

Article

The Chimborazo Fauna Production Reserve: Biocultural Landscapes, Sustainability Challenges, and Integrative Governance in High-Andean Protected Areas

Carlos Renato Chávez-Velasquez ^{1,2,*}, Jhony F. Cruz-Román ^{1,2}, Alba M. Sinaluisa-Pilco ³, Sandra P. Miranda-Salazar ¹, Alden Yépez-Noboa ⁴, José Sánchez-Agudo ², Emilio R. Díaz-Varela ⁵ and Fausto O. Sarmiento ⁶

¹ Faculty of Natural Resources, Escuela Superior Politécnica de Chimborazo, Riobamba 060155, Ecuador; jhony.cruz@esPOCH.edu.ec (J.F.C.-R.); spmiranda@esPOCH.edu.ec (S.P.M.-S.)

² Biodiversity Conservation Division, University of Salamanca, 37008 Salamanca, Spain; jasagudo@usal.es

³ Independent Researcher, Riobamba 060155, Ecuador; alba_sinaluisa@hotmail.com

⁴ Regional Archaeological Laboratory of Water and Glaciers, Pontific Catholic University of Ecuador, Quito 170525, Ecuador; amyep@puce.edu.ec

⁵ Department of Plant Production and Project Engineering, Escola Politécnica Superior, University of Santiago de Compostela, Campus Universitario, 27002 Lugo, Spain; emilio.diaz@usc.es

⁶ Neotropical Montology Collaboratory, Department of Geography, University of Georgia, Athens, GA 30602, USA; fsarmien@uga.edu

* Correspondence: renato.chavez@esPOCH.edu.ec; Tel.: +593-987-170-149

Abstract

High-mountain protected areas are increasingly exposed to climate change, governance fragmentation, and limited integration of cultural dimensions into conservation strategies. In this context, this study examines the Chimborazo Fauna Production Reserve (Ecuador) as a high-Andean biocultural landscape, integrating ecological, geological, climatic, and cultural evidence within a common interpretive framework based on the concepts of integrity and authenticity. Using an interdisciplinary synthesis of secondary sources, the analysis explores six analytical dimensions encompassing geodiversity, ecosystems, biodiversity, climate dynamics, archaeological evidence, and cultural practices. The results suggest that the Chimborazo system maintains a notable degree of structural and functional coherence across its ecological and geomorphological components, while also experiencing increasing pressures associated with climate change, particularly glacier retreat and hydrological variability. At the same time, the persistence of archaeological records, Andean epistemologies, ritual practices, and biocultural traditions supports the interpretation of a landscape characterized by continuity of cultural meaning and long-term human–environment interaction. Rather than proposing a definitive or directly transferable model, this study offers a conceptual perspective that highlights the interdependence between ecological processes and cultural values in high-mountain environments. Interpreting Chimborazo as a biocultural landscape offers a useful approach for exploring sustainability-oriented governance and adaptive management in Andean protected areas. The findings may inform ongoing discussions on the integration of biodiversity conservation, cultural continuity, and climate adaptation, while further empirical validation is required to assess the broader applicability of this approach in other mountain contexts.

Academic Editor: John Carman

Received: 15 January 2026

Revised: 9 April 2026

Accepted: 18 May 2026

Published: 14 July 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: biocultural landscapes; sustainability; high-Andean protected areas; governance; social–ecological systems; climate change adaptation; Indigenous knowledge; Chimborazo volcano; UNESCO frameworks

1. Introduction

High-mountain landscapes are increasingly recognized as complex socioecological systems in which geological processes, climate dynamics, biodiversity, and human societies have coevolved over long temporal scales. In the tropical Andes, this coevolution has produced landscapes of exceptional ecological heterogeneity and deep cultural significance, while simultaneously generating high vulnerability to climate change and socio-environmental transformation [1–4].

Within this context, the United Nations Educational, Scientific and Cultural Organization (UNESCO) provides the international framework for understanding and managing heritage as an integrated system of natural and cultural values. Through instruments such as the World Heritage Convention, the Man and the Biosphere (MAB) Program, and the Global Geoparks Network, UNESCO has progressively moved beyond sectoral conservation approaches to embrace landscapes where tangible biodiversity, geodiversity, cultural practices, and intangible symbolic meanings are inseparable [5–9].

The World Heritage framework’s central contribution is the articulation of integrity and authenticity as complementary criteria for assessing heritage values. Integrity refers to the wholeness, completeness, and functional coherence of natural systems and ecological processes, whereas authenticity addresses the credibility, continuity, and living expression of cultural meanings, practices, and relationships associated with a site [8,10]. In mountain regions, where environmental processes and cultural practices are deeply intertwined, these criteria offer a powerful conceptual lens for interpreting landscapes as indivisible socioecological systems rather than as separate either natural or cultural entities [11,12].

In parallel, heritage and conservation scholarship has increasingly challenged the notion of “pristine” or socially empty nature. Many protected areas are now understood as historically inhabited and culturally produced landscapes shaped through long-term human–environment interactions. This shift has led to the recognition of biocultural landscapes, where biodiversity, geodiversity, and cultural practices are co-produced and mutually reinforcing [13–15]. In the Andes, Indigenous relational epistemologies grounded in concepts such as *ayllu*, *pachamama*, and *sumak kawsay* exemplify integrated understandings of territory, governance, and resilience [16–18].

The Chimborazo volcanic massif in central Ecuador constitutes a paradigmatic example of this convergence. As Ecuador’s highest mountain, Chimborazo hosts tropical glaciers, páramo ecosystems, and high-altitude wetlands that play a critical role in hydrological regulation, biodiversity maintenance, and climate sensitivity. At the same time, archaeological, historical, and ethnographic evidence documents sustained human engagement with this high-mountain environment, expressed through ritual landscapes, ancestral routes, scientific exploration, symbolic representations, and traditional practices such as glacier ice extraction (*hieleros*) [19,20].

Despite this integrative perspective, conservation frameworks applied to high-mountain environments—including Chimborazo—have often reflected sectoral and exclusionary approaches. These models, frequently centered on wildlife management or resource control, have limited the recognition of archaeological heritage, sacred landscapes, and living cultural practices, while also restricting the integration of Indigenous and local knowledge systems into decision-making processes [21–24]. This logic underpins the cre-

ation of the CFPR, a management category primarily oriented toward reintroduction of vicuña (*Vicugna vicugna*) and fur production, rather than toward the integrated conservation of a biocultural landscape [25,26].

At present, the CFPR faces converging pressures from accelerated glacier retreat, degradation of high-altitude wetlands, biodiversity loss, and the erosion of biocultural practices under climate change trends [27–29]. From a UNESCO-oriented perspective, these dynamics raise critical questions regarding both the integrity of natural systems and the authenticity of cultural and biocultural values within the reserve.

From a sustainability science perspective, such limitations constrain the capacity of protected areas to address the coupled ecological and cultural dynamics of mountain systems under climate change. In this context, biocultural landscape frameworks provide an alternative pathway for integrating ecological integrity, cultural continuity, and adaptive governance.

The retreat of glaciers, transformations in hydrological regimes, pressures on páramo ecosystems, and evolving pastoral and ritual practices illustrate how environmental and cultural processes are deeply intertwined. Yet, although these dynamics have been widely documented across disciplines, their integration into a structured evaluative framework capable of guiding governance remains insufficiently developed.

Despite the growing body of interdisciplinary research on high-Andean environments, limited efforts have translated biophysical, historical, and cultural evidence into structured interpretive frameworks that can inform decision-making in protected mountain areas. In the CFPR, this gap becomes particularly visible, where ecological transformation, heritage values, and institutional fragmentation coexist without a clearly articulated analytical integration. In this context, the Chimborazo Fauna Production Reserve illustrates a case where ecological fragility, cultural depth, and institutional complexity converge within a single high-mountain socioecological system. By organizing ecological, cultural, and historical evidence within a coherent analytical perspective, the study seeks to clarify how these dimensions interact within a biocultural landscape context. Rather than offering a fully operational or directly transferable model, this contribution should be understood as a conceptual and perspective-based approach that helps interpret the socioecological complexity of high-Andean landscapes. In this sense, the study provides insights that may inform ongoing discussions on integrative conservation and sustainability-oriented governance, while requiring further empirical application and validation in different contexts [7,10,30,31].

2. Materials and Methods

2.1. Study Area

This perspective adopts a sustainability science approach, integrating interdisciplinary secondary data to examine biocultural landscapes and to inform governance pathways for high-mountain protected areas under climate change. The CFPR is characterized by the presence of volcanic landforms, tropical glaciers, páramo ecosystems, high-altitude wetlands (bofedales), and pronounced altitudinal and hydrological gradients see Figure 1. These features configure an ecological system that is highly sensitive to climate change and of major relevance for hydrological regulation, biodiversity maintenance, and ecosystem services in the tropical Andes. At the same time, the area presents a long history of human occupation, evidenced by high-altitude archaeological sites, ritual landscapes, ancestral routes, and cultural practices associated with Chimborazo as a sacred mountain [32].

The convergence of natural, cultural, and symbolic values makes the CFPR a particularly suitable case for examining the interaction between ecological processes and soci-

ocultural practices, as well as for analyzing, from an integrated perspective, the notions of integrity and authenticity converging in high-mountain landscapes [11,33,34].

