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Adaptive Responses and Resilience of Small Livestock Producers to Climate Variability in the Cruz Verde-Sumapaz Páramo, Colombia

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Abstract: Enhanced anthropogenic climatic variability challenges small farmers. In the Sumapaz *páramo* (Colombia), higher irregularity in precipitation and temperature reduces the quality of pasture and cattle health. Data from surveys, semi-structured interviews, and focus groups were analyzed to understand livestock farmers' responses to the impacts of climatic variability. To estimate the communities' resilience in the *páramo*, we used the capitals framework, the Baseline Resilience Indicator for Communities (BRIC), and cluster analysis. The responses of most households aim to reduce the impacts of climatic variability on the production system, chiefly intensifying practices such as the rotation of paddocks, livelihood diversification, purchase of grass, and buying and selling livestock. Interestingly, farmers did not recognize the value of the types of capital for responding to climatic variability. Results showed that the use of available physical, social, and economic capitals render the farming system resilient. Our probit model estimated that economic and human capitals are the largest and most significant contributors to communities' capacity to respond to climatic variability. However, pre-existing non-climatic vulnerabilities are also important. For example, poverty hinders farmers from using their income in response to climatic variability. The place-based measurements used in this research are easily understood and applicable by local policy makers to address increasing climate variability.

Keywords: adaptation; vulnerability; farming systems; small farmers; climate change; extreme events; Andes; Baseline Resilience Indicator for Communities (BRIC)

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1. Introduction

The impacts of anthropogenically intensified climate variability challenge the resilience of small farmers worldwide, particularly pastoralists and mountain farmers [1]. Observed and projected trends have confirmed the increasing frequency and intensity of climate extremes [2]. While drought and floods produce the most dramatic and devastating impacts, less extreme variability reduces crop yield and income, increases pests and diseases, and compromises the food security of small farmers [3]. This trend will only exacerbate as estimations of food security will diminish further with future projected climate change [4]. In this context, it is crucial to understand how small farmers in marginal regions respond to the impacts of climatic variability. As these responses relate to small farmers' resilience, unveiling the underlying components of such resilience may offer critical insights to inform research and action to enhance resilience to climate variability. This paper is a contribution to that understanding.

Resilient systems either maintain their organization, structure, and function after a disturbance [5] or transform when the situation is untenable to continue on the desired trajectories [6,7]. Small farmers are familiar with climate variability and harsh environmental conditions and have implemented strategies to respond to these challenges. Small farmers practicing crop and livestock production in marginal environments, highly variable climates, or ones highly prone to natural hazards have developed livelihood strategies to reduce their climate-related vulnerability and cope with climate-related impacts [8,9]. For instance, farmers are modifying farming practices such as the timing of planting and harvesting, implementing soil management practices, and using different varieties of crops in response to climate change [1,4,9,10]. While unfavorable climate and environment urge responses and motivate adaptive practices, it is worth asking which conditions and characteristics allow and enable the conception, development, and implementation of these resilient responses?

Flora et al. [11,12] used the Capitals Framework for understanding how rural communities change and formulated that different types of capital (Table 1) are the result of communities using their resources or assets to create new resources. We use this framework to understand how implementing adaptive responses that make communities resilient relies on access to different types of capital [13]. Arguing that capitals enable communities' capacity to "cope with, adapt to and shape change" [14], the use of different forms of capital has been associated with the adaptation and resilience of small farmers to climatic variability [15–17]. For example, Kais et al. argue that communities' resilience is partly related to how intensively community capitals are used. Recently, Carmen and colleagues conducted a meta-synthesis to disentangle the nuanced relationship between social capital and resilience, finding that different components of social capital became salient at different moments of crises. Bonding social capital enhanced households' capacity to cope during crises, bridging and linking social capital were relevant post-crisis, whereas the combined effect of bonding and bridging hindered the perception of the need for change [18].

Table 1. Different types of capital.

Natural capital	Natural elements that surround us such as air, water, altitude, latitude, climate slope, soil, and wildlife.
Cultural capital	It is created over generations and shapes how a group sees the world. This view informs what is valued, what is changeable, and what is deserved. It includes ways of knowing and acting, and language.
Human capital	It is the local intelligence, abilities, education, and health of individuals in a community. It entails the capabilities and individuals' potential based upon their genetics and socio-environmental conditions.
Social capital	It relates to the ties among individuals. It involves elements such as mutual trust, reciprocity, and collective action. Bonding and bridging social capitals are the interactions intra and inter groups, respectively.
Political capital	It is a group's capacity to make its norms the standard, which then generates rules for distributing resources.
Financial capital	It encompasses income, poverty, savings, fees, credit, loans, and taxes.
Built capital	It is the physical infrastructure constructed by humans. It is usually used for the production of other capitals. It includes buildings, roads, vehicles, communication, and water systems, among others.

Source: [11,12].

Having a balanced assortment of capitals enhances community resilience to stress factors including climatic changes [19]. Consequently, it is expected that strengthening the social, financial, natural, and physical capitals would facilitate, for instance, the sustainable intensification needed to supply a growing demand for food [4]. However, we cannot overlook that types of capitals are related, whereby changes in the availability or intensity of one type may impact the others. The availability, intensity of use, and interrelations among types of capital is then critical in the relation between capitals and resilience. For instance, Thompson et al. found that impacts of development on natural and built capitals limited the use of social capital for resilient responses. We contribute to this body of literature by understanding the interactions among capitals and their contribution to resilience. We leverage our analysis of the responses of livestock farmers to the impacts of climatic variability and assessment of community resilience in relation to the different forms of capital in two communities of the *páramo* Sumapaz (Colombia) (Figure 1).

