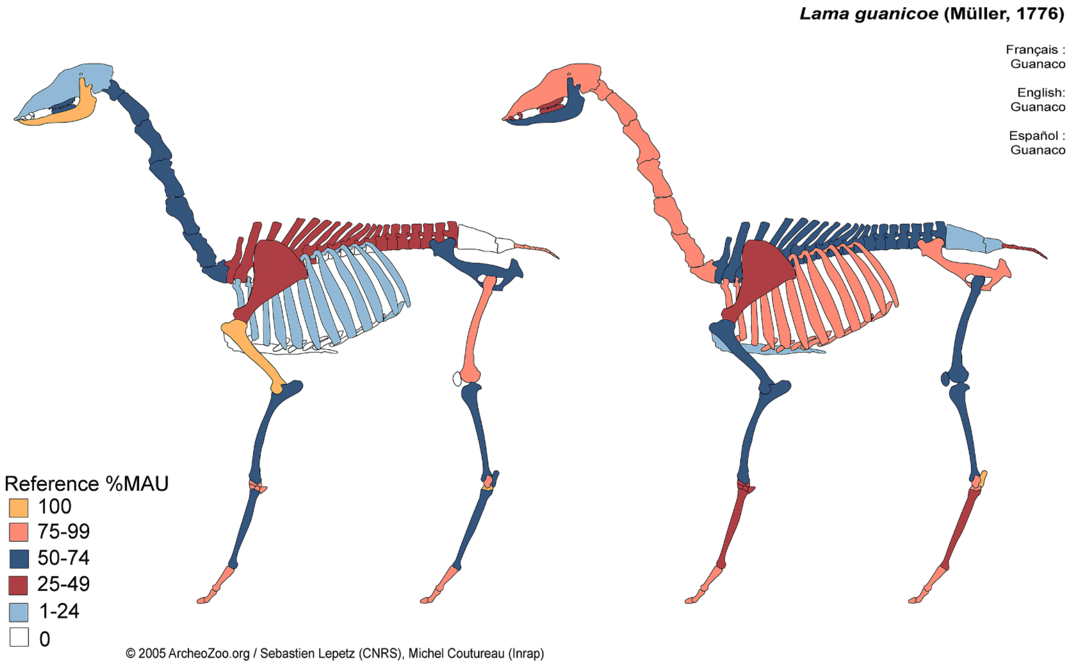

Fig. 5. Color-coded diagram of guanaco (*Lama guanicoe*) skeletal part representation at Jiskairumoko, based on the Minimum Animal Units (MAU) reference percentage, highlighting the most common skeletal parts found. Both the camelid (left illustration) and overall artiodactyl (right illustration) skeletal representations (included camelid, deer, and unidentified large mammal bones) have high skeletal completeness. This suggests that entire carcasses of camelids and deer were transported to the site.

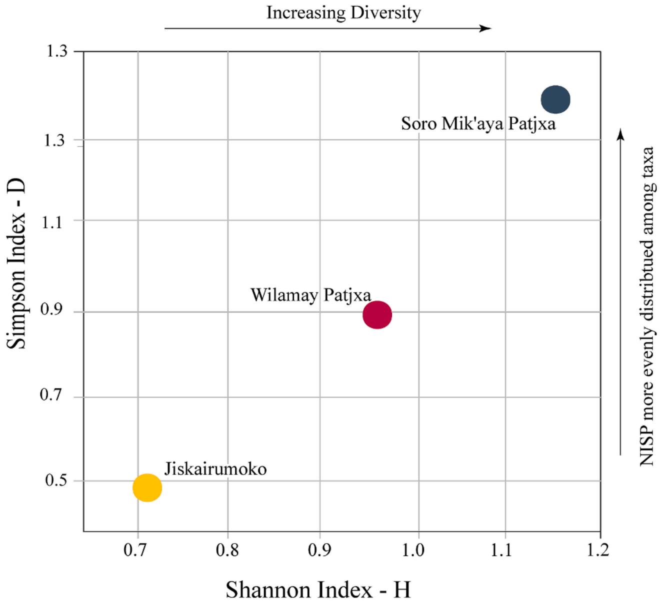

Fig. 6. Comparative plots of ecological diversity indices at Jiskairumoko, Soro Mik'aya Patjxa, and Wilamaya Patjxa, featuring the Shannon Index (H) on the left and the Simpson Index (D) on the right, with standard error bars. Soro Mik'aya Patjxa has the highest diversity and evenness in taxonomic representation, while Jiskairumoko has the lowest, with Wilamaya Patjxa having intermediate values for both indices.