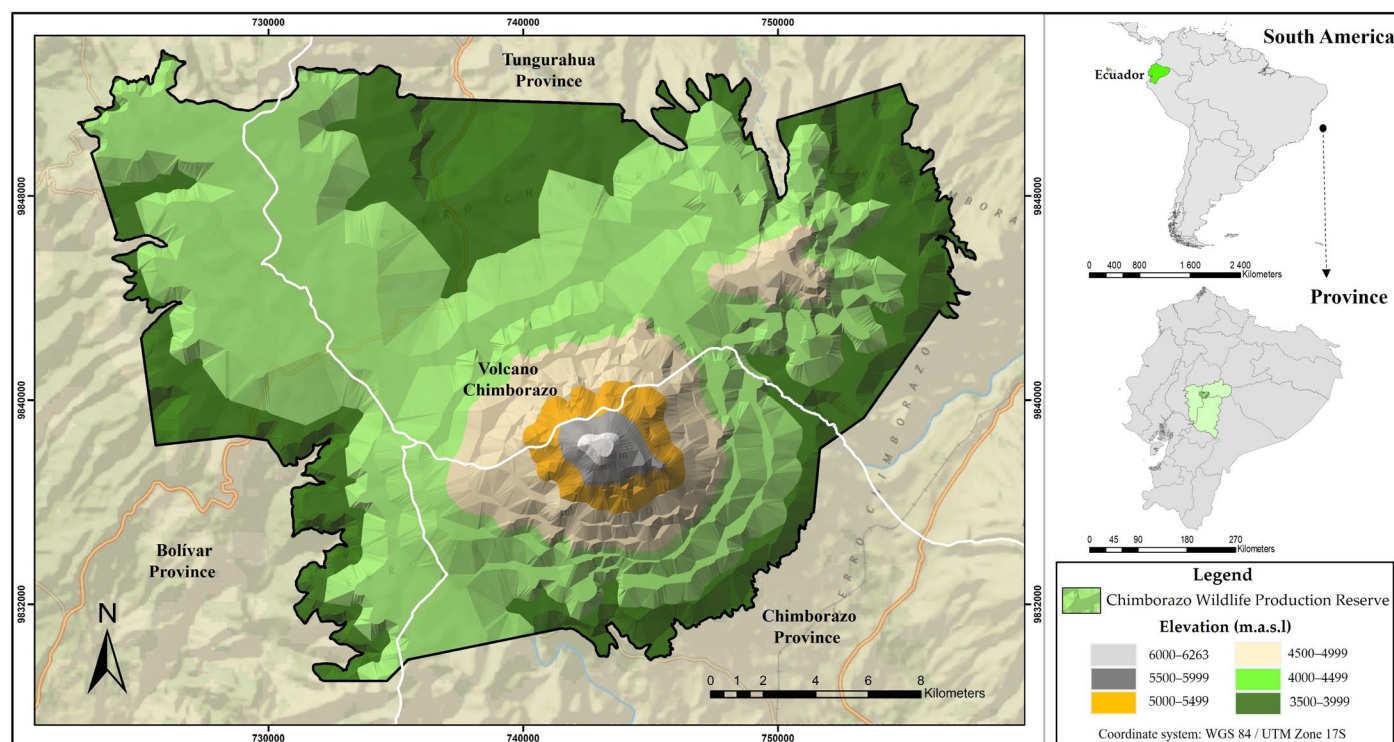


Figure 1. Location of the CFPR as a study area. The right-hand column shows Ecuador's location in South America and the location of the Chimborazo province within Ecuador. The black outline on the map marks the boundaries of the CFPR; the elevation ranges are indicated in the legend.

2.2. Conceptual and Analytical Framework

The study analyzes the CFPR as a high-Andean biocultural landscape using a sustainability-oriented framework. The analysis is guided by the concepts of integrity and authenticity, as defined within the UNESCO World Heritage framework, and employed here as analytical criteria to assess and interpret the relationships between natural systems, cultural practices, and the meanings associated with the territory.

Integrity is used to examine the coherence, functionality, and continuity of the natural systems of Chimborazo, including geological, ecological, and climatic processes, as well as their capacity to sustain environmental values over time. Analytically, it enables the identification of systemic coherence, ecological resilience, and potential disruptions affecting environmental functioning. Authenticity is applied to analyze the continuity and credibility of cultural and biocultural values, expressed through ritual practices, Andean epistemologies, historical occupation, and symbolic relationships between local communities and the mountainscape [8,10], allowing the assessment of cultural continuity, transformations, and the persistence of meaning-making practices.

This framework supports interpreting Chimborazo as an indivisible socioecological system consistent with mixed natural-cultural heritage, which is particularly relevant in mountain landscapes where environmental processes and cultural practices are deeply interconnected [5,11,12,35].

To enhance analytical clarity and consistency, the concepts of integrity and authenticity were operationalized through a set of qualitative indicators applied across the six analytical dimensions. Integrity was assessed through indicators such as: (i) structural continuity of geological and geomorphological systems, (ii) functional coherence of ecological and hydrological processes, (iii) landscape connectivity across altitudinal gradi-

ents, and (iv) resilience of ecosystem dynamics under environmental change. Authenticity was evaluated through: (i) continuity of cultural practices and ritual expressions, (ii) persistence of symbolic meanings associated with the landscape, (iii) temporal depth of human–environment interactions, and (iv) credibility of cultural expressions supported by archaeological, historical, and ethnographic evidence. These indicators were used to guide the interpretation of evidence within each analytical dimension, ensuring consistency between descriptive material and evaluative conclusions.

2.3. Sources of Information and Analytical Procedure

The study follows a qualitative integrative design based on the systematic compilation, classification, and cross-disciplinary interpretation of secondary sources. Materials were selected according to their relevance to high-Andean socioecological dynamics, explicit reference to the Chimborazo massif or comparable mountain systems, and contribution to understanding long-term environmental and cultural transformations. The corpus includes peer-reviewed scientific literature, historical and archival documents, archaeological and ethnographic studies, institutional management reports, and official cartographic and geospatial data. Sources in both Spanish and English were considered in order to ensure comprehensive coverage of regional and international scholarship.

Following compilation, materials were classified according to six interrelated analytical dimensions: (i) geological and geomorphological; (ii) ecological and vegetation cover; (iii) climatic and glaciological; (iv) cultural and archaeological; (v) historical and symbolic; and (vi) institutional and management-related. Several sources contributed to more than one dimension, enabling cross-scale interpretation and interdisciplinary triangulation.

The analytical procedure consisted of three sequential steps. First, key findings and documented transformations were extracted from each source and organized according to the six dimensions. Second, convergences and tensions among ecological, cultural, and institutional evidence were identified through comparative reading. Third, these findings were interpreted through the lenses of integrity and authenticity, allowing the translation of heterogeneous empirical data into evaluative insights relevant to governance and sustainability. This structured workflow provides an initial level of traceability between empirical evidence, analytical interpretation, and policy-relevant conclusions, supporting the articulation of long-term society–nature coevolution processes within a coherent biocultural framework [13–15,36].

To strengthen analytical transparency, each piece of evidence was systematically associated with one or more indicators of integrity or authenticity. Comparative assessment across the six dimensions was conducted by identifying convergences, complementarities, and tensions among ecological, cultural, and institutional findings. When conflicting or contrasting evidence was identified, priority was given to peer-reviewed and empirically grounded sources, while discrepancies were interpreted as expressions of socioecological complexity rather than inconsistencies. This procedure enables a structured transition from descriptive synthesis to evaluative interpretation, ensuring traceability between sources, analytical criteria, and the conclusions presented.

3. Results

3.1. Integrity of the Chimborazo High-Mountain System

3.1.1. Geological and Geomorphological Integrity

The Chimborazo massif constitutes a high-altitude andesitic–dacitic volcanic edifice whose evolution is associated with successive eruptive phases, structural collapses, and Quaternary glaciation processes. Geological studies describe Chimborazo as a composite volcano whose eruptive history produced extensive pyroclastic deposits, volcanic ash lay-

ers, and reworked volcanic materials, which currently structure the relief and control geomorphological dynamics across the reserve [37,38].

The interaction between volcanism, tectonics, and glaciation has generated steep relief forms, relict moraines, periglacial deposits, and eroded surfaces that stay clearly identifiable in the contemporary landscape. These landforms reflect the long-term continuity of geological processes and contribute to the physical coherence of the high-mountain system. Young volcanic soils derived from these processes show high porosity, substantial water retention capacity, and marked spatial variability in nutrient availability, directly influencing slope stability, hydrological regulation, and vegetation distribution across the massif [39,40].

Across the CFPR, volcanic structures, glacial deposits, and geomorphological features are preserved along a broad altitudinal gradient, from upper páramo environments and periglacial deposits to the summit zone see Figure 2. This spatial continuity supports the expression of geological processes at landscape scale and may provide a coherent abiotic framework that underpins ecological dynamics. Although contemporary environmental pressures—particularly glacier retreat—are changing surface processes, the fundamental geological architecture of the Chimborazo massif remains intact and functionally connected.

Descriptive evidence indicates that the geodiversity of Chimborazo, expressed through its volcanic architecture, glacial legacy, and high-altitude landforms, reflects the long-term persistence of geomorphological processes. From an interpretive perspective, the spatial continuity of volcanic structures and glacial deposits suggests a coherent geological framework that underpins ecological and hydrological dynamics across the landscape. In terms of integrity, these patterns support the interpretation of a structurally coherent and functionally connected high-mountain system, where process continuity and landscape-scale organization remain largely intact despite ongoing environmental pressures [39,40].