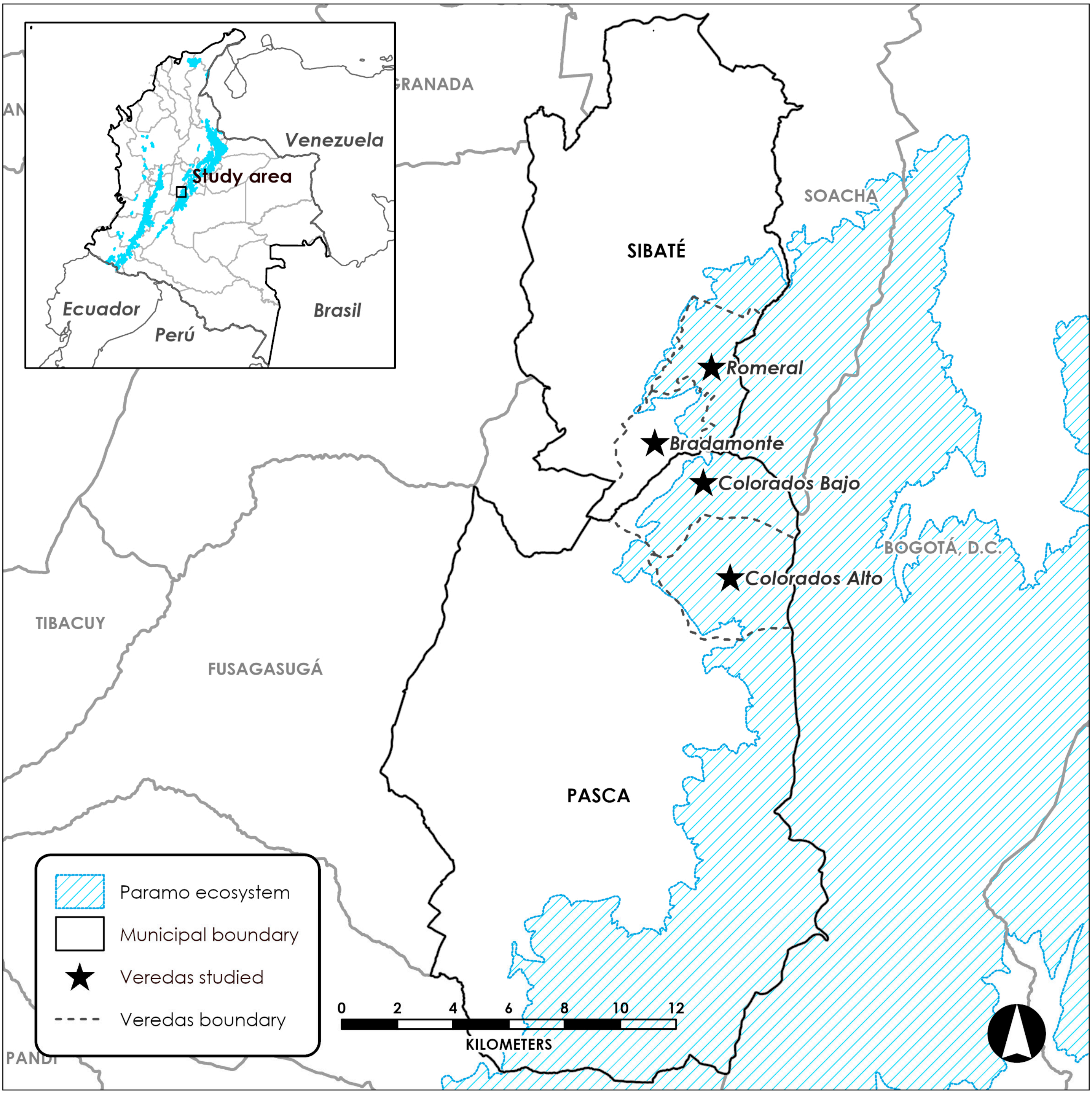

Figure 1. Study area.

Most research has focused on the impacts of climate change on the capacity of *páramos* to continue providing its ecosystem services [20,21]. These ecosystems provide crucial hydrological services such as the regulation of water consumed downstream by households, farms, and hydropower plants [22]. Compounded climate change and intensified human activities (e.g., cattle grazing, industrial farming, and afforestation) affect the hydrological regime of *páramos*. Interestingly though, the low intensity and local scale of small farming has not affected the hydrology of the *páramos*. Arguably, small farming has maintained the hydrological services of these ecosystems by preventing the overuse of *páramos*.

The extensive understanding of the impacts of climate change on *páramos* outmatches the research on impacts on small farmers living on these ecosystems [21,23]. Moreover, research on the responses of small farmers on the *páramo* is scant. We contribute to this gap by analyzing the responses of livestock small farmers to the impacts of climatic variability in the *páramo* Cruz Verde-Sumapaz. Impacts of climate variability on *páramos* indirectly affect small farmers living and using these ecosystems, hence the salience of understanding human responses to these changes and the foundational elements of the resilience of small farmers. Our understanding of the relation between types of capital and small farmers' resilience may offer insights to guide policymaking for supporting small farmers, and in so doing, these policies indirectly contribute to maintaining the provision of ecosystem services by the Colombian *páramo* of Cruz Verde-Sumapaz. We estimate that economic and human capital are significant contributors to community resilience, while knowledge is foundational to household adaptive strategies. Further, farmers appear to use available capitals to address more pressing non-climatic stressors, which may explain the limited use of capitals to respond to climatic variability.

2. Study Area

Páramo is the local name for the neotropical alpine grassland ecosystems covering sections of Andean mountain landscapes latitudinally located between the Cordillera de Merida in Venezuela and the Huancabamba depression in northern Peru [21]. Altitudinally, *páramos* are a discontinuous belt between the permanent snow (ca. 4500 + m) and the cloud forests (ca. 2000–3500 m) [22,24].