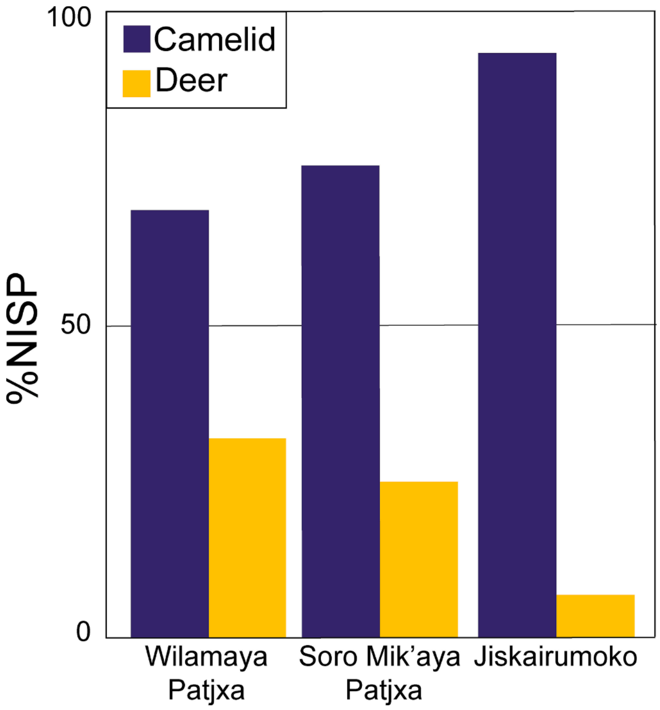

Fig. 7. Bar chart comparing the proportions of camelids and deer at the Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko sites, categorized by the Number of Identified Specimens (NISP) percentages. This deer:camelid ratio demonstrates an increase in the targeting of camelids from Wilamaya Patjxa through to Jiskairumoko and a corresponding decline in the acquisition of deer.

support the inference of consistently short transportation distances for large mammals during all three Archaic periods.

Osteometric analyses were conducted on the first phalanges of camelids from the Soro Mik'aya Patjxa and Jiskairumoko sites, with

