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Original Article

Between plaza and peak: a montological perspective on verticality and urbanization in highland Peru

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Abstract: Under the influence of concentrated and extended urbanization, Andean cities and the different altitudinal zones of their "hinterlands" are experiencing profound changes in land cover — from the central plazas up to the highest peaks. The complex regional-geographic characteristics of these socioecological systems, such as the vertical complementarity of land use, require a montological perspective on verticality and urbanization: it transcends disciplinary approaches and can be crucial to properly interpret the trajectories of land cover change and formulate hypotheses for future practice-oriented research. Which trajectories of land cover change characterized altitudinal zones of Andean cities and their surroundings over the last three decades? Are there similarities that allow for the formulation of more general hypotheses? Using the Peruvian cases of Cusco and Huaraz, and combining a traditional altitudinal zonation model of land use in Peru with direct field observations and GIS-based analyses of remotely sensed data from 1991, 2001, 2011, and 2021, this study identifies the main trajectories of land cover change in the Quechua (>2300–3500 m), Suni (>3500–4000 m), and Puna (>4000–4800 m) regions — and finds insightful similarities between Cusco and Huaraz: (1) an impressive area of built-up land substitutes grassland in the Quechua, which, following regional altitudinal zonation models, is characterized by irrigated and rain-fed cropland; (2) an unexpected expansion of irrigated cropland takes place in the Suni, which, in theory, often lacks irrigation infrastructure and is mostly used for rain-fed tuber cultivation; and (3) a clear change from "other land" to grassland occurs in the Puna — where grassland is thought to predominate, anyway, since pre-Hispanic times. Hypothesizing that these changes reflect the interplay between speculative fallow, agricultural intensification, and ecological restoration, the results can be read as vertically complementary, local manifestations of concentrated and extended urbanization in a formerly peripheral mountain region of the Global South — and they underscore the need to overcome mental city-mountain dichotomies for a socially inclusive and ecologically balanced Andean development between plaza and peak.

Keywords: Mountain cities; Mountain agriculture; Land use change; Land cover change; Rural–urban linkages; Montology

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1 Introduction

1.1 Background and aims

Physical urbanization and related demographic, economic, and sociocultural processes are among the greatest challenges for periurban smallholders in the world's mountains (as defined by Kapos et al. 2000; see also Price et al. 2019) — especially in the tropical Global South, where subsistence farming is still playing an important role alongside market-oriented production. For mountain agriculture in the East African mountains, the Andes, or the Himalayas is often organized in a vertically complementary way — with smallholders seeking to reduce their vulnerability by using the full range of altitudinal zones (Guillet 1986) — the unbridled expansion of urban settlements, encroaching on plateaus (e.g., Moshi/Tanzania; Bart 2016), valleys (e.g., Cuenca/Ecuador; Donoso and Sarmiento 2021), or ridges (e.g., Darjeeling/India; Mell and Sturzaker 2014), can mean the loss of an important altitudinal zone. Beyond this "concentrated" form, an "extended" form of urbanization influences vertically organized land use in higher altitudinal zones of mountains, which increasingly undergo processes of urbanization that counter common imaginaries of an urban condition exclusively found in cities (Brenner and Schmid 2015). Eventually, these changes may alter the physical-material land cover and have repercussions on the cities and their inhabitants, for instance through changes in provisioning, regulating, or cultural ecosystem services (Alcántara Ayala et al. 2022; Borsdorf and Haller 2020; Grêt-Regamey et al. 2012). Tracing and understanding the spatial manifestations of vertical rural–urban linkages (Haller and Branca 2022a) can be of crucial importance for sustainable mountain development in the tropical Global South.

Peru is a perfect case in point: Since the beginning of the economically liberal era in the 1990s, many cities in the Peruvian Andes have become vibrant urban mountain regions of 100,000–500,000 inhabitants (Borsdorf and Stadel 2015) — for instance, mining-dominated Cajamarca (Vega Centeno 2011) or markedly commercial Huancayo (Haller and Borsdorf 2013) — and expanded rapidly into agriculturally used areas (Stadel 2000). Today, this fact strongly alters vertical land use systems and changes land cover at different altitudinal zones. In tourism-focused cities like Cusco and Huaraz (Branca and Haller 2021a, 2021b), the impacts of concentrated urbanization on vertically complementary agriculture are particularly pronounced, for the tourism sector boosts the demand for land, water, energy, and food on the valley floors, where several planned real-estate projects are developed (including amusement parks, restaurants, hotels, and condominiums for second homes and/or short-time vacation rental) in addition to the growth of unplanned marginal settlements of poorer population groups. In addition, the tourism sector is increasingly contributing to the extended urbanization of the valley floors, adjoining slopes, and high plains, which often serve as assets for the Andean cities in the development of their tourist offer. Consequently, this leads to increased connectivity through infrastructure as well as appropriation of land, including interventions in existing land use practices.

Considering the three decades between 1991 and 2021, this study links approaches of inductive and abductive reasoning and seeks to trace and understand trajectories of land cover change around the Andean cities of Cusco and Huaraz at three altitudinal zones. It differs from strongly disciplinary work on remote sensing and land cover change (e.g., Amini et al. 2022; Gondwe 2021; Hassan et al. 2016) in that, transcending disciplinary boundaries, geographic and anthropological forms of knowledge acquisition merge into a montological approach aiming to (1) facilitate communication between disciplines and (2) strengthen methodological pluralism (e.g., going beyond purely positivist modes of thinking; Sarmiento 2020, 2022; Sarmiento et al. 2023). This montological ambition is also in line with Dematteis (2012: 88), who states that "we should value more the heuristic role of geography, its ability to discover the new as the possible, in the dual sense of what can be and what can be done" — meaning a shift from focusing on causalities to concentrating on possibilities. Combining a traditional altitudinal zonation model of land use in Peru with direct field observations and GIS-based analyses of remotely sensed data — considering the hypsometric variation of geographic forms (Lautensach 1952) — allows for proper interpretations of land cover classes, going beyond the spectral values of pixels, and helps to answer the three specific aims of this work: (1) to calculate portions of land cover for 1991–2001, 2001–2011, and 2011–2021; (2) to identify and interpret the most significant change trajectories (1991–2001–2011–2021) in the contiguous built-up areas and three altitudinal zones of their "hinterland"; and (3) to compare these significant changes from Cusco and Huaraz to find commonalities.

1.2 Conceptual context

The "third mission" calls for scientific contributions that help solve real-world problems and reach the sustainable development goals of the United Nations. In the case of mountain regions, the transdisciplinary perspective of montology (inextricably linked with the names of Jack Ives, Bruno Messerli, Robert Rhoades, and, more recently, Fausto Sarmiento) has much to offer (Haller and Branca 2020). While mountains are often perceived as primarily rural spaces, urban montology considers the fact that, in the course of "planetary urbanization," all high-altitude zones of the world's mountains are now undergoing some kind of urbanization process. From a conceptual point of view, the ideas of "verticality" and "extended urbanization" are central.

Considering the vertical dimension in the central Andes is far from a new phenomenon, as illustrates von Humboldt's *Tableau physique des Andes et pays voisins* (see also Troll 1959). Studies by high-mountain archaeologists show that Andean cultures in pre-Columbian times had strong sociocultural relationships with mountains, implying horizontal and vertical movement in space (Reinhard and Ceruti 2010). This verticality of movement and control of space is clearly explained by Murra (1975) in his classic scheme of vertical archipelagos in precolonial and colonial times. The various local lordships controlled a territory characterized by altitudinal zones, seeking to cultivate and adapt a variety of crops in different ecological niches to reduce their vulnerability. Despite many changes over the last centuries, several authors show continuities and adaptations to the original model (Brush 1976; Forman 1978; Fioravanti-Molinié 1981; Stadel 1991; Stadel 2019).

According to Sarmiento et al. (2023), the classic Humboldtian paradigm of altitudinal zonation, which explains plant and animal change through "ecological" altitudinal gradients, is challenged by the recognition that human influence is a critical factor in the reshaping of the Andean space. They call for the inclusion of "socioecological gradients," which are gradients of plant and animal species influenced by both altitude and human activity. These factors generate significant biocultural diversity in "socioecological production landscapes" (Sarmiento et al. 2023: 453; on the challenge of applying the "landscape" concept globally see Haller and Branca 2022b). It is "a bulge of socioecological factors that could be discerned from archaeological evidence of ancient socioecological productive landscapes of the Andean flanks" (Sarmiento et al. 2023; Sarmiento and Sarmiento 2021) and which can currently be found in "isolated microrefugia," notably in indigenous contexts of rural-urban fringes. As Sarmiento et al. (2023: 452) argue, "these new mixed territories of the 'rurban' landscape are the productive zones, economic and otherwise, that are in the tipping point either to lose their identity or to reinforce their sense of microrefugium."

Today, the socioecological complementarities of vertical land use continue: through "traditional," but also through "modern" human-environmental relationships influenced by the increasing movement of capital, people, and ideas-tendencies affecting local land use and blurring the rural-urban boundaries (Kingman and Bretón 2017). Overcoming the (functional) dichotomy between the rural and the urban is one of the main points of Brenner and Schmid's (2015) conceptual proposal of "planetary urbanization." The latter can be defined as the current planetary configuration of urban processes and their connections with the flows of capital and goods, drawing a global space shaped by the dialectic between concentrated and extended urbanization (Monte-Mór and Castriota 2018). These processes, taking place also in the central Andes of Peru, produce the pervasiveness of connections, socioecological transformations, and profound land use changes — spatial manifestations of the operationalization of seemingly distant "hinterlands," their inclusion through infrastructures, and their appropriation for the sake of capital accumulation (Brenner and Schmid 2015; Ghosh and Meer 2021). Although the proposal of planetary urbanization faces several criticisms (e.g., Krause 2013; Ruddick et al. 2018), it significantly contributes to the discourse on contemporary urban processes within the social sciences and humanities. As noted by Castriota and Tonucci (2018: 514), planetary urbanization serves as both a "theoretical conceptualization" and a "research agenda." This concept underscores that "capitalist urbanization and relations of production have been extended, to some degree, across the entire planet." However, ethnographically speaking, this does not imply that any place — for example, a village near Cusco or Huaraz in the Andes — necessarily transforms into a "mountainous New York." Instead, it assumes that all socioterritorial contexts, even those isolated and distanced from the primary currents of contemporary globalization, experience urban influences mediated by heterogeneous actors — be they local, national, or transnational (as evident in mining exploration and exploitation projects in the Andes).

The contribution of Brenner and Schmid remains pertinent on the theoretical plane, particularly for its decentering of the "city" as a confined and enclosed space. In their opinion, it becomes imperative not only to present "the 'city as ideology' (Wachsmuth 2014) but also the critique of 'methodological cityism' (Angelo and Wachsmuth 2015) and of the 'urban age discourse' (Brenner and Schmid 2014) to (re)affirm the distinctiveness of the city-centric and the ex-centric urban and, ultimately, to move towards a new epistemology of the urban (Brenner and Schmid 2015)" (Castriota and Tonucci 2018: 514). This perspective goes further by "provincializing" (Chakrabarty 2000) the city, introducing three moments of urbanization: (1) concentrated, (2) differential, and (3) extended urbanization. While interlinked within a broader system, these moments are analyzed separately for clarity (Brenner and Schmid 2015: 166).

