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Encounters Between Experiences and Measurements: The Role of Local Knowledge in Climate Change Research

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Innovative approaches could enhance scientific insights into how climate change affects mountain ecosystems and livelihoods and enrich climate action. Using an inter- and transdisciplinary approach in a remote tropical dry forest region of the Andes in southern Ecuador, this article combines local knowledge about climate change and adaptation, based on perceptions and experiences, with quantitative climate measurements. Our theoretical framework is based on the concept of vulnerability and sustainable livelihoods perspectives. Methodologically, we draw on the Participatory Rural Appraisal approach. Participatory workshops and qualitative interviews were carried out in the canton of Macará between 2015 and 2017. Local and regional climate data series were analyzed for climate trends and extreme events. Our study improves understanding of the social and physical dimension of climate change. Especially in mountain areas, differing scales of climate data must be considered to capture local climate conditions and changes. Thus, local knowledge could make a major contribution to selecting representative climate datasets, estimating local impacts of climate change, and developing adaptation policies.

Keywords: *Climatic changes; climate adaptation; local/regional climate data analysis; participatory approach; rural livelihoods; context vulnerability; Ecuador; Andes.*

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Introduction

Climate change, specifically its impacts on socio–ecological systems and ways to address it, is a major concern in academic and political debates (IPCC 2014a; UN 2017; IPBES 2018). Social dimensions of climate change are increasingly considered in climate change research (Mearns and Norton 2010), altering understanding of climate change: as a scientific issue that requires a better understanding of key biophysical processes and impacts, but also as a human-security issue that requires understanding of differential capacities of people to respond to changing conditions (O'Brien et al 2007). One central concept from natural and social science perspectives is vulnerability (Miller et al 2010). Among many conceptualizations, two major interpretations can be identified: *outcome vulnerability* as a linear result of projected impacts of climate change on a particular exposure unit (biophysical or social), offset by adaptation measures, and *context vulnerability* based on a processual and multidimensional view of climate–society interactions (O'Brien et al 2007; Paul 2013). In the latter, vulnerability is seen as a current inability to cope with changing climatic conditions, where "climate variability and change are considered to occur in the context of political, institutional, economic, and social structures and changes, which interact dynamically with contextual conditions associated with a particular 'exposure unit'" (O'Brien et al 2007: 76).

Effective responses to climate change require inter- and transdisciplinary research that fosters knowledge transfer and the development of novel methodological approaches. These should account for the hybrid character of climate change across temporal and spatial scales (Crate 2011; Reyes-García 2016; López et al 2017). Initially, the framing of climate change was rooted in the natural sciences (Bjurström and Polk 2011), and "early approaches to adaptation took a 'top-down' perspective moving from global climate model scenarios to sectoral impact studies and then to assessments of adaptation options" (van Aalst et al 2008: 165). Top-down scenario-driven approaches in climate change adaptation fail to consider local particularities, and thus growing dissatisfaction has resulted in a call for bottom-up approaches to include the existing knowledge and adaptation initiatives of local stakeholders right from the beginning (Eakin and Luers 2006; van Aalst et al 2008; Gidley et al 2009; Bizikova et al 2014). Consequently, debate is ongoing about linking local and scientific knowledge from natural and social sciences in climate research. López et al (2017: 31) suggest using a "hybrid epistemology" that is "an assemblage of science-based rationalities and experiential and intuition-based knowledge. Both inter- and transdisciplinary research imply a collaborative knowledge production process between different disciplines; transdisciplinarity additionally aims to involve multiple nonacademic participants (for a detailed description of the conceptual distinction in sustainability research see Stock and Burton 2011). With growing interest in knowledge coproduction many case studies focus on local peoples' observations of changes, of impacts on biophysical and social systems, and of their adaptation initiatives (eg Postigo et al 2012; Lebel 2013; Reyes-García et al 2016). A systematic, quantitative analysis of literature on the contribution of local knowledge to climate change research by Reyes-García et al (2016) shows regional foci in sub-Saharan Africa, the Himalayan range, polar regions, and, to a lesser extent, Southeast Asia. In Latin America, case studies have been conducted, for instance, in Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Nicaragua, and Peru (eg Lagos 2007; Kronik and Verner 2010; Boillat and Berkes 2013; Aldunce et al 2017; López et al 2017; Paerregaard 2018). Nonetheless, Reyes-García et al (2016) identified weaknesses due to a lack of primary data, incipient methodological development, and unbalanced geographical extent. This is especially true for mountain areas, where local climate data are sparse (Xu and Grumbine 2014) and climate change poses a significant threat to rural livelihoods. Rural populations depend on locally accessible natural resources for their livelihoods; however, they are often not considered in decision-making due to, for example, isolation, inaccessibility, and relative poverty (UNEP 2016; Poudel et al 2017). Despite several studies on issues such as perceptions of climate change, adaptation, and policy implications undertaken in Asia (Ingty 2017; Barrett and Bosack 2018), Africa (Hameso 2017; Mkonda and He 2017), and Latin America (Postigo et al 2012; Vidaurre de Mulczyk 2016; López et al 2017; Weber-Alvarez 2017; Paerregaard 2018), there is still little evidence of the value added by integrative approaches in mountain areas (McDowell and Koppes 2017). The Tropical Andes are highly vulnerable to climate change (Malcolm et al 2006; Peters et al. 2013) and will experience the most drastic impacts in South America (UNEP 2016; Palomo 2017). Thus further locally specific information is needed for climate action and sustainable mountain development.