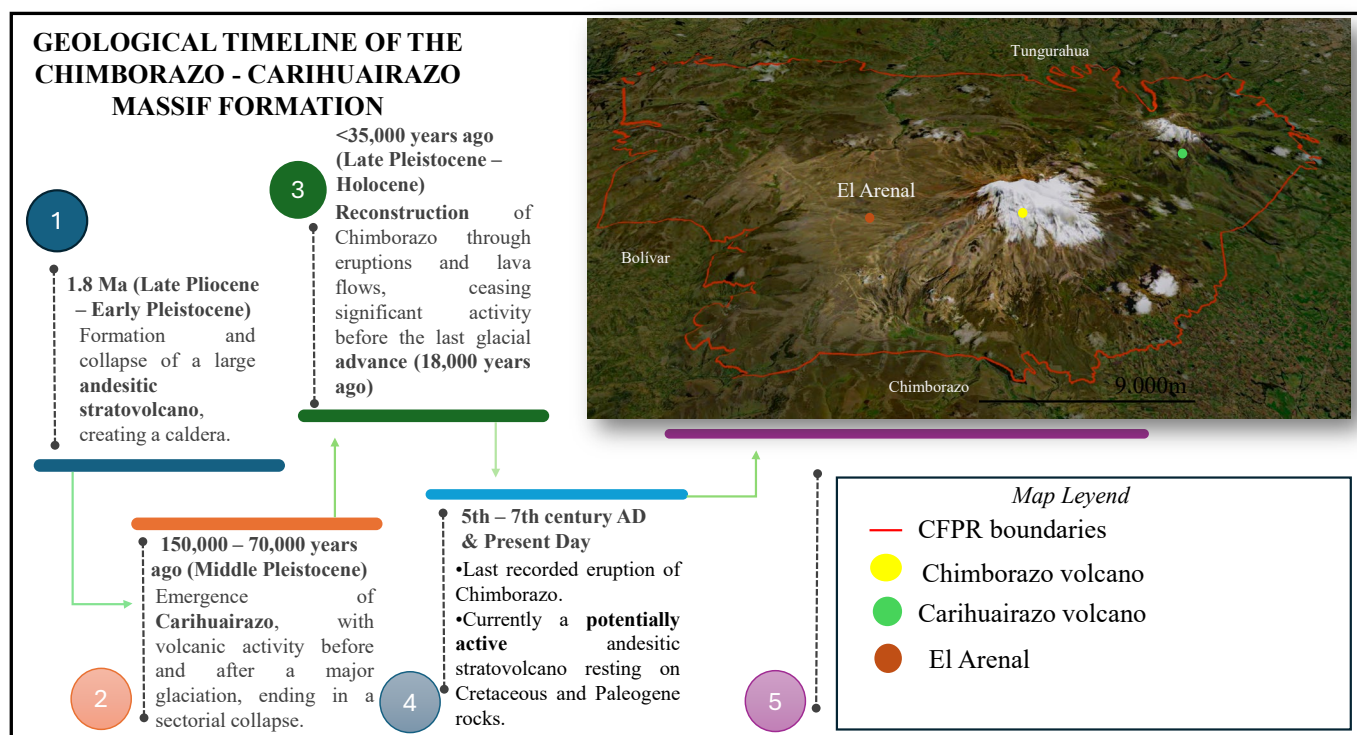


Figure 2. Chimborazo–Carihuairazo Massif. Adapted from [38,39].

3.1.2. Ecological Integrity of Páramo Ecosystems and Bofedales

The CFPR encompasses a mosaic of high-Andean páramo ecosystems and high-altitude wetlands (bofedales), distributed along a broad altitudinal gradient and strongly conditioned by geomorphological, edaphic, and hydrological factors. Together, these ecosystems can be understood as the dominant ecological matrix of the reserve and play an important role [40,41].

The páramos of Chimborazo exhibit high structural and floristic heterogeneity, with plant assemblages adapted to extreme conditions of low temperatures, high solar radiation, strong winds, and young volcanic soils. Vegetation cover is dominated by tussock grasses, cushion plants, rosette shrubs, bryophytes and lichens, whose distribution responds to altitude, slope, aspect, and water availability. This diversity of life forms contributes to soil stability, water retention, and the regulation of hydrological flows at the catchment scale see Figure 3 [42,43].

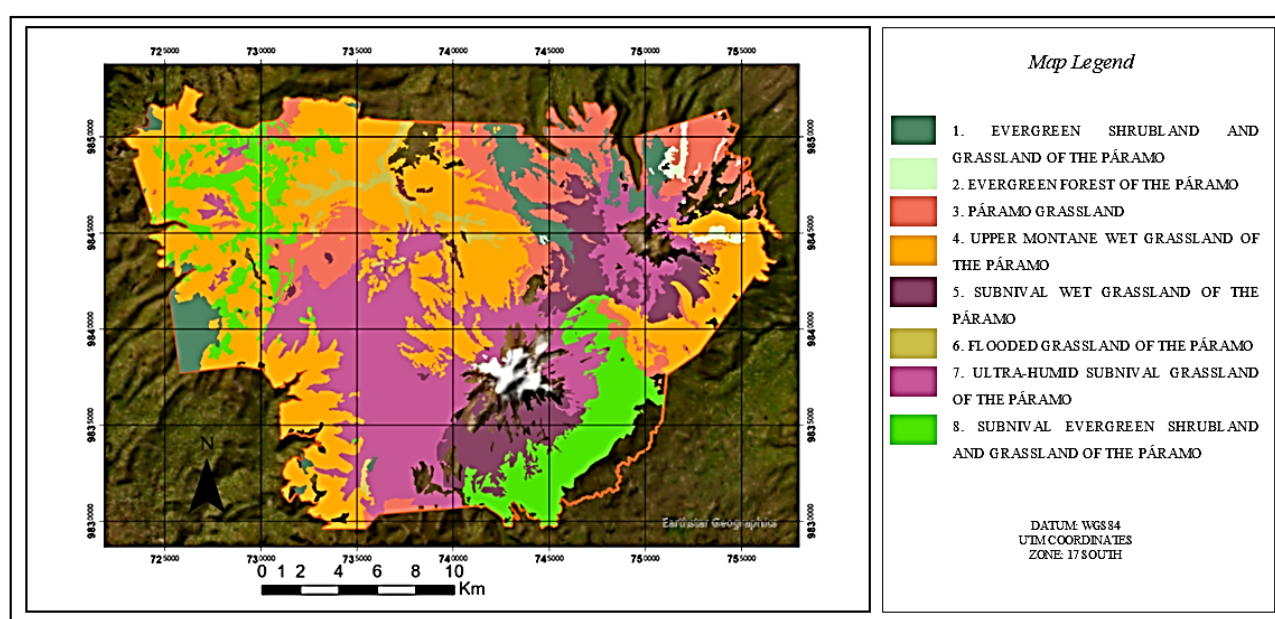


Figure 3. Vegetation cover map of the CFPR. Source: based on Ministerio del Ambiente, Agua y Transición Ecológica del Ecuador (MAATE) and Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAG) cartography of SIG-TIERRAS 2017 Project. (http://geoportal.agricultura.gob.ec/geonetwork/srv/spa/catalog.search#/metadata/Ficha_cobertura_natural_10052016 (accessed on 15 March 2026)).

Bofedales constitute key ecological elements within the Chimborazo páramo system. Associated with zones of water accumulation, glacier melt, and groundwater discharge, these high-altitude wetlands function as natural water reservoirs and flow regulators, buffering seasonal climatic variability. Their specialized vegetation, dominated by hydrophilic species and cushion-forming communities, enhances sediment and nutrient retention, thereby sustaining essential ecological processes that support the functioning of the high-mountain landscape. Thus, their hydrological buffering and nutrient retention functions provide measurable indicators of ecosystem functionality and resilience [40,44,45].

Descriptive evidence indicates that connectivity among páramos, bofedales, and altitudinal transition zones maintains continuous ecological gradients across the CFPR. From an interpretive perspective, this connectivity facilitates species movement, seed dispersal, and the persistence of ecological processes in a climatically dynamic environment. In terms of integrity, the widespread presence and functional continuity of these ecosystems support the interpretation of a coherent ecological system, where structural and

functional attributes characteristic of high-Andean environments remain largely conserved [40,41].

3.1.3. Faunal Assemblages as Indicators of Integrity

Faunal assemblages within the CFPR reflect the structural coherence and functional continuity of high-Andean ecosystems across a wide altitudinal gradient. Mammals, birds, and amphibians are closely linked with the integrity of páramo ecosystems and bofedales, responding to habitat heterogeneity, hydrological availability, and landscape connectivity. As such, faunal distribution patterns provide functional indicators of habitat continuity and ecosystem integrity across the altitudinal gradient.

Large herbivores, particularly the vicuña (*Vicugna vicugna*), represent a conspicuous component of the high-Andean fauna of the CFPR see Figure 4. The presence of stable vicuña populations across extensive areas of páramo indicates the availability of suitable forage, open grassland structure, and relatively continuous habitats. As a species historically extirpated and later reintroduced, the vicuña also reflects long-term ecological recovery processes linked to habitat conservation and management within the reserve. Their recovery and spatial stability suggest ecosystem functionality and landscape connectivity [33,46].



Figure 4. On the left, herd of vicuñas feeding in “El Arenal” páramo in 2013. Note the overall shrouding of cloudiness creating a mystical early morning browsing camelid packs. On the right, vicuñas (*Vicugna vicugna*) grazing in front of the Chimborazo volcano during the dry season of 2022, illustrating the presence of emblematic high-Andean fauna within páramo landscapes. Source: photos by Jhony Cruz.

Avifaunal assemblages further illustrate the ecological integrity of the Chimborazo landscape. The reserve supports a diversity of bird species adapted to high-altitude environments, including grassland specialists, wetland-associated species, and raptors. These assemblages depend on the spatial continuity of páramo vegetation, the presence of bofedales and water bodies, and the maintenance of altitudinal gradients, which collectively provide nesting, feeding, and movement opportunities across the landscape. These assemblages reflect the integrity of ecological gradients and habitat networks essential for high-Andean biodiversity persistence [46,47].

Amphibian and reptile species, although less conspicuous, function as sensitive indicators of environmental conditions in high-mountain ecosystems. Their occurrence is closely linked to microhabitat availability, moisture regimes, and water quality in bofedales and adjacent páramo environments. Descriptive evidence indicates that amphibian and reptile assemblages are closely linked to microhabitat availability and hydrological conditions. From an interpretive perspective, their presence reflects the maintenance of localized ecological conditions within high-mountain environments. In terms of integrity, these patterns support the interpretation that hydrological processes and microhabitat

structures remain sufficiently conserved to sustain sensitive species, highlighting the importance of localized conditions for overall ecosystem integrity [48].

3.1.4. Climatic and Glaciological Processes Affecting Integrity

Climatic and glaciological processes constitute a central component of the functioning of the Chimborazo high-mountain system and exert a direct influence on the ecological and geomorphological integrity of the CFPR. The Chimborazo massif hosts one of the most emblematic tropical glaciers in the Andes, whose dynamics have historically been linked to hydrological regulation, and to the maintenance of high-altitude wetland systems (see Section 2.1), thereby sustaining water availability in surrounding páramo ecosystems. These cryospheric processes are integral to the hydrological and ecological functioning that sustains landscape integrity.

Studies document a pronounced retreat of tropical glaciers in the Andes over recent decades, associated with rising air temperatures and changes in precipitation patterns. In the case of Chimborazo, a sustained reduction in glacier extent has been recorded since the mid-twentieth century, with a marked acceleration in recent decades, altering accumulation–ablation dynamics at higher elevations. This trend represents a measurable disruption in the cryospheric processes that historically regulated high-mountain system stability [27,29].