Concentrated urbanization, a well-established concept in urban studies, illustrates how companies, workers, and infrastructure cluster spatially "during successive cycles of capitalist industrial development" (Brenner and Schmid 2015: 166). The second model is that of "differential urbanization," "in which inherited sociospatial configurations are continually creatively destroyed in relation to the broader developmental dynamics and crisis-tendencies of modern capitalism" (Brenner and Schmid 2015: 168). Finally, extended urbanization is closely intertwined with the former two. While the authors acknowledge the role of large agglomerations and the imperative to study them, they counter the notion that agglomerations exclusively represent the right domain for studying urban transformations. Instead, they posit that such transformations often encompass wider regions and landscapes unevenly. Even sparsely populated or remote areas can be influenced by urbanization, given its potential to trigger significant socioeconomic, infrastructural, and sociometabolic shifts. These shifts may occur "in support of, or as a consequence of, the everyday operations and growth imperatives of often-distant agglomerations" (Brenner and Schmid 2015: 167).

Originally introduced within the Brazilian Amazonian context by Monte-Mór (1994; see also Castriota and Tonucci 2018), Brenner and Schmid outline extended urbanization through three defining characteristics. First, it encompasses regions and landscapes sometimes distant from agglomerations, contributing to everyday urban activities and economic pursuits. These spaces emerge from fundamental urban requirements such as food, energy, water production and circulation, waste management, and raw material extraction. The second aspect pertains to the reorganization and construction of fixed infrastructures supporting the abovementioned processes. This expansion eventually spans "around much of the entire planet" (Brenner and Schmid 2015: 167). The third aspect connects with changes in land use, particularly the enclosure of areas initially designated for collective use, leading to privatization for various reasons — for instance, resource extraction, large-scale agriculture, and logistics. Akin to Harvey's concept (Harvey 2003), the authors link this phenomenon to accumulation by dispossession, whereby noncommodified modes of social life are disrupted and linked to global spatial divisions of labor and systems of exchange (Brenner and Schmid 2015: 167). Consequently, the "operational landscapes" that arise from these processes no longer remain "nonurban" but inherently form part of the broader urbanization process. This also applies to the various altitudinal zones of mountains.

2 Material and Methods

2.1 Study areas

To delimit the study areas of Cusco (Fig. 1) and Huaraz (Fig. 2), we manually mapped the contiguous built-up area (Borsdorf and Haller 2020) on high-resolution satellite images from 2021 (in Google Earth; view from 5 km; Fig. 3). Next, we calculated a 10 km buffer around the external boundary of the contiguous built-up area and defined the minimum

Fig. 1 View from the area of Santa María toward Cusco. The physical limits of a city in a valley location are clearly evident. Photo taken by Andreas Haller.

Fig. 2 View from the area of El Pinar toward Huaraz. The physical limits of a city in a valley location are clearly evident. Photo taken by Andreas Haller.

bounding rectangle in an open-source Geographic Information System (QGIS).

The resulting study areas comprise the altitudinal zones of the Quechua (>2300–3500 m above sea level), Suni (>3500–4000 m), Puna (>4000–4800 m), and — in Huaraz — Janca (above 4800 m; mainly rocks, ice, and snow) *sensu* Pulgar Vidal's traditional model of vertical land use in Peru (1996; see also Zimmerer and Bell 2013). Following this model of "eight natural regions," the Quechua, Suni, and Puna regions differ in particular on the basis of climatic conditions as well as the predominant forms of land use, which is often described in terms of the upper limit of cultivation of characteristic food crops (*productos límite*). For the present research, the differential hypsographic curves also point to the fact that these altitudinal zones have different portions of the study areas in Cusco in Huaraz (Fig. 4).

Both cities are nestled in the central Andes of Peru and function as the capitals of their departments,

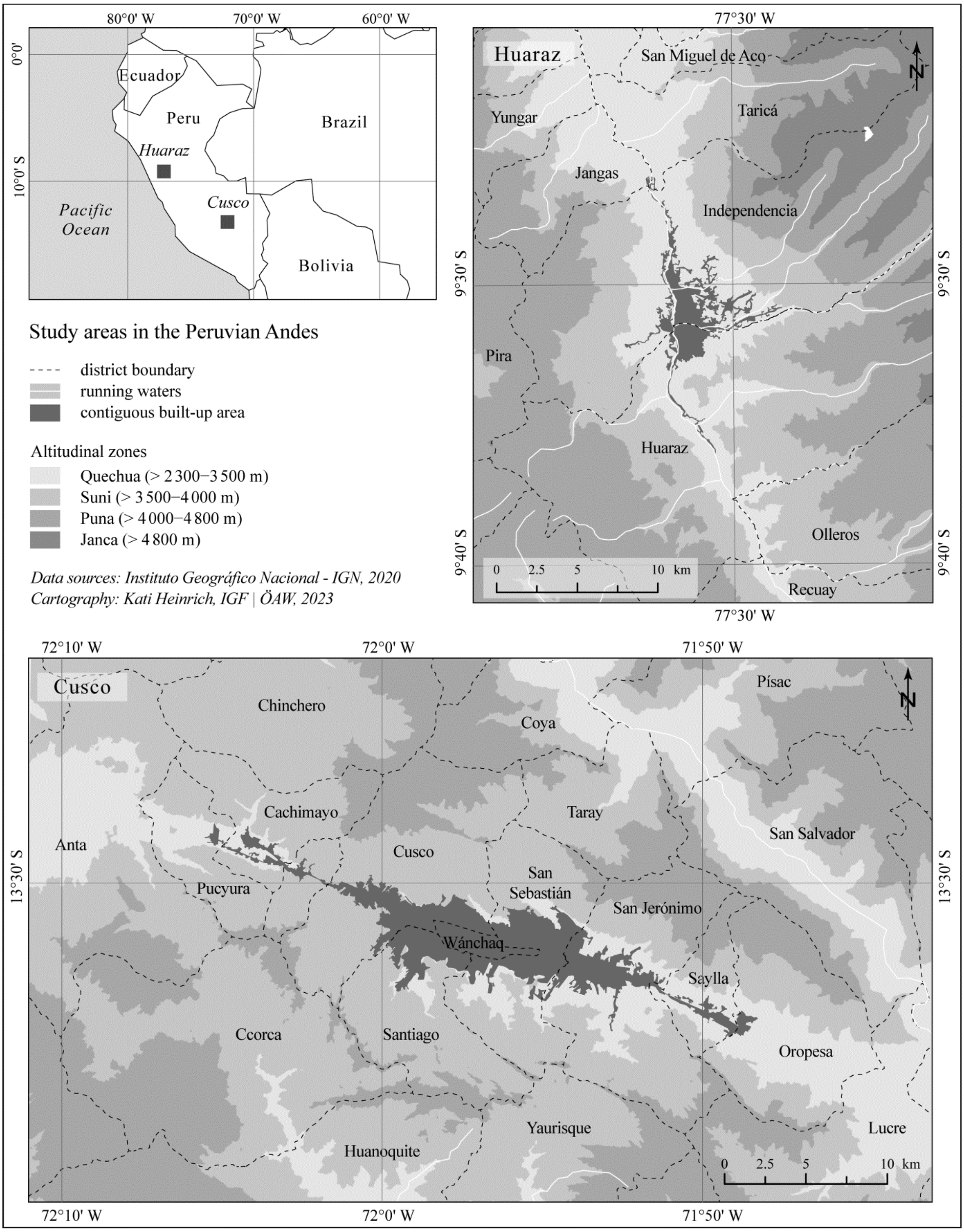

Fig. 3 Location of the study areas in the Peruvian Andes. 30 districts of Cusco and 15 districts of Áncash have a share in the study areas. Graphic: Kati Heinrich.

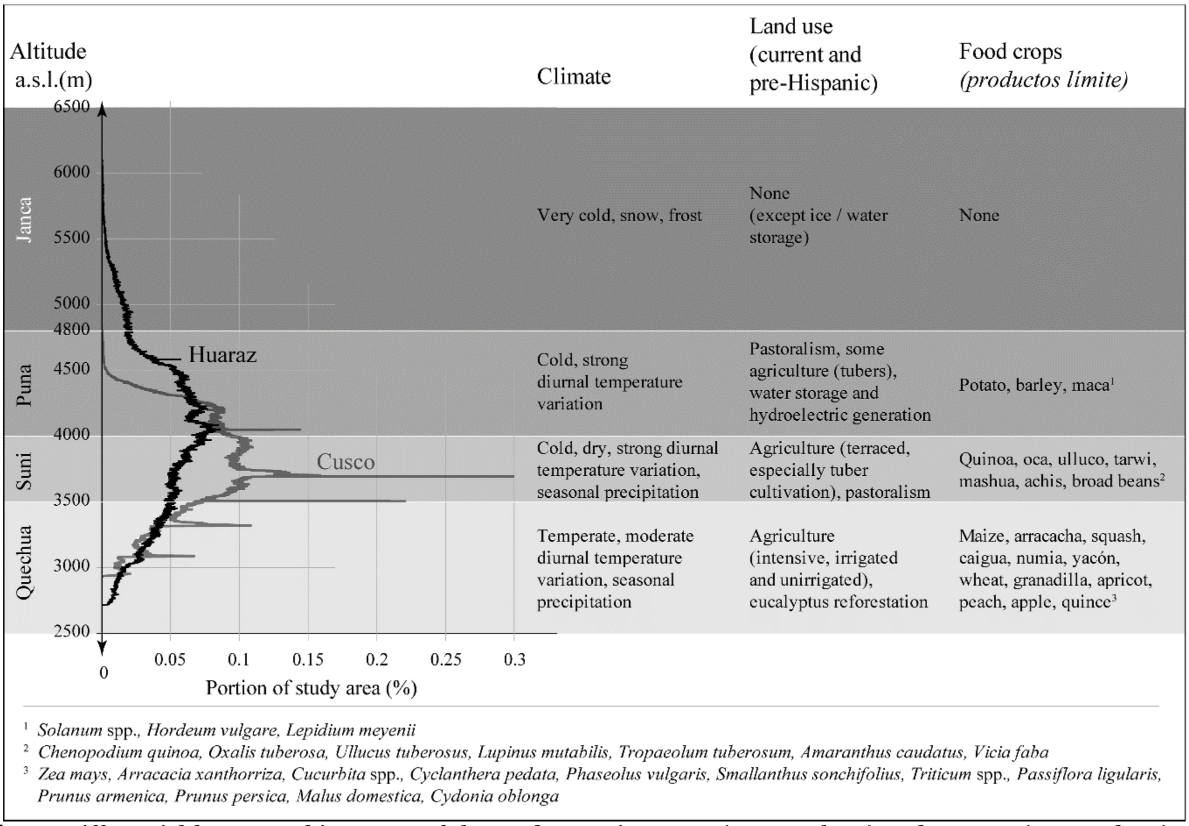

Fig. 4 Differential hypsographic curves of the study area in Cusco (1601.04 km²) and Huaraz (1111.08 km²) using elevation data from Terra ASTER. The figure shows key characteristics of Pulgar Vidal's altitudinal zones (adapted from Zimmerer and Bell 2013). Graphic: Kati Heinrich.