The altitudinal range of the Cruz Verde-Sumapaz *páramo* is 3000–3800 m above sea level (masl). The dominant vegetation of this cold and humid ecosystem is bushes and shrubs [25]. In the *páramo*, we conducted this research in the *veredas* Romeral and Bradamonte (municipality of Sibaté), and *veredas* Colorados Alto and Colorados Bajo (municipality of Pasca). We selected these municipalities because 70% of their territory is within the *páramo* and they have the largest livestock production in the area. The average annual precipitation in these municipalities ranges between 800 and 873 mm, and the average temperature is between 12 °C and 14 °C.

Livestock herding is the farmers' main livelihood in the study area. Almost three quarters (71%) of the households use livestock for milk production, 21% for both milk and meat, and 8% for solo meat production. The main land use is pasture for livestock, occupying an approximate area of 52,523 ha, which corresponds to 28% of the area's land cover [26,27]. The average production area is 5 ha, although there are at least 5 farms with an area of 20 hectares. Though livestock is the main source of income, 99% of those surveyed also develop agriculture as a secondary activity, with strawberries and potatoes being the main crops.

Livestock herding in the study area is carried out by households of up to 5 people. The average age of the household is 45 years. The education level is low: 50% have a primary school education, 35% have a high school education, 13% have a technical diploma, and only 2% have a university degree.

Since the 2000s, there has been a clear trend in population growth in the study area in both urban and rural areas. Agricultural production shows a similar trend. The factors influencing this process are the high population density in Bogotá, growing demand for fresh produce, expansion of the agricultural frontier, immigration, and being located within a metropolitan area [28,29]. On the other hand, agricultural systems demand a permanent water supply, production technology, labor, and stable climatological conditions. In the study area, we observed the following elements: a) decreasing water supply due to deforestation and ongoing conversion of Andean ecosystems to agriculture, b) increasing crop plagues and diseases, and c) a lack in technology transfer leading to a dependence on commercial enterprises (particularly agrochemicals) and increasing costs of production [30]. All these elements represent long-term challenges for food and water security within the metropolitan areas.

3. Materials and Methods

This research used quantitative and qualitative data collected in four *veredas* in the Cruz Verde-Sumapaz *páramo*: Romeral, Bradamonte, Colorados Alto, and Colorados Bajo (Figure 1). We conducted a survey (n = 103) using a simple random sampling (see the survey applied in Supplementary Material File S1). We gathered qualitative data through 12 semi-structured interviews with livestock producers, veterinary technicians, and representatives of the municipal governments of Sibaté and Pasca. We also conducted two focus groups with small farmers (owners of estates < 5 ha) from the *veredas* and veterinarian technicians. Twenty people participated in each focus group. These focus groups identified the variables for the analysis of community livelihoods (see Table 2).

Table 2. Variables for the analysis of community livelihoods by type of capital.

Capital	Explanatory Variables
Social	Participation in organizations; type of organizations; frequency of decision-making by leaders and by family participation in decision-making; participation of women and youth; activities carried out by community leaders; type of conflicts and actors involved in conflict resolution.
Cultural	Traditional knowledge; cultural practices for adaptation; knowledge of young people.
Physical	Basic household services; condition of household services and roads.
Economic	Available land and cash; income sources; use of cash; savings; use of savings; use of income for responding to disturbances; area of land use change; influence of disturbances on food security and access to credit.
Human	Number of household members and workforce; age and education level of household members.
Natural	Condition of water resources, soil, and forests; threatened natural resources, factors impacting natural resources; practices for conservation of water, soil, and forest.

We obtained meteorological, economic, and environmental data from local agencies and environmental authorities such as the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) and the Corporación Autónoma Regional de Cundinamarca (CAR). Active meteorological stations covering the study area provided monthly precipitation and temperature data for the 2000–2023 period. We excluded stations with less than 70% of data in a consecutive period to generate a robust series of climatic data. The perceptions of livestock farmers about the impacts of climate variability and their responses to such disturbances complemented the meteorological data.

To characterize the six forms of capital, we employed 52 indicators collected from the survey (see Table 2). Following Cutter [31], the values were normalized using a Min-Max rescaling scheme to have indicators on a similar measurement scale between 0 and 1 (0 being the worst rank and 1 being the best value of an indicator).

$$Mini - max : x' = \frac{x - xmin}{x - xmin}$$

Having the normalized values, we estimated the Baseline Resilience Indicator for Communities (BRIC) [31]. BRIC is an aggregate measure of disaster resilience [31]. In our study, the value of BRIC is the result of the sum of the SUB $_i$ averages (total average of the 6 analyzed capitals).

$$\text{BRIC} = \sum_{i}^{1} SUBi$$

SUB is the average of the total sum of normalized variables (*i*) of each capital (*k*):

$$SUB = \frac{1}{n}\sum_{i}^{1} x_{ik}$$

The BRIC index was calculated for each observation and then summed up to obtain an overall community index.

We grouped and compared the differences between the indices of observation through a cluster analysis. The clusters are homogeneous groups of individuals. In doing so, we identified the heterogeneity of the indices in the study area.

The survey variables considered important for adaptation were used to adjust a probit model to estimate the probability of producers responding to climatic events based on the types of capital at their disposal.

4. Results

4.1. Characteristics of Climate Variability and Its Perceived Impacts by Livestock Producers

In the 2000–2023 period, the study area showed remarkable variability in the mean annual precipitation, ranging from 444 mm to 1369 mm (Figure 2). We identified an association between this variability and both phases of the El Niño-Southern Oscillation (ENSO). The years with the highest precipitation were 2008, 2011, 2017, and 2022, which correspond to the La Niña years. Conversely, low precipitation years like 2001, 2004, 2009, 2014, and 2015 were influenced by the El Niño phenomenon.