Glacier retreat has direct consequences for hydrological processes across the high-mountain landscape. Reduced meltwater inputs affect the recharge of high-altitude wetlands and modify streamflow regimes, particularly during the dry season. These changes influence the extent and functionality of bofedales, as well as the availability of humid microhabitats that are critical for various plant and animal species. Such changes reveal the dependence of wetland functionality and ecosystem resilience on glacial inputs [28,40].

At the ecological scale, increasing climatic variability and progressive warming drive altitudinal shifts in species distributions and compress ecological gradients near Andean summits. Such processes reduce the spatial extent of cold-adapted habitats and increase the vulnerability of high-mountain species to habitat loss and extreme climatic events, indicating emerging pressures on ecological integrity [28,29,49].

Descriptive evidence indicates that glacier retreat and climatic variability are altering hydrological regimes and ecological conditions within the Chimborazo high-mountain system. From an interpretive perspective, these transformations reflect increasing pressure on cryospheric and ecological processes that historically sustained system stability. In terms of integrity, these changes suggest a progressive disruption of the functional coherence of the system, particularly in relation to hydrological regulation and ecosystem resilience. While the overall structure of the landscape remains recognizable, climate change represents a growing pressure on long-term landscape integrity.

3.2. Authenticity of Cultural and Biocultural Values

3.2.1. Archaeological Continuity and High-Altitude Occupation

Archaeological evidence indicates a long history of human presence and use of the high-mountain environments of the Chimborazo massif. Surveys and studies conducted in the region document archaeological sites located at high altitudes, including ceremonial structures, pathways, and activity areas associated with pre-Hispanic occupation and mobility across the central Ecuadorian Andes. These sites demonstrate that high-altitude landscapes were not marginal or uninhabited spaces, but rather integral components of broader territorial and cultural systems. These findings suggest sustained human engagement [50,51].

The spatial distribution of archaeological features around Chimborazo reflects sustained patterns of movement, ritual use, and symbolic appropriation of the mountain landscape. High-altitude sites are frequently associated with ridgelines, passes, and prominent geomorphological features, suggesting deliberate placement linked to visibility, cosmological significance, and control of movement across ecological zones see Figure 5. This pattern is consistent with broader Andean traditions of mountain worship and ritualized engagement with high peaks (*Apus*). Such spatial patterns reinforce the cultural credibility and continuity of sacred mountain traditions [20,52].

Evidence of continuity is further supported by the integration of archaeological remains with later historical and ethnographic records. Colonial and republican sources, as well as oral histories, indicate the persistence of cultural meanings attached to Chimborazo as a sacred and symbolic mountain. These layered temporal expressions reinforce the credibility and continuity of cultural values associated with the massif, extending from pre-Hispanic occupation through historical periods into the present, supporting the interpretation of temporal continuity that underpins cultural authenticity [53].

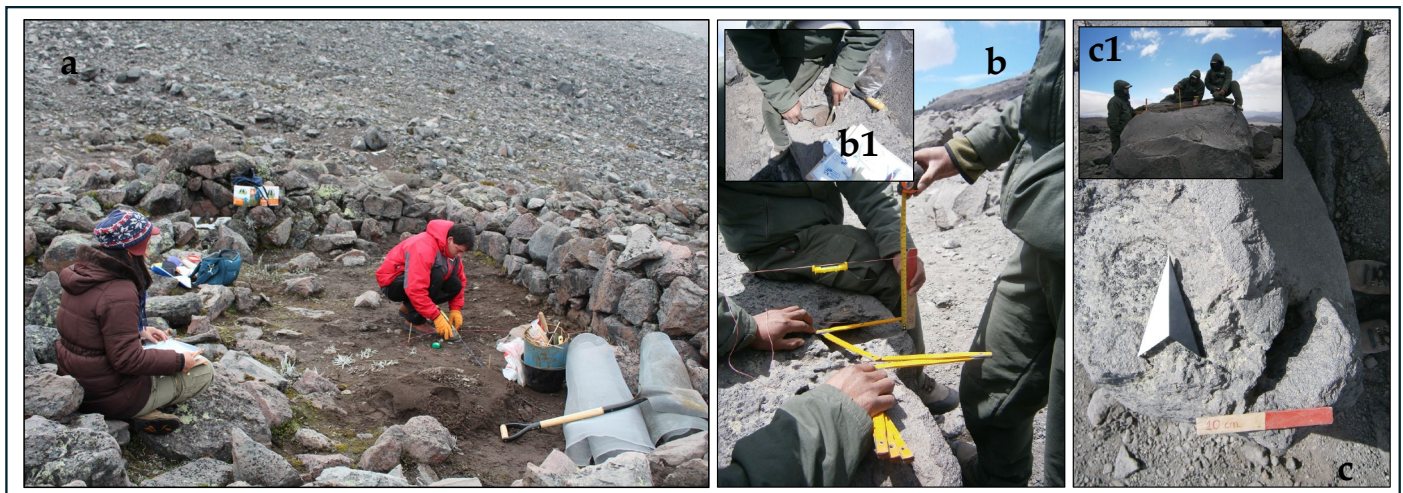


Figure 5. (a) Archaeological excavations within the southern rectangular enclosure of the Inka kan-cha. (b) Measurements for the removal of sediment from artificial cavities in natural rock. (b1) Documentation of the origin of sediments extracted from rocks. (c) Artificial cavity in natural rock. (c1) Teamwork for mapping the contours of the cavities. Source: photograph by Alden Yépez.

3.2.2. Andean Epistemologies and Ritual Landscapes

Andean epistemologies conceive mountains as living entities endowed with agency, memory, and the capacity to interact with human societies. Within this relational framework, Chimborazo is recognized as an *Apu* or *waka*, a sacred mountain that articulates spiritual, territorial, and ecological dimensions and occupies a central place in Andean worldviews. This understanding integrates nature and culture within a relational ontology in which humans, mountains, waters, and other beings coexist and mutually influence one another. This relational ontology sustains culturally grounded interpretations of landscape meaning, reinforcing authenticity [16,52,54].

Ritual landscapes associated with Chimborazo are expressed through ceremonial practices, offerings, pilgrimages, and symbolic narratives that link local communities to the mountain and its constituent elements. These practices take place at specific locations across the territory—such as summits, slopes, passes, and water sources—and are closely connected to agricultural, climatic, and ritual cycles. The persistence of these ritual uses demonstrates continuity in the ways the landscape is socially interpreted, experienced,

and reproduced over time. The persistence of these practices evidences continuity in landscape interpretation and cultural transmission [51,52].

From this perspective, the Chimborazo landscape is not merely a physical setting, but a lived space constructed through symbolic relationships and everyday practices. Concepts such as *ayllu*, *pachamama*, and *sumak kawsay* structure these relationships, shaping social organization, territorial management, and reciprocal interactions with the environment. These epistemologies also influence local understandings of environmental change and responses to transformations in the high-mountain landscape. Also, these concepts structure enduring human–environment relationships that support the credibility of biocultural values [16,55].

The continuity of Andean epistemologies and ritual landscapes associated with Chimborazo constitutes a central component of the cultural and biocultural authenticity of the CFPR. The persistence of these practices and meanings indicates that the cultural values of the landscape are not confined to remnants of the past but remain embedded within living systems of knowledge and human–environment relationships, affirming the authenticity of the Chimborazo biocultural landscape.

3.2.3. The Hieleros of Chimborazo as Biocultural Indicators

The traditional practice of glacier ice extraction on Mt. Chimborazo, carried out by the icemen (hieleros), represents a documented biocultural relationship linking livelihoods, high-mountain environments, and the symbolic meaning of the glacier. This activity involved the manual extraction of ice blocks from the upper slopes of the volcano and their transport to lower-altitude communities and colonial markets, where ice was used for food preservation, medicinal purposes, and everyday consumption. Practices like this illustrate a historically embedded relationship between livelihoods, glacier dynamics, and cultural meaning [56,57].

Ethnographic and documentary accounts indicate that the hieleros' work combined physical endurance, experiential knowledge of the mountain, and ritualized interaction with the glacier environment. Routes, timing, and extraction techniques were shaped by seasonal climatic conditions and culturally embedded norms of respect toward the mountain, reflecting long-term adaptation to extreme high-altitude environments. Such practices reflect culturally regulated interactions with extreme environments [52].

In recent decades, accelerated glacier retreat and changes in ice accessibility have significantly constrained the continuity of this practice. Reduced ice availability and transformed extraction routes have led to the near disappearance of glacier ice harvesting as a regular livelihood activity, persisting mainly in symbolic or commemorative forms. These transformations reveal the vulnerability of culturally embedded practices to cryospheric change [57].

Descriptive evidence indicates that the hieleros practice has undergone significant transformation due to glacier retreat and reduced ice accessibility. From an interpretive perspective, these changes reflect the close coupling between climatic processes and culturally embedded practices in high-mountain environments. In terms of authenticity, the transformation and partial persistence of this practice suggest both the continuity and vulnerability of biocultural traditions, highlighting how environmental change affects the credibility and transmission of culturally embedded relationships with the landscape (see Figure 6).



Figure 6. Traditional process of extracting ice blocks from Chimborazo volcano (“Hieleros de Chimborazo”): (a) Ascent to glacier, (b) Extraction and cutting of ice blocks, (c) Wrapping of ice blocks in straw, (d) Loading of ice in animal transport, (e) Descent from the volcano, and (f) Delivery of ice to the “La Merced” market in Riobamba for marketing. Source: Adapted from Pérez (2013) [58].

3.2.4. Scientific, Historical, and Symbolic Authenticity

The Chimborazo volcano has played a central role in the history of scientific exploration and in the construction of symbolic meanings associated with high-mountain landscapes. Since the early nineteenth century, the mountain has been documented as a key reference for the development of ideas related to altitudinal zonation, climate–vegetation relationships, and global comparisons among mountain systems, particularly through the work of Alexander von Humboldt, who positioned Mt. Chimborazo as a natural laboratory for understanding environmental patterns at a planetary scale [59], thus making Mt. Chimborazo ‘the birthplace of ecology’ [60]. This scientific legacy contributes to the authenticity of Chimborazo as a historically grounded landscape of global environmental knowledge.

