When The Mountain Turns Grey

How and why do Quechua communities in the Cordillera Vilcanota interpret and respond to glacial retreat and climatic disruption through indigenous knowledge systems, and how do these knowledge systems shape the trajectory of adaptation strategies in the region?

James Williams

SNHU, ATH-489

7-1 Final Submission: White Paper

Abstract

The glaciers of the Cordillera Vilcanota in southeastern Peru are retreating at accelerating rates, transforming the hydrological systems, pastures, and agricultural conditions on which indigenous Quechua communities depend. This paper examines how communities in the Ausangate region interpret and respond to glacial retreat and climatic disruption through indigenous knowledge systems, and how those systems shape the trajectory of adaptation strategies in the region. Drawing on glaciological and climatological research, ethnographic scholarship, direct personal communications, relayed family accounts, and public cooperative reporting the analysis identifies three distinct registers through which indigenous knowledge operates in the Vilcanota. These registers are practical astronomical forecasting, cosmological and ritual reciprocity with the apus and Pachamama, and embodied pastoral knowledge generated through daily herding practice. Applying sacred ecology (Berkes, 2018) as a primary theoretical framework, the paper argues that adaptation strategies embedded in existing cosmological, social, and institutional structures are more likely to be self-sustaining, while externally introduced strategies that depend on outside inputs are fragile and risk becoming liabilities when institutional support is withdrawn. The greenhouse agriculture case in Pukarumi provides the clearest trajectory evidence for this finding. The paper concludes with recommendations for climate adaptation policy that engages indigenous knowledge systems as substantive interpretive frameworks rather than supplementary data, and identifies future research directions including longitudinal forecasting study, downstream hydrological analysis, and underwater and terrestrial archaeology at Laguna Sibinacocha.

Statement of Purpose

Climate change is among the most pressing global environmental crises of our time, characterized by rising average global temperatures, accelerating glacial and polar ice loss, increasing frequency and intensity of extreme weather events, disruption of hydrological cycles, and sea level rise. The scientific consensus, supported by decades of atmospheric, oceanographic, and glaciological research, identifies the rapid accumulation of greenhouse gases from industrialization, deforestation, and fossil fuel combustion as the primary driver of these changes.

In late January and early February 2026, in the southern hemisphere, the Cordillera Vilcanota received an unseasonable snowstorm. February falls within the southern hemisphere's summer and the Peruvian Andes' rainy season, a period when high-altitude pastoralists expect wet but relatively mild conditions and when potato crops planted according to traditional astronomical calendars are in active growth. Near Laguna Singrenacocha, pastoralists affiliated with the Cultural Threads cooperative spent five consecutive days managing the crisis. Kristen Kempt of Cultural Threads reported on the cooperative's Instagram account that community members had resorted to clearing snow by hand using sticks, in the absence of shovels, struggling to create space for their animals to lie down. The snowfall was described as wet and lingering, qualitatively unlike the dry hail events that communities at this altitude are accustomed to weathering. According to those present, no storm of comparable intensity had been seen since July 2017, which falls in the southern hemisphere's winter and represents the more climatically expected season for severe highland weather (Cultural Threads [@cultural_threads], 2026).

In the nearby community of Pukarumi, situated in the shadow of Ausangate, one of the most sacred mountain spirits in the Quechua cosmological tradition, the storm exposed a division

in planting strategy that reflects the complexity of indigenous meteorological knowledge under conditions of increasing climatic unpredictability. As community member Wilian Crispin explained, some families had planted potatoes earlier in the season, following traditional forecasting methods based on stellar observation, a practice locally referred to as reading "*miran el tiempo.*" Those who planted early found that their crops had matured sufficiently to withstand the storm. Others who planted later, whether because their own astronomical readings predicted a different outcome or because they delayed for other reasons, suffered significant crop losses and were left requesting emergency assistance from the Peruvian government. Crispin noted that government support in such cases tends to be minimal (W. Crispin, personal communication, February 5, 2026).

The Cordillera Vilcanota is a mountain range in southeastern Peru, home to one of Peru's highest and most venerated peaks, Ausangate (6,384 meters), and to Laguna Sibinacocha, one of the largest alpine lakes in the world, sitting at 4,873 meters in elevation. The Sibinacocha Watershed is one of the primary headwaters of the Amazon River *(See Appendix A, Figure 1)*. What makes this region particularly significant is its situation within a tropical latitude, hosting the largest concentration of tropical glaciers in Peru outside of the Cordillera Blanca, as well as the Quelccaya Ice Cap, the largest tropical ice body in the world (Hanshaw & Bookhagen, 2014). Because of their tropical location, these glaciers exist in a constant state at or near their melting point, even absent from the effects of climate change. This makes the region particularly vulnerable, as minor shifts in atmospheric conditions can affect the glaciers before impacts are felt elsewhere in the world.

The region's unique glaciological character has made it a site of sustained multidisciplinary scientific research, spanning glaciology, climatology, paleolimnology, and

ecology. I have had the opportunity to witness this science firsthand. During a 2017 archaeological diving expedition in the region, I was among the divers who recovered a pre-Inca ceramic vessel from an underwater site in Laguna Sibinacocha, an artifact that researchers subsequently used to extract sediment cores providing a paleolimnological record of marked hydrological change spanning centuries (Michelutti et al., 2019). On a separate occasion in 2024, at the Universidad Nacional de San Antonio Abad del Cusco (UNSAAC), I attended a presentation by Dr. Anton Seimon of Bard College and Dr. Julio Postigo of Indiana University in which they detailed the ongoing work of locating the precise aerial vantage points used by the 1931 National Geographic Shippee-Johnson Expedition (Iris, 2019) and recreating those photographs from the same positions today. The resulting archive documents more than 90 years of glacial retreat across the Cordillera Vilcanota and illustrates the socioeconomic consequences of that retreat for rural communities in the region (Seimon & Seimon, 2025).