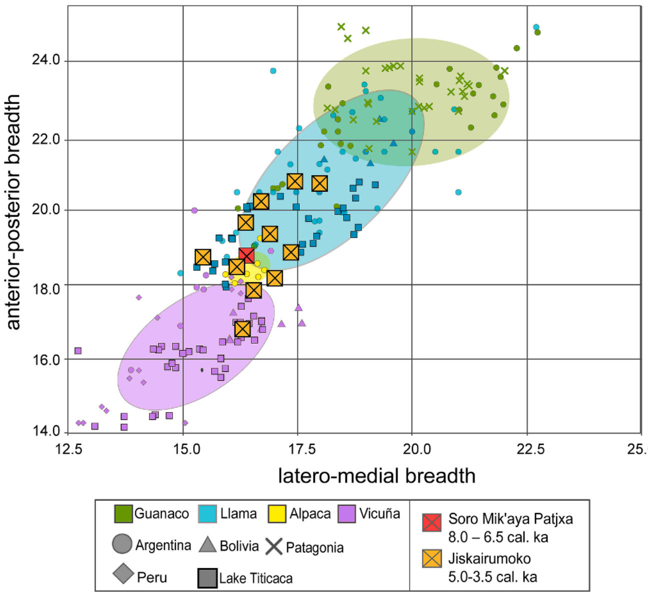

Fig. 8. Scatterplot illustrating morphometric variability in camelid phalanges, comparing anterior-posterior and latero-medial breadths across different taxa and geographic origins (Cartajena et al., 2009, 2007; Gasco and Marsh, 2015; Izeta et al., 2009; Kent, 1982; L'Heureux et al., 2010). The Soro Mik'aya Patjxa phalanx and the majority of the phalanges from Jiskairumoko fall between the measurements of wild guanaco and vicuña. These results are interpretive, as there are difficulties reliably differentiating between wild and domestic camelid forms via phalanx measurements (see Le Neün's, 2023).

measurements compared to established data for both domestic and wild South American camelid species (referenced in Table 3 and Fig. 8). The data were visualized using multivariate ellipses, constructed through covariance matrices to represent the 95 % confidence intervals for each group. This method statistically characterizes the distribution of measurements and helps differentiate between species groups based on their size and morphological traits. This analysis of the Soro Mik'aya Patjxa and Jiskairumoko assemblages suggests that the camelids belonged to either wild vicuñas, domestic llamas, or species undergoing domestication. These findings are consistent with a model of morphological and size changes in camelid phalanges over time and thus provisionally support shift toward herd management during the Late-Terminal Archaic transition. We underscore that while the evidence is consistent with the herd management model and suggestive, the limited sample size requires interpretive caution.

A comparative density-mediated attrition analysis across the Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko assemblages (Fig. 2) reveals a lack of significant correlation between bone density and fragmentation (Wilamaya Patjxa: r = 0.25, p = 0.37; Soro Mik'aya Patjxa: r = -0.19, p = 0.11; Jiskairumoko: r = 0.10, P = 0.43), suggesting that taphonomic processes like weathering or trampling were not the primary drivers of fragmentation (Stahl, 1999). Despite signs of natural effects like gnawing and weathering, the consistent lack of correlation between survivorship and bone density across all sites implies that the observed fragmentation patterns were more likely a result of human activity. This is consistent with practices observed in contemporary assemblages across the Altiplano where such fragmentation was interpreted as a technique for marrow and grease extraction from bones (Capriles et al., 2018; Capriles and Albarracin-Jordan, 2013).

The density-mediated attrition analysis indicates that natural transformation processes alone cannot account for bone fragmentation and that human activity was the major factor driving fragmentation. The Wilamaya Patjxa assemblage exhibited significant heat-related modifications on bones while only four cut marks were identified. In contrast, Soro Mik'aya Patjxa displayed thermal alterations at higher temperatures (400–500 °C) and more evident human interaction, with 28 bones showing cut and percussion marks. The Jiskairumoko site had the clearest signs of human processing, with 139 cut marks and a third of bones showing burn marks, suggesting systematic butchering and potentially cooking practices, as evidenced by the variation in burn patterns particularly on camelid bones.

The age profiles of camelids from the Soro Mik'aya Patjxa and Jiskairumoko assemblages were then assessed, providing insights into changes in animal use strategies (Table 4) (Klein, 1982; Zeder, 2006). A predominance of adult remains often suggests targeted hunting of healthy, mature animals, while a prevalence of juvenile remains could hint at more opportunistic hunting or environmental stresses, such as overhunting. A higher frequency of juveniles could also imply early evidence of breeding and managing of animal populations, contrasting with wild population age structures. In the case of the Wilamaya Patjxa assemblage, extensive bone fragmentation precluded precise age determination through epiphyseal fusion analysis. However, the camelid mortality profile for the Soro Mik'aya Patjxa assemblage, deduced from postcranial epiphyses fusion and isolated molars, suggests consumption of adult animals on-site, mirroring the pattern observed at Wilamaya Patjxa. At Jiskairumoko, the analysis primarily indicates the presence of adult camelids alongside the identification of elements belonging to juvenile camelids, while neonatal bones are absent. This analysis highlights a temporal transition from focusing on adult camelids to an increase in juveniles alongside adults (Table 5).