Subsequently, scientific expeditions and mountaineering narratives reinforced the relevance of the Chimborazo volcano within the global imagination of great mountains. Accounts by explorers and naturalists, including Edward Whymper, contributed to the international recognition of the volcano as a site of scientific inquiry, physical challenge, and symbolic significance, integrating Chimborazo into historical narratives of exploration, measurement, and altitude conquest [19]; see Figure 7.



Figure 7. Depictions by memory of the likely landscape of the Tapia Plateau (on the left) and the base camp preparing for the excursion to Mt. Chimborazo (on the right). Painted by Friedrich Alexander Weitsch in 1810–1816. (Source: Adapted from [59], public domain.)

Beyond its importance in the history of modern science, archaeological and ethnohistorical evidence indicates that the Chimborazo volcano occupied a central place for pre-Inka societies and indigenous populations of the central Ecuadorian Andes. These groups interacted with the mountain as a sacred and strategic landscape, incorporating it into systems of mobility, ritual practice, and territorial organization that preceded and later intersected with Inka expansion [61]. The presence of archaeological sites, ceremonial spaces, and ancient pathways in the surroundings of the volcano documents a long-term human engagement with Chimborazo as a lived and meaningful landscape, demonstrating long-term cultural continuity and territorial significance [61,62].

Within this broader Andean context, the Chimborazo volcano was also connected to the imperial Inka road system (Qhapaq Ñan), which structured communication, mobility, and political integration across the Andes. Segments and associated routes linked to the Qhapaq Ñan in the Chimborazo region provide material evidence of the incorporation of the volcano into large-scale pre-Hispanic networks of exchange, governance, and symbolic geography. These connections situate Chimborazo within broader systems of mobility and symbolic geography, reinforcing its cultural authenticity [20,61,63,64].

In addition to its cultural and historical relevance, the Chimborazo volcano holds a unique geodetic significance. Due to the Earth's equatorial bulge, its summit represents the point on the Earth's surface farthest from the planet's center and, therefore, the terrestrial point closest to the Sun in geodetic terms. This exceptional condition has consolidated Chimborazo as a reference in scientific discussions related to Earth's shape, altitude measurement, and global physical geography, defining a unique geodetic condition that strengthens the scientific authenticity and global singularity of the site [65–67].

The symbolic authenticity of the Chimborazo volcano is also expressed through its presence in official state iconography. In the national coat of arms of Ecuador, the Chimborazo volcano is depicted in the background, with the Guayas River originating at its base. This representation constitutes an official and enduring visual reference that links Mt. Chimborazo to the country's natural geography, the origin of major hydrological systems, and national historical identity, affirming its enduring symbolic authenticity at the state level [68]. Descriptive evidence indicates that Chimborazo holds a unique scientific, historical, and symbolic significance at both national and global scales. From an interpretive perspective, these multiple layers of meaning reflect the integration of scientific knowledge, historical narratives, and cultural-symbolic values within a single high-mountain landscape. In terms of authenticity, these elements support the interpretation of Chimborazo as a landscape with credible, continuous, and multi-scalar cultural signif-

icance, where historical, scientific, and symbolic dimensions reinforce its status as a biocultural heritage system.

4. Discussion

4.1. Integrity, Authenticity, and Biocultural Continuity in the Chimborazo Landscape

The Chimborazo volcano can be interpreted as a high-mountain landscape where ecological integrity and cultural authenticity are closely interconnected. Integrity is expressed through the continuity of volcanic structure, altitudinal gradients, remnant glaciers, páramo ecosystems, and bofedales, which together sustain key hydrological and ecological processes. Moreover, bofedales play a central role as high-Andean wetlands, regulating water availability, supporting biodiversity, and linking the nival zone with downstream ecosystems. Taken together, the evidence presented in Section 3 indicates that integrity and authenticity operate as interdependent socioecological properties rather than isolated attributes [27,40,45].

This bio-physical framework supports representative assemblages of Andean high-mountain biodiversity, including emblematic fauna such as the vicuña (*Vicugna vicugna*), the Andean condor (*Vultur gryphus*), and the Chimborazo hillstar (*Oreotrochilus chimborazo*), as well as characteristic páramo and puna flora (e.g., *Calamagrostis*, *Festuca*, *Chuquiraga*, cushion plants, and localized *Polylepis* formations) [43,69]. Beyond their ecological roles, biocultural interactions are evident, particularly in the relationship between *Chuquiraga jussieui* (see Figure 8) and *Oreotrochilus chimborazo*, where nectar provision and pollination sustain ecosystem functioning, while the hillstar—known as wakcha quyllur (orphan star) in Kichwa Puruwa narratives—is embedded in local identity as a guardian of the high páramo. Together, these components define an integrity based on system functionality rather than on isolated natural elements [47,51]. Also, these interactions illustrate how ecological functionality and cultural meaning co-evolve, reinforcing system integrity.

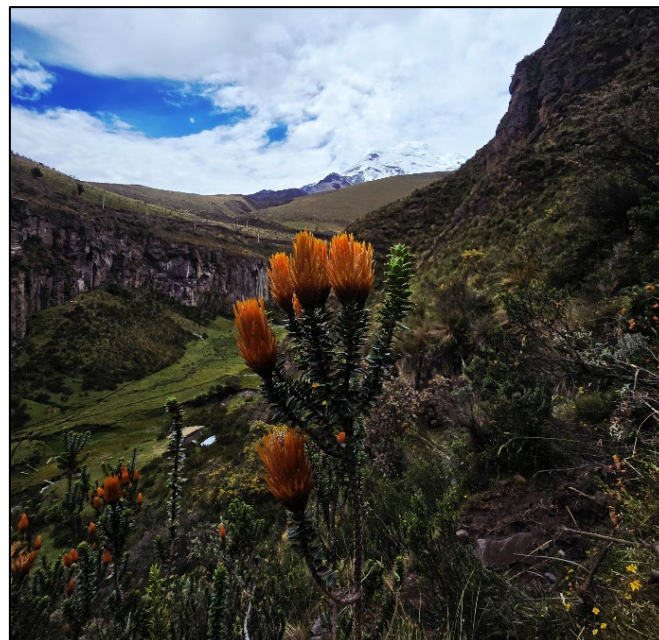


Figure 8. The figure depicts *Chuquiraga jussieui* (approximately 1.5 m in height) in the foreground with the Chimborazo volcano in the background, highlighting the ecological importance and biocultural significance of this emblematic species within Ecuadorian high-Andean páramo landscapes. Source: photograph by Jhony Cruz.

Cultural authenticity is manifested through the continuity of territorially anchored practices, meanings, and memories. Archaeological materiality, ritual traditions, mobility systems, scientific narratives, and symbolic representations demonstrate that Mt. Chimborazo functions as a lived and meaningful landscape. Ecological processes sustain cultural practices, while human uses and meanings contribute to the long-term social continuity of the landscape, a continuity which demonstrates that authenticity resides in living practices and meanings sustained through ecological processes.

Spiritual and cosmological dimensions are also present in the Mountain Protected Area (MtPA). Rocks with votive cavities and the alignment of Chimborazo's summits reflect the sacred dimension of the landscape [20], emphasizing the integration of cosmology and conservation, which has materialized in the form of a typical *Kancha* (4 lateral rectangular buildings surrounding a square) of the Inka culture (see Figure 9) and a series of circular stone rings 1–2 m in diameter alongside micro-summits of a rockscape, probably affiliated with the earlier Puruwa culture or Puruwa people of the colonial period (see Figure 10). Such sites highlight how the mountain is not only an ecological space but also a sacred being (*apu*) within the Andean worldview, reinforcing the principle of reciprocity embedded in *ayllu* and *Pachamama*. Such sacred dimensions reinforce reciprocal human–environment relationships central to biocultural continuity [20,56,70].



Figure 9. Shows the oblique projection view of the walled areas of the *Kancha* site, the archaeological work with on-site preparations, and the high-altitude excavations at Inka sites at 4880 m on the southwestern slopes of Chimborazo volcano. Source: photograph by Alden Yépez.

The archaeological record further emphasizes the importance of integrating cultural and ecological heritage in conservation planning. High-altitude Inka sites at 4880 m reveal how human presence and ritual activities have long been integrated into the ecological fabric of Chimborazo (see Figure 9). Similarly, the *Yat'a Chimburasu* walls illustrate ancestral engineering for resource use, refuge, or the rounding-up of fauna (see Figure 10). These findings reinforce the idea that conservation strategies for the CFPR cannot be limited to ecological values alone but must also incorporate the archaeological and cultural dimensions of the landscape, supporting an integrated interpretation of heritage and conservation [20].

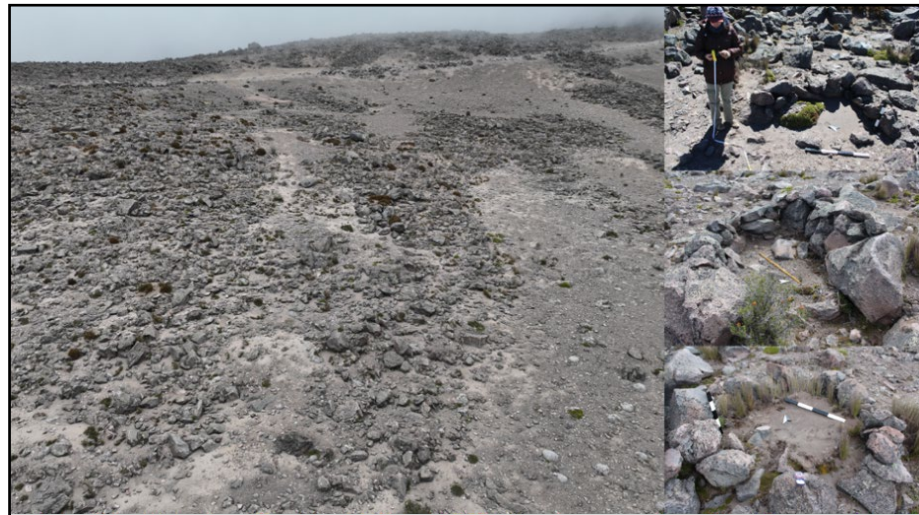


Figure 10. Panoramic view of the collection of walls or *Yat'a* Chimburasu towards the northeast, attention to the engineering of enclosures that could have served for refuge, storage or rounded-up useful fauna. Source: photograph by Alden Yépez.