Cusco and Áncash. The urban centers are in the Quechua region of the fertile valleys of the rivers Huatanay (at 13°30′45″S and 71°58′33″W; 3403 m) and Santa (at 09°31′48″S and 77°31′44″W; 3052 m). According to figures from 2018 (Servicio Nacional de Meteorología e Hidrología 2020), both cities have a diurnal climate: Cusco with a daily maximum of 26.4°C on November 23 and a daily minimum of −4.6°C on July 9 (measured at Granja Kcayra), and Huaraz with a daily maximum of 26.4°C on January 30 and a daily minimum of 2.6°C on July 8 (measured at the Santiago Antúnez de Mayolo National University). The multiannual average of annual precipitation reaches approximately 730 mm in Cusco (1950–1991; Instituto Geofísico del Perú 2009a) and 666 mm in Huaraz (1971–1991; Instituto Geofísico del Perú 2009b), mainly during the rainy season from November to April. This has to be seen together with the quality of soils around Cusco and Huaraz (Oficina Nacional de Evaluación de Recursos Naturales 1981): both study areas have only a few areas officially classified as *tierras aptas para cultivos en limpio* (land suitable for crops); while most land in the Quechua region is considered suitable for forests (*tierras aptas para producción forestal*), land in the Suni and Puna is predominantly classified as suitable to graze livestock (*tierras aptas para pastos*) or as marginal land inappropriate for a profitable production of crops, wood, or livestock under existing economic conditions (*tierras de protección*). In both cases, soil quality is either medium or low, with harsh climate, severe erosion, and reduced water availability limiting land use. This underscores the increased effort required to grow crops around Cusco and Huaraz.

The cities' infrastructural, economic, and sociocultural importance, alongside their administrative power, place them as destinations of intradepartmental migration with marked population growth rates (according to census data, the total population of the 10 districts having a share in the contiguous built-up area of Cusco increased from 277,594 in 1993 to 500,095 in 2017, while the population of the four districts of Huaraz grew from 100,697 in 1993 to 157,545 people in 2017; Branca and Haller 2021a, 2021b). Moreover, they serve as international tourism destinations and central places for tourists visiting the natural and cultural heritage of Cusco (especially the Historic Sanctuary of Machu Picchu with 1,411,279 visitors in 2017; Observatorio Turístico del Perú 2020) and Áncash (especially the Huascarán National Park with 283,369 visitors in 2017; Ministerio de Comercio Exterior y Turismo 2021).

2.2 Direct field observation

In the present montological study, direct field observation — also called material observation in anthropology (Birx 2006) — in March 2022 "linked" the study area and the GIS-based analysis. The aim was to identify, record, and interpret the spatial manifestations of concentrated and extended urbanization *in situ* (on observation in urban morphology see Larkham 2018). This step, which was preceded by the preparation of two urban environmental profiles of Cusco and Huaraz (Branca and Haller 2021a, 2021b), eventually resulted in photographic and written documentation (i.e., field notes).

Considering the problem-oriented approach of *Länderkunde* — which is still useful today for grasping the complexity of the real world in a structured way (Borsdorf 2018) — and the pillars of Romanticist research (Gade 2011), going into "the field" to compare existing knowledge with new observations, to gain a deeper understanding of place, is key to appropriately interpret information from a variety of qualitative and quantitative sources. Therefore, direct field observation in montology goes far beyond the narrow search for sample sites ("ground truthing") that is common in remote sensing. While the latter serves to increase the reliability of the image classification results, the former aims at contextualizing the classification results by intensively dealing with the physical-geographical and cultural-historical settings of the people shaping the land.

2.3 GIS-based analysis

To analyze land cover changes using an open-source Geographic Information System (QGIS), remotely sensed data were used, especially Landsat imagery—three 742 (RGB) false-color composites of Landsat 5 TM scenes (considering wavelengths of 2.08–2.35 µm, 0.76–0.90 µm, and 0.52–0.60 µm) and a similar 753 (RGB) composite of Landsat 8 OLI/TIRS scenes (2.11–2.29 µm, 0.85–0.88 µm, and 0.53–0.59 µm) from 1991 (August 17), 2001 (August 9), 2011 (August 5), and 2021 (September 1) — and a Terra ASTER digital elevation model acquired between March 1, 2000 and November 30, 2011. While the Landsat composites had a horizontal spatial resolution of 30 m, the global Terra dataset had a horizontal spatial resolution of approximately 30 m (at the equator) and an estimated vertical accuracy of about 10–30 m (Li et al. 2013). The imagery was clipped to the extent of the study areas, which were found to be cloud-free (Fig. 5, Fig. 6). Training samples for classification (larger than 30 m × 30 m; 25 per category) were gathered in the study areas by purposive GPS measurements on-site in the District of San Sebastián (Province of Cusco) and the District of Independencia (Province of Huaraz) in March 2022. Moreover, stratified random sample points (375) for assessing the accuracy of classification were created in QGIS.

Next, a supervised digital classification (maximum likelihood algorithm) of the four composites was carried out in QGIS using the Semi-Automatic Classification plug-in (Congedo 2021). Each of the three Landsat 5 TM and the Landsat 8 OLI/TIRS composites was classified into "built-up land" (BL), "cropland" (CL), "grassland" (GL), "woodland" (WL) or "other land" (OL) — always applying the same process (Table 1). Post-classification processing comprised the reclassification of BL outside the contiguous built-up area as OL. It was also assumed that a pixel classified as built-up land could not change into a different land cover class. Therefore, the 2001, 2011, and 2021 built-up land classifications had to be merged with the respective previous data to correct misclassification. Finally, land cover trajectories were calculated for each pixel of the study area divided into the altitudinal zones of the Quechua, Suni, Puna, and — in the case of Huaraz — Janca.

To assess the accuracy of the 2011 classifications of Cusco and Huaraz (Landsat 5 TM) in a cross-tabulation (or error) matrix, we compared them with the land cover identified at the randomly sampled reference points — 75 per land cover class according to Congalton (1991) — on very high-resolution imagery (acquired during the dry season May–October 2011) available in the virtual globe software Google Earth Pro (a powerful tool suitable for accuracy assessment at low cost; Potere 2008; Stehman and Foody 2019; Maharjan et al. 2020;

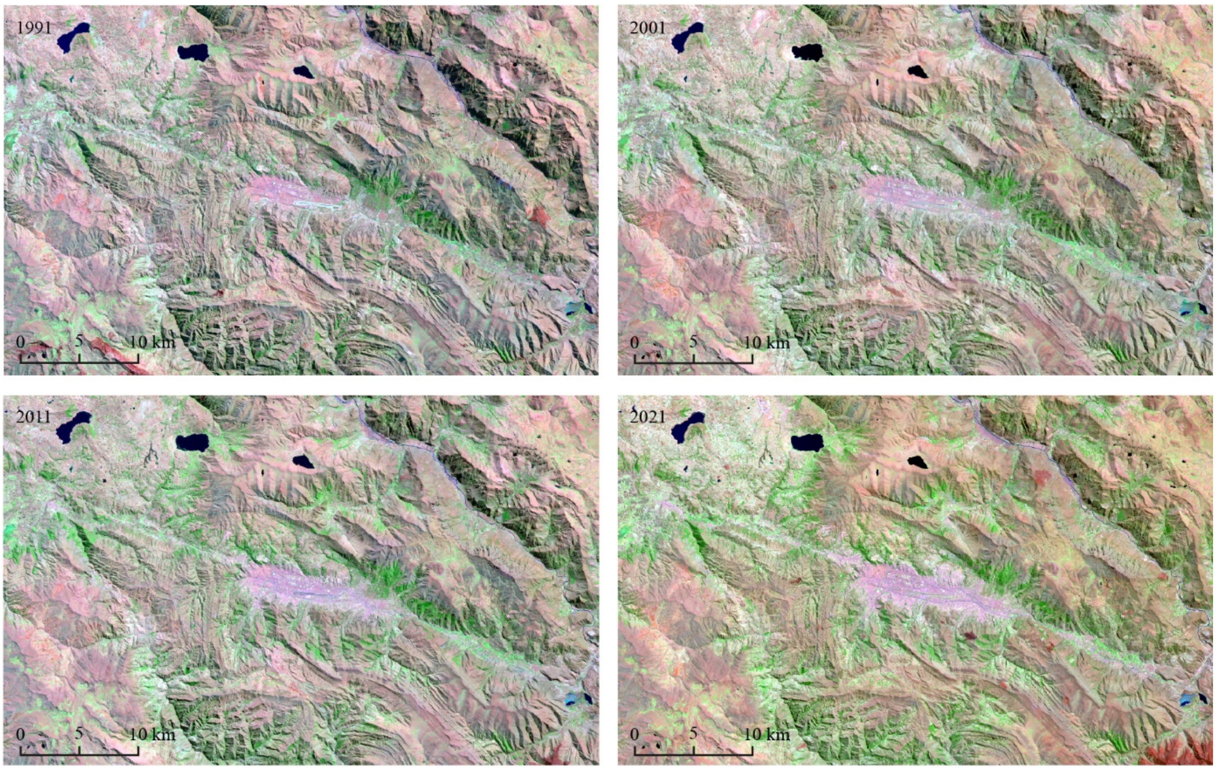

Fig. 5 Three 742 (RGB) false-color composites of Landsat 5 TM scenes (1991, 2001, 2011) and one 753 (RGB) composite of Landsat 8 OLI/TIRS scenes (2021) from Cusco. Source: NASA/USGS Landsat Program.

Table 1 Heuristic and mutually exclusive classes by predominant land cover. Source: adapted from Haller (2012)

ID	Class name	Predominant land cover	Examples
BL	Built-up land	Settlement and infrastructure inside the 2021 contiguous built-up area	Buildings, streets, channels
CL	Cropland	Cultivated graminoids and legumes used for their seeds and/or leaves; several other plant species cultivated for roots/tubers, leaves, buds, and/or fruits; moist or wet bare soil	Maize (*Zea mays*), barley (*Hordeum vulgare*), broad beans (*Vicia faba*), alfalfa (*Medicago sativa*), potatoes (*Solanum* spp.), oca (*Oxalis tuberosa*), squash (*Cucurbita* spp.)
GL	Grassland	Naturally grown herbaceous vegetation dominated by tussock-forming or carpet-forming graminoids; other naturally grown herbaceous vegetation spontaneously covering fallow land	Ichu (*Stipa ichu*), paku paku (*Aciachne pulvinata*), kikuyu (*Pennisetum clandestinum*)
WL	Woodland	Cultivated and naturally grown woody plants (both trees and shrubs)	Eucalyptus (*Eucalyptus* spp.), pine (*Pinus* spp.), queñual (*Polylepis* spp.), quishuar (*Buddleja incana*)
OL	Other land	Settlement and infrastructure outside the 2021 contiguous built-up area; dry or damp bare soil; rocks; water bodies; ice and snow	Buildings, streets, channels, reservoirs, rivers, lakes, wetlands, open-pit mines, glaciers

Ottosen et al. 2020). The interpretation of the data used was facilitated by the authors' regional-geographic experience gained in these areas since 2009.

The overall accuracy reached 84.49% in Cusco (Table 2) and 84.53% in Huaraz (Table 3). All classes had individual producer and user accuracy values of 74.66% or more (except for the OL producer accuracy of Huaraz, which was due to the challenge of interpreting dry bare soil and rocks with encroaching herbaceous and/or woody vegetation as either GL, WL, or OL for areas of 30 m × 30 m in the Huascarán National Park). Thomlinson et al. (1999) set accuracy targets of 85% (or more) of correctly allocated pixels with individual classes of 75% or more. These were achieved for the two 2011 classifications. Finally, quantity and allocation disagreement values were calculated — instead of little practical Kappa indices

— as recommended by Pontius and Millones (2011). In Cusco, allocation disagreement (12.52%) was higher than quantity disagreement (3.21%); results similar to Huaraz, where allocation disagreement (10.94%) was also higher than quantity disagreement (4.53%).