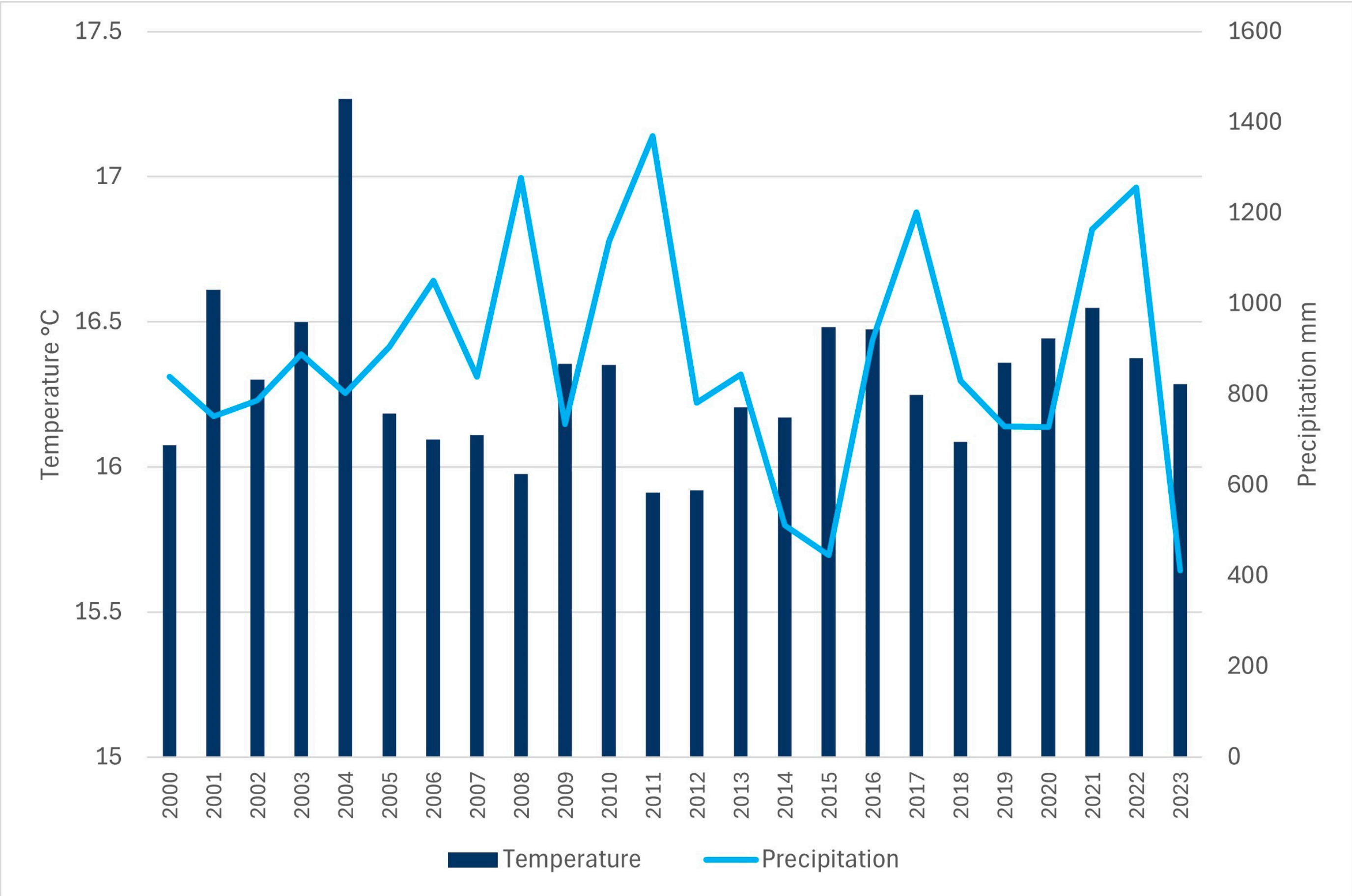

Figure 2. Average annual precipitation and temperature from 2000 to 2023 in the study area.

According to farmers, the increase in rainfall affected both the pasture quality and cattle health. They agreed that the intense rains of 2011 and 2017 increased waterlogging in the paddocks, rotting of pastures, and sole ulcers in cattle—a hoof injury caused by soil moisture. In response to increased precipitation, farmers built cattle stalls and cement structures to facilitate milking and prevent milk contamination. The years of low precipitation did not raise concerns among farmers about water scarcity, possibly because low precipitation years were less frequent and not as severe as the heavy rainfall ones. However, it is noteworthy that 10 farms with water sources are reforesting and building fences to prevent animals from accessing the sources.

The average monthly precipitation shows a marked bimodal pattern of rainy and dry seasons. The rainy seasons are April–May and October–November with maximum precipitation ranges of 87–242 mm and 42–123 mm, respectively. The dry seasons are July–August and December–January with minimum precipitation ranges of 24–54 mm and 22–39 mm, respectively.

In the first dry season (July and August), farmers plant common grass (*Megathyrsus maximus*). This grass grows for approximately two months and is ready by the beginning of the second rainy season (October to November), precisely when feed is scarcer for the animals. According to the farmers, this practice of planting grass has not been altered by the change in rainfall. Further to this, they claim that the soils have become more suitable for pasture because of the higher temperatures in the Niño years, incentivizing them to increase the number of animals in the herds.

A monthly analysis of precipitation revealed that the April–May rainy season had shifted. Since 2011, the onset of this season has been earlier by at least two months (Figure 3). This did not happen in the October rainfall cycle where no change in the daily rainfall pattern is identified. The farmers do not perceive any impact of the earlier onset of the rainy season. It is likely that it has positive effects as it may reduce the duration of the December–January dry season.