4.2. Indigenous Mobility, Glacier Dynamics, and Socioecological Vulnerability

Pre-Inka societies and contemporary Indigenous communities have historically engaged with Chimborazo as a sacred Apu/waka and as a strategic node within broader systems of Andean mobility. The incorporation of the volcano into routes associated with the Qhapaq Ñan situates it within continental-scale networks that articulated ecological zones, ritual spaces, and political organization. These routes functioned as cultural corridors for the circulation of goods, knowledge, and ceremonial practices, making mobility a structuring component of the cultural landscape [51,61]. Mobility thus emerges as a structuring component of landscape authenticity and territorial continuity.

Glacier retreat provides a critical lens for understanding both integrity and authenticity under climate change. Accelerated ice loss alters hydrological dynamics and affects bofedales, while simultaneously undermining biocultural practices historically associated with ice, such as those carried out by the hieleros [56,57]. Chimborazo thus exemplifies how climate-driven impacts on a natural component produce simultaneous ecological and cultural effects. These dynamics suggest that integrity may be more appropriately understood as a socioecological property [27,29,71].

4.3. Science, Symbolism, and Outstanding Universal Value

Chimborazo occupies a central place in the history of scientific thought on mountain environments, considered for many decolonial scholars as the ‘tallest mountain on Earth’. Starting from the Franco–Spanish Geodetic Mission to the observations of Alexander von Humboldt, and later expeditions by Edward Whymper, the volcano served as a reference for understanding altitudinal zonation, climate–vegetation relationships, and mountain measurement [1,65]. This scientific trajectory contributes to Chimborazo’s universal significance as a reference landscape for environmental knowledge.

This scientific relevance is reinforced by Chimborazo’s unique geodetic condition as the point on Earth’s surface farthest from the planet’s center, situating it within global debates on Earth system measurement. Scientific narratives coexist with Indigenous meanings and symbolic representations, producing layered interpretations of the volcano as a space of knowledge, sacrality, and universal heritage significance [65,67]. Literary, artistic, and institutional representations further consolidate this symbolic dimension. The famed prose ‘Mi delirio sobre el Chimborazo’ by Simón Bolívar, and the depiction of

Chimborazo in Ecuador's national coat of arms embed the volcano within universal narratives of freedom, identity, and state formation [18].

4.4. *Implications for Sustainability and Protected Area Governance*

The Chimborazo case highlights broader sustainability challenges faced by high-mountain protected areas, particularly where sectoral conservation models prioritize wildlife production or resource control while marginalizing cultural heritage and Indigenous knowledge systems. Such exclusionary approaches have been widely documented to undermine social legitimacy and limit the effectiveness of conservation strategies, especially in historically inhabited mountain landscapes [21–23]. In the CFPR, the emphasis on faunal production as a primary management objective reflects these limitations and constrains the capacity of conservation frameworks to address coupled social–ecological dynamics under accelerating climate change.

Interpreting Chimborazo as a biocultural landscape offers an alternative governance pathway that integrates ecological integrity, cultural continuity, and adaptive management. This approach is consistent with biocultural conservation frameworks that recognize biodiversity, cultural practices, and knowledge systems as mutually reinforcing components of social–ecological systems [14,15,35]. By acknowledging Indigenous epistemologies and territorially grounded practices, biocultural governance models enhance resilience and adaptive capacity in mountain landscapes facing glacier retreat, hydrological change, and ecosystem transformation [4,17].

Beyond the Chimborazo case, these insights may be relevant for other high-Andean and global mountain protected areas experiencing similar sustainability pressures. Integrative governance models grounded in biocultural values may provide a useful basis for reconciling conservation objectives with social inclusion, climate adaptation, and long-term sustainability in mountain social–ecological systems worldwide [29,30,49].

4.5. *UNESCO Criteria, Mixed Heritage Interpretation, and Governance Models*

The integrated evidence contributes to the interpretation of Chimborazo as a site with potential Outstanding Universal Value, grounded in the convergence of cultural criteria (iii), (v), and (vi). Criterion (iii) is expressed through living Andean traditions associated with sacrality (Apu/waka) and ongoing ritual practices; criterion (v) through the long-term interaction between society and mountain, articulated via mobility systems and landscape use in highland/lowland interactions; and criterion (vi) through Mt. Chimborazo's direct association with universal scientific, literary, and symbolic narratives [10]. Together, these criteria suggest the convergence of living traditions, landscape interaction, and universal symbolic associations.

These cultural values are inseparable from an exceptional natural system—a tropical glaciated volcano with pronounced ecological gradients, functional bofedales, active hydrological processes, and representative high-Andean biodiversity—forming a coherent case of mixed natural–cultural heritage [14,35]. This inseparability supports interpreting Chimborazo as a coherent mixed natural–cultural heritage system.

This interpretation aligns with UNESCO-integrated governance models, particularly UNESCO Global Geoparks, Biosphere Reserves, and biocultural landscape approaches, which promote articulated conservation of geological, ecological, and cultural heritage through community participation, recognition of traditional knowledge, education, and adaptive management under climate change [72]. For Chimborazo, such models may provide a coherent framework to safeguard ecological integrity, cultural authenticity, and the landscape's role as a living socioecological system of global relevance.

Recognition of mountains as sentient landscapes with their own rights protected by the constitution is now granted in several countries, including Bolivia, Canada, Colombia,

Ecuador, Mexico, New Zealand, Romania, and the United States of America [73]. While designation of the MtPA of Chimborazo as a faunal reserve was implemented in the 1970s, it is clear that the difficulty of isolating biodiversity from the sociocultural system of the mountain, these elements support the consideration of Chimborazo as a candidate for mixed World Heritage recognition, although further formal evaluation would be required under UNESCO criteria. Examples of emblematic mountains considered hybrid territories come from Mt. Uluru in Chata Yujta National Park, Australia; Mt. Fujiyama in Japan; Mt. Kilimanjaro in Tanzania; Mt. Shasta in the United States of America; Mt. Kailash in India; Mt. Machu Picchu in Peru; Banaue slopes in Ifugao, Philippines; and the ‘maunga’ of Mt. Taranaki and Mt. Tongariro in New Zealand [32]. From this perspective, Chimborazo may be considered a strong candidate for mixed World Heritage recognition, given the convergence of ecological, cultural, and symbolic values identified in this study. However, further interdisciplinary assessment and formal evaluation under UNESCO criteria would be required to substantiate such a designation [32].

5. Conclusions

This perspective has examined the MtPA of the Chimborazo volcano as a high-Andean landscape in which natural processes and cultural meanings are closely intertwined, supporting its interpretation as a site with potential Outstanding Universal Value (OUV) and mixed natural–cultural heritage relevance. Rather than deriving from isolated attributes, Chimborazo’s significance emerges from the long-term convergence of ecological integrity, living Andean sacrality, historical mobility systems, scientific exploration, and symbolic representations.

The analysis suggests that UNESCO cultural criteria (iii), (v), and (vi) may be reflected through the continuity of living traditions associated with Andean sacrality (Apu/waka), the sustained interaction between societies and the mountain articulated through territorial use and mobility systems linked to the Qhapaq Ñan, and Chimborazo’s association with scientific, literary, and symbolic narratives. These cultural values are closely linked to an exceptional natural system characterized by altitudinal gradients, bofedales, hydrological processes, and representative high-Andean biodiversity.

By integrating glacier dynamics, páramo ecosystems, bofedales, and emblematic flora and fauna with archaeological evidence, ritual practices, and historical mobility, this study supports the interpretation of integrity as a socioecological property and authenticity as a function of culturally grounded continuity. Climate-driven glacier retreat illustrates how environmental change may simultaneously affect ecological processes and biocultural practices, highlighting the importance of integrated perspectives in high-mountain environments.

Conceptually, this study contributes a structured interpretive approach that integrates integrity and authenticity as complementary analytical lenses. Rather than constituting a fully operational or directly transferable framework, this approach provides a basis for interpreting socioecological complexity in high-mountain biocultural landscapes.

This study is based on secondary interdisciplinary sources and comparative synthesis; therefore, the approach would benefit from further empirical validation through participatory research, co-production of knowledge, and long-term environmental monitoring. Additionally, governance analyses remain constrained by the availability of institutional data and evolving policy contexts.

The Chimborazo case highlights the potential relevance of UNESCO-aligned integrated governance models—such as Global Geoparks, Biosphere Reserves, and biocultural landscape approaches—for addressing sustainability challenges in high-mountain systems. In this context, initiatives such as the Satoyama Initiative illustrate how socioec-

ological production landscapes may contribute to integrating nature and culture through participatory governance frameworks.

Future research may further explore the application of this approach through participatory methodologies, climate adaptation scenarios, and comparative analyses across Andean and global mountain systems. While the Chimborazo case provides useful insights, further research is required to assess the broader applicability of these interpretations in other contexts.