This study aims to combine local knowledge about climate change and adaptation with quantitative climate data by means of a place-based study in a remote tropical dry forest region in the Andes of South Ecuador. It addresses the following research questions:

- Which climatic changes are observed by local people and to what extent do they coincide with local and regional climate measurement series?
- How do local people experience the impacts of climate change, and what coping practices and strategies have they developed?
- What relevance do local inhabitants ascribe to climatic conditions in relation to their agricultural production and rural livelihoods?

We adopt a socio–ecological perspective and apply a new inter- and transdisciplinary mixed-methods approach to elucidate the human and physical dimensions of climate change. We address climate change as a multiscale process and focus on the social meanings that local actors ascribe to climate change, as well as to underlying causes of vulnerability.

Study area and research sites

Fieldwork was conducted in the Ecuadorian canton of Macará (4°23′S, 79°57′W) in three administrative units, the so-called rural *parroquias* (subdivision of the canton) of La Victoria with 1557 inhabitants, Larama with 1080, and Sabiango with 651 (INEC 2010) (Figure 1). All areas are located on the western escarpment of the Andes between 590 and 2611 masl. The natural ecosystem is a semideciduous tropical dry forest, which provides vital ecosystem services to the rural population (Aguirre et al 2006; Pucha-Cofrep et al 2015).

The regional precipitation regime shows only one rainy season, typically lasting from January to the end of April (Figure 1). Local annual precipitation varies widely from year to year (Sabiango: $SD = 125.6$). Temperature shows little variability, with an annual mean of 22.3°C (Era-Interim dataset: $SD = 0.2$). The western escarpment of the Ecuadorian Andes is affected by the El Niño-Southern Oscillation (ENSO) phenomenon with heavy rain events during El Niño periods and droughts during La Niña phases (Morán-Tejeda et al 2016).

Historically, high outmigration occurred during the droughts of the 1960s, causing 40–70% of the local population to abandon the canton of Macará between 1964 and 1968 (Temme 1972: 337). There is still a negative migration balance within the study area, and 2029 persons left the area between 2005 and 2010 (INEC 2010). Despite the unfavorable rainfall conditions of high seasonality, annual variations, and risk of extreme events, small-scale agriculture for subsistence, and sometimes sale at local markets, is the most important source of livelihood (Aguirre et al 2015; GAD Macará 2015).

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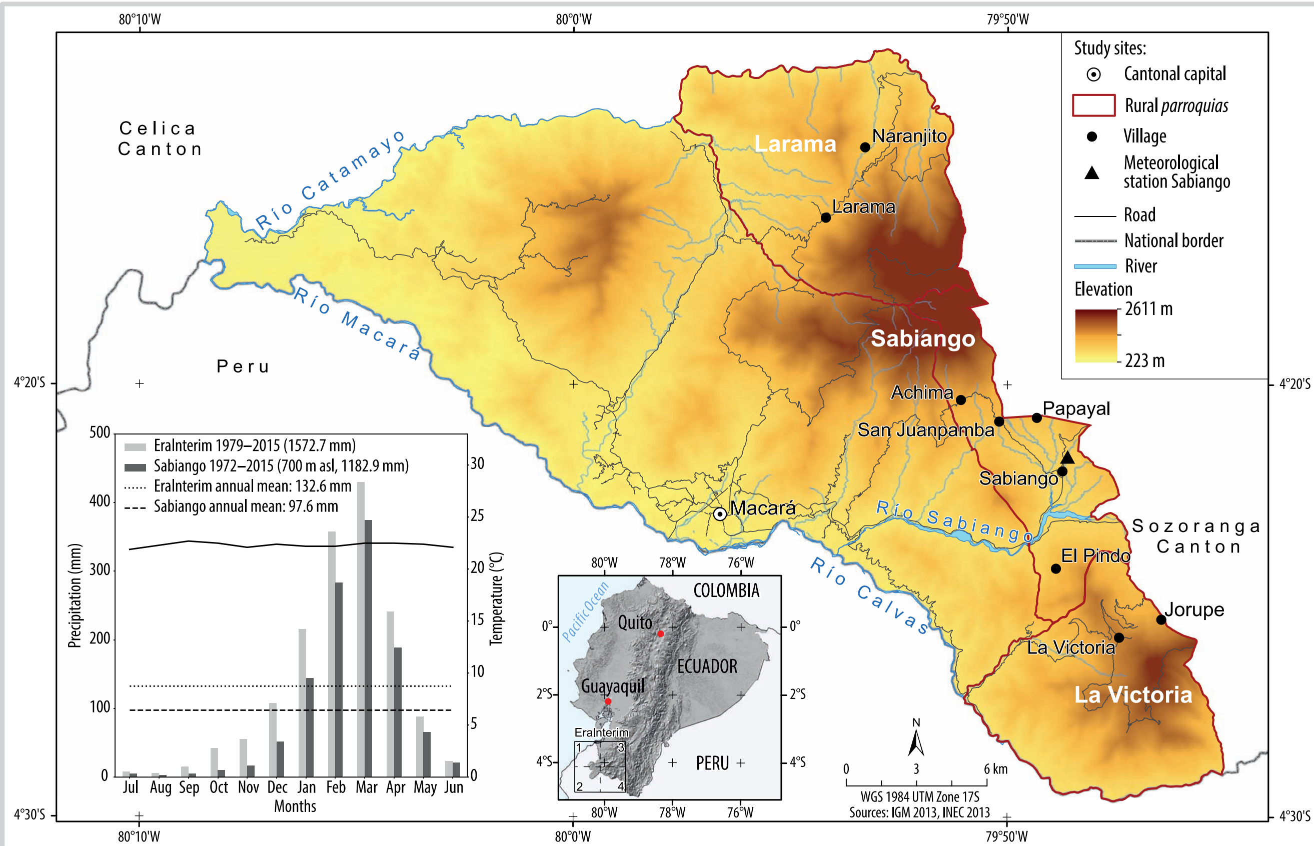
FIGURE 1 Canton of Macará and climate diagram (map by Viviana Buitrón). Climate data taken from INAMHI (2015) and Era-Interim (Dee et al 2011).