This region of Peru is home to numerous rural communities that primarily rely on agriculture and pastoralism. Communities raise alpaca, sheep, llama, and cattle at high altitude, while cultivating potatoes and other crops according to seasonal cycles informed by traditional astronomical observation. Some families also cultivate vegetables in small greenhouses; an adaptation introduced approximately fifteen years ago through an international development organization (G. Crispin, as cited in W. Crispin, personal communication, April 3, 2025). As highland pastures become less sustainable for grazing, some pastoralists have resorted to cutting grasses at lower elevations and transporting them up to where their herds are located (K. Kempt, personal communication, March 10, 2026). Culturally, these communities are predominantly Quechua, with some Aymara influence, and carry the deep imprint of Spanish colonialism. The older generations maintain knowledge systems that frame the relationship between community

and landscape in terms of reciprocity with sacred beings. As relayed by community member Wilian Crispin, his uncle Gumercindo Crispin of Pukarumi recounts that his father Severino taught that Ausangate is a sacred mountain considered to be a provider of water and protector of cultivated land, to whom community members direct ceremonial payments to ensure good planting and harvest throughout the year. Ceremonies of gratitude are also offered to the Pachamama, or Mother Earth, for productive yields, and these rituals are performed at Laguna Hariwanaku, located behind the headwaters of Sibinacocha in the high country (G. Crispin, as cited in W. Crispin, personal communication, April 3, 2025).

Research Question

The selected problem is the impact of climate change on indigenous Quechua communities in the Cordillera Vilcanota region of southeastern Peru. As established above, the region's tropical glaciers are particularly sensitive to rising temperatures, and their retreat is already reshaping the hydrological systems, pastures, and agricultural conditions on which these communities depend. This study asks: *How and why do Quechua communities in the Cordillera Vilcanota interpret and respond to glacial retreat and climatic disruption through indigenous knowledge systems, and how do these knowledge systems shape the trajectory of adaptation strategies in the region?*

The Cordillera Vilcanota has been the subject of sustained scientific inquiry spanning decades, producing a robust body of glaciological, climatological, and paleolimnological research that documents the pace and consequences of environmental change in the region. Ethnographic scholarship from this specific region is equally substantial, with researchers including Michael Sallnow, Karsten Paerregaard, and Allison Caine having produced detailed

accounts of Quechua cosmology, pastoral livelihoods, and community responses to environmental change in and around the Cordillera Vilcanota. Beyond published scholarship, I draw on firsthand and secondhand primary source material collected through my decade-long relationship with the region, including communications with community members in Pukarumi, observations from collaborators working with pastoralist communities near Laguna Singrenacocha, and my own participation in archaeological expeditions. This study does not include new ethnographic fieldwork in Peru; it is designed as a literature-based analysis supplemented by primary source communications gathered through established relationships. Taken together, these sources constitute a sufficient evidentiary base to support an interpretive anthropological analysis of climate adaptation in the Cordillera Vilcanota.

All personal communications cited in this paper were shared with the knowledge and consent of the individuals involved. The account of the February 2026 snowstorm draws on both public reporting by the Cultural Threads cooperative and private communications with Kristen Kempt, founder of Cultural Threads. Communications with Wilian Crispin of Pukarumi, including his relay of his uncle Gumercindo Crispin's account of community ceremonial practices, were similarly shared with awareness of their use in this research. These citations reflect ongoing collaborative relationships developed over a decade of engagement with the region, rather than extractive research practices. Gumercindo Crispin's accounts of ceremonial practice and greenhouse agriculture were accessed through Wilian Crispin's translation and framing, a mediation structure reflected in the layered citation format used throughout this paper. The implications of this evidence chain, including an additional generational layer through Gumercindo's father Severino, are addressed in the ethical implications discussion.

This research question holds value for the field of anthropology because it examines how a specific population understands and responds to environmental crisis through cultural and cosmological frameworks that are often absent from mainstream climate adaptation discourse. Anthropology is uniquely positioned to address this gap. Where climate science can document the rate and extent of glacial retreat, and where policy institutions can design adaptation programs, anthropology asks how the people living within these landscapes actually experience and make sense of the changes occurring around them, and what their own responses reveal about the adequacy of externally imposed solutions.

In the Cordillera Vilcanota, the relationship between communities and their environment is not solely material. It is cosmological. The glaciated peaks of the region, particularly Ausangate, are understood as living beings, *apus*, with whom communities maintain relationships of reciprocity and obligation. In a myth recorded by Sallnow (1987) from the community of Paqchanta, located in the shadow of Ausangate, the deity *Inkariy* warns apu Ausangate that if he is no longer revered and respected in the hearts of the people, final judgment will come, and the mountain will gradually turn grey, then black, until it becomes a mountain of black cinder (Sallnow, 1987, p. 212). That prophecy, recorded during fieldwork in the early 1980s, now converges with observable glaciological reality. The glaciers of Ausangate are visibly receding. For the communities who hold this cosmological framework, glacial retreat is not merely an environmental phenomenon; it is a sign legible within a system of moral and spiritual meaning that long predates the scientific study of climate change.

It is worth noting that this prophecy is not a straightforward expression of pre-colonial cosmology. The Paqchanta myth narrates the creation of Ausangate by *Inkariy*, but it also narrates the arrival of *Españariy* and the placement of a silver cross on the mountain's summit to

arrest its growth (Sallnow, 1987, p. 212). The prophecy emerges from a framework in which indigenous and colonial-Christian spiritual authorities are already in competition for the devotion of the people, and in which the mountain spirit's power is understood as waning in proportion to the spread of Christian worship on its slopes. The greying and blackening of Ausangate signals not climate change, but the final judgment that will come when the apu is no longer revered in the hearts of the *runa*. The prophecy's register is moral and cosmological, not environmental. Yet, this distinction may be less stable than it first appears. If the continued emission of greenhouse gases, undertaken with full knowledge of the damage being caused, constitutes its own form of moral failure, then the prophecy becomes legible across both registers, and the convergence between cosmological narrative and environmental reality becomes even more analytically productive precisely because the two registers remain distinct.

This convergence between cosmological narrative and physical transformation is precisely what makes the Cordillera Vilcanota a compelling site for anthropological inquiry. By examining how Quechua communities are adapting to the environmental changes caused by climate change, this study contributes to ongoing conversations within sacred ecology about how indigenous communities navigate environmental crisis on their own terms. It also contributes to a growing body of applied anthropological work that argues for the inclusion of indigenous knowledge systems in climate adaptation planning, not as supplementary or anecdotal, but as substantive frameworks for understanding and responding to environmental change.