4. Model Evaluation

Having characterized the three zooarchaeological assemblages and their variation over time, it is now possible to confront the working explanatory models with the data. Again, we consider four behavioral models: diet breadth, risk management, climate, and herd management. The diet breadth model posited that hunter-gatherers initially target high-yield prey such as camelids and deer, expanding their diet to include less productive taxa as high-ranked resources dwindle due to depletion, population growth, or environmental shifts. In the Lake Titicaca region, early hunter-gatherers would have prioritized high-yield prey—camelids and deer—to meet high caloric demands while plant material constituted the majority of their diet. As large mammal resources became less abundant, foragers would have broadened their diet to include small mammals, plants, aquatic resources, insects, and birds. Early assemblages, such as Wilamaya Patjxa, would show limited diversity with many large, high-ranked prey, while later assemblages, like Jiskairumoko, would show increased diversity with higher quantities of lower-ranked prey. This shift would also lead to changes in hunting strategies, resulting in more incomplete skeletal representations due to greater transport distances, as well as a decline in the average age of large mammals and increased bone fragmentation rates due to more intensive processing.

Table 4
Age class distribution of camelids from Soro Mik'aya Patjxa and Jiskairumoko.

Fusion Category	Age Class	Soro Mik'aya Patjxa		Jiskairumoko	
		Fused	Unfused	Fused	Unfused
Early Fusion (12–18 months)	Newborn and Juvenile	2	0	18	2
Intermediate Fusion (18–36 months)	Young Adult	4	0	4	2
Late Fusion (36–48 months)	Adult and Senile	3	0	9	3
Total		9	0	31	7

Table 5
Formation models and predictions for zooarchaeological assemblages against WMP, SMP, and Jiskairumoko.

Criteria	Model					Site		
	Diet Breadth	Risk Management	Climate Model	Herd Management	Taphonomic process	Wilamaya Patjxa	Soro Mik'aya Patjxa	Jiskairumoko
Taxonomic profile	Diversification over time with early emphasis on large taxa	Adult inflated	Increasing differentiation over time	Increasing fragmentation through time	Constant	High proportion of high-ranked mammals	High proportion of high-ranked mammals	High proportion of high-ranked mammals
Age Profile	High diversity in all periods	Population profile	Complete carcass	Always high fragmentation	Constant	High proportion of adult high-ranked prey	High proportion of adult high-ranked prey	High proportion of adult high-ranked prey
Body Part Representation	Large prey during favorable period, greater diversity during unfavorable periods	Adult bias during favorable periods, increase in juvenile prey during arid periods	Complete carcass in favorable periods, increasing differentiation during unfavorable periods	Less fragmentation in favorable periods, more in unfavorable	Constant	Primarily hindlimb bones	Primarily hindlimb bones	Bones from entire carcass
Bone Fragmentation	Large mammals consistently emphasized, domesticated species increase over time	Increase in juvenile camelids through time	Increasing completeness over time	Constant	Increase through time	High bone fragmentation	High bone fragmentation	Low bone fragmentation
Skeletal Morphology	Selection bias towards robust bones from large animals	selection bias for older animals	Preservation favoring dense over porous bones	fragmentation correlated with age	NA	Change in phalanx size and shape	Change in phalanx size and shape	Change in phalanx size and shape

Our findings do not align with the DBM, instead, revealing consistently restricted taxonomic profiles and no apparent dietary diversification. Emphasis was on large herbivores, particularly camelids and deer, at all three sites. Extensive bone fragmentation, likely for marrow and grease extraction, in all three assemblages indicates sustained focus on high-yield prey. Skeletal completeness highlights consistent processing and transport practices over time. Although the DBM anticipates a focus on large-bodied mammals, it fails to anticipate a lack of diet breadth expansion over the five millennia represented by the Titicaca Basin. In contrast, analyses of Archaic Period faunal assemblages from the dry puna to the south reveal that the animal portion of the residents' diet included the exploitation of diverse resources, including high frequencies of artiodactyls and a variety of other prey such as medium-sized rodents, birds, and aquatic resources (Capriles et al., 2018; Hesse, 1984; Osorio et al., 2017a, 2017b). Prey choice in the dry puna thus may be more consistent with the DBM; however, systematic diachronic analysis is needed.