Material and methods

For this place-based study, we used a mixed-methods approach (Bazeley 2009; Elwood 2010; Plano Clark and Ivankova 2017) to understand the human and physical dimensions of climate change. To elucidate local conceptualizations of climate change and adaptation, we drew on the Participatory Rural Appraisal (PRA) approach, which presumes that people construct social meanings and that every individual, regardless of education and status, is capable of research, analysis, and planning (Beazley and Ennew 2014). PRA offers a variety of tools for involving local actors as research partners in the knowledge-production process (Chambers 1994; Kumar 2007). This allows local experiences with climate change and ascribed meanings to be unfolded through local actors' own forms of expression. To address the physical perspective of climate change, we analyzed data from different climate measurement series for trends and extreme events on local and regional scales.

Collection and analysis of data from local knowledge

Empirical data were collected during three 6-week campaigns between 2015 and 2017. Thematic foci included, inter alia, climate change, land use, natural resources, population development, and rural livelihoods. On site, two Ecuadorian field assistants were hired (gender balanced) and trained as co-investigators (von Unger 2014). As shown in Table 1, fieldwork encompassed various methods and data collection tools to include different local stakeholders.

To follow the local organizational structures, we first conducted semistructured interviews with local authorities (M1) as key informants, because of their administrative functions in the study area (purposive sampling, Bernard 2006: 189–191). Two participatory workshops (M2, M4) were then organized in collaboration with the local authorities (M1) who officially invited local people to participate. Thus, local people voluntarily attended and contributed to our research. Together with the participants of M1 and M2, the study sites for the household interviews (M3) were selected to gain perspectives from both remote and main villages of the *parroquias*. As we were interested in in-depth life stories (M3), we used purposive sampling for household selection (Bernard 2006: 189–191), based on fieldwork experience and data outputs of M1, M2, and M4.

TABLE 1 Methods applied during fieldwork between 2015 and 2017.

Type, sample size, duration	Respondents/ participants	Tools applied[a]	Data documentation
Method 1 (M1): 4 expert interviews, 2–3 hours	Local authorities (canton: mayor; rural *parroquias*: presidents)	Semistructured interview	Audio recording
Method 2 (M2): 3 participatory workshops (total participants: $n = 53$), 3–4 hours	Members of farmers' associations	Social mapping, timelines, matrix ranking, and scoring	Audio recording, photo documentation, digital summaries according to PRA tools
Method 3 (M3): 9 household interviews, 3–4 hours	Person who considered him- or herself head of household and other members encountered	Life-story interview, timelines, cause–effect diagrams, network diagrams, matrix ranking and scoring, resource mapping	Audio recording, inventories, photo documentation, digital summaries according to PRA tools
Method 4 (M4): 2 participatory workshops (total participants: $n = 13$), 3–4 hours	Focus groups of local smallholders	Seasonal calendars, matrix ranking and scoring, SWOT-analysis[b]	Audio recording, photo documentation, digital summaries according to PRA tools

[a] Sources: Atkinson 2002; Kumar 2007; Jackson and Russel 2010; Beazley and Ennew 2014; Lloyd-Evans 2014; Willis 2014.
[b] SWOT stands for strengths, weaknesses, opportunities, and threats analysis, where participants reflect on their own situation (McCall and Peters-Guarin 2011).

After each participatory workshop, we drew up memorandums and summaries, based on the documented data material (Table 1). For data processing of the interviews, we used literal transcription and open, axial, and selective coding (Strauss and Corbin 1990; Bernard 2006). To analyze the output of textual and visual data, we organized data according to our research questions. Finally, outputs and quotes were translated from Spanish to English to avoid bias in the coding and analysis processes.

Data analysis of climate measurement series

Precipitation in the Andes of South Ecuador is highly variable in time and space (Peters 2016a) and few long-term series of meteorological measurements are available (Peters et al. 2013). Only the Instituto Nacional de Meteorología e Hidrología (INAMHI) station "Sabiango" (InaSab, 700 masl), located at the center of our study area (Figure 1), has provided continuous precipitation data since 1972 (INAMHI 2015). The lack of ground-based weather station data is a problem in many tropical regions, such as South America, Central Africa, Indo-Malaysia, and, in part, Australia (Peters 2016b). Consequently, other options must be considered to close the gaps. Based on the regional character of the multisited observations of local stakeholders in the study area, we selected the reanalysis dataset Era-Interim (Era-Int) from the European Centre for Medium-Range Weather Forecasts (Dee et al 2011), which has high spatial and temporal resolutions.