Application of Theory

Several anthropological theories could be applied to analyze how Quechua communities in the Cordillera Vilcanota interpret and respond to glacial retreat. The primary framework

guiding this paper is *sacred ecology*, as articulated by Fikret Berkes (2018), who defines traditional ecological knowledge as "*a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment*" (p. 8). Sacred ecology insists that such knowledge cannot be understood apart from the cosmological, ethical, and social systems in which it is embedded, because worldview functions as "*the organizing concept behind the cultural ecology of a group, without which the logic of many traditional management systems would be difficult, if not impossible to access*" (Berkes, 2018, p. 79).

In the Vilcanota context, this means that stellar observation for rainfall forecasting, ceremonial offerings to the apus, and adjustments to pastoral habits should not be analyzed as isolated adaptive behaviors. They are expressions of a cosmological system in which the mountain is not a backdrop to human activity, but an active agent in it. Sánchez Garrafa (2005) documents this directly, noting that apus are understood as guardians and progenitors whose authority organizes both sacred space and social life across the region.

Gumercindo Crispin's accounts of Ausangate ceremonies, transmitted from his father Severino and relayed through Wilian Crispin, belong to exactly the relational system Berkes describes, one in which ecological practice and cosmological obligation are inseparable (G. Crispin, as cited in W. Crispin, personal communication, April 3, 2025).

A secondary theoretical thread is drawn from Caine (2019), whose dissertation on herding communities in Chillca documents how Quechua pastoralists interpret climatic disruption through the behavioral signals of animals responding to destabilized ecosystems. Caine's framework makes visible a register of indigenous knowledge that is embodied, pastoral,

and transmitted through daily practice with animals and landscapes. This is analytically distinct from the cosmological register of apu ceremony and from the practical astronomical register of stellar observation, and keeping these registers distinct prevents indigenous knowledge systems from doing undifferentiated work in the analysis.

Applying sacred ecology also carries ethical obligations that shape how this research is conducted and how its findings are represented. Berkes (2018) insists that traditional ecological knowledge cannot be extracted from the social and cosmological context in which it is produced without distorting it. To document stellar observation practices or ceremonial reciprocity with Ausangate as data points in a climate adaptation argument, without attending to the relational logic that gives those practices their meaning, would reproduce the extractive dynamic that sacred ecology as a framework is designed to critique. For this research, that means treating the apu not as a symbolic representation of ecological conditions but as an agent whose relationship with human communities organizes the social and moral dimensions of adaptation. As the glaciers recede, communities face not only water insecurity and disrupted agricultural calendars, but the erosion of the relational framework through which they have historically understood and responded to environmental change.

Literature Review

The following review first briefly establishes the environmental changes unfolding across the Cordillera Vilcanota, drawing on the physical sciences to document the scope and trajectory of glacial retreat, hydrological disruption, and ecological transformation. It then turns to the social, cultural, and political dimensions of adaptation, examining how indigenous communities

perceive, interpret, and respond to these changes through cosmological frameworks, ritual practice, pastoralist livelihoods, and structural negotiation.

The glaciers of the Cordillera Vilcanota have lost approximately 25 percent of their area since the mid-1970s (Hanshaw & Bookhagen, 2014), and that retreat is accelerating. King et al. (2025) found that mass loss rates in the Suyuparina catchment during 2016 to 2024 more than doubled relative to the long-term average since 1977, driven by positive feedback mechanisms involving supraglacial ice cliffs and ponds. Snow cover in the Laguna Sibinacocha watershed declined by 26 percent between 1984 and 2019 (Mendoza Villavicencio et al., 2021), and paleoclimate records from the nearby Quelccaya Ice Cap indicate that contemporary warming is unprecedented for at least the last two millennia (Thompson et al., 2013 as cited by Michelutti et al., 2019).

These losses cascade through the hydrological and pastoral systems upon which highland communities depend. Bofedal wetlands provide critical dry season pasturage, but their viability depends on continued moisture inputs from receding glacial sources (Caine, 2019; Drenkhan et al., 2018). Dam regulation at Laguna Sibinacocha further alters natural flow regimes (Bello et al., 2023), while the lake itself is projected to warm by 2.5 to 5.9°C by the end of the century (Sae-Lim et al., 2025). Newly deglaciated terrain, meanwhile, is being colonized by wild vicuñas whose nutrient deposition accelerates ecosystem development on glacial forefields (Reider et al., 2024), reshaping the very landscapes that pastoralist communities graze.

Orlove et al. (2002) documented how Aymara and Quechua potato farmers across Peru and Bolivia observe the Pleiades star cluster in the pre-dawn sky around the winter solstice in late June, using the apparent brightness and timing of the cluster's visibility to forecast precipitation during the coming rainy season. Their study demonstrated a sound scientific basis

for the practice, linked to El Niño's atmospheric effects on stellar visibility, and estimated forecast accuracy of approximately 65 percent, exceeding modern scientific forecasts with comparable lead times for the same region. Because the mechanism Orlove et al. (2002) identified depends on the correlation between El Niño conditions and high cirrus cloud cover, the system's predictive power is implicitly contingent on the relative stability of those atmospheric dynamics, leaving open how the practice fares as those conditions become more erratic under accelerating warming. In the Cordillera Vilcanota, this question has a community-level answer. Wilian Crispin of Pukarumi described a multi-method system combining early morning stellar observation in June and July with day-by-day weather reading across August, in which each August day serves as a proxy for the corresponding month of the agricultural year (W. Crispin, personal communication, September 29, 2025). The cross-checking structure of this system suggests adaptive elaboration within the knowledge tradition itself. Yet its limits under contemporary conditions were visible during the February 2026 snowstorm in the Ausangate region, when forecasters had disagreed about planting timing, those who planted early found their crops had matured sufficiently to withstand the storm, while those who planted later suffered significant losses and sought emergency government assistance (W. Crispin, personal communication, February 5, 2026). The divergence between forecasters does not represent a failure of the knowledge system so much as evidence of increasing difficulty reading a destabilized atmospheric signal, and it documents the trajectory of the astronomical register under conditions for which it was not historically calibrated.