The risk mitigation model predicted diverse diets in all time periods as a mechanism for smoothing over temporal uncertainty in diverse and unpredictable environments. Prior research has explored how Archaic populations of the Andes may have implemented risk-reduction strategies, including diversifying food sources to avoid reliance on a single resource. This would result in a broad spectrum of foraging and hunting practices targeting a wide range of species (Pintar and Fernanda Rodríguez, 2022; Santoro et al., 2017; Zori and Brant, 2012). In this view, foragers of the high Andes would be expected to have pursued not only large mammals but also small mammals, fish, and birds. Species such as viscacha, wild cuy, ducks, coots, and freshwater fish would have consistently been on the menu alongside large prey such as wild deer and camelids.

The archaeological evidence from Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko does not support the expectations of a risk mitigation model. Rather, the data reveal a consistent preference for large herbivores, particularly camelids and deer, to the near exclusion of small taxa. Again, this subsistence pattern diverges from that which is documented in the southern dry puna, where Archaic communities appear to have diversified their prey and strategically chose hunting grounds to ensure access to both water and food (Pintar and Fernanda Rodríguez, 2022; Santoro and Núñez, 1987; Yacobaccio and Morales, 2005; Zori and Brant, 2012).

The climate model posited that dietary patterns were synchronous with climatic patterns. In the Lake Titicaca Basin, paleoclimatic reconstructions reveal a major shift from warm, humid conditions in the Early Holocene to a prolonged Middle Holocene drought between 9.0 and 4.2 cal. ka, and a return to warmer and wetter conditions by the Late Holocene (Abbott et al., 2000; Baied and Wheeler, 1993; Baker et al., 2005). A Titicaca Basin climate model for subsistence practice thus predicts similar subsistence strategies in the Early (Wilamaya Patjxa) Archaic periods and the Middle Archaic (Soro Mik'aya Patjxa) exhibiting distinct subsistence practices. During the Early and Late Holocene wet periods, which would have been climatically favorable periods, faunal assemblages are predicted to be characterized by an abundance of high-ranked prey like wild deer and camelids due to enhanced forage for those taxa. In contrast, the arid Middle Holocene would have reduced large-mammal populations, encouraging more diverse subsistence strategies and a broader spectrum of taxa, including waterfowl, fish, and smaller game. Additionally, the skeletal representation, age, and processing intensity of faunal remains are expected to correlate with climatic conditions and transportation costs, with periods of abundance showing more complete skeletal representations and lower bone fragmentation rates, and periods of scarcity exhibiting more uneven skeletal representations and higher fragmentation rates due to increased processing intensity.

The archaeological evidence fails to corroborate the anticipated dietary diversification or adoption of alternative fauna during the Middle Holocene dry period. The faunal assemblages from Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko show a remarkably uniform focus on large herbivores across the various climatic periods. Additional research has documented that the Altiplano's shift towards aridity around 8,000–4,000 cal BP prompted movements towards ecological refuges like Lake Suches in southern Peru, which provided vital moisture and acted as a haven for diverse species, including humans, during the mid-Holocene aridity (Vining, 2016; Vining et al., 2019). While this multimillennial drying period induced major socioeconomic changes, it does not appear to have disrupted large patterns in subsistence strategies within the Lake Titicaca Basin. Although we reject this Climate Model as an explanation for subsistence change, we acknowledge that environmental dynamics could have influenced the domestication process, a relationship that warrants further investigation.