For the images from 1991, 2001, 2011, and 2021 had band combinations with the same or similar

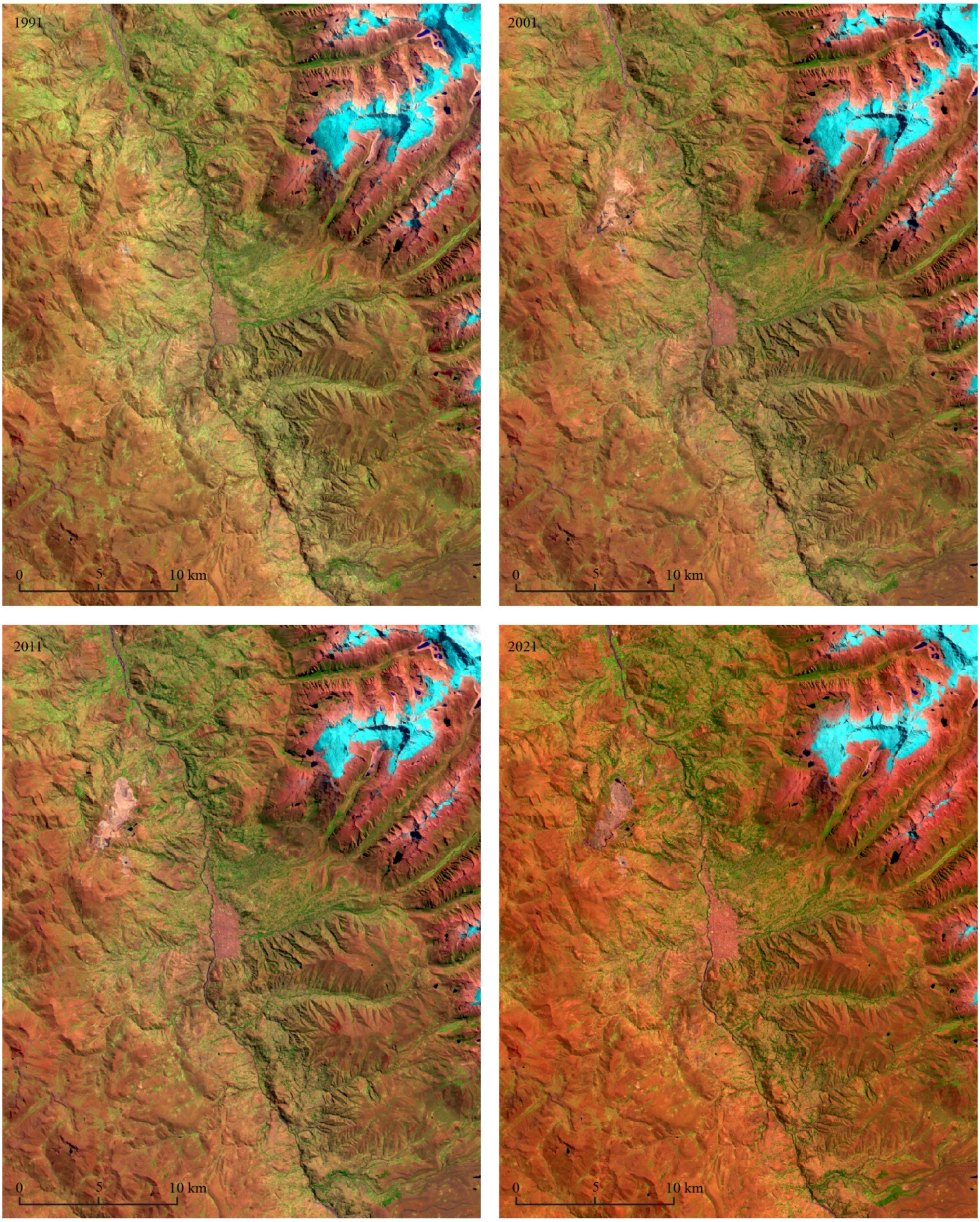

Fig. 6 Three 742 (RGB) false-color composites of Landsat 5 TM scenes (1991, 2001, 2011) and one 753 (RGB) composite of Landsat 8 OLI/TIRS scenes (2021) from Huaraz. Source: NASA/USGS Landsat Program.

spectral characteristics, were acquired during the same season (between August 5 and September 1), and were processed identically, we assumed that the accuracy of classifications from 1991, 2001, and 2021 was comparable to the 2011 images from Cusco and Huaraz. Finally, another cross-tabulation (or transition) matrix was calculated and land cover change trajectories for 1991–2001–2011–2021 were analyzed using pixel-wise comparison.

3 Results

3.1 Land cover change in Cusco

The study area in Cusco, counting 1,778,932 pixels (about 1601 km²), shows interesting portions of land cover classes over the last three decades (Table 4). Regarding BL, a clear and steady growth can be observed, although with slightly decreasing change rates varying between 49.9% (1991–2001) and 43.4% (2011–2021). Also, CL increases constantly during 1991–2021, yet almost twice as much as BL, with changes between 88.3% (2011–2021) and 102.4% (2001–2011). Less clear is the case of GL, which is generally decreasing during 1991–2021, yet with only minimal change rates (between −14.7% over the period 2011–2021 and 7.4% within 2001–2011), that do not show a steady development. A similar up and down accompanies the overall decrease of WL (1991–2021), with change rates that reach from −18.0% (1991–2001) to 4.2% (2001–2011). Finally, the OL category in Cusco presents an impressive total decrease (1991–2021) that started after a slight increase during 1991–2001 (5.2%) with reductions in the two following decades (−72.0% during 2001–2011).

Yet these changes are not distributed equally over the study area, and a closer look at the distribution of land cover classes by altitudinal zone bears additional, interesting insights. While the Quechua makes up 20.48% of the total study area of 1,778,932 pixels, the Suni and Puna have a share of 50.35% and 29.17%, respectively. Fig. 7 shows that the increase in BL takes place mainly in the Quechua region. In contrast, the increase of CL can be observed in all three altitudinal zones, although with the highest relative shares in the Quechua and Suni. In the case of GL, a decrease characterized the Quechua and Suni, while this category increased in the Puna.

Table 2 Accuracy assessment results for Cusco. The overall accuracy is 84.27%. Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown.

Classified data	Reference data					Total	User's accuracy (%)
	BL	CL	GL	WL	OL		
BL	67	6	1	1	0	75	89.33
CL	1	66	5	3	0	75	88.00
GL	0	6	62	2	5	75	82.66
WL	0	6	10	56	3	75	74.66
OL	0	0	0	10	65	75	86.66
Total	68	84	78	72	73		
Producer's accuracy (%)	98.52	78.57	79.49	77.77	89.04		

Table 3 Accuracy assessment results for Huaraz. The overall accuracy is 84.53%. Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown.

Classified data	Reference data					Total	User's accuracy (%)
	BL	CL	GL	WL	OL		
BL	74	0	0	0	1	75	98.66
CL	0	64	5	1	5	75	85.33
GL	0	1	60	0	14	75	80.00
WL	0	0	8	57	10	75	76.00
OL	0	2	0	11	62	75	82.66
Total	74	67	73	69	92		
Producer's accuracy (%)	100.00	95.52	82.19	82.61	67.40		

Table 4 Portions in Cusco. Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown.

ID	1991		1991–2001	2001		2001–2011	2011		2011–2021	2021	
	Area (pixel)	Area (km²)	Change (%)	Area (pixel)	Area (km²)	Change (%)	Area (pixel)	Area (km²)	Change (%)	Area (pixel)	Area (km²)
BL	13,696	12.33	49.9	20,531	18.48	44.8	29,720	26.75	43.4	42,609	38.35
CL	60,266	54.24	91.6	115,483	103.93	102.4	233,755	210.38	88.3	440,207	396.19
GL	1,253,414	1128.07	−3.9	1,205,056	1084.55	7.4	1,293,817	1164.44	−14.7	1,103,536	993.18
WL	160,854	144.77	−18.0	131,938	118.74	4.2	137,482	123.73	−14.9	117,065	105.36
OL	290,702	261.63	5.2	305,924	275.33	−72.5	84,158	75.74	−10.3	75,515	67.96
Total	1,778,932	1601.04	0.0	1,778,932	1601.04	0.0	1,778,932	1601.04	0.0	1,778,932	1601.04

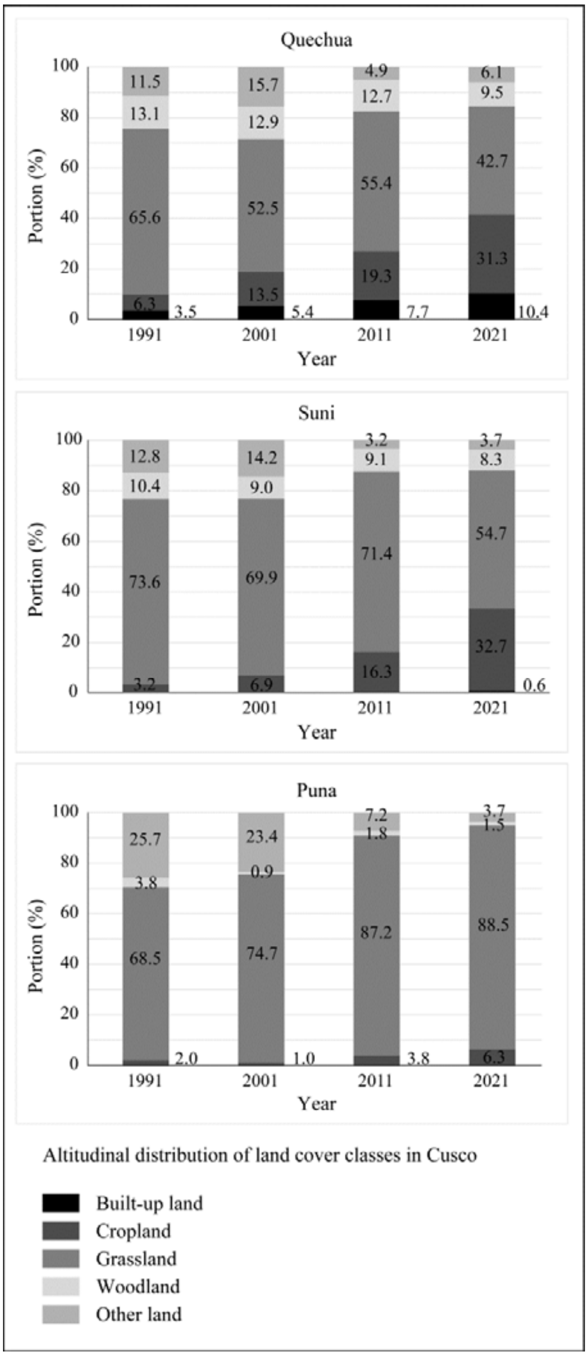

Fig. 7 Altitudinal distribution of land cover classes in Cusco 1991, 2001, 2011, and 2021. The Quechua (>2300–3500 m above sea level; 328 km²), Suni (>3500–4000 m; 806 km²), and Puna regions (>4000–4800 m; 467 km²) are indicated. Graphic: Kati Heinrich.

The development of WL shows no clear patterns, with almost constant shares (with ups and downs) in the Quechua and Suni — and with a small and decreasing relative share in the Puna. Finally, OL decreases in all three regions, although this development is clearest in the Suni and Puna regions, while in the Quechua there are ups and downs.

The analysis of land cover trajectories (1991–2001–2011–2021) in Cusco reveals that the Quechua region (364,325 pixels) is the most dynamic altitudinal zone, with a share of 65.93% of changed pixels (34.07% persistent). In the Suni region (895,692 pixels), 60.00% of pixels changed and 40.00% were persistent. The Puna region (518,915 pixels), in turn, shows a majority of persistent pixels (52.88%), while 47.12% changed.