The cosmological framework within which such environmental knowledge is situated has deep roots in Andean understandings of the sacred landscape. Sánchez Garrafa (2005) provided an extensive reconstruction of the mythology and spiritual significance of apu mountain deities

across the four *suyos*, or quarters, of the former Inca empire. Drawing on ethnographic, historical, and mythological sources, he documented how glaciated peaks occupy the highest tier in the hierarchy of apu spirits, with their power understood to govern weather, water, fertility, and the wellbeing of human and animal populations. Mountains such as Ausangate, which anchors the Cordillera Vilcanota, function not merely as geographic features but as sentient beings whose moods and dispositions are read through environmental signs. This cosmological system means that glacier retreat is experienced not only as a loss of water resources but as a transformation in the spiritual order of the landscape, carrying implications for community identity, ritual obligation, and the perceived balance between human communities and the forces that sustain them.

Paerregaard (2023) situated these cosmological understandings within a broader framework of water as what he termed a "total social phenomenon" in Andean life. Drawing on four decades of ethnographic fieldwork across multiple highland Peruvian communities, he argued that water in the Andes is never merely a physical resource but is simultaneously a medium of spiritual exchange, political power, and cultural identity. Glaciated mountains are understood as living beings, or apus, who release water to human communities in return for ritual offerings, and the retreat of glaciers is therefore experienced as a rupture in a relationship of reciprocity rather than simply as a hydrological decline. Paerregaard (2023) documented how communities across the Peruvian highlands perform *pagos* and *ofrendas* to maintain this relationship, and how the diminishing of glaciers has provoked not only material anxiety about water scarcity but existential questions about whether the apus are withdrawing their favor. This framing of glacier retreat as relational crisis rather than resource deficit is essential to

understanding why indigenous communities' adaptive responses so often take spiritual and ritual forms alongside material ones.

Scoville-Simonds (2018) complicated these cosmological accounts by demonstrating that religious identity within highland communities is not monolithic but actively shapes how climate change is perceived and narrated. Working in agro-pastoral communities in the province of Canas in highland Cusco, she documented what she termed "entangled narratives" of cultural and climatic change, in which Catholic and Evangelical affiliations produce distinct but intertwined interpretive orientations. Catholic community members maintained traditional practices of *pago a la tierra* and interpreted environmental degradation as a consequence of failing to uphold ritual obligations, while Evangelical converts rejected pagos as idolatry, framed the earth as inert rather than sacred, and understood climatic disruption through eschatological narratives of divine judgment. Scoville-Simonds (2018) cautioned against treating these as neatly separable positions, arguing instead that they are deeply embedded in ongoing processes of social identification and cultural change. Nevertheless, the divergence in how the earth itself is conceived, as sacred social person or as inert creation, produces fundamentally different orientations toward adaptation, revealing that even within geographically proximate communities, the cosmological lens through which climate change is perceived can generate divergent adaptive logics.

Sallnow's (1987) foundational analysis established that the Qoyllur Rit'i pilgrimage is structured around a vertical Andean axis ascending from the valley floor to the glaciers of Qolqepunku and Sinakara, understood as powerful apu companions of Ausangate. The ritual climax of the pilgrimage is the ascent of the ukukus, ambiguous bear-like ceremonial figures, to the glacier at night to harvest blocks of sacred ice, an act that enacts the community's reciprocal

relationship with the apu at the point where the sacred landscape is most concentrated. This structural analysis is essential to understanding how the pilgrimage has subsequently been transformed by glacier retreat.

Paerregaard (2023) provided the most extensive ethnographic treatment of the pilgrimage's transformation in the context of glacier retreat. His ethnography documented the deliberations through which community leaders and the *hermandad* that administers the festival decided to ban ice extraction, a decision Paerregaard framed not merely as environmental pragmatism but as an assertion of indigenous ritual authority in the face of glacial crisis. He further documented how the retreat of the Sinakara glacier has forced the ukukus to ascend to increasingly higher and more dangerous elevations, how the festival's timing and spatial organization have been adjusted to accommodate changing conditions, and how some participants now interpret the glacier's disappearance as a sign that the apu's power is not diminishing but rather transforming. This last observation, that adaptation involves not only behavioral adjustment but cosmological reinterpretation, reveals a deeper process of spiritual adaptation in which the meaning of the glacier itself is being renegotiated.

The most sustained ethnographic engagement with climate adaptation in the Cordillera Vilcanota comes from Caine's (2019) doctoral research in the community of Chillca, situated on the slopes of Mount Ausangate at elevations exceeding 4,500 meters above sea level. Caine introduced the concept of "*restless ecologies*" to describe the condition of perpetual instability that characterizes life in this high-altitude pastoralist community, where alpaca and llama herding have been the primary livelihood for generations. Her ethnographic work documented how the landscape itself is in constant motion, with glaciers retreating, pastures shifting, water sources appearing and disappearing, and weather patterns becoming increasingly unpredictable.

Rather than framing adaptation as a discrete set of responses to an external shock, Caine (2019) argued that for the herders of Chillca, living with environmental instability is a fundamental condition of existence in the high Andes, and that their adaptive practices are woven into the daily rhythms of herding, movement, and attentiveness to the land and its animals.

Caine (2022) framed herding at the "edges" as both a spatial and temporal condition, in which pastoralists operate at the margins of viable grazing land and at the limits of inherited knowledge about seasonal patterns. This multispecies perspective demonstrates that adaptive knowledge in pastoralist communities is generated through ongoing, embodied relationships with livestock rather than through abstract assessment of environmental data, and that the trajectory of pastoral adaptation is therefore self-directing in ways that externally introduced strategies are not. Caine (2021) further demonstrated that within these communities women bear the primary responsibility for the daily work of watching and tending animals, positioning them as the principal generators of pastoral environmental knowledge, yet their expertise is not always recognized or valued within community decision-making structures, a gap that itself represents a risk to the adaptive trajectory that depends on that knowledge being heard and acted upon.