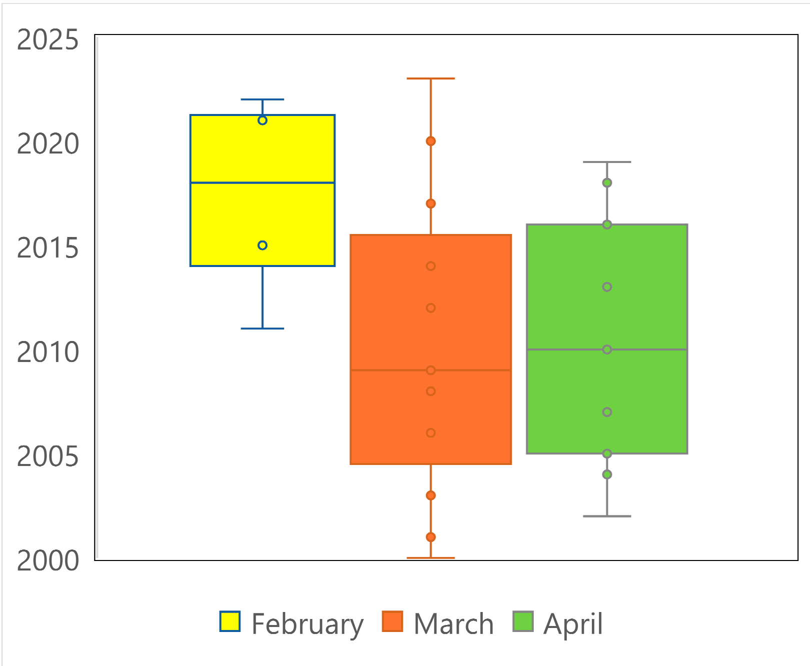

Figure 3. Changes in the onset months of the April rain cycle since 2000 in the study area.

In the 2000–2023 period, the study area showed a relatively stable annual mean temperature ranging from 15.9 to 17.2 °C (Figure 2). The average annual temperature was 16.3 °C. The hot years with the highest mean annual temperatures were 2001, 2004, and 2021. The average monthly temperature was 16.2 °C. The hot months with the highest mean temperatures were November and December, whereas the cold months with the lowest mean temperatures were June and September.

The farmers' general perception of warm temperatures was positive, they even associate it to larger herds and higher milk production. This improvement has led to a livelihood diversification of the traditional cattle ranchers, cultivating strawberries throughout the *páramo* in the last 2 years. It should be noted, though, that a warmer climate favors the maintenance of pastures and stables.

4.2. Livestock Farmers' Household's Types of Capital

Economic capital: Most of the households (88%) have less than one Colombian legal monthly minimum wage (USD 270) to support their families, while 12% receive an income of up to USD 400. Ninety-one percent of the income goes to cover basic needs: 74% goes to food, 10% to housing improvement, and 7% to clothing. The remaining 9% is reinvested in productive inputs like the purchase of salt and fodder in some cases. Only two households purchased plant materials for reforesting around water sources, but the planting and care were carried out by environmental volunteers from the region and the municipal government of Sibaté. The goal of this strategy was to limit the impact of water stress on the ecosystem by reducing evapotranspiration and to guarantee water supply in times of drought.

Having little economic capital limits access to agricultural technology. Only 45% of the surveyed population has subsidized access to innovations such as genetic improvement and technical assistance. Moreover, 12% of the households surveyed spend at least 9% of their income on important costs of production (e.g., soil preparation for crops and pasture improvement).

Physical capital: It is considered an important type of capital but at a less than ideal state. Housing improvement is a priority for the farmers. For most of the households (72%) surveyed, their houses do not have satisfactory conditions or good household services such as sewage or heating. Consistently, virtually all the farmers (99%) have taken out loans to improve their housing. Though 82% of the milking is done in the paddocks and not in a parlor with a cement floor, only 56% have used their loans to improve the infrastructure of their farms (e.g., fences, stables, and milking points) and buy animals.

Social capital: Almost a quarter (22%) of the farmers participate in livestock associations. However, no collective decisions are made to improve the production of farms, evidencing that the individual (household) private property of farms entails the decision making for production. Conversely, 55% of households participate in the assemblies of Community Action Boards (JAC), which decide upon improvements to shared infrastructure, like rural schools and support for families living in poverty. From the participation in the JAC we infer that social capital may combine participation in collective spaces, household decision-making about livelihoods, and collective action to improve common goods and support those in need. The majority (95%) of farmers indicated that though collective spaces do not address impacts of climatic variability, the JACs share environmental projects and management of the territory. However, 91% do not participate actively in environmental activities.

Social capital was affected by political and environmental conflicts between livestock herders and strawberry growers. Conflicts alienate people from each other, weakening social cohesion and breaking ties. These conflicts were borne out of the lack of institutional support to regulate access to water sources. The impact on social capital is further confirmed by the fact that in most cases, mediation and resolution of the conflicts require an exogenous actor such as the mayors' office rather than endogenous elements like trust or reciprocity. Furthermore, the exclusion of the conflicting parties from the management of the conflict hinders any collective activity to preserve natural capital.

Cultural capital: Local knowledge is a crucial component of cultural capital. In *páramo* Sumapaz, virtually all (99%) households surveyed indicated that they inherited their livestock herding knowledge from their parents. The salience of cultural capital may be observed in that 95% of the children and young people were interested in continuing cattle raising. Along with this interest, however, they were also concerned with the challenges of their economic capital such as lowering milk prices and the rising price of inputs that compromise dairy production.

Another component of cultural capital is empirical knowledge about conserving natural resources and biodiversity, which was also very common among respondents. This knowledge, however, is dynamic and open. Most farmers (96%) have information associated with the rotation of pastures, protection of water resources, reforestation of springs, and planting live fences. Part of this information is from other knowledge systems through training provided by external entities such as conservation agencies and non-governmental organizations.

Natural capital: Most households (99%) indicated that the condition of water and soil on the farm is mostly good in both villages. However, farmers perceived that the soil is compacted and has low fertility. The recognition of these problems, though, does not lead to investment in tackling these issues. As opposed to the condition of water and soils, farmers perceive that most of the forests are in fair to poor condition due to cattle ranching activity and forest fires.