Regarding the top-ten trajectories of change into BL (1991–2001–2011–2021; Table 5) in the Quechua region, the largest comprise a single change from GL. The tendency is steadily decreasing, that is, the number of pixels changed from GL into BL is highest between 1991 and 2001 and continuously reduces until 2011–2021. The following large trajectories show mainly two changes, where pixels of CL substituted GL (or *vice versa*) before changing into BL. Here it is interesting to observe that BL mainly follows GL.

In the Quechua region of Cusco, outside the 2021 contiguous built-up area, the top-ten trajectories of change are mainly into CL (Table 6). Six trajectories lead to CL cover in 2021, coming mostly from GL and/or OL, four of them with a single change. Here, the tendency is continuously increasing, with the largest number of pixels changed into CL during 2011–2021 and continuously reduced pixel numbers 2001–2011 and 1991–2001.

In the Suni region of Cusco, the situation is less clear, yet half of the top-ten trajectories still show changes into 2021 CL from GL and/or OL, three of them with a single change (Table 7). The tendency is slightly increasing, with the largest trajectory showing a change from GL to CL during 2011–2021 and continuously decreasing values for these changes in 2001–2011 and 1991–2001. Other important trajectories in the Suni region mainly comprise alterations between OL and GL, with three trajectories leading to 2021 GL and one resulting in 2021 OL (two with a single change and the others showing two).

In the Puna region of Cusco, the top-ten trajectories show, again, clear signs of changes from OL and, to a lesser degree CL and WL, into 2021 GL (eight out of ten trajectories; Table 8). Trajectories with a single change and 2021 GL show a steadily decreasing tendency, that is, the substitution of OL by GL was — by far — highest in 1991–2001, and continuously reducing in the following two periods.

3.2 Land cover change in Huaraz

The study area in Huaraz, counting 1,234,530 pixels (about 1111 km²), presents interesting portions of land cover classes over the last three decades (Table 9). Regarding BL, a clear and steady growth can be observed, although with continuously decreasing change rates varying between 31.1% (1991–2001) and 4.5% (2011–2021). Also, CL increases during 1991–2021, although with a temporal decrease from 1991 to 2001 (−14.6%), showing the highest growth rate of 89.2% during 2001–2011. Less clear is the case of GL, which is generally decreasing during 1991–2021, with change rates (between −26.3% over the period 2001–2011 and 15.3% within 1991–2001) that show ups and downs. An overall increase characterizes WL (1991–2021), which shows a period of decrease (1991–2001; −24.4%) followed by two growth periods (especially 2001–2011 with 64.5%). Finally, the OL category in Huaraz presents a clear and constant total decrease in the period 1991–2021 with reductions ranging

Table 5 Top-ten trajectories of change in the 2021 contiguous built-up area of Cusco by area.

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
C01	GL	BL	BL	BL	5460	4.91
C02	GL	GL	BL	BL	4836	4.35
C03	GL	GL	GL	BL	4797	4.32
C04	GL	CL	BL	BL	1225	1.10
C05	GL	GL	CL	BL	1110	1.00
C06	CL	BL	BL	BL	976	0.88
C07	CL	GL	BL	BL	840	0.76
C08	GL	CL	GL	BL	814	0.73
C09	GL	CL	CL	BL	716	0.64
C10	CL	CL	BL	BL	675	0.61

Table 6 Top-ten trajectories of change outside the 2021 contiguous built-up area in Cusco by area (Quechua altitudinal zone).

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
C11	GL	GL	GL	CL	30,823	27.74
C12	GL	GL	CL	CL	19,540	17.59
C03	GL	OL	GL	GL	14,477	13.03
C14	GL	CL	CL	CL	13,698	12.33
C15	OL	GL	GL	GL	9956	8.96
C16	GL	GL	CL	GL	8276	7.45
C17	GL	CL	GL	CL	6200	5.58
C18	OL	OL	GL	GL	5649	5.08
C19	GL	OL	GL	CL	4681	4.21
C20	WL	WL	WL	CL	4250	3.83

Notes: Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown in Tables 5, 6.

Table 7 Top-ten trajectories of change outside the 2021 contiguous built-up area in Cusco by area (Suni altitudinal zone).

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
C21	GL	GL	GL	CL	112,585	101.33
C22	GL	GL	CL	CL	59,846	53.86
C23	OL	GL	GL	GL	41,683	37.51
C24	GL	OL	GL	GL	37,408	33.67
C25	GL	GL	CL	GL	22,246	20.02
C26	GL	CL	CL	CL	19,397	17.46
C27	OL	OL	GL	GL	18,558	16.70
C28	GL	GL	GL	OL	11,538	10.38
C29	GL	CL	GL	CL	9819	8.84
C30	OL	GL	GL	CL	9407	8.47

Table 8 Top-ten trajectories of change outside the 2021 contiguous built-up area in Cusco by area (Puna altitudinal zone).

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
C31	OL	GL	GL	GL	68,820	61.94
C32	GL	OL	GL	GL	43,678	39.31
C33	OL	OL	GL	GL	30,062	27.06
C34	GL	GL	GL	CL	12,436	11.19
C35	OL	OL	OL	GL	10,479	9.43
C36	WL	OL	GL	GL	7106	6.40
C37	GL	GL	OL	GL	6003	5.40
C38	GL	GL	CL	GL	5360	4.82
C39	GL	OL	OL	GL	5199	4.68
C40	GL	GL	CL	CL	4597	4.14

Notes: Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown in Tables 7, 8.

Table 9 Portions in Huaraz. Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown.

ID	1991		1991–2001	2001		2001–2011	2011		2011–2021	2021	
	Area (pixel)	Area (km²)	Change (%)	Area (pixel)	Area (km²)	Change (%)	Area (pixel)	Area (km²)	Change (%)	Area (pixel)	Area (km²)
BL	5683	5.11	31.1	7452	6.71	17.4	8748	7.87	4.5	9140	8.23
CL	176,422	158.78	−14.6	150,726	135.65	89.2	285,188	256.67	2.5	292,276	263.05
GL	673,450	606.11	15.3	776,360	698.72	−26.3	572,492	515.24	4.7	599,186	539.27
WL	161,200	145.08	−24.4	121,836	109.65	64.5	200,438	180.39	2.6	205,605	185.04
OL	217,775	196.00	−18.2	178,156	160.34	−5.9	167,664	150.90	−23.5	128,323	115.49
Total	1,234,530	1111.08	0.0	1,234,530	1111.08	0.0	1,234,530	1111.08	0.0	1,234,530	1111.08

between −23.0% (2011–2021) and −5.9% (2001–2011).

However, these changes are not distributed equally over the study area, and a closer look at the distribution of land cover classes by altitudinal zone bears additional, interesting insights. While the Quechua makes up 21.23% of the total study area of 1,234,530 pixels, the Suni and Puna have a share of 28.67% and 41.83%, respectively; the remaining 8.27% are in the Janca, which is hardly used for agricultural purposes and not considered in the following. Fig. 8 shows that the increase in BL takes place mainly in the Quechua region. In contrast, the increase of CL can be observed in all studied altitudinal zones up to 4800 m, although with the highest relative shares in the Quechua and Suni. In the case of GL, a decrease characterized the Quechua and Suni, while it remains almost stable in the Puna (with minimal ups and downs). The development of WL shows no clear patterns, with an almost constant relative share (with ups and downs) in the Quechua and a slight increase in the Suni and Puna (with minimal ups and downs). Finally, OL decreases in all regions.

The analysis of land cover trajectories (1991–2001–2011–2021) in Huaraz shows that the Quechua region (262,091 pixels) is the most dynamic altitudinal zone, with a share of 65.50% of changed pixels (34.50% persistent). In the Suni region (353,640 pixels), 57.91% of pixels changed and 42.09% were persistent. The Puna region (516,404 pixels), in turn, shows a majority of persistent pixels (67.59%), while 32.41% changed.

Regarding the top-ten trajectories of change into BL (1991–2001–2011–2021; Table 10) in the Quechua region, the largest comprise a single change from either GL, CL, WL, or OL between 1991 and 2001. Other important trajectories with a single change are from GL and OL to BL between 2001 and 2011. For the latter, the tendency is steadily decreasing, that is, the number of pixels changed from GL and OL into BL between 1991 and 2001 is higher than between 2001 and 2011. The remaining large trajectories show mainly two changes, where pixels of GL substituted CL or WL before changing into BL. Here it is interesting to observe that BL follows different land cover classes during 1991–2001, while between 2001 and 2021 it predominantly follows GL.

In the Quechua region of Huaraz, outside the 2021 contiguous built-up area, the top-ten trajectories of change are mainly into CL (Table 11). Six trajectories lead to CL cover in 2021, coming mostly from GL and — to a minor degree — OL, four of them with a single change. The tendency from GL to CL is less clear: the largest number of pixels changed into CL during 2001–2011, closely followed by 1991–2001, while changes during 2011–2021 are less. Changes from OL to CL took place in the period 1991–2001.

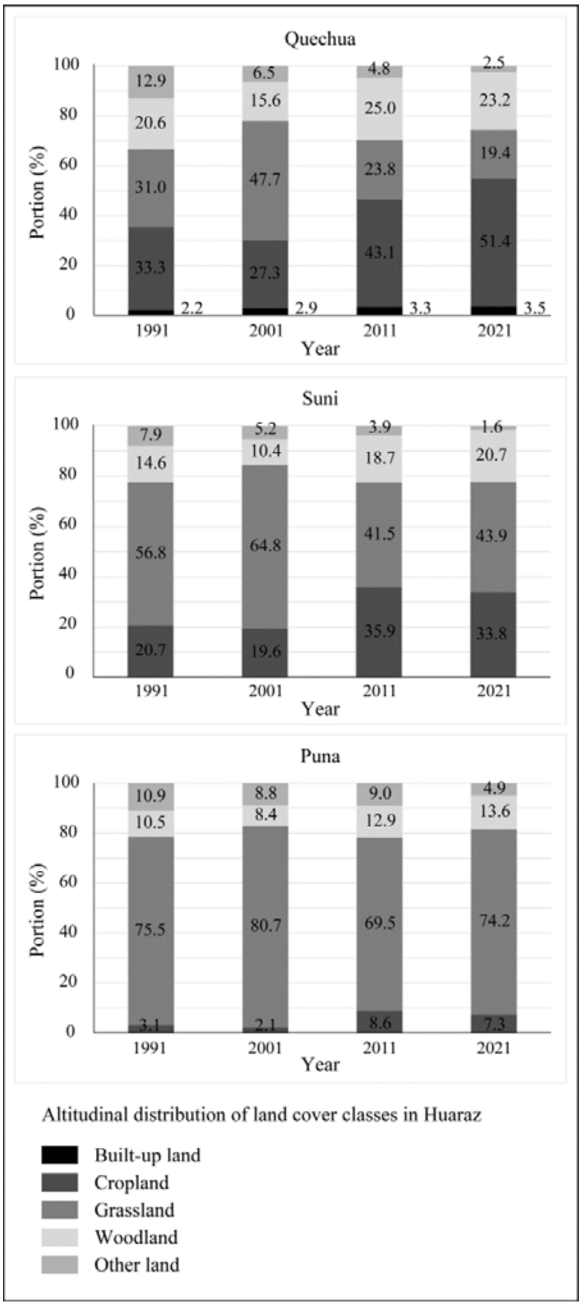

Fig. 8 Altitudinal distribution of land cover classes in Huaraz 1991, 2001, 2011, and 2021. The Quechua (>2300–3500 m above sea level; 236 km^2), Suni (>3500–4000 m; 319 km^2), and Puna regions (>4000–4800 m; 465 km^2) are indicated. Graphic: Kati Heinrich.