The final model to evaluate is the herd management model, which considered changing relationships between people and their prey over time, presumably in response to increasing human populations and decreasing prey availability. For the Andean Archaic, this would have entailed a shift from camelid hunting to herd management strategies. As inhabitants moved towards managing camelids, camelid skeletal representation is expected to increase relative to deer in the time-transgressive archaeological assemblages. This model furthermore anticipates changes in camelid age demographics, skeletal representation, and skeletal morphology. Early assemblages, such as those at Wilamaya Patjxa, are expected to reflect camelid and deer hunting with an emphasis on adult animals. In contrast, later assemblages, especially Jiskairumoko, are expected to show increased presence of juvenile and neonatal bones, aligning with intensified management practices. Additionally, changes in the size of camelid first phalanges are anticipated, reflecting morphological adaptations linked to the initiation and intensification of herd management and selective breeding practices.

Our analysis of data from the Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko sites corroborates the predictions for this model, showing a sustained focus on camelids without diversification in diet or notable shifts to alternative prey types. Moreover, the data reveal an increase in camelid representation relative to deer over time, supporting the model's assertion of targeted camelid management. This proportional change, coupled with an increase in juvenile camelids at Jiskairumoko, suggests a move towards herd management, as younger animals' presence often signals human-led breeding and care practices. Moreover, the discovery of complete camelid carcasses at Jiskairumoko indicates localized herd management with minimal carcass transport, further validating the model. The persistence of camelid use over more than five millennia suggests remarkably sustainable animal management practices. Finally, in the broad assemblages from Wilamaya Patjxa and Soro Mik'aya Patjxa, the only tools identified that are associated with animals were projectile points, flakes, scrapers, choppers, and burnishing stones (Chen et al., 2022; Haas et al., 2020; Haas and Viviano Llave, 2015; Smallwood et al., 2023). Conversely, at Jiskairumoko, in addition to projectile points, scrapers, and flakes, other identified tools include an earthen spindle whorl and two wichuñas. The spindle whorl shows evidence of fiber spinning, while the two wichuña indicate that the residents wove textiles (Craig, 2005, 2011).

While phalanx measurements align with those of domestic camelids, further analysis is needed to increase the sample size and distinguish between wild and domestic types. A potentially confounding interpretation can be found in recent genetics research, which shows that vicuña may have been domesticated from a now-extinct camelid species (Le Neün et al., 2023). Lacking phalanx measurements on that extinct taxon, we cannot be sure that our measurements do not align with it as opposed to those of llama. Nonetheless, the collective findings support the herd management model of subsistence strategies of Archaic residents of the Lake Titicaca Basin who transitioned from hunting toward camelid management. No other model considered here so neatly captures faunal assemblage structure in the three sites and five millennia under consideration.

5. Management in high altitudes

The herd management model provides a comprehensive framework for interpreting faunal patterns and for deciphering the subsistence strategies of residents during the Archaic Period within the Lake Titicaca Basin. Our findings reveal a significant shift from specialized hunting to incipient camelid herding, which is the first line of evidence indicative of the broader process of animal domestication. Early research into the domestication of South American camelids was primarily focused in the Central Andes (Fig. 9). That research incorporated various analytical approaches, such as osteometry, age profiles, and dental morphology, as outlined in seminal works by Kent (1982) and Moore (1989). Critical to the research were the faunal remains from high-altitude cave sites in Peru's Puna region, including Uchcumachay, Pachamachay, Acomachay, and Telarmachay. These sites were pivotal in shaping the prevailing view of camelid domestication as evidenced by the extensive scholarly contributions over several decades (Kent, 1982; Moore, 1989; Pires-Ferreira et al., 1976; Wing, 1975). Detailed analysis of sites such as Uchcumachay, Panaulauca, and Telarmachay has revealed a steady increase in camelid use from 7450 to 4450 cal. BP, transitioning from generalized hunting to targeted camelid hunting and eventually leading to domestication (Pires-Ferreira et al., 1976). Wheeler's research (1995,1984, 2003) proposed the existence of domestic camelid management at Telarmachay as early as 6000 cal. BP, based on evidence such as high neonatal mortality rates and alpaca-like lower incisor morphology.