The elders noticed that the endemic fauna have become scarcer over time. They attribute this to the transformation of the ecosystem by deforestation, introduction of animals, and traditional hunting of the *borugos* (*Cuniculus paca*) and *armadillos* (*Dasypus novemcinctus*).

In general, land use change in the *páramo* has affected the natural capital of the study area. According to 93% of surveyed households, increased livestock activity has contributed the most to this change, followed by the expansion of crop land.

4.3. Livestock Farmers' Adaptive Responses to Climate Variability and the Capitals Involved in These Responses

Table 3 shows household practices implemented in response to increased precipitation and temperature, and the capital used to respond. Out of a total of 16 response practices, 8 address the impacts of rising temperature and 14 address the impacts of precipitation variability. More than half of the 16 practices are associated with activities to maintain livestock production, reflecting the centrality of cattle raising as a livelihood in the study area. We identified one practice to conserve natural resources, and two practices related to livelihood diversification through crop farming.

Table 3. Response Strategies to Increased Precipitation and Temperature and the Underlying Capitals.

Response to Increased Precipitation	**Capital Used**
Planting of trees and live fences to create shaded areas	Natural
Purchasing grass Rotation of paddocks inter and intra fields Increasing doses of salt, medicines, and vitamins Increasing frequency of herd sales and liquidation Concentrate purchase Periodic bathing Livelihood diversification	Economic
Use of groundwater Maintenance of animal rounds and watering areas	Cultural
Response to Increased Temperature	Capital Used
Purchasing grass Constructing ditches and drains Increasing purchases of vitamins, salt, and molasses Selling cattle Increasing the purchase of supplements and concentrates Constructing drinking troughs with hoses to prevent cattle in the water source	Economic

Most (97%) practices for responding to climate variability events exclusively aimed to reduce the impacts on the production system. In doing so, they may be reactive practices rather than proactive preventive strategies. However, responses to the impact of climate variability would improve with the allocation of a higher percentage of income to the improvement of soil conditions, water sources, and forests, and with the improvement of productive infrastructure and activation of more cooperative action through community associations.

Despite the generalized low income of the households in the study area, 80% of the farmers have had to respond to the impacts of rainfall and drought. These farmers have used more than 5% of their income to develop climate variability adaptive strategies, or to carry out actions to conserve soil, forests, and water sources. The responses to these impacts, however, were sporadic and unplanned.

While we identified the types of capital underlying farmers' responses to the impacts of climatic variability, farmers, interestingly, found very little or no usefulness of their capitals to face these climatic events. This scant recognition is consistent with the finding of our regression analysis of the forms of capitals' contribution to the responses to climate variability (Table 4). The most significant variables are *Access to public utilities and productive infrastructure* and *Use of money and income to adapt*. Though these two variables are components of physical and economic capitals, respectively, households and the communities have neither control nor access to these types of capital. Because of lacking control and access, these elements are unavailable, hence their perceived absence of usefulness. It is also worth considering that non-climatic factors may take precedence over the climatic ones, whereby the forms of capital that are used or consumed in addressing those events are perceived as more urgent and immediate. For example, income (economic capital) is used for health issues or fixing the house. However, in our probit model, most of the significant variables that contribute in the responses to climatic variability are in the economic, physical, and social capitals (Table 4). The implication of this finding is that farmers' responses to climatic variability may be more robust if economic, physical, and social capitals are improved and do not need to be used for addressing non-climatic events.

Table 4. Estimates from a linear probabilistic model of the contribution of different capitals to responding to climate variability.

Capitals	Variables	Estimate
	Intercept	−0.36 **
Physical	Road conditions	0.15 †
	Access to public utilities and productive infrastructure	0.07 **
Social	Participation in local organizations	0.06 *
	Institutional support	0.06
Economic	Diversity of production	0.01
	Access to credit	0.06
	Use of money and income to adapt	0.16 **
	Saving capacity	0.05
Human	Access to technical assistance	0.18 †
	Educational level	0.10
	Youth participation in production	0.18 †
Cultural	Traditional knowledge for production	0.10
	Traditional knowledge for the conservation of natural resources	0.18
Natural	Soil conservation	0.08 †
	Conservation agreements	0.12
	Forest conservation	0.10
	Water conservation	0.12

Notes: ** indicates significance at $p < 0.01$, * at $p < 0.05$, and † at $p < 0.10$.

4.4. The Resilience Index for Sumapaz Livestock Farmers

The estimates of the resilience index show that the resilience to variability in precipitation and temperature of livestock farmers in Sumapaz draws on the combination of capitals.

The overall amount of the index was 3.20 (Table 5). The capital that contributes most to resilience is economic (0.72), followed by physical (0.58), and finally, social capital (0.50) (Table 5). In contrast, the capitals that contribute the least are cultural, natural, and human: 0.49, 0.49, and 0.42, respectively (Table 5). These results are consistent with the linear regression analysis that found the high significance of the economic, physical, and social capitals for responsive actions against the impacts of climatic variability in the study area.

Table 5. Contribution of Types of Capital and Total Baseline Resilience Index for Communities (BRIC).

Capital	Index
Economic	0.72
Social	0.50
Cultural	0.49
Physical	0.58
Human	0.42
Natural	0.49
Total	3.20

The maximum total possible is 6 as there are 6 capitals (SUB). The estimated total is the sum of the six SUB. The SUB results from adding the normalized value of the variables in each capital. The normalization uses the mini-max formula, where the maximum value of each SUB is 1 and the minimum 0.