Table 10 Top-ten trajectories of change in the 2021 contiguous built-up area of Huaraz by area.

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
H01	GL	BL	BL	BL	700	0.63
H02	CL	BL	BL	BL	597	0.54
H03	OL	BL	BL	BL	332	0.30
H04	GL	GL	BL	BL	273	0.25
H05	WL	BL	BL	BL	219	0.20
H06	CL	GL	BL	BL	155	0.14
H07	WL	GL	BL	BL	150	0.14
H08	OL	OL	BL	BL	117	0.11
H09	WL	GL	GL	BL	65	0.06
H10	CL	GL	GL	BL	62	0.06

Table 11 Top-ten trajectories of change outside the 2021 contiguous built-up area in Huaraz by area (Quechua altitudinal zone).

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
H11	CL	GL	CL	CL	17,496	15.75
H12	GL	GL	CL	CL	11,581	10.42
H13	GL	CL	CL	CL	9088	8.18
H14	OL	CL	CL	CL	6697	6.03
H15	GL	GL	GL	CL	6575	5.92
H16	WL	GL	WL	WL	5834	5.25
H17	GL	GL	WL	WL	4903	4.41
H18	CL	GL	GL	CL	4762	4.29
H19	GL	GL	CL	GL	4704	4.23
H20	CL	WL	WL	WL	3273	2.95

Notes: Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown in Tables 10, 11.

Apart from changes to CL, the Quechua region also shows important trajectories from GL and CL to WL.

In the Suni region of Huaraz, the situation is less clear, yet half of the top-ten trajectories still show changes into 2021 CL from GL and/or OL, four of them with a single change (Table 12). The tendency from GL to CL is less clear, with the largest trajectory showing a single change from GL to CL during 2001–2011, followed by the period 1991–2001, and the lowest values for 2011–2021. Other important alterations in the Suni region comprise four trajectories toward 2021 WL, whereas three show a single change from GL (again, no clear tendency; highest values between 2001–2011, followed by 1991–2001 and 2011–2021). Finally, WL substitutes the former GL.

In the Puna region of Huaraz, the top-ten trajectories show, above all, changes from OL and, to a lesser degree, CL and WL, into 2021 GL (five out of ten trajectories; Table 13). Trajectories with a single change from OL to 2021 GL do not show a clear tendency, for the substitution of OL by GL was highest in 1991–2001, followed by 2011–2021 (2001–2011 is not among the top ten).

Table 12 Top-ten trajectories of change outside the 2021 contiguous built-up area in Huaraz by area (Suni altitudinal zone).

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
H21	GL	GL	CL	CL	18,699	16.83
H22	GL	GL	CL	GL	15,988	14.39
H23	CL	GL	CL	CL	13,143	11.83
H24	GL	CL	CL	CL	12,024	10.82
H25	GL	GL	WL	WL	9954	8.96
H26	GL	GL	GL	WL	9068	8.16
H27	GL	GL	GL	CL	8634	7.77
H28	WL	GL	WL	WL	7631	6.87
H29	OL	CL	CL	CL	6446	5.80
H30	GL	WL	WL	WL	6219	5.60

Table 13 Top-ten trajectories of change outside the 2021 contiguous built-up area in Huaraz by area (Puna altitudinal zone).

Change trajectory					Area	Area
ID	1991	2001	2011	2021	(pixel)	(km²)
H31	OL	GL	GL	GL	18,433	16.59
H32	GL	GL	CL	GL	13,802	12.42
H33	GL	GL	CL	CL	11,839	10.66
H34	GL	GL	WL	WL	8592	7.73
H35	GL	GL	GL	WL	8172	7.35
H36	OL	OL	OL	GL	7734	6.96
H37	WL	GL	GL	GL	7525	6.77
H38	GL	WL	WL	WL	7387	6.65
H39	WL	GL	WL	WL	6559	5.90
H40	GL	GL	OL	GL	5139	4.63

Notes: Built-up land (BL), cropland (CL), grassland (GL), woodland (WL), and other land (OL) are shown in Tables 12, 13.

3.3 Comparison of Cusco and Huaraz

A comparison of land cover change in the two study areas reveals similarities between the Quechua (inside and outside the contiguous built-up area), Suni, and Puna of Cusco and Huaraz: (1) the shares of changed and persistent pixels per altitudinal zones are comparable — showing more dynamic spaces up to 4000 m and more static areas above — and (2) at least four top-ten change trajectories per altitudinal zone appear in both study areas.

Inside the 2021 contiguous built-up area of the Quechua region, both Cusco and Huaraz are characterized by single changes from GL to BL during 1991–2001 and 2001–2011 (IDs C01, C02, H01, H04), by a single change from CL to BL during 1991–2001

(IDs C06, H02) and a trajectory from CL (1991) via GL (2001) to BL (IDs C07, H06). Here, it becomes clear that the area of the identified trajectories to built-up land was almost seven times larger in Cusco (10.90 km²) than in Huaraz (1.56 km²) — roughly reflecting the ratio between the total increase of built-up land in Cusco (26.02 km²; Table 4) and Huaraz (3.12 km²; Table 9) during 1991–2021. Outside the 2021 contiguous built-up area, the Quechua region in both cities shows single changes from GL to CL during 1991–2001, 2001–2011, and 2011–2021 (IDs C14, C12, C11, H13, H12, H15), as well as a trajectory from GL (1991 and 2001) via CL (2011) to GL (2021) (IDs C16, H19). In sum, the shared top-ten trajectories of the Quechua (inside and outside the contiguous built-up area) represent 23.18% and 12.85% of the total area of this altitudinal zone in Cusco and Huaraz, respectively. The Suni region in both study areas also experiences single changes from GL to CL during 1991–2001, 2001–2011, and 2011–2021 (IDs C26, C22, C21, H24, H21, H27), and a trajectory from GL (1991 and 2001) via CL (2011) to GL (2021) (IDs C25, H22). In sum, the shared top-ten trajectories of the Suni make up 23.90% of the total area of this altitudinal zone in Cusco and 15.63% in Huaraz. In the Puna of both Andean cities, single changes from OL to GL (1991–2001 and 2011–2021) (IDs C31, C35, H31, H36) and from GL to CL (2001–2011) (IDs C40, H33) are characteristic. Additionally, a trajectory from GL (1991 and 2001) via CL (2011) to GL (2021) can be identified in both cases (IDs C38, H32). In sum, the shared top-ten trajectories of the Puna amount to 17.20% of the total area of this altitudinal zone in Cusco and 10.03% in Huaraz.

4 Discussions

At first glance, the land cover trajectories of the Cusco and Huaraz study areas suggest a certain vertical divide: into a more changing lower part (Quechua and Suni) and a more persisting upper part (Puna). However, this should by no means be taken as a sign of a lack of interdependencies (or separated binary units; Zimmerer and Bell 2015). The results of this study may suggest that selected land cover change trajectories in Cusco and Huaraz have similar underlying drivers that are related to national/international developments. Three vertically complementary trends in particular, identified during direct field observations in March 2022 (i.e., during the rainy season) and seen in the context of conceptual thoughts on concentrated and expanded urbanization, represent plausible explanations: (1) speculative fallow; (2) agricultural intensification; and (3) ecological restoration.

Within the contiguous built-up area of 2021 in both Cusco and Huaraz, land cover change trajectories show the expansion of built-up land on grassland. From the perspective of traditional altitudinal zonation models of land use in Peru, this is surprising because the Quechua region is considered a classic altitudinal zone for market-oriented cultivation of crops like maize (*Zea mays*), broad beans (*Vicia faba*), or potatoes (*Solanum* spp.). The concentrated urbanization of grassland (instead of cropland) visible in both Andean cities can possibly be attributed to speculative fallow — a relative of the early concept of the “social fallow” (Hartke 1956), which today can be linked with processes of farmland abandonment (Li and Li 2017), land grabbing (Zoomers et al 2017), and the commodification of mountain landscapes (Perlik 2019). Many owners of cropland near the cities no longer cultivate it — nor do they lease it to other farmers — because they speculate on selling their property as building lots due to sharply rising land prices. According to direct field observations, this process does not only result in the expansion of marginal settlements but is particularly driven by real-estate developers. In addition to some larger periurban condominiums, such as the Condominio Santa María in Cusco, aimed at nature lovers, or the Condominio El Pinar in Huaraz, built for employees of the Antamina mining company (Branca and Haller 2021a, 2021b), several smaller projects on the fringes of the contiguous built-up area are also increasingly contributing to the expansion of built-up land; examples include the municipalities of Oropesa (near Cusco) and Taricá (near Huaraz), where mostly regional real-estate developers like Valles Verdes (e.g., Condominio San Isidro, Oropesa) and La Libertad (e.g., Residencial Montecristo, Taricá) are trying to profit from the construction boom in the Andean cities. The sale of the lots is obviously preceded by a speculative phase — which often lasts several years —, during which cropland is increasingly substituted by grassland due to spontaneous growth of herbaceous vegetation. This observed process is close to the model of Sinclair (1967), who decades ago pointed out agricultural extensification processes in the surrounding areas of expanding cities, stating that "land which the owner thinks might become urban land at some vague future date changes in value. It does not generally change hands, but the owner carries out his activities, or changes his activities, with the feeling that something is going to happen. In short, there is an air of anticipation associated with rural land near modern urbanized areas" (Sinclair 1967: 78).

In the Quechua region, outside the contiguous built-up area, as well as in the Suni region, land cover change trajectories show a continuous, stable trend of substitution of grassland by cropland. While this seems quite logical for the Quechua region, this trend is somewhat surprising for the Suni region. Traditional altitudinal zonation models of land use in Peru often classify the Suni as a classic zone for subsistence-oriented cultivation of Andean roots/tubers — like mashua (*Tropaeolum tuberosum*), oca (*Oxalis tuberosa*), and ulluco (*Ullucus tuberosus*) — which is usually limited to the rainy season due to a lack of irrigation infrastructure. However, the present land cover change trajectories are based on satellite imagery taken in the middle of the dry season, when the soils of purely rain-fed cropland are already dry or damp and would appear as "other land," and they show a continuous, stable expansion of cropland on former grassland over the years — justifying the assumption that irrigation infrastructure has been expanded in recent decades. This hypothesis regarding agricultural intensification (Keys and McConnell 2005) is strengthened by numbers of the Peruvian National Agricultural Censuses from 1994 and 2012: these show intercensal total increases in the number of *unidades agropecuarias* (i.e., farmsteads) with access to irrigation infrastructure for the 30 districts having a share in the study area of Cusco (+42.25%) and the 15 districts being part of the study area of Huaraz (+51.79%) (Instituto Nacional de Estadística e Informática 1994; Instituto Nacional de Estadística e Informática 2012). Moreover, a publication by the World Bank states that "[b]eginning in 1991 [with Alberto Fujimori's Legislative Decree 653; a law for the promotion of investments in the agricultural sector], the state granted a considerable number of resources to the Programa Nacional de Manejo de Cuencas Hidrográficas y Conservación de Suelos [...], almost exclusively for the Sierra. [...] [Yet] [a]lthough the promotion of private investment in (major) water infrastructure began in the early 1990s, it was implemented mainly from the late 2000s [and the formulation of the national irrigation policy and strategy by the Peruvian government]" (World Bank 2013: 11). In addition to the Quechua and Suni regions, this trajectory is even visible in the Puna region of Cusco and Huaraz, where selected legumes like tarwi (*Lupinus mutabilis*), roots/tubers like potatoes (*Solanum* spp.), and cereals like barley (*Hordeum vulgare*) are cultivated on irrigated land (for example, between August 2011 and July 2012; Instituto Nacional de Estadística e Informática 2012). While Rolando et al. (2017) state that the substitution of grassland by cropland in the Puna region might be due to warming and incremental pest pressures, the important role of extended urbanization — intensifying land use, infrastructural connections, and socioecological transformations (for example due to agribusiness-based contract growing; Zimmerer 2003) — should not be neglected.