Recent studies in southern Peru, northern Chile, and northwestern Argentina have identified a pattern of camelid use intensification and domestication dating back to between 5000 and 3500 cal. BP (Fig. 9; Mengoni Goñalons and Yacobaccio, 2006). In the Puna regions of northwestern Argentina, osteometric and dental morphology data provide evidence of larger domesticated camelids around 4,400 cal. BP (Cartajena et al., 2007; Gallardo and Yacobaccio, 2005; Gasco et al., 2014; Yacobaccio, 2001). Allometric analyses at Tulan 52 and Puripica 1 in the Salar de Atacama of Chile indicate domestic llama management around 4,800–4,300 cal. BP (Núñez et al., 2005). The findings in this article suggest that the possible intensification of camelid use began sometime between 6,000 and 4,500 cal. BP, with the timing of camelid use intensification in the Lake Titicaca Basin consistent with broader patterns observed across the Andes (Mengoni Goñalons and Yacobaccio, 2006; Moore, 2016). It is important to note that recent genetic studies suggest a complex model of domestication with multiple domestication centers across the Andes (Díaz-Maroto et al., 2019, 2021; Barreta et al., 2013). Currently, it is not possible to identify interaction between Lake Titicaca and other possible centers of domestication including the Central Andes, Northwest Argentina, and Northern Chile. Further research will help clarify the spatial and temporal patterns of camelid domestication across the Andes.

Sites near the Lake Titicaca Basin have also yielded evidence of camelid domestication, albeit indirectly. At the Asana site in the Osmore basin of southern Peru, the presence of dung-derived soil deposits ringed by post-molds has been interpreted as evidence of corrals 4330 –4640 cal BP, suggesting the management of domestic camelids during the Terminal Archaic Period (Aldenderfer, 1998). Similarly, at Inca Cueva 7 in the Argentine Puna, dung pellets and an enclosing stone wall have been dated 4540–4468 cal BP (Aschero and Yacobaccio, 1998), representing some of the earliest evidence of such enclosures in the high Andes.

Our research presented here marks the first empirical evidence for a discernible shift from camelid hunting to herding within the Lake Titicaca Basin. The temporal shifts, marked by the increased exploitation of camelids relative to deer, the identification of juvenile camelids, the