In the Era-Int dataset, temperature and precipitation are computed from four regular $0.75° \times 0.75°$ grid cells for a $1.5° \times 1.5°$ area that includes the rural *parroquias* of La Victoria, Larama, and Sabiango (Figure 1). The conformity of both datasets was tested using a Pearson correlation test: correlation coefficient $R = 0.86$ and P value < 0.01. Era-Interim data are calculated on a regional scale and might not fully reflect local precipitation patterns in mountainous areas (Gao et al. 2013; Posada-Marín et al. 2018). Combining these data with in situ measurements places local weather in a regional context, especially in regions with few meteorological observations (Peters 2016b).

The duration of the rainy season was calculated using long-term means and the number of heavy rain events is based on the monthly 95 percentile. We also conducted long-term and monthly linear trend analysis (Pruscha 2013).

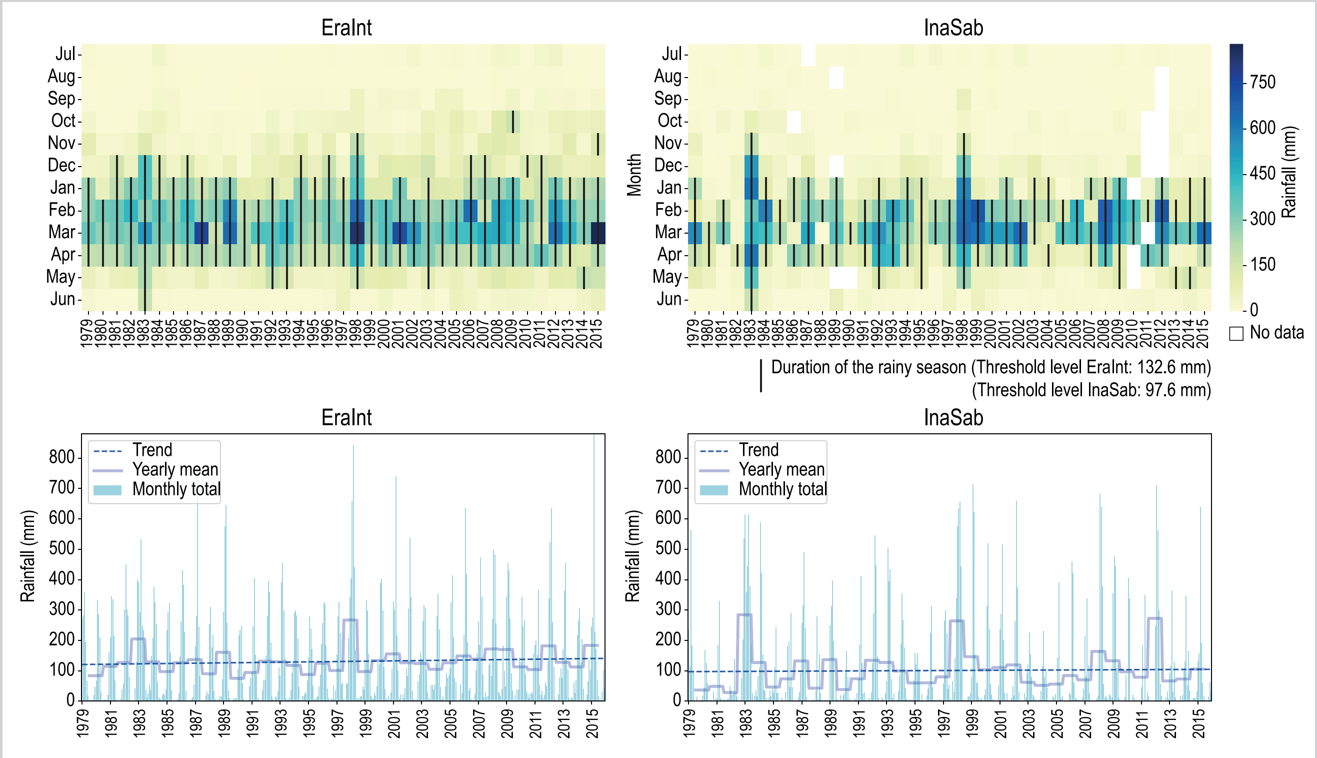
Results

Observed and recorded climatic changes

Participants (M1, M2, M3, M4) reported an increase in temperature and higher daily thermal amplitudes. High variation of the start of the rainy season was also observed, with a shift from the end (October–December) to the beginning of the year (January–February) as well as a foreshortening of the season. According to their statements, rainfall amounts and heavy rain events during the rainy seasons increased, and severe droughts during the dry seasons decreased.

Here, we are affected by both [heavy rainfall and dry periods]. In the past, about 38 years ago, the summer [dry periods] affected us more,

FIGURE 2 Monthly rainfall amounts and long-term trends of Era-Int and InaSab data. (Data source: INAMHI 2015, Dee et al 2011)



but now it's the rainfall. It's raining too heavily and the temperatures are crazy, even the animals get sick because of the strong heat. . . . Now the sun is too hot.