There are differences in the resilience index at the municipal level. In the municipality of Pasca, the availability of capital increases resilience (Table 6). Furthermore, Pasca farmers have better physical capital, which translates into better milking infrastructure, stables to shelter cattle, better access roads, and more live fences in the pastures. Additionally, the natural capital is also in better condition, having better soils, water resources, and forests than the municipality of Sibaté (Table 6).

Table 6. Community Resilience Index by Municipality.

Capital	BRIC Pasca	BRIC Sibaté
Economic	0.70	0.74
Social	0.42	0.53
Cultural	0.52	0.62
Physical	0.62	0.49
Human	0.44	0.41
Natural	0.52	0.40
Total	3.22	3.19

Conversely, farmers in Sibaté have better economic and cultural capitals. The former shows through higher income and more capacity to access credit and savings. The indication of better cultural capital is the inherited knowledge that contributes to managing livestock production. The capitals that contribute the least to resilience capacity in Pasca are social, cultural, and human. In Sibaté, however, the least relevant for resilience are mainly human and natural capitals.

Figure 4 shows the two clusters of households formed by their similarities along the two most significant dimensions (DIM—axis of the figure) that explain their values in the resilience index. The two DIMs explain 80% of the variability of 15 variables. In so doing, our analysis reduces the variability of a large number of variables to 2 DIMs. Moreover, the 2 dimensions explain around 50% of the variability of the households' resilience index. Cluster 1 is composed of households with high cultural and natural capitals. These households, for instance, use traditional knowledge in their livestock production and implement practices to conserve the natural resources on their farms (Table 7). Cluster 2 groups households with high economic, cultural, physical, and natural capitals (Table 7). These households have higher income and better productive infrastructure, use traditional knowledge for livestock management, and conserve the natural resources on their farms

(Table 7). The overlap of the clusters represents households that share variables from both clusters (e.g., traditional knowledge). This group of households has all the types of capital analyzed (economic, social, cultural, physical, human, and natural).

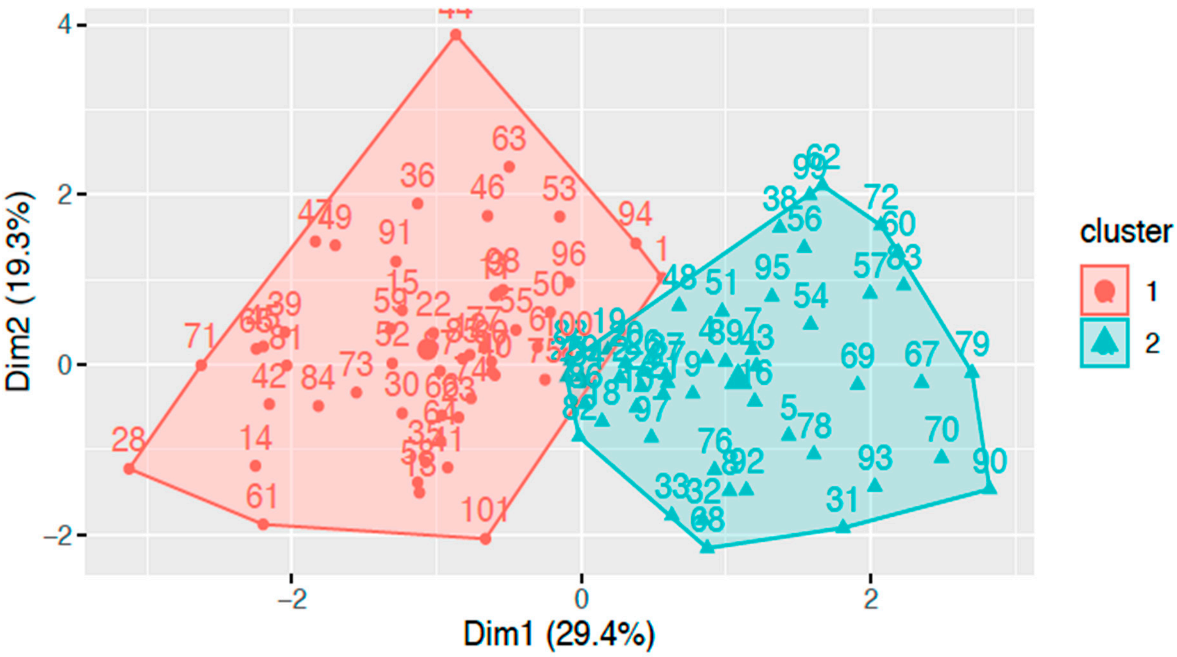

Figure 4. Cluster Analysis of Households' Values in the BRIC.

Table 7. Contribution of Each Capital to the BRIC of the Clusters.

Capital	Cluster 1	Cluster 2
Economic	0.31	0.67
Social	0.45	0.55
Cultural	0.55	0.63
Physical	0.35	0.64
Human	0.33	0.51
Natural	0.66	0.77
Total	2.65	3.76

5. Discussion

The ENSO is one of the major factors influencing the hydroclimatic variability of the Andes [32–34]. The influence is particularly strong in increasing interannual variability in precipitation [35]. However, a systematic analysis of meteorological data (1950–1994) for the Andean region seems inconclusive about whether there is an increasing or decreasing precipitation trend [36]. With this study, we identify increasing variability of precipitation and temperature in the study area. The variability in annual precipitation which causes the alternation of dry and wet years appears associated with occurrences of El Niño and La Niña. The association that we find of El Niño with dry years is consistent with research that reviewed the hydroclimatic variability on the Colombian Andes and identified negative mass balance trends during the dry years [37]. Whether this pattern will continue in future years is unclear because it is uncertain whether ENSO activity will increase, reduce, or remain the same under intensifying climate change [38,39]. Currently, the insufficient understanding of the interactions between ENSO and climate change limits scientists' abilities to generate predictions and projections, which are needed to inform policymakers' adaptation strategies. Similarly, the lack of projections hinders preparatory actions from small farmers about climatic variability and its potential impacts.