The most obvious change in the Puna region of Cusco and Huaraz is the continuous, stable substitution of grassland for "other land." Surprising here is first of all the strong presence of "other land" in an altitudinal zone, which, according to traditional altitudinal zonation models of land use in Peru, is dominated by grassland. In the present case, "other land" could be degraded, probably overgrazed grassland (if dry bare soil makes up a large part of it). "Other land's" change to grassland might then point to vegetation recovery over the last decades. Given numerous efforts (e.g., the reduction of range burning activities, the practice of rotational grazing, and the replacement of cattle and sheep by llamas and alpacas) by different actors for the ecological restoration (Christmann and Oliveras Menor 2021) of the Puna region, this seems highly plausible. These increased efforts are also due to the realization that a functioning ecosystem in the Puna is of utmost importance for supplying Andean cities with water (for domestic/industrial and hydroelectric power uses) and locally produced food. Examples, that perfectly fit into the conceptual assumptions of extended urbanization, include the Fondo de Promoción del Riego en la Sierra, initiated in 2013 (Supreme Decree 002-2013-AG), and its follow-up, the Fondo Sierra Azul (Supreme Decree 002-2017-MINAGRI). These focus on vegetation restoration/conservation and the construction of artificial lagoons (*qochas*) or reservoirs in the Puna, for the sake of the "rediscovered" and reinterpreted Andean techniques of the "sowing and harvesting of water," and point to the ongoing processes of extended urbanization around Peruvian mountain cities like Cusco and Huaraz (Branca and Haller 2021a, 2021b), where population growth represents a major stressor on water resources (Buytaert and De Bièvre 2012). Hence, these efforts to safeguard key ecosystem services in the Puna region (Rolando et al. 2017) may be critically interpreted as results of an extended urbanization aiming at the creation of so-called "operational landscapes" for cities. In this context, it is central for future research to use methods from the social sciences and humanities to examine how the processes of speculative fallow, agricultural intensification, and ecological restoration, taking place at different altitudinal zones, interact at local and regional levels — and how this web of effects is embedded at national and global scales.

5 Conclusions

Due to the complex regional-geographic characteristics of the socioecological systems, physical urbanization and related demographic, economic, and sociocultural processes profoundly impact the agricultural use of the "hinterlands" of Andean cities. The results of this research point to the vertical distribution of major trajectories of land cover change in and around Cusco and Huaraz — combining a traditional altitudinal zonation model of land use in Peru with direct field observations and GIS-based analyses of Landsat imagery from the dry season of 1991, 2001, 2011, and 2021. For the period 1991–2021, this study shows that there are very similar change trajectories in both study areas at the same altitudinal zones. It interprets them against the experiences gained during the direct field observation, compares them with theoretical thoughts on the Quechua (>2300–3500 m), Suni (>3500–4000 m), and Puna (>4000–4800 m) regions, and hypothesizes that speculative fallow, agricultural intensification, and ecological restoration are among the drivers of land cover change in these altitudinal zones. These vertically arranged alterations should not be considered independent but can be seen as mutually interdependent, spatial manifestations of concentrated and extended urbanization around Andean cities influenced by the enormous challenges of global environmental changes (Sarmiento 2008).

Future testing of the hypothesis articulated here should consider both the individual spatial perceptions of land use decision-makers (i.e., periurban smallholders), as well as the societal conditions that influence those decisions. How is concentrated urbanization in the Quechua assessed by periurban farmers? Do they perceive extended urbanization in the Quechua, Suni, and Puna? What land cover development would be desirable in the "hinterland" to preserve the diversity of vertically organized land use in these "operational landscapes" of Andean cities?

Going beyond purely disciplinary approaches, a montological perspective (Sarmiento 2020; Sarmiento et al. 2023) on verticality and urbanization is key for the holistic study of land cover change trajectories in mountains of the tropical Global South. It can drive the progress of an urban montology (Borsdorf and Haller 2020; Huang 2021), facilitating communication between urban mountain researchers from different disciplinary backgrounds, supporting the inclusion of nonscientists, and opening the way forward to an ecologically balanced, economically viable, and socially inclusive future for mountain regions: between plaza and peak.

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Author Contributions

Andreas HALLER (conceptualization, methodology, investigation, resources, writing original draft, review and editing). Domenico BRANCA (methodology, investigation, writing original draft, review and editing). Deyvis CANO (methodology, review and editing).

Ethics Declaration

Data availability statement: Data will be provided by the corresponding author upon request.

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References

Alcántara Ayala I, Cui P, Pasuto A (2022) Disaster risk reduction in mountain areas: a research overview. J Mt Sci 19: 1487-1494. https://doi.org/10.1007/s11629-022-7487-2

Amini S, Saber M, Rabiei-Dastjerdi H, Homayouni S (2022) Urban land use and land cover change analysis using random forest classification of Landsat time series. Remote Sens 14(11): 2654. https://doi.org/10.3390/rs14112654

Angelo H, Wachsmuth D (2015) Urbanizing urban political ecology: A critique of methodological cityism. Int J Urban Reg Res 39(1): 16-27. https://doi.org/10.1111/1468-2427.12105

Bart, F (2016) Moshi (Kilimanjaro, Tanzania): The urban dynamics of a rural region. In: Bart F, Nakileza BR, Racaud S, Charlery de la Masselière B (eds.), Rural-Urban Dynamics in the East African Mountains. Nairobi: Africae. pp 47-65. https://doi.org/10.4000/books.africae.1048

Birx HJ (ed.) (2006) Encyclopedia of Anthropology 1. Thousand Oaks: Sage. p 2373. https://doi.org/10.4135/9781412952453

Borsdorf A (2018) Regional geography abolished? The importance of regional geography in the German-language speaking region before and 50 years after Kiel, with particular reference to geographical Latin American studies. Lecture on the occasion of the 80th birthday of Christoph Stadel. Mitt Osterr Geogr Ges 160: 351-359. (In German). https://doi.org/10.1553/moegg160s351

Borsdorf A, Haller A (2020) Urban montology: mountain cities as transdisciplinary research focus. In: Sarmiento FO, Frolich L (eds.), The Elgar Companion to Geography, Transdisciplinarity and Sustainability. Cheltenham: Edward Elgar. pp 140-154. https://doi.org/10.4337/9781786430106.00016

Borsdorf A, Stadel C (2015) The Andes: A Geographical Portrait. Berlin: Springer. p 368. https://doi.org/10.1007/978-3-319-03530-7

Branca D, Haller A (2021a) Cusco: Profile of an Andean city. Cities 113: 103169. https://doi.org/10.1016/j.cities.2021.103169

Branca D, Haller A (2021b) Urbanization, touristification and verticality in the Andes: A profile of Huaraz, Peru. Sustainability 13(11): 6438. https://doi.org/10.3390/su13116438

Brenner N, Schmid C (2014) The 'Urban Age' in question. Int J Urban Reg Res 38(3): 731-755. https://doi.org/10.1111/1468-2427.12115

Brenner N, Schmid C (2015) Towards a new epistemology of the urban? City 19(2-3): 151-182. https://doi.org/10.1080/13604813.2015.1014712

Brush SB (1976) Man's use of an Andean ecosystem. Hum Ecol 4: 147-166. https://doi.org/10.1007/BF01531218

Buytaert W, De Bièvre B (2012) Water for cities: The impact of climate change and demographic growth in the tropical Andes. Water Resour Res 48(8). https://doi.org/10.1029/2011WR011755

Castriota R, Tonucci J (2018) Extended urbanization in and from Brazil. Environ Plan D 36(3): 512-528. https://doi.org/10.1177/0263775818775426

Chakrabarty, D (2000). Provincializing Europe: Postcolonial Thought and Historical Difference. Princeton: Princeton University Press.

Christmann T, Oliveras Menor I (2021) A synthesis and future research directions for tropical mountain ecosystem restoration. Sci Rep 11: 23948. https://doi.org/10.1038/s41598-021-03205-y

Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens Environ 37(1): 35-46. https://doi.org/10.1016/0034-4257(91)90048-B

Congedo L (2021) Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS. J Open Source Softw 6(64): 3172. https://doi.org/10.21105/joss.03172

Dematteis G (2012) On repositioning geography as knowledge of the possible. Riv Geogr Ital 119: 85-100. (In Italian).

Donoso ME, Sarmiento FO (2021) Changing mountain farmscapes: Vulnerability and migration drivers in the Paute River watershed, Southern Ecuador. J Mt Sci 18: 1902-1919. https://doi.org/10.1007/s11629-020-6127-y

Fioravanti-Molinié A (1981) Current variations on an old Andean theme: The vertical ideal. Études Rurales 81-82: 89-