(*respondent HLV1b, M3 2016*)

In the past the rains [rainy seasons] were fixed, . . . the seasons have changed a lot. [In the past,] already in October, there were the drizzling rains; we started to prepare the fields in November and the winter [rainy season] came in December. Now sometimes it's coming in February.

(*respondent HS2, M3 2016*)

Since the local stakeholders considered the seasonal rainfall patterns and extreme events to have the greatest effect on rural livelihoods, we focus on these in the climate data analysis. Figure 2 shows that the monthly duration of the rainy season clearly varies from year to year (Era-Int: SD = 1.1 InaSab: SD = 1.5). The longest wet seasons and the highest annual precipitation amounts were observed in 1982–1983 and 1997–1998 during two strong El Niño events, whereas the rainy seasons were shorter in the early 1980s, 1990s, and 2000s. Although no long-term trend for a shortening or lengthening of the rainy season is recognizable for either dataset (*Supplemental material*, Figure S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-18-00063.1.S1), rainfall seems to have increased slightly since 1979, although this change is not significant (Figure 2).

Figure 3 shows monthly rainfall and the number of heavy rain events (1979–2015). Although the Era-Int dataset depicts slight increases in precipitation since 1979 in July and August, from April to June, and even stronger increases from September to November, the InaSab dataset shows opposite. Both datasets show negative trends for December and January, while there is a clear increase in amount of precipitation amounts for February and March from 1979–2015. The InaSab trends explicitly correspond to the local stakeholders' observations. They described changes in the beginning and duration of the seasons with a shift from the end to the beginning of the year and a foreshortening of the rainy seasons with a decline in precipitation in October, November, December, May, and June. However, this does not hold true for the Era-Int dataset, which shows different trends in the transition periods and in heavy rain events (Figure 3). The number of heavy rainfall events decreased slightly from May to October according to the InaSab dataset, becoming more pronounced for November, December, and April. For the Era-Int dataset, heavy rainfall events were distinctive, with a clear increase in all months except for February from 1979–2015. Again, the trends of the InaSab dataset are particularly in line with local stakeholders' observations of increasing numbers of heavy rain events in the middle of the rainy season.

FIGURE 3 Monthly precipitation trends of Era-Int and InaSab data and number of heavy rain events per month. (Data source: INAMHI 2015, Dee et al 2011)