Despite the uncertainty of long-term projections of ENSO, its impacts in the short-term may be significant. The alteration in annual and seasonal precipitation and temperature strongly suggests a cumulative, long-term, and large-scale change in climate conditions, which strongly affects *páramos* ecosystems negatively [24,40]. Giráldez and colleagues [41] found that, for the Central Peruvian Andes, El Niño favors a late onset and an early end of the rainy season, whereas La Niña favors an early onset and a late end. Conversely, our findings of a shift, in the April–May rainy season, towards an earlier onset of about two months compared to 2011. The difference in our findings in Colombia with the findings from the Peruvian Andes may reflect the diversity of ENSO, regional heterogeneity, or ENSO's variability within and outside of the Pacific [39].

Irrespective of the drivers of variability, shifts in the rainy season strongly impact livestock producers who are directly dependent on rainfall patterns [42,43]. When and how much precipitation will fall determines the yields and, consequently, household incomes. Further, agrarian calendars are structured around activities marked by rainfall. Irregular calendars require adjustments to preserve access to the household's labor force for agricultural activities. These adjustments directly reduce households' ability to undertake off-farm labor. In turn, less off-farm labor compromises livelihood diversification and the household's income, which are fundamental for adaptation to climate change [42,44].

In addition to having the labor force to implement responses to impacts of climate, livestock farmers rely on different types of capital to enable the implementation of adaptive strategies [42,45]. In our study area, livestock farmers use a series of adaptive strategies that include moving the animals to different pastures, buying inputs and grass, and building infrastructure. These responses are consistent with the findings of scholarly work on the adaptive responses of Colombian farmers [46,47]. We found that social, cultural, and economic capital supports most of the responses to the increased variability in precipitation and temperature. Scholarship on climatic changes in the Andes has also found that cultural and social capital underlie adaptive farming practices [48,49]. Similarly social capital allows institutional arrangements among households within the community to expand physical capital (i.e., canals) to irrigate wetlands [50,51]. In general, research shows that social capital enables institutional governance for addressing climate risks [52,53]. While adaptive responses are critical to addressing the impacts of climatic variability, identifying what types of capital are allowing these responses may help policymakers to strengthen and improve resources critical for adaptation.

Policies strengthening different forms of capital may have longer lasting positive impacts on households' and communities' resilience. For instance, rural development programs may improve economic capital by increasing households' access to markets or income. Similarly, extension services may strengthen cultural capital by including local knowledge. Furthermore, community-based management of protected areas may contribute to maintaining natural capital without alienating local communities.

Though this study identified types of capital that supported farmers' responses, farmers generally felt that their capitals were not useful for responding to climate variability. This discrepancy between researchers' findings and farmers' perception may indicate researchers' over attribution to forms of capital a foundational role in adaptive responses. The discrepancy may also be partly explained by the fact that households use their resources to respond to multiple stressors, including non-climatic ones, some of which have more immediate impacts such as poverty. The implication of this is that climatic variability is not always the most urgent event affecting farmers; a concern researchers should consider as they develop research agendas narrowly focused on climatic change and variability. However, it confirms the importance of forms of capital for the responses of households and communities exposed to any kind of disturbance.

This is not the first study to note that farmers are often experiencing multiple exposures at once and that these exposures have compounding impacts on their livelihoods [54–58]. Specifically, for the Colombian case, Feola et al. found that farmers are simultaneously exposed to the impacts of climate change, trade liberalization, and violent conflict, while

Guáqueta-Solórzano et al. identified vulnerability to non-climatic factors such as deforestation and outmigration. Despite this work, research on interconnections among multiple stressors is still insufficient. We contribute to narrowing this gap by showing how non-climatic and climatic stressors operate, and the 'subtracting effect'—households' responses to some stressors entail using capitals that may become unavailable for future responses [59]. For example, economic capital spent addressing one stressor will then not be available in the future, and even giving and receiving help—i.e., reciprocity—may have limits under sustained challenging times. In sum, households' responses needed to address multiple stressors compete for limited capital, whereby implementing an urgent response now, may hinder implementing a future important one.

There is much potential explanatory power in the analysis of both the interactions among types of capital in households responding to the stressors and how the interplay of multiple stressors impact households and communities [54,60,61]. Future research may analyze how the types of capital available shape the degree and location of households' responses to stressors in diverse climatic, socioeconomic, and geographic conditions. The goal of such research would be to simultaneously improve farmers' wellbeing, ecosystems' conservation, and resilience to climatic variability.

6. Conclusions

Small scale livestock farmers in Colombia perceive the recent variability of precipitation and temperature associated with climatic changes and respond to their impacts. These responses are chiefly farming practices that use economic (e.g., buying grass and inputs, selling cattle, and diversifying livelihoods) and cultural capital (e.g., knowledge of watering areas, and springs). However, farmers also use capitals to address non-climatic stressors such as health, poor housing conditions, and productive infrastructure. In doing so, they highlight the importance of understanding and tackling pre-existing non-climatic vulnerabilities. The limited use of capitals for addressing the impacts of climatic variability, nevertheless, confirms that these communities have capitals to be expanded; policies can improve roads (i.e., built capital) and alleviate poverty (i.e., economic capital), for example. The resilience index and linear regression show that community resilience is based upon the combination of capitals. As may be expected, economic capital is the major contributor to the index and the most statistically significant variable as well.

The rapidly accentuating climatic variability enhances the relevance of our results of analyzing small livestock farmers' responses to the impacts of climate variability in a high Andean ecosystem (*páramo*). Intensifying shifts in precipitation and temperature will affect the most marginal groups such as those living in the Sumapaz-Cruz Verde *páramo*. Furthermore, identifying the types of capital that underpin farmers' responses may inform policies to expand the most impactful capitals on efficient and sustainable adaptation and resilience.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13040499/s1, File S1: Household Survey.

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