Adaptation in the Cordillera Vilcanota is shaped not only by local knowledge and practice but also by broader structures of power that determine which communities and individuals are most exposed to climate impacts and least equipped to respond. Heikkinen (2021) investigated the relationships among climate change, power, and vulnerability among smallholder farmers in the Mantaro River Valley in central Peru, a region whose structural dynamics parallel those of the Vilcanota. Her analysis examined how pre-existing social, economic, and political inequalities mediate the distribution of climate risk. She demonstrated that indigenous highland communities occupy positions of structural disadvantage within

Peruvian society, facing limited access to political representation, economic resources, and institutional support for adaptation. Heikkinen (2021) argued that vulnerability to climate change in the highlands is not simply a function of geographic exposure to glacial retreat or precipitation variability but is produced through historical processes of marginalization that constrain the range of adaptive options available to communities.

Moulton (2024) advanced the structural analysis by arguing that territorial sovereignty, understood as the capacity of indigenous communities to exercise self-governance over their ancestral lands, is an indispensable precondition for just climate adaptation. Her ethnographic work documented how extractive industries and state-led development projects systematically undermine the foundations upon which indigenous adaptive practices depend, and that when communities lack effective control over their territories, adaptation interventions risk reproducing colonial power dynamics by treating indigenous communities as passive beneficiaries rather than sovereign agents. By centering territorial sovereignty as the political foundation upon which culturally grounded adaptation depends, Moulton (2024) reframed the question of structural vulnerability in which the very capacity for indigenous self-determined adaptation is contingent upon territorial integrity that is itself under threat. Where territorial integrity is compromised, the relational and place-based foundations through which indigenous knowledge systems are generated and transmitted are disrupted, threatening not only material adaptive capacity but the knowledge trajectories themselves.

The case of greenhouse agriculture in Pukarumi illustrates the fragility of externally introduced adaptation when institutional support is withdrawn. Approximately fifteen years ago, an international development organization introduced greenhouse construction to highland communities in the Ausangate region, enabling families to cultivate vegetables year-round

despite intensifying frosts, droughts, and hailstorms. Community members adopted the technology and integrated it into household food security, using organic fertilizers from their own livestock rather than chemical inputs from lowland markets. The adobe walls of the greenhouses were built using reciprocal labor exchanges known as *ayni*, the same system through which highland families construct their homes, as documented in the neighboring community of Chillca by Caine (2019), and the labor to build and maintain such structures remains available within the community. Gumercindo Crispin of Pukarumi reported that families came to view greenhouses as a necessary adaptation they intended to pass to future generations, yet the organization that introduced them eventually left Peru, and without continued support, the infrastructure has deteriorated. Kempt, who visits the region regularly through her work with the Cultural Threads cooperative, reported that adobe walls in community greenhouses show wear and have not been maintained against the elements (K. Kempt, personal communication, March 10, 2026). Wilian Crispin, who lives in Pukarumi, identified the most pressing material need as replacement greenhouse plastic, a purchased input that must be procured from urban markets and that individual families lack the financial resources to obtain on their own (W. Crispin, personal communication, April 9, 2025; G. Crispin, as cited in W. Crispin, personal communication, April 3, 2025). This trajectory concretizes the structural dynamic that both Heikkinen (2021) and Moulton (2024) identify, namely that interventions which do not build durable local capacity risk becoming liabilities rather than assets.

Conclusion

This paper set out to examine how Quechua communities of the Cordillera Vilcanota interpret and respond to glacial retreat through indigenous knowledge systems, and what the trajectory of those responses reveals about the conditions under which community-generated

versus externally introduced strategies succeed or fail. Drawing on glaciological research, ethnographic scholarship, and primary and secondary communications with community members in the Ausangate region, the central finding is that, in the cases examined here, adaptations most likely to sustain themselves under accelerating environmental change are those embedded in the cosmological, social, and institutional structures through which communities already organize their relationships with the landscape. Interventions introduced from outside those structures and then abandoned become liabilities rather than assets.

The physical sciences establish the scale and urgency of this transformation. Glaciers in the Vilcanota have lost approximately 25 percent of their area since the mid-1970s (Hanshaw & Bookhagen, 2014), mass loss rates in the Suyuparina catchment have more than doubled in recent years (King et al., 2025), and Laguna Sibinacocha is projected to warm by 2.5 to 5.9°C by the end of the century (Sae-Lim et al., 2025). The ethnographic and primary source evidence reveals that communities are responding to this transformation through at least three distinct registers of indigenous knowledge, practical astronomical forecasting, cosmological and ritual reciprocity with Ausangate and Pachamama, and embodied pastoral knowledge generated through daily herding practice, each under pressure from climatic disruption but each responding through its own adaptive logic.

Any policy framework applied to climate adaptation in the region must engage with indigenous knowledge systems not as supplementary data but as substantive interpretive frameworks with their own adaptive logics. The astronomical forecasting practices documented by Orlove et al. (2002) and elaborated by community members in Pukarumi (W. Crispin, personal communication, September 29, 2025) are actively evolving systems whose practitioners are already cross-checking and refining their methods in response to a destabilized atmospheric

signal. The forecaster disagreement during the February 2026 storm (W. Crispin, personal communication, February 5, 2026) demonstrates increasing interpretive difficulty, but the community's capacity to organize itself around competing forecasts, with some families planting early and others late based on their own readings, meant the storm produced partial losses rather than total crop failure across Pukarumi. The projected success of this recommendation rests not on a claim that indigenous forecasting will remain accurate under all future atmospheric conditions, but on the recognition that the deliberative and distributed structure through which it operates is itself an adaptive asset that policy frameworks should support rather than supplant. Equally critical is recognizing that pastoral environmental knowledge in these communities is generated primarily by women whose daily work with livestock positions them as the principal interpreters of ecological change (Caine, 2021). That knowledge must be recognized within community decision-making structures, not extracted from them as a monitoring input for external assessment.

The greenhouse case in Pukarumi illustrates both the potential and the fragility of externally introduced adaptation. The technology succeeded because the community integrated it into existing structures with ayni labor exchange for adobe wall construction, composted manure from household herds for fertilization, and local agricultural knowledge for year-round cultivation. It began to fail when the organization that introduced it left Peru and the single purchased input the community could not independently produce, clear plastic roofing, went unreplenished (K. Kempt, personal communication, March 10, 2026; W. Crispin, personal communication, April 9, 2025). The failure originated at a specific, identifiable bottleneck within an otherwise functional adaptation that the community has demonstrated the capacity and desire to sustain across generations (G. Crispin, as cited in W. Crispin, personal communication, April

3, 2025). The recommendation is not simply to restore greenhouse plastic but to establish a partnership model, whether through sustained NGO engagement, cooperative purchasing arrangements, or regional supply chain development through Cusco, that eliminates the single point of failure the current model has exposed.