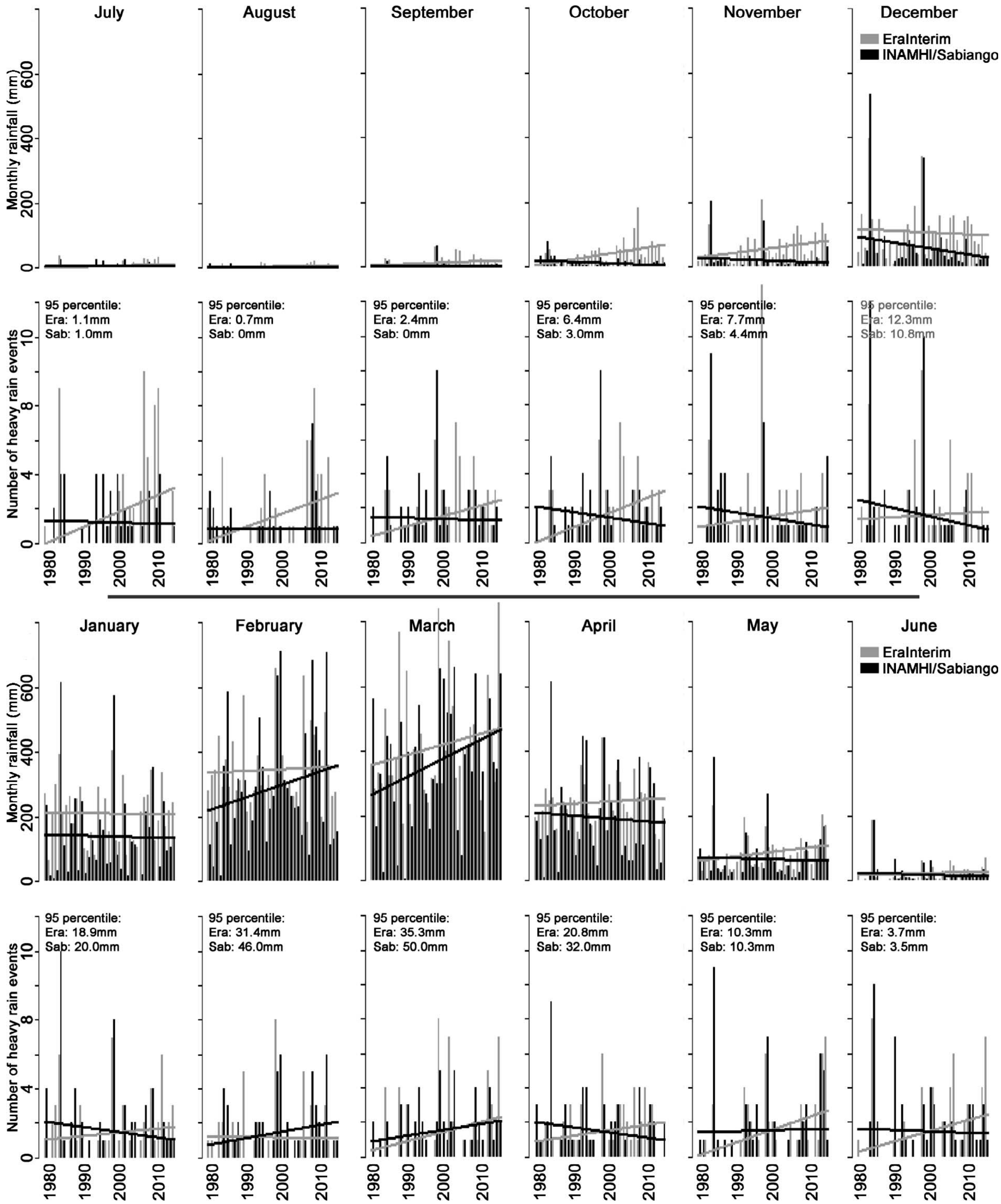


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TABLE 2 Observed climatic changes, extreme events, and stated impacts (Data source: M1, M2, M3, M4 2015–2017).

Observed climatic changes	Stated impacts of climatic changes
Higher variability of seasons: Beginning of the rainy season	Lack of predictability of beginning of the seasons due to higher variation in indicators, such as flowering periods of trees and (dis)appearance of species; reduces planning capability and increases insecurity in agricultural production, seed damage, and crop failures
Foreshortening of the rainy seasons	Foreshortening of growing period, lower output from rain-fed agriculture, shorter period of water availability in rivers/creeks (for irrigation and water system), creeks dry out by the end of dry seasons
Increased amount of rainwater in rainy seasons	Depending on intensity: rising water levels in rivers/creeks, higher agricultural productivity or crop failures, worse water quality for consumption due to sedimentation, collapse of the water system, increase in pests and diseases affecting crops, animals and humans, increased leaf canopy density in TDF[a]
Increase of heavy rain events in rainy seasons	Massive rise in water levels of rivers/creeks, rivers busting their banks, floods (especially in lower altitudes), mass movements (especially on steep slopes), destruction of infrastructure (houses, streets, bridges, water system), areas cut off, danger to life, seed damage, crop failures, prevention of arable farming
Decrease of heavy droughts in dry seasons	Depending on duration: dried out rivers/creeks with gradual decrease in water availability at higher altitudes, water scarcity for agriculture and consumption, damage to seeds, crop failures, prevention of arable farming, and, in the worst case, livestock production, soil is unprotected (TDF)[a)]
Increase in temperatures	Increases in pests and diseases affecting crops, animals, and humans, crop failures when plants dry out, poorer animal health

[a)] TDF, tropical dry forest.

Local impacts and responses to climatic changes

During the workshops and interviews (M1, M2, M3, M4), participants reported many impacts of the observed climatic changes and extreme events (Table 2).

Concerning changing rainfall patterns, local stakeholders stated that variability in seasons, rainfall duration, and intensity affected rural livelihoods:

> *Here we abide by the two seasons, summer [dry season] and winter [rainy season]. … In the past, nature was wise and showed us when the seasons began. Now it isn't like that anymore, the indicators, like flowering of trees or the appearance and disappearance of certain animals, aren't working.*
>
> (*resp. E1, M1 2016*

> *It's not raining like it used to, when a lot of water remained in the creeks. … Now … there isn't much water left; in the past, the summer [dry season] came and they [the creeks] didn't dry out.*
>
> (*resp. E4, M1 2015*)

> *The winter should be regular because more humidity infiltrates [the ground] and heavy rainfall only washes everything away, leading to a collapse of the water supply system and sedimentation.*
>
> (*resp. E1, M1 2016*)

When talking about practices to cope with climatic changes and adaptation strategies, the local stakeholders (M1, M2, M3, M4) particularly focused on extreme climatic events (Table 3).

Coping practices are mediated intergenerationally by means of oral histories. It is, therefore, essential to consider local knowledge in the context of the period. Impressive examples are the drought in the 1960s (Temme 1972: 337) and the heavy rainfall during the 1982–1983 El Niño:

> *The drought [1960s] was the whole reason people left the area. … It was very sad, trucks fully laden with people left the area and they never came back, … because here living is hard, there is no water. … But I stayed here, I had already married and I had nothing, that's why I couldn't leave. … We were six families who stayed here. … There was no water left … we couldn't plant anything and our animals died of hunger. That's why we went to the river of Catamayo to pan gold. … We sold it in Macará [city] … and bought food until the rain came back. We took water from wells hand-dug in the creek beds. Further up there was a creek and we brought the water with hoses. … There would not have been enough [water] for more than six families.*
>
> (*resp. E2, M1 2015*)

The same respondent also describes the situation during the heavy rainfalls as a result of the El Niño phenomenon in 1982–1983:

> *It started in November and ended in August the following year. Nothing was left, the whole seeding was lost. Although there was pasture for the animals, the people didn't have anything to cultivate. We went to the river again to pan gold, he [the river] was the father of our survival, and everyone went to the river.*
>
> (*resp. E2, M1 2015*)

During the 1960s drought, whole families or family members (especially young men) left the area, mainly to find new properties in more productive agricultural areas,

TABLE 3 Practices to cope with extreme events.[a)]