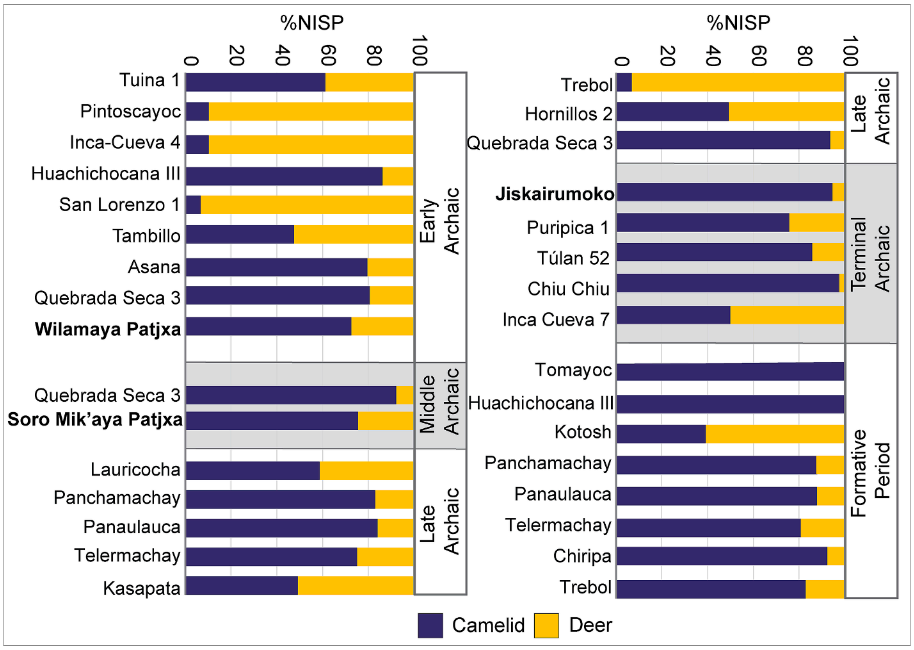

Fig. 9. Proportional distribution of camelid and deer remains in the Central and South Central Andes from the Archaic to Formative Periods, as determined by the Number of Identified Specimens (NISP). The proportions of camelid to deer from Wilamaya Patjxa, Soro Mik'aya Patjxa and Jiskairumoko are compared against Asana (Aldenderfer, 1998); Chiripa (Moore et al., 1999);Chiu Chiu (Cartajena, 1994); Hornillos 2 (Yacobaccio et al., 2013); Huachichocana III (Fernández Distel, 1986; Yacobaccio and Madero, 1992); Inca Cueva 7 (Aschero and Yacobaccio, 1998); Inca-Cueva 4 (Yacobaccio, 1994); Kotosh (Wing, 1972); Lauricocha (Wheeler et al., 1976); Pachamachay (Kent, 1982); Panaulauca (Moore, 1989); Pintoscayoc (Hernández Llosas, 2000); Puripica 1 (Hesse, 1982b; 1982a); Quebrada Seca 3 (Olivera and Elkin, 1994; Elkin, 1995); San Lorenzo 1 (Núñez, 1983); Tambillo (Hesse 1982a, 1982b); Telarmachay (Lavallée et al., 1985); Tomayoc (Lavallée et al., 1997); Treblo (Lezcano et al., 2010); Tuina 1 (Núñez, 1983a, 1983b); Túlan 52 (Hesse, 1982b; 1982a). Adapted from Fig. 3.3 (Moore, 2016) and Table 16.2 Archaeological Sites in the South-Central Andes (Mengoni Goñalons and Yacobaccio, 2006). The figure shows that the deer-to-camelid ratio at Wilamaya Patjxa, Soro Mik'aya Patjxa, and Jiskairumoko follows previously identified trends in the Andes that have been interpreted as the progressive intensification of camelid usage from the Archaic into the Formative Period, in line with the shift from hunting to herding.

presence of complete camelid carcasses, phalanx measurements, and the appearance of wichuñas, collectively suggest a transition from hunting to intensive camelid management among the Archaic residents of the Lake Titicaca Basin. The inferred transition and its timing align with domestication patterns noted across the Andes. The strategic pivot towards increased camelid exploitation—simultaneously diminishing the hunting of other species—reflects the Archaic inhabitants' calculated efforts to maintain the benefits of camelids despite growing human populations (Fig. 9). This economic transformation parallels the transition from mobile to sedentary settlements and signifies a broader societal evolution towards agro-pastoralism and increased social complexity during the subsequent Formative Period after 3.5 cal. ka.

The Lake Titicaca Basin has long been proposed as a pivotal region where escalating hunting specialization and intensification led to the development of management practices and, ultimately, camelid domestication (Aldenderfer et al., 2008; Lynch, 1983; Moore, 1989; Rick, 1980). The empirical data from this study lend the first substantial support to this longstanding premise. The scarcity of excavated Archaic sites on the Altiplano has previously limited our understanding of the behavioral shifts of early residents. However, our analysis of faunal deposits from three open-air residential sites sheds light on the deliberate choices favoring the pursuit, management, and the ultimate domestication of camelids.

Our research affirms Lake Titicaca Basin's pivotal role in the broader Andean trajectory of camelid domestication, aligning with prior research while contributing new insights into the early stages of this process. The domestication of camelids fostered increasing sociopolitical complexity, providing the necessary food resources to allow for the development of some of the earliest Andean states. The future integration of genetic studies is needed to resolve unanswered questions concerning the domestication of camelids in the Lake Titicaca Basin. Although the identification and analysis of the domestication of camelids is far from simple, the development and integration of new lines of evidence continue to offer new opportunities to understand this complex process.

CRediT authorship contribution statement

Sarah J. Noe: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft. **Randall Haas:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – original draft. **Mark Aldenderfer:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing.

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Declaration of competing interest

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

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