Both recommendations require sensitivity to the fact that climate impacts and adaptive capacities are not evenly distributed within communities. Women's pastoral knowledge, elder ceremonial authority, and the Catholic and Evangelical divergence Scoville-Simonds (2018) documented all illustrate how different community members experience and respond to the same environmental transformation, and any intervention that treats a community as a uniform population risks reinforcing the very marginalization that Heikkinen (2021) and Moulton (2024) identify as a constraint on adaptive capacity.

This research contributes to the anthropological study of climate adaptation by demonstrating that indigenous knowledge systems in the Cordillera Vilcanota operate through analytically distinct registers that cannot be collapsed into a single category without distorting how they function. Berkes (2018) argues that traditional ecological knowledge cannot be understood apart from the worldview in which it is embedded, but the Vilcanota evidence suggests that the relationship between knowledge and worldview is itself internally differentiated. The practical astronomical register operates through empirical observation and cross-checking that can be described in terms familiar to climate science; the cosmological register is inseparable from the moral and relational logic of apu reciprocity and resists the kind of translation that applied frameworks typically require. Keeping these registers analytically distinct is a methodological contribution that future research in sacred ecology and environmental anthropology could extend to other indigenous contexts where "traditional

ecological knowledge" risks becoming an undifferentiated category. The greenhouse case further contributes a materially grounded trajectory study that gives empirical texture to the arguments Heikkinen (2021) and Moulton (2024) make about how structural marginalization constrains adaptive capacity, documenting exactly how an externally introduced adaptation can succeed on a community's own terms and then fail at a single point of material dependency when institutional support is withdrawn.

Future research would benefit from sustained engagement with several questions this paper raises but cannot resolve. Longitudinally, tracking the astronomical forecasting system across multiple agricultural cycles would test whether the elaboration of cross-checking methods can keep pace with atmospheric destabilization, or whether the February 2026 disagreement signals a structural threshold. The cosmological heterogeneity Scoville-Simonds (2018) documented, particularly the Catholic and Evangelical divergence in how communities narrate environmental change, has significant implications for adaptation trajectory that remain empirically untested. The gendered dimensions of pastoral knowledge that Caine (2021) identified warrant investigation into whether and how women's ecological observations are incorporated into household and community-level decisions under accelerating change. Beyond the headwater communities this paper examines, the hydrological consequences of glacial retreat propagate downstream through river systems feeding the Amazon basin, and future research could examine how adaptation unfolds at different points along that gradient, testing whether the relationship between knowledge systems and adaptation trajectory holds where the connection between community and glacier is material but not cosmological. Finally, the submerged and terrestrial archaeological material at Laguna Sibinacocha, of which the pre-Inca ceramic vessel documented by Michelutti et al. (2019) represents only a fraction, could extend the trajectory this

paper traces backward into a deeper past than contemporary ethnography can reach, situating today's adaptive patterns within a longer record of how highland communities have responded to previous periods of climatic variability.

The ethical implications of this research are inseparable from the theoretical framework that guides it. Sacred ecology insists that traditional ecological knowledge cannot be understood apart from the cosmological and social systems in which it is produced, and that extracting such knowledge from its relational context distorts it (Berkes, 2018). This paper has attempted to honor that principle by treating the apus as agents within a relational system and by analyzing indigenous knowledge practices within the cosmological frameworks that give them meaning. Yet the act of academic publication inevitably performs a degree of the extraction that sacred ecology critiques, rendering knowledge generated within and for specific communities available to audiences whose purposes may not align with those of the knowledge holders. All personal communications cited in this paper were shared with the knowledge and consent of the individuals involved, and the collaborative relationships through which they were gathered reflect a decade of engagement rather than extractive fieldwork. But consent to share is not the same as control over how shared knowledge is subsequently used, and future research should develop protocols that give communities ongoing authority over how their knowledge is represented and applied. The layered citation structure this paper employs for Gumercindo Crispin's accounts, relayed through Wilian Crispin's translation and framing, raises an additional concern in which future research involving these accounts should seek direct engagement with elder knowledge holders in Quechua to ensure that ceremonial and practical knowledge is represented on its own terms. The transmission chain is in fact deeper than the two-link citation suggests: Gumercindo attributes his ceremonial knowledge to his father Severino, meaning the

accounts in this paper traverse at least two generations of oral transmission within the family before reaching Wilian, who translates and relays them in Spanish, adding a further layer of linguistic mediation before they arrive in this paper.

The paper's recommendations carry their own ethical weight. Recommending external partnership to supply greenhouse roofing material risks reproducing the dependency cycle the paper has documented as a failure. Any future intervention should be evaluated not only by whether it addresses an immediate material need but by whether it leaves the community more capable of sustaining the adaptation independently after the partnership ends. Finally, the Sallnow (1987) prophecy of Ausangate turning grey carries profound spiritual significance for the communities who hold it, and care must be taken to avoid reducing it to a dramatic illustration of climate change or treating its convergence with glaciological reality as confirmation of indigenous "accuracy." The prophecy operates within a moral and cosmological register distinct from the environmental register of climate science and collapsing those registers would violate the analytical principle this paper has argued for throughout.

References

Bello, O., Suarez, W., Drenkhan, F., & Vega-Jácome, F. (2023). Hydrological impacts of dam regulation for hydropower production: The case of Sibinacocha Lake, Peru. Journal of Hydrology: Regional Studies, 46, 101319. https://doi.org/10.1016/j.ejrh.2023.101319

Berkes, F. (2018). Sacred ecology (4th ed.). Routledge.

Caine, A. (2019). Restless ecologies in the Andean highlands. [Doctoral dissertation, University of Michigan].

Caine, A. (2021). “Who would watch the animals?”: Gendered knowledge and expert performance among Andean pastoralists. Culture, Agriculture, Food and Environment, 43(1), 4-13. https://doi.org/10.1111/cuag.12261

Caine, A. (2022). Herding at the edges: Climate change and animal restlessness in the Peruvian Andes. Ethnos, 89(5), 827–847. https://doi.org/10.1080/00141844.2022.2142266

Cultural Threads [@cultural_threads]. (2026, February 3). The high Andes have been experiencing an extreme snowstorm [Instagram photograph]. Instagram. https://www.instagram.com/p/DUTse7ZEjd6/

Drenkhan, F., Guardamino, L., Huggel, C., & Frey, H. (2018). Current and future glacier and lake assessment in the deglaciating Vilcanota, Peru. Global and Planetary Change, 169, 105–118. https://doi.org/10.1016/j.gloplacha.2018.07.005

Hanshaw, M. N., & Bookhagen, B. (2014). Glacial areas, lake areas, and snow lines from 1975 to 2012: Status of the Cordillera Vilcanota, including the Quelccaya Ice Cap, northern central Andes, Peru. The Cryosphere, 8, 359–376. https://doi.org/10.5194/tc-8-359-2014

Heikkinen, A. M. (2021). Climate change, power, and vulnerabilities in the Peruvian Highlands. Regional Environmental Change, 21(3), Article 82. https://doi.org/10.1007/s10113-021-01825-8

Iris, L. (2019, September 23). Shippee-Johnson Peruvian Expedition. American Museum of Natural History. https://data.library.amnh.org/archives-authorities/id/amnhc_2000744

King, O., Quincey, D. J., Carrivick, J. L., Rowan, A. V., & Bolch, T. (2025). The impact of supraglacial ice cliff and pond formation on debris-free tropical glacier mass loss. Journal of Glaciology. Advance online publication. https://doi.org/10.1017/jog.2025.10109

Mendoza Villavicencio, L. M., Mendes, D., Mendes da Silva, G. A., Monteiro, F. F., & Andrade, L. D. M. B. (2021). Snow cover area analysis and its relation with the temperature in Sibinacocha Lake watershed, Peru, during 1984–2019 using Landsat and ERA5 data. Remote Sensing Letters, 12(4), 353–363. https://doi.org/10.1080/2150704X.2020.1868603

Michelutti, N., Sowell, P., Tapia, P. M., Grooms, C., Polo, M., Gambetta, A., Ausejo, C., & Smol, J. P. (2019). A pre-Inca pot from underwater ruins discovered in an Andean lake provides a sedimentary record of marked hydrological change. Scientific Reports, 9, 19193. https://doi.org/10.1038/s41598-019-55422-1

Moulton, H. (2024). Indigenous women as guardians of Pachamama: Territorial sovereignty and climate adaptation in Peru. Global Environmental Change, 89, 102934. https://doi.org/10.1016/j.gloenvcha.2024.102934

Orlove, B. S., Chiang, J. C. H., & Cane, M. A. (2002). Ethnoclimatology in the Andes: A cross-disciplinary study uncovers a scientific basis for the scheme Andean potato farmers traditionally use to predict the coming rains. American Scientist, 90(5), 428–435. https://www.jstor.org/stable/27857722

Paerregaard, K. (2023). Andean Meltdown: A climate ethnography of water, power, and culture in Peru. University of California Press.

Reider, K. E., Bueno de Mesquita, C. P., Anderson, K., Quispe Pilco, R., Luza Victorio, M. A., Gelona, A. R., III, & Schmidt, S. K. (2024). Wild Andean camelids promote rapid ecosystem development after glacier retreat. Scientific Reports, 14, 31913. https://doi.org/10.1038/s41598-024-83457-6

Sae-Lim, J., Konecky, B. L., Morrill, C., Michelutti, N., Grooms, C., & Smol, J. P. (2025). Lake energy balance response to 21st century warming in the tropical high Andes. Global and Planetary Change, 248, 104741. https://doi.org/10.1016/j.gloplacha.2025.104741

Sallnow, M. J. (1987). Pilgrims of the Andes: Regional cults in Cusco. Smithsonian Institution Press.

Sánchez Garrafa, R. (2005). Apus de los cuatro suyos: Construcción del mundo en los ciclos mitológicos de las deidades montaña. [Doctoral dissertation, Universidad Nacional Mayor de San Marcos].

Scoville-Simonds, M. (2018). Climate, the earth, and God: Entangled narratives of cultural and climatic change in the Peruvian Andes. World Development, 110, 345–359. https://doi.org/10.1016/j.worlddev.2018.06.012

Seimon, A., & Seimon, T. (2025, January 27). Evidencia: A century of high alpine landscape change in the Peruvian Andes revealed by mining lost aerial photo archives [Video]. The Explorers Club. https://www.youtube.com/watch?v=svKnSYTr1dU

Appendix A: Cordillera Vilcanota Research Area

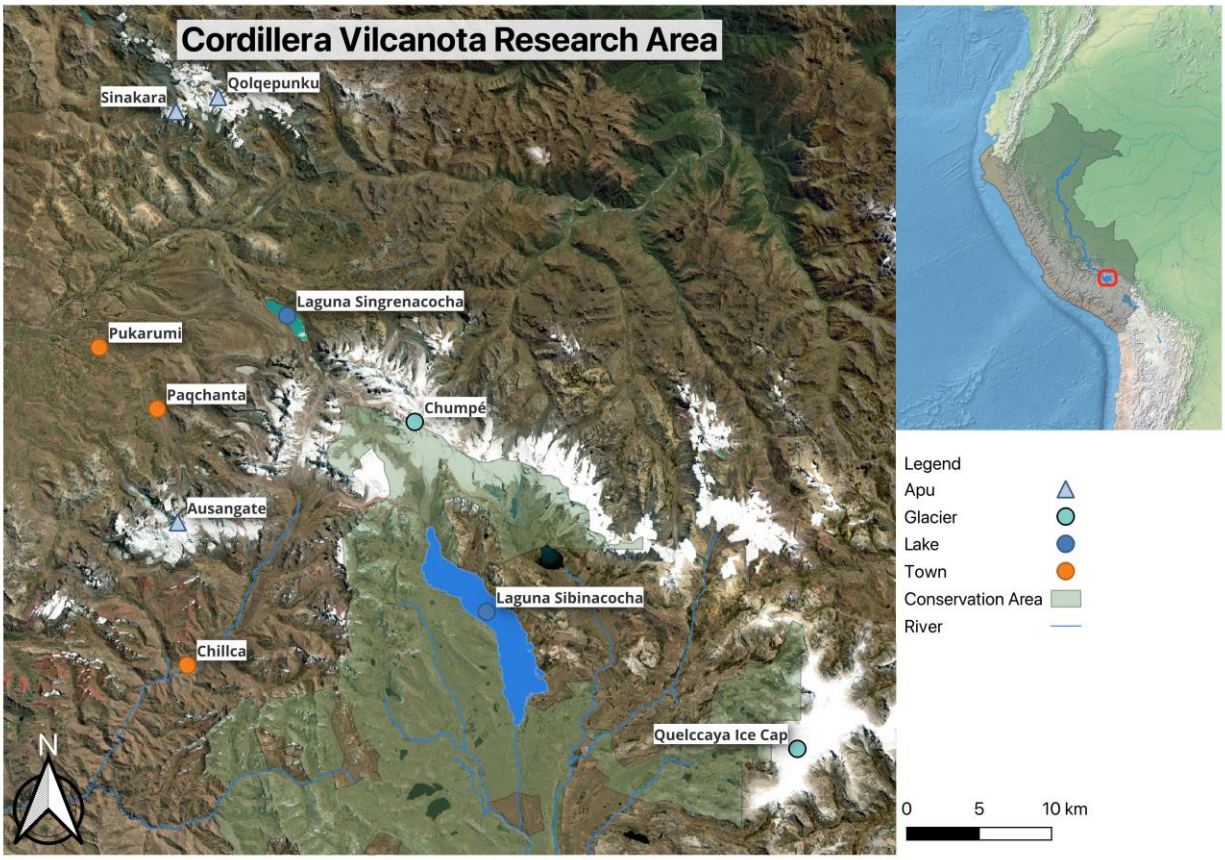

Figure 1: The Cordillera Vilcanota research area, showing key communities (Pukarumi, Chillca), glaciated peaks (Ausangate, Sinakara), glacial lakes (Laguna Singrenacocha, Laguna Sibinacocha), and the Quelccaya Ice Cap. Inset shows location within southeastern Peru and traces the river system from the Cordillera Vilcanota to the Amazon, illustrating the range's role as a major headwater of the Amazon Basin. Map by James Williams, created in QGIS. Satellite basemap: Esri World Imagery. Inset basemap: Natural Earth II. Hydrological features (rivers, lakes) and conservation area boundaries from Natural Earth. Waypoints digitized by James Williams.

Appendix B: Glossary of Quechua Terms

Apu: A mountain deity or spirit, understood as a sentient being who governs weather, water, fertility, and the wellbeing of human and animal populations. Glaciated peaks such as Ausangate occupy the highest tier in the hierarchy of apu spirits.

Ayni: A system of symmetrical reciprocal labor exchange in which work performed for another person or household is returned in kind later. Ayni undergirds economic, social, and political life in Andean rural communities and is practiced across domains including agriculture, house construction, and animal herding (Caine, 2019).

Españariy: The Spanish king figure in Andean syncretic mythology, who in the Paqchanta creation narrative places a silver cross on Ausangate's summit to arrest its growth.

Inkariy: The Inka king figure in Andean mythology, who in the Paqchanta narrative creates Ausangate and warns that if the apu is no longer revered, final judgment will come and the mountain will turn to cinder.

K'ita: A condition of agitated, socially aberrant wandering; a concept Caine (2019) elevates into an analytical framework for understanding how animals and landscapes behave under ecological destabilization.

Pachamama: Mother Earth; a sacred being to whom communities direct ceremonies of gratitude for productive yields.

Qolqepunku: A glacier and apu companion of Ausangate, site of the ritual ice extraction during the Qoyllur Rit'i pilgrimage.

Qoyllur Rit'i: Snow Star; a major Andean pilgrimage festival structured around a vertical ascent from the valley floor to the glaciers, centering the community's reciprocal relationship with the apus.

Runa: The Quechua people; used in the Paqchanta prophecy to refer to the community whose devotion sustains the apu's power.

Sibinacocha (warmiqocha): Woman Lake; from the Quechua sibina (woman) and cocha (lake). A high-altitude alpine lake in the Cordillera Vilcanota sitting at 4,873 meters, one of the primary headwaters of the Amazon River and a site of ongoing scientific and archaeological research (W. Crispin, personal communication, April 4, 2026).

Singrenacocha (Layqa qocha): Enchanted Lake; from the Quechua sengrina (siren/mermaid) and cocha (lake). A glacial lake in the Cordillera Vilcanota near the pastoralist communities of the Ausangate region, including those affiliated with the Cultural Threads cooperative (W. Crispin, personal communication, April 4, 2026).

Sinakara: A glacier and apu companion of Ausangate, associated with the Qoyllur Rit'i pilgrimage site.

Suyo: Region or territory; the four suyos refer to the quarters of the former Inca empire.

Ukuku: The Andean spectacled bear; also, the ambiguous bear-like ceremonial figures who ascend to the glacier during Qoyllur Rit'i to harvest sacred ice.

Appendix C: Glossary of Spanish Terms

Bofedal: A high-altitude wetland that provides critical dry-season pasturage for livestock; its viability depends on continued moisture inputs from glacial sources.

Hermandad: Brotherhood; the religious organization that administers the Qoyllur Rit'i festival and deliberated the decision to ban ice extraction from the glacier.

Invernadero: Greenhouse; the small agricultural structures introduced by an international development organization approximately fifteen years ago, enabling year-round vegetable cultivation at high altitude.

Miran el tiempo: Literally "they watch the time/weather"; the local expression for traditional forecasting methods based on stellar observation and weather reading.

Naciones: Nations; the regional groupings of pilgrims who participate in the Qoyllur Rit'i festival.

Ofrendas: Offerings made to the earth and the apus as part of the reciprocal relationship between communities and the sacred landscape.

Pagos: Payments to the earth (*pago a la tierra*); ritual offerings performed to maintain the reciprocal relationship with Pachamama and the apus, ensuring continued provision of water and agricultural fertility.