Practices	Drought	Heavy rainfall
Income generation		
Saving money	X	X
Paid labor (eg daily wage) in situ and ex situ[b)]	X	X
Artisanal gold panning in the Catamayo River	X	X
Agricultural production		
Moving to higher and more humid altitudes	X	
Giving up arable farming	X	X
Giving up cattle breeding	X	
Small animal breeding[c)]	X	X
Storage of agricultural products and seeds	X	X
Water supply		
Water use only for personal consumption	X	
Using hoses to transport water from higher altitudes	X	
Hand-dug wells in creek beds	X	
Alimentation		
Eating more animal products	X	
Buying food at local markets	X	X
Bartering and sharing products	X	X
Preparation of simple traditional food	X	X
Reduction in number and size of daily meals	X	
Infrastructure		
Digging trenches around the houses as protection against water and mass movements		X
Searching for/using other paths		X
Municipality of the canton of Macará: Designation of risk areas, stricter regulations for construction, development of emergency procedures, reconstruction work		X

a) Data sources: M1, M2, M3, M4 2015–2017.
b) Paid labor is related to human mobility (permanent or temporary migrations).
c) Small animal breeding is practiced the whole year to complement farming activities and alleviate possible crop failures; it is also practiced during droughts, if possible.

such as the Amazon region, or to work on the plantations of the coastal areas (M1, M2, M3, see also Temme 1972). According to the participants, people who left during the drought never came back. Nevertheless, the people who stayed developed practices to adapt to the harsh conditions (Table 3). During heavy rainfall events in the 1980s, people also searched for paid labor to bridge losses in agriculture, but outmigration to live in other areas was not stated as a common strategy. The historical analysis of human (im)mobilities in the study area from the 1960s until 2017, based on M1, M2, and M3, shows various mobility processes and patterns. Historically, outmigration predominated with changing patterns (domestic rural–rural, rural–external, domestic rural–urban). Recently, mobility processes have become more diverse and complex due to translocal and/or transnational networks, including, for example, return migration. Both types of extreme climatic events affected practices regarding income generation, agricultural production, and alimentation. Droughts, in particular, have led to practices to ensure a water supply for consumption, while heavy rainfall prompts maintenance of infrastructure.

Agricultural production and rural livelihoods in the context of climate change

Our dialogue partners often commented that the main livelihood in the study area is agricultural production (for subsistence and sometimes sale); rainfall patterns are, therefore, crucial, and extreme climatic events could have severe impacts. The seasonal calendars elaborated during the participatory workshops (M4) are a well-established tool to depict livelihood activities over the year. According to the participants (M1, M2, M3, M4) and in line with the seasonal calendar for Sabiango elaborated in June 2017 (Figure 4) and our participants (M1, M2, M3, M4), water availability, which is naturally limited due to strong rainfall seasonality, is the main climate issue for smallholders.

Farmers mainly practice rainfed agriculture, and so their activities follow rainfall patterns, such as seeding at the beginning and harvesting shortly after the rainy season. The most important agricultural product named is maize; hybrid species are used for sale and local varieties for personal consumption. For the latter, hoses are used to transport water from creeks during the dry season.

Livestock production is practiced throughout the whole year, principally for subsistence, and only a few animals or animal products are sold sporadically. Small animal breeding complements farming activities, particularly during the dry season and to alleviate crop failures. Rural livelihoods are also affected by pests and diseases, as well as the declining water quality for consumption due to sedimentation, during the rainy seasons.

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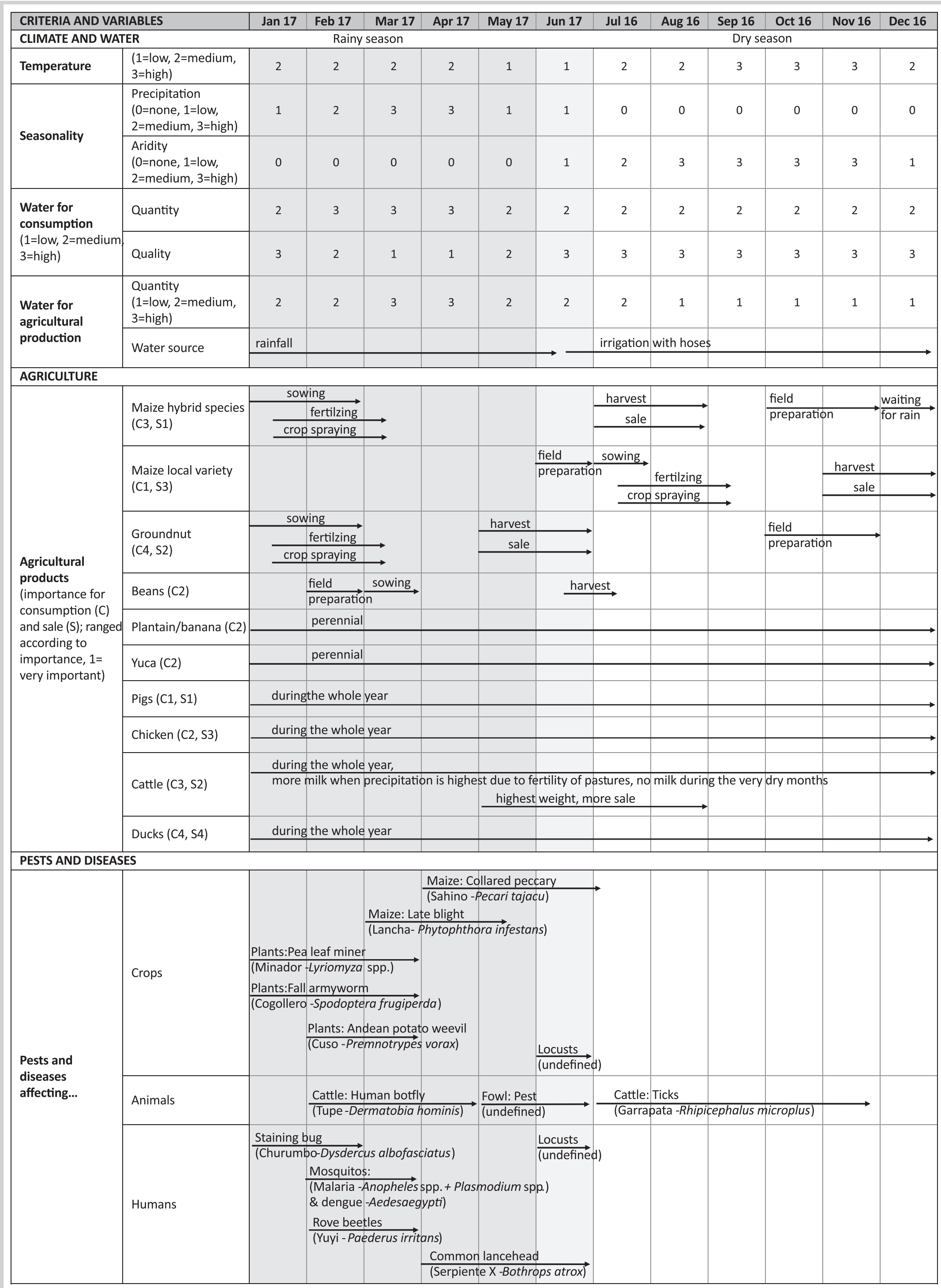
FIGURE 4 Seasonal calendar (July 2016 to June 2017) elaborated by local smallholders depicting the climatic conditions in Sabiango and interrelated issues of concern. (Data source: M4 2017 Sabiango)



Since climate change is deeply entwined in daily life, it is impossible to separate climatic changes from the complex livelihood contexts.

In the past … the crops were more natural and now it's more chemical and there is more expenditure. When the winter [rainy season] is too rainy, the farmer loses a lot. … Therefore, that season is more critical than in the past. For example, … if some people start sowing … in January and it is raining too much, it is an enormous

FIGURE 5 Stated issues of local stakeholders about interrelated conditions and transformations shaping vulnerabilities of rural livelihoods in the context of climate change. (Data sources: M1, M2, M3, M4 2015–2017)

Examples of interrelated topics highlighted by local stakeholders discussing climate change

LIVELIHOODS
- Relevance of agriculture for subsistence and sale
- Unequal access to resources (eg land, water)
- Need for money (eg agriculture, basic services, transportation)
- Lack of income possibilities
- Lack of competitiveness with cheaper Peruvian products and workforce
- Dependency on market prices (eg inputs, maize prices determined by intermediaries)
- Dependency on banks and informal money lenders/debts

AGRICULTURAL PRACTICES
- Increasing use of new varieties (hybrid maize)
- Changing irrigation system (from hand-dug trenches to hoses in order to bring water from higher elevations)
- Increasing agricultural inputs (eg seeds, mineral fertilizers, agrochemicals, materials for irrigation, seasonal Peruvian workers)
- Contamination of water resources has led to the extinction of animal species (eg fishes)

FOREST RESOURCES
- Importance for protection of water resources
- Importance for soil protection
- Only few products used for subsistence
- Implementation of conservation practices by governmental institutions and local population

HUMAN MOBILITY
- High historical and recent outmigration (eg in search for work and higher education)
- Lack of workforce in agriculture
- Less agricultural production
- Landowners living elsewhere (eg land abandonment or transfer to family members)
- Translocal networks (eg financial support)

INFRASTRUCTURE/TECHNICAL EQUIPMENT
Lack of/ poor...
- Water supply system for consumption and agriculture
- Basic services (eg higher education, health care)
- Transport system (eg road connections, public transport)
- Stores for agricultural products
- Local markets for purchase and sale (city of Macará)

GOVERNANCE/ORGANIZATION
- Dependence on local forms of organization (eg land tenure/use, water use, exchange of workforce or products; but inequalities and missing participation)
- Lack of governmental support (eg capacity building, control)
- Governmental programs do not address local problems
- High bureaucratic obstacles in governmental institutions
- Lack of trust in governmental institutions

loss … of own workforce, payments for workers, the agrochemicals, everything is lost. One spends more than one earns.
(*resp. HLV1a, M3 2016*)

When discussing climate and climatic changes with local actors, and how they evaluate and experience their own living conditions (M1, M2, M3, M4), we detected major issues of concern (Figure 5). These reflect broader conditions and transformations shaping vulnerabilities of rural livelihoods in the study area.

Rural people in the area depend on agriculture to meet two basic needs (M1, M2, M3, M4): first, to ensure subsistence based on a variety of products; and, second, to generate financial income, which depends mainly on hybrid maize production. In general, the demand for agricultural inputs, which is dependent on market prices, has increased. Few alternative income possibilities are available, and so farmers usually obtain credit from banks or informal moneylenders at the beginning of the cultivation period to