Author Contributions: Conceptualization, J.F.C.-R., C.R.C.-V. and F.O.S.; methodology, J.F.C.-R. and C.R.C.-V.; software, J.F.C.-R.; validation, J.F.C.-R., C.R.C.-V. and F.O.S.; formal analysis, J.F.C.-R., C.R.C.-V. and E.R.D.-V.; investigation, J.F.C.-R., C.R.C.-V., A.M.S.-P., S.P.M.-S., A.Y.-N. and J.S.-A.; resources, C.R.C.-V. and F.O.S.; data curation, J.F.C.-R. and A.M.S.-P.; writing—original draft preparation, J.F.C.-R.; writing—review and editing, J.F.C.-R., C.R.C.-V. and F.O.S.; visualization, J.F.C.-R. and A.Y.-N.; supervision, C.R.C.-V. and F.O.S.; project administration, J.F.C.-R. and C.R.C.-V.; funding acquisition, C.R.C.-V. and F.O.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Escuela Superior Politécnica de Chimborazo (ES-POCH) grant number DI004. The APC was funded by ESPOCH.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Acknowledgments: The authors would like to express their sincere gratitude to all co-authors for their collaborative contributions throughout the development of this research. We also acknowledge the institutional support provided by the Escuela Superior Politécnica de Chimborazo (ESPOCH), which facilitated the academic and logistical conditions necessary for the completion of this study.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Sarmiento, F.O. Breaking Mountain Paradigms: Ecological Effects on Human Impacts in Man-Aged Tropandean Landscapes. *AMBIO A J. Hum. Environ.* **2000**, *29*, 423–431. <https://doi.org/10.1579/0044-7447-29.7.423>.
2. Buytaert, W.; Vuille, M.; Dewulf, A.; Urrutia, R.; Karmalkar, A.; Céleri, R. Uncertainties in Climate Change Projections and Regional Downscaling in the Tropical Andes: Implications for Water Resources Management. *Hydrol. Earth Syst. Sci.* **2010**, *14*, 1247–1258. <https://doi.org/10.5194/hess-14-1247-2010>.
3. Körner, C.; Jetz, W.; Paulsen, J.; Payne, D.; Rudmann-Maurer, K.; M. Spehn, E. A Global Inventory of Mountains for Bio-Geographical Applications. *Alp. Bot.* **2017**, *127*, 1–15. <https://doi.org/10.1007/s00035-016-0182-6>.
4. Ibarra, J.T.; Caviedes, J.; Marchant, C.; Mathez-Stiefel, S.-L.; Navarro-Manquilef, S.; Sarmiento, F.O. Mountain Social-Ecological Resilience Requires Transdisciplinarity with Indigenous and Local Worldviews. *Trends Ecol. Evol.* **2023**, *38*, 1005–1009. <https://doi.org/10.1016/j.tree.2023.07.004>.
5. Jokilehto, J. World Heritage: Defining the Outstanding Universal Value. *City Time* **2006**, *2*, 1–10.
6. Askew, M. The Magic List of Global Status: UNESCO, World Heritage and the Agendas of States. In *Heritage and Globalisation*; Routledge: Oxfordshire, UK, 2010.
7. Henriques, M.H.; Brilha, J. UNESCO Global Geoparks: A Strategy towards Global Understanding and Sustainability. *Epis. J. Int. Geosci.* **2017**, *40*, 349–355. <https://doi.org/10.18814/epiuiugs/2017/v40i4/017036>.
8. Ringbeck, B. The World Heritage Convention and Its Management Concept. In *Aspects of Management Planning for Cultural World Heritage Sites: Principles, Approaches and Practices*; Makuvaza, S., Ed.; Springer International Publishing: Cham, Switzerland, 2018; pp. 15–24. ISBN 978-3-319-69856-4.

9. Sarmiento, F.O.; Inaba, N.; Iida, Y.; Yoshida, M. Mountain Graticules: Bridging Latitude, Longitude, Altitude, and Historicity to Biocultural Heritage. *Geographies* **2023**, *3*, 19–39. <https://doi.org/10.3390/geographies3010002>.
10. UNESCO (World Heritage Convention). The Operational Guidelines for the Implementation of the World Heritage Convention. Available online: <https://whc.unesco.org/en/guidelines/> (accessed on 29 December 2025).
11. Mitchell, N.; Rössler, M.; Tricaud, P.-M. *World Heritage Cultural Landscapes: A Handbook for Conservation and Management*; UNESCO: Paris, France, 2009. ISBN 978-92-3-104147-1.
12. Khalaf, R.W. The Implementation of the UNESCO World Heritage Convention: Continuity and Compatibility as Qualifying Conditions of Integrity. *Heritage* **2020**, *3*, 384–401. <https://doi.org/10.3390/heritage3020023>.
13. Ruggles, D.F.; Silverman, H. From Tangible to Intangible Heritage. In *Intangible Heritage Embodied*; Silverman, H., Ruggles, D.F., Eds.; Springer: New York, NY, USA, 2009; pp. 1–14, ISBN 978-1-4419-0072-2.
14. Hitchner, S.; Sarmiento, F. *Indigeneity and the Sacred: Indigenous Revival and the Conservation of Sacred Natural Sites in the Americas*; Berghahn Books, Oxford, New York, 2017; pp. 1–278.
15. Rozzi, R.; May, R.H.; Chapin, F.S.; Massardo, F.; Gavin, M.C.; Klaver, I.J.; Pauchard, A.; Nuñez, M.A.; Simberloff, D. From Biocultural Homogenization to Biocultural Conservation: A Conceptual Framework to Reorient Society Toward Sustainability of Life. In *From Biocultural Homogenization to Biocultural Conservation*; Rozzi, R., May, R.H., Jr., Chapin, F.S., III, Massardo, F., Gavin, M.C., Klaver, I.J., Pauchard, A., Nuñez, M.A., Simberloff, D., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 1–17. ISBN 978-3-319-99513-7.
16. Gudynas, E. Buen Vivir: Today's Tomorrow. *Development* **2011**, *54*, 441–447. <https://doi.org/10.1057/dev.2011.86>.
17. Sarmiento, F.O. Elgar Companion to Geography, Transdisciplinarity and Sustainability. *The Elgar Companion to Geography, Transdisciplinarity and Sustainability*; Edward Elgar Publishing: Gloucestershire, UK, 2020.
18. Brown, D.; Gabrys, J. Community-Led Landscape Regeneration: A Review of and Framework for Engagement in Restoration Initiatives. *Ambio* **2026**, *55*, 227–244. <https://doi.org/10.1007/s13280-025-02236-3>.
19. Moreno, Y. La Arqueología y La Etnohistoria: Un Encuentro Andino. In *El Chimborazo, Ecuador: Un Ancestro Sagrado Andino*; Instituto de Estudios Peruanos: Lima, Peru; Institute of Andean Research: New York, NY, USA, 2009.
20. Yépez, A. Las Huacas Del Volcán Chimborazo (Ecuador) y Sus Relaciones de Visibilidad Con Santuarios de Altura Prehispánicos. *Anthropos* **2017**, *112*, 127–152. <https://doi.org/10.5771/0257-9774-2017-1-127>.
21. Korovkin, T. Indigenous Peasant Struggles and the Capitalist Modernization of Agriculture: Chimborazo, 1964–1991. *Lat. Am. Perspect.* **1997**, *24*, 25–49.
22. West, P.; Igoe, J.; Brockington, D. Parks and Peoples: The Social Impact of Protected Areas. *Annu. Rev. Anthropol.* **2006**, *35*, 251–277. <https://doi.org/10.1146/annurev.anthro.35.081705.123308>.
23. Adams, W.M.; Hutton, J. People, Parks and Poverty: Political Ecology and Biodiversity Conservation. *Conserv. Soc.* **2007**, *5*, 147–183.
24. Sarmiento, F.; Gunya, A.; Kremsa, V. *Montology Vol. 2: Mountain Lexicon: A Corpus of Montology and Innovation*; Springer Nature: Cham, Switzerland, 2024.
25. Rodríguez, N.; Morales, A. *La Vicuña Ecuatoriana y su Entorno/Ecuador Mamallaktapi Tiyak Wikuña Paypak Kuskapi*, 1st ed.; MAE: Quito, Ecuador, 2017; ISBN 978-9942-8611-1-5.
26. Gross, M.; Pearson, J.; Arbieu, U.; Riechers, M.; Thomsen, S.; Martín-López, B. Tourists' Valuation of Nature in Protected Areas: A Systematic Review. *Ambio* **2023**, *52*, 1065–1084. <https://doi.org/10.1007/s13280-023-01845-0>.
27. Rabatel, A.; Francou, B.; Soruco, A.; Gomez, J.; Cáceres, B.; Ceballos, J.L.; Basantes, R.; Vuille, M.; Sicart, J.-E.; Huggel, C.; et al. Current State of Glaciers in the Tropical Andes: A Multi-Century Perspective on Glacier Evolution and Climate Change. *Cryosphere* **2013**, *7*, 81–102. <https://doi.org/10.5194/tc-7-81-2013>.
28. Morueta-Holme, N.; Engemann, K.; Sandoval-Acuña, P.; Jonas, J.D.; Segnitz, R.M.; Svenning, J.-C. Strong Upslope Shifts in Chimborazo's Vegetation over Two Centuries since Humboldt. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 12741–12745. <https://doi.org/10.1073/pnas.1509938112>.
29. Vuille, M.; Carey, M.; Huggel, C.; Buytaert, W.; Rabatel, A.; Jacobsen, D.; Soruco, A.; Villacis, M.; Yarleque, C.; Elison Timm, O.; et al. Rapid Decline of Snow and Ice in the Tropical Andes—Impacts, Uncertainties and Challenges Ahead. *Earth-Sci. Rev.* **2018**, *176*, 195–213. <https://doi.org/10.1016/j.earscirev.2017.09.019>.
30. Silvius, J.; Hoogstra, A.G.; Candel, J.J.L.; de Olde, E.M.; de Boer, I.J.M.; Termeer, C.J.A.M. Determining the Transformative Potential of Circular Agriculture Initiatives. *Ambio* **2023**, *52*, 1968–1980. <https://doi.org/10.1007/s13280-023-01894-5>.
31. Hay-Edie, T. *World Heritage and Sustainable Development: The Role of Local Communities*; Routledge: Oxfordshire, UK, 2018.
32. Bernbaum, E.; Bernbaum, E. *Sacred Mountains of the World*; Cambridge University Press: Cambridge, UK, 2022.