107. (In French).
https://doi.org/10.3406/rural.1981.2654
Forman SH (1978) The future of value of the verticality concept: Implications and possible applications in the Andes. In: Société des américanistes (eds.), Actes du XLIIe Congrès International des Américanistes. Paris: Fondation Singer-Polignac. pp 234-256.
Gade DW (2011) Curiosity, Inquiry, and the Geographical Imagination. New York: Peter Lang. p 307.
https://doi.org/10.3726/978-1-4539-0789-4
Ghosh S, Meer G (2021) Extended urbanisation and the agrarian question: Convergences, divergences and openings. Urban Stud 58(6): 1097-1119.
https://doi.org/10.1177/0042098020943758
Gondwe JF, Lin S, Munthali RM (2021) Analysis of land use and land cover changes in urban areas using remote sensing: Case of Blantyre City. Discrete Dyn Nat Soc 25: 8011565.
https://doi.org/10.1155/2021/8011565
Grêt-Regamey A, Brunner SH, Kienast F (2012) Mountain ecosystem services: Who cares? Mt Res Dev 32: S23-S34.
https://doi.org/10.1659/MRD-JOURNAL-D-10-00115.S1
Guillet D (1986) Toward a cultural ecology of mountains: The Central Andes and the Himalaya compared. Mt Res Dev 6(3): 206-214. https://doi.org/10.2307/3673389
Haller A (2012) Vivid valleys, pallid peaks? Hypsometric variations and rural-urban land change in the Central Peruvian Andes. Appl Geogr 35(1-2): 439-447.
https://doi.org/10.1016/j.apgeog.2012.09.009
Haller A, Branca D (2020) Montology: A mountain perspective on transdisciplinary research and sustainable development. Rev Investig Altoandin 22(4): 313-322. (In Spanish).
https://doi.org/10.18271/ria.2020.193
Haller A, Branca D (2022a) Urbanization and the verticality of rural-urban linkages in mountains. In: Sarmiento FO (ed.), Montology Palimpsest. A Primer of Mountain Geographies. Berlin: Springer. pp 133-148.
https://doi.org/10.1007/978-3-031-13298-8_8
Haller A, Branca D (2022b) More than landscape: Toward cosmophanic diversity in environmental planning and governance. Soc Nat Resour 35(10): 1123-1133.
https://doi.org/10.1080/08941920.2022.2105461
Hartke W (1956) The “Social Fallow” as an index of the geographical differentiation of the landscape. Erdkunde 10(4): 257-269. (In German).
https://doi.org/10.3112/erdkunde.1956.04.01
Harvey D (2003) The New Imperialism. Oxford: Oxford University Press. p 253.
Hassan Z, Shabbir R, Ahmad SS, et al. (2016) Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. SpringerPlus 5: 812. https://doi.org/10.1186/s40064-016-2414-z
Huang G (2021) Theory of Mountainurbanology. Berlin: Springer. p 269.
https://doi.org/10.1007/978-981-16-0819-3
Instituto Geofísico del Perú (2009a) The Climate in Peru: Cuzco. (In Spanish).
http://web.archive.org/web/20200128175804/http://www.met.igp.gob.pe/clima/HTML/cuzco.html (Accessed on 27 September 2023)
Instituto Geofísico del Perú (2009b) The Cimate in Peru: Anta. (In Spanish).
https://web.archive.org/web/20200619202811/http://met.igp.gob.pe/clima/HTML/anta.html (Accessed on 27 September 2023)
Instituto Nacional de Estadística e Informática (1994) III National Agricultural Census 1994. Lima: INEI. (In Spanish).
Instituto Nacional de Estadística e Informática (2012) III National Agricultural Census 2012. Lima: INEI. (In Spanish).
Kapos V, Rhind J, Edwards M, et al. (2000) Developing a map of the world’s mountain forests. In: Price MF, Butt N (eds.), Forests in Sustainable Mountain Development. IUFRO Research Series 5. Wallingford: CABI Publishing. pp 4-9.
https://doi.org/10.1079/9780851994468.0000
Keys E, McConnell WJ (2005) Global change and the intensification of agriculture in the tropics. Glob Environ Change 15(4): 320-337.
https://doi.org/10.1016/j.gloenvcha.2005.04.004
Kingman E, Bretón V (2017) The arbitrary and diffuse borders between the urban-modern and the rural-traditional in the Andes. J Lat Am Caribb Anthropol 22(2): 235-253. (In Spanish). https://doi.org/10.1111/jlca.12216
Krause M (2013) The ruralization of the world. Public Cult 25(2): 233-248. https://doi.org/10.1215/08992363-2020575
Larkham P (2018) The importance of observation: Urban morphology in the field. In: Oliveira V (ed.), Teaching Urban Morphology. Cham: Springer. pp 265-279.
https://doi.org/10.1007/978-3-319-76126-8_15
Lautensach H (1952) The variation of geographic forms. Studies on landscape systematics. Bonn: Ferdinand Dümmlers Verlag. p 191. (In German).
Li P, Shi C, Li Z, et al. (2013) Evaluation of ASTER GDEM using GPS benchmarks and SRTM in China. Int J Remote Sens 34(5): 1744-1771.
https://doi.org/10.1080/01431161.2012.726752
Li S, Li X (2017) Global understanding of farmland abandonment: A review and prospects. J Geogr Sci 27: 1123-1150. https://doi.org/10.1007/s11442-017-1426-0
Maharjan A, Kochhar I, Chitale VS, et al. (2020) Understanding rural outmigration and agricultural land use change in the Gandaki Basin, Nepal. Appl Geogr 124: 102278.
https://doi.org/10.1016/j.apgeog.2020.102278
Mell IC, Sturzaker J (2014) Sustainable urban development in tightly constrained areas: A case study of Darjeeling, India. Int J Urban Sust Dev 6(1):65-88.
https://doi.org/10.1080/19463138.2014.883994
Ministerio de Comercio Exterior y Turismo (2021) Ancash: Visitor arrivals to Huascarán National Park, January 2015-December 2021. Lima: MINCETUR. (In Spanish).
https://web.archive.org/web/20230412094026/https://cdn.www.gob.pe/uploads/document/file/2863485/Compendio_Cifras_Turismo_ENERO-2022.pdf
Monte-Mór R (1994) Extensive urbanization and logics of settlement: An environmental perspective. In: Santos M, Souza M, Silveira M (eds.), Territory, Globalization, and Fragmentation. São Paulo: Hucitec Editora. pp 169-181. (In Portuguese).
Monte-Mór R, Castriota R (2018) Extended urbanization: Implications for urban and regional theory. In: Paasi P, Harrison J, Jones M (eds.), Handbook on the Geographies of Regions and Territories. Cheltenham: Edward Edgar. pp 332-345. https://doi.org/10.4337/9781785365805.00038
Murra JV (1975) Economic and Political Formations of the Andean World. Lima: Instituto de Estudios Peruanos. p 339. (In Spanish).
Observatorio Turístico del Perú (2020) Entrances to Machu Picchu: nationals and foreigners 1980-2019. Lima: USMP. (In Spanish).
http://web.archive.org/web/20200303181358/http://www.observatorioturisticodelperu.com/mapas/impne.pdf
Oficina Nacional de Evaluación de Recursos Naturales (1981)

Map of major land use capacity in Peru. Lima: ONERN. (In Spanish).
Ottosen TB, Petch G, Hanson M, Skjøth CA (2020) Tree cover mapping based on Sentinel-2 images demonstrate high thematic accuracy in Europe. Int J Appl Earth Obs Geoinf 84: 101947. https://doi.org/10.1016/j.jag.2019.101947
Perlik M (2019) The Spatial and Economic Transformation of Mountain Regions. Landscapes as Commodities. London: Routledge. p 278. https://doi.org/10.4324/9781315768366
Pontius RG, Millones M (2011) Death to Kappa: birth of quantity disagreement and allocation disagreement for accuracy assessment. Int J Remote Sens 32(15): 4407-4429. https://doi.org/10.1080/01431161.2011.552923
Potere D (2008) Horizontal positional accuracy of Google Earth's high-resolution imagery archive. Sensors 8(12): 7973-7981. https://doi.org/10.3390/s8127973
Price MF, Arnesen T, Gløersen E, Metzger MJ (2019) Mapping mountain areas: Learning from global, European and Norwegian perspectives. J Mt Sci 16: 1-15. https://doi.org/10.1007/s11629-018-4916-3
Pulgar Vidal J (1996) Geography of Peru. The Eight Natural Regions, Transversal Regionalization, Traditional Ecological Wisdom. Lima: Peisa. p 302. (In Spanish).
Reinhard J, Ceruti MC (2010) Inca Rituals and Sacred Mountains: A Study of the World's Highest Archaeological Sites. Berkeley: University of California Press. p 264.
Ruddick S, Peake L, Tanyildiz GS, Patrick D (2018) Planetary urbanization: An urban theory for our time? Environ Plan D 36(3): 387-404. https://doi.org/10.1177/0263775817721489
Rolando JL, Turin C, Ramírez DA, et al. (2017) Key ecosystem services and ecological intensification of agriculture in the tropical high-Andean Puna as affected by land-use and climate changes. Agric Ecosyst Environ 236: 221-236. https://doi.org/10.1016/j.agee.2016.12.010
Sarmiento FO (2008) Andes mountains and human dimensions of global change, an overview. Pirineos 163: 7-13. https://doi.org/10.3989/pirineos.2008.v163.18
Sarmiento FO (2020) Montology manifesto: Echoes towards a transdisciplinary science of mountains. J Mt Sci 17: 2512-2527. https://doi.org/10.1007/s11629-019-5536-2
Sarmiento FO, Sarmiento EV (eds.) (2021) Andean Flanks: Paleoecology, Critical Biogeography and Political Ecology of the Changing Climates of Neotropical Mountain Forests. Chachapoyas: UNTRM. p 202. (In Spanish). https://doi.org/10.5281/zenodo.4961560
Sarmiento FO (ed.) (2022) Montology Palimpsest: A Primer of Mountain Geographies. Cham: Springer. p 506. https://doi.org/10.1007/978-3-031-13298-8
Sarmiento FO, Haller A, Branca D, et al. (2023) Socioecological gradients: Contesting traditional ecoclines to explain the high biocultural diversity of the Andean verdant. In: Myster RW (ed.), Neotropical Gradients and Their Analysis. Berlin: Springer. pp 454-459. https://doi.org/10.1007/978-3-031-22848-3_16
Sarmiento FO, Haller A, Marchant C, et al. (2023) 4D global montology: Toward convergent and transdisciplinary mountain sciences across time and space. Pirineos 178: e075. https://doi.org/10.3989/pirineos.2023.178001
Servicio Nacional de Meteorología e Hidrología (2020) Hydrometeorological data at national level. (In Spanish). https://web.archive.org/web/20200520085500/https://www.senamhi.gob.pe/?p=estaciones (Accessed on 27 September 2023)
Sinclair R (1967) Von Thünen and urban sprawl. Ann Assoc Am Geogr 57(1): 72-87. https://doi.org/10.1111/j.1467-8306.1967.tb00591.x
Stadel C (1991) Altitudinal belts in the tropical Andes: Their ecology and human utilization. Yearb Conf Lat Am Geogr 17/18: 45-60.
Stadel C (2000) Medium-sized cities and aspects of urban sustainability in the Andean region. Espac Desarro 12: 25-43. (In Spanish).
Stadel C (2019) Horizontal and vertical archipelagoes of agriculture and rural development in the Andean realm. In: Bastante-Ceca MJ, Fuentes-Bargues JL, Hufnagel L, et al. (eds.), Sustainability Assessment at the 21st Century. London: IntechOpen. https://doi.org/10.5772/intechopen.86841
Stehman SV, Foody GM (2019) Key issues in rigorous accuracy assessment of land cover products. Remote Sens Environ 231: 111199. https://doi.org/10.1016/j.rse.2019.05.018
Thomlinson JR, Bolstad PV, Cohen WB (1999) Coordinating methodologies for scaling landcover classifications from site-specific to global: Steps toward validating global map products. Remote Sens Environ 79(1): 16-28. https://doi.org/10.1016/S0034-4257(99)00055-3
Troll C (1959) The Tropical Mountains. Their Three-Dimensional Climatic and Phytogeographical Zonation. Bonn: Ferdinand Dümmlers Verlag. p 93. (In German).
Vega Centeno P (2011) The urban effects of mining in Peru: From the Cerro de Pasco and La Oroya model to the Cajamarca model. Apuntes 38(6): 109-136. (In Spanish). https://doi.org/10.21678/apuntes.68.621
Wachsmuth D (2014) City as ideology: Reconciling the explosion of the city form with the tenacity of the city concept. Environ Plan D 32(1): 75-90. https://doi.org/10.1068/d21911
World Bank (2013) The Future of Irrigation in Peru. Challenges and Recommendations. Vol. II: Main Report. Washington: World Bank. (In Spanish). https://web.archive.org/web/20220119114535/https://documents1.worldbank.org/curated/en/696591468265790621/pdf/795270v20WP0P10asional0Paper0Series.pdf
Zimmerer KS (2003) Geographies of seed networks for food plants (potato, ulluco) and approaches to agrobiodiversity conservation in the Andean countries. Soc Nat Resour 16(7): 583-601. https://doi.org/10.1080/08941920309185
Zimmerer KS, Bell MG (2013) An early framework of national land use and geovisualization: Policy attributes and application of Pulgar Vidal's state-indigenous vision of Peru (1941-present). Land Use Policy 30(1): 305-316. https://doi.org/10.1016/j.landusepol.2012.03.023
Zimmerer KS, Bell MG (2015) Time for change: The legacy of a Euro-Andean model of landscape versus the need for landscape connectivity. Landsc Urban Plan 139: 104-116. https://doi.org/10.1016/j.landurbplan.2015.02.002
Zoomers A, van Noorloos F, Otsuki K, et al. (2017) The rush for land in an urbanizing world: From land grabbing toward developing safe, resilient, and sustainable cities and landscapes. World Dev 92: 242-252. https://doi.org/10.1016/j.worlddev.2016.11.016