33. Gallo, N.; Cevallos, A. Contexto nacional y regional de la Reserva Faunística Chimborazo. Dirección Nacional Forestal: Riobamba, Ecuador, 1992.
34. MAATE. *Plan de Manejo de Visitantes de la Reserva de Producción de Fauna Chimborazo*; MAATE: Riobamba, Ecuador, 2023.
35. Sarmiento, F.O.; Viteri, O. Discursive Heritage: Sustaining Andean Cultural Landscapes Amidst Environmental Change. In *Conserving Cultural Landscapes: Challenges and New Directions*; Routledge: New York, NY, USA, 2015.
36. Sarmiento, F.O. Montology Manifesto: Echoes towards a Transdisciplinary Science of Mountains. *J. Mt. Sci.* **2020**, *17*, 2512–2527. <https://doi.org/10.1007/s11629-019-5536-2>.
37. Kilian, R. Der Chimborazo (6310 m) Und Carihuairazo (5102 m) in Ecuador-Aufbau und Entwicklung Eines Grossen Stratovulkan-Komplexes. Ph. D. Thesis, University of Tübingen, Tübingen, Germany, 1987; pp. 1–244.
38. Samaniego, P.; Barba, D.; Robin, C.; Fornari, M.; Bernard, B. Eruptive History of Chimborazo Volcano (Ecuador): A Large, Ice-Capped and Hazardous Compound Volcano in the Northern Andes. *J. Volcanol. Geotherm. Res.* **2012**, 221–222, 33–51. <https://doi.org/10.1016/j.jvolgeores.2012.01.014>.
39. Clapperton, C.M. Glacial and Volcanic Geomorphology of the Chimborazo-Carihuairazo Massif, Ecuadorian Andes. *Earth Environ. Sci. Trans. R. Soc. Edinb.* **1990**, *81*, 91–116. <https://doi.org/10.1017/S0263593300005174>.
40. Hofstede, R. *Los Páramos Andinos: ¿Qué Sabemos? Estado de Conocimiento Sobre el Impacto del Cambio Climático en el Ecosistema Páramo*; UICN: Quito, Ecuador, 2014.
41. MAE. *Sistema de Clasificación de los Ecosistemas del Ecuador Continental*; Ministerio del Ambiente del Ecuador: Quito, Ecuador, 2013.
42. Fernández, D.; Ulloa, C.; Palacios, W.; Freire, E.; Peñafiel Cevallos, M.; Cuamacás, B.; Unda, M.; Rea, E.; Haro, M.; Herrera, V.; et al. *Plantas de Los Páramos del Distrito Metropolitano de Quito, Ecuador*; Instituto Nacional de Biodiversidad: Quito, Ecuador, 2015. ISBN 978-9942-9988-4-2.
43. Caranqui, J.; Lozano, P.; Reyes, J. Composición y diversidad florística de los páramos en la Reserva de Producción de Fauna Chimborazo, Ecuador. *Enfoque UTE* **2016**, *7*, 33–45.
44. Sarmiento, F.O. Contesting Páramo: Critical Biogeography of the Northern Andean Highlands. *UGA Today* **2012**.
45. Carrasco-Baquero, J.C.; Caballero-Serrano, V.; Carrasco-López, D.C.; Romero-Cañizares, F.; León-Gualán, D.A.; Córdova-Lliquin, J.D.; Vieira-Lanero, R.; Cobo-Gradín, F. Aquatic Macroinvertebrates as Indicators of Water Quality in the Wetlands of the Chimborazo Wildlife Reserve–Ecuador. *Limnologia* **2025**, *112*, 126234. <https://doi.org/10.1016/j.limno.2025.126234>.
46. Tirira, D. *Guía de Campo de Los Mamíferos del Ecuador*; Ediciones Murciélagos Blanco, Publicación especial sobre los mamíferos del Ecuador: Quito, Ecuador, 2007. ISBN 978-9978-44-651-5.
47. Bayancela-Delgado, S.B.; Cajas-Bermeo, C.A. Vertebrados terrestres del ecosistema Bosque siempre verde del páramo en la Reserva de Producción de Fauna Chimborazo. *Polo Del Conoc.* **2021**, *6*, 304–316.
48. Torres-Carvajal, O.; Pazmiño-Otamendi, G.; Salazar-Valenzuela, D. Reptiles of Ecuador: A Resource-Rich Online Portal, with Dynamic Checklists and Photographic Guides. *Amphib. Reptile Conserv.* **2019**, *13*, 209–229.
49. Dangles, O.; Rabatel, A.; Kraemer, M.; Zeballos, G.; Soruco, A.; Jacobsen, D.; Anthelme, F. Ecosystem Sentinels for Climate Change? Evidence of Wetland Cover Changes over the Last 30 Years in the Tropical Andes. *PLoS ONE* **2017**, *12*, e0175814. <https://doi.org/10.1371/journal.pone.0175814>.
50. Ugalde Mora, M.F. *Volcanes, Cenizas y Ocupaciones Antiguas en Perspectiva Geoarqueológica en América Latina*; Estudios de Antropología y Arqueología; Pontificia Universidad Católica del Ecuador, Facultad de Ciencias Humanas, Escuela de Antropología: Quito, Ecuador, 2017.
51. Yépez, A. Sobre las nieblas de los volcanes chimborazo y sangay: Asentamientos humanos milenarios y paleoambiente. *Volcanes Cenizas Y Ocup. Antig. Perspect. Geoarqueológica América Lat.* **2017**, *2*, 146–152. ISBN 978-9978-77-308-6.
52. Ceruti, C. Inka Mountaintop Shrines and Glaciers in the High Andes. *J. Glacial Archaeol.* **2016**, *3*, 59–78. <https://doi.org/10.1558/jga.34465>.
53. Yépez, A. Empty Spaces That Are Full of Cultural History: An Innovative Proposal for the Management of a Protected Area of Chimborazo Volcano (Ecuador). *eco.mont (J. Prot. Mt. Areas Res.)* **2020**, *12*, 43–49. <https://doi.org/10.1553/eco.mont-12-1s43>.
54. Sarmiento, F.O. (Ed.) *Montology Palimpsest: A Primer of Mountain Geographies*; Montology; Springer International Publishing: Cham, Switzerland, 2022; Volume 1; ISBN 978-3-031-13297-1.
55. Sarmiento, F.O.; Velásquez, R.C.; Merino, C.A.; Abrams, J. Desarrollo sustentable y regenerativo de los paisajes socioecológicos de montaña: Montología del Chimborazo como referente insigne del cambio global. *Antropol. Sur* **2022**, *9*, 121–145. <https://doi.org/10.25074/rantros.v9i17.2316>.

56. Falconí Trávez, D.F. Los hieleros del Chimborazo y Baltazar Ushca, el tiempo congelado: Narraciones fílmicas y literarias del indigenismo ecuatoriano. Un análisis comparatista decolonial de la subalternización nativa. *Extravío Rev. Electrónica Lit. Comp.* **2015**, *8*, 38–57.
57. Germán, G.; Cadena, J.P. Extracción Del Hielo En El Nevado Chimborazo En Ecuador: Un Trabajo Que Transciende En La Historia. *Espacios* **2020**, *40*, 1–10.
58. Pérez, R. El Último Cazador de Hielo. Ecuador. Available online: <https://kamaleon.viajes/el-ultimo-cazador-de-hielo/> (accessed on 29 December 2026).
59. von Humboldt, A.; Otté, E.C.; Bohn, H.G. *Views of Nature, or, Contemplations on the Sublime Phenomena of Creation: With Scientific Illustrations*; H.G. Bohn: London, UK, 1850.
60. Sarmiento, F.O. The Mountains of Ecuador as a Birth Place of Ecology and Endangered Landscape. *Environ. Conserv.* **1997**, *24*, 3–4. <https://doi.org/10.1017/S0376892997000039>.
61. Anhalzer, J. *El Capacñán en Ecuador: El Hallazgo de un Olvido*; Imprenta Mariscal: Quito, Ecuador, 2022.
62. Yepez, A.; Sevilla, A.M.; Anhalzer, J.; Vásquez, M.A. Ruta y camino: Memoria, historia y arqueología del Qhapaq Ñan. *INPC Rev. Patrim. Cult. Ecuad.* **2023**, *1*, e2. <https://doi.org/10.5281/zenodo.10037192>.
63. Sarmiento, F.; Bernbaum, E. *Managing Cultural Uses and Features*; ANU Press: Canberra, Australia, 2015. ISBN 978-1-925021-69-1.
64. Chávez Velásquez, C.R.; Sinaluisa Pilco, A.M.; Lema Palaquibay, L.F.; Velasteguí Arévalo, P.A.; Ureña Moreno, J.E.; Yépez Noboa, A.M.; Latimer, J.B.; Sarmiento, F.O. The Heritagescape of Kichwa People of Nizag Built upon Traditional Plant Usage along a Chimborazo Variant of the Andean Road System or Qhapaq Ñan. *Geographies* **2024**, *4*, 537–562. <https://doi.org/10.3390/geographies4030029>.
65. Dangles, O. *Climate Change on Mountains: Reviving Humboldt's Approach to Science*; Springer Nature Switzerland: Cham, Switzerland, 2023. ISBN 978-3-031-39530-7.
66. IGM CHIMBORAZO-Instituto Geofísico-EPN. Available online: <https://www.igepn.edu.ec/chimborazo> (accessed on 30 December 2025).
67. Sarmiento, F. *The Birthplace of Ecology*; Bulletin of the Ecological Society of America: Philadelphia, PA, USA, 1995.
68. Hofstede, R.G.M.; Lips, J.M.; Jongsma, W. *Geografía, Ecología y Forestación de la Sierra Alta del Ecuador: Revisión de Literatura*; Ediciones Abya-Yala: Quito, Ecuador, 1998.
69. Sarmiento, F.O.; Ibarra, J.T.; Barreau, A.; Pizarro, J.C.; Rozzi, R.; González, J.A.; Frolich, L.M. Applied Montology Using Critical Biogeography in the Andes. *Ann. Am. Assoc. Geogr.* **2017**, *107*, 416–428. <https://doi.org/10.1080/24694452.2016.1260438>.
70. Paula, P.; Zambrano, L.; Paula, P. Análisis Multitemporal de Los Cambios de La Vegetación, En La Reserva de Producción de Fauna Chimborazo Como Consecuencia Del Cambio Climático. *Enfoque UTE* **2018**, *9*, 125–137. <https://doi.org/10.29019/enfoqueute.v9n2.252>.
71. Nibleus, K.; Lundin, R. Climate Change and Mitigation. *AMBIO* **2010**, *39*, 11–17. <https://doi.org/10.1007/s13280-010-0058-8>.
72. Oriel, E.; Sateesh, D.; Dissanayaka, A. *Language as an Ecological Phenomenon*; Landscape Sentience: Mumbai, India, 2024.
73. Sarmiento, F.O. Critical Biogeography of Neotropical Mountains: A Panoptic Approach for Biocultural Microrefugia Conservation. *Biodivers. Online J.* **2021**, *1*, 1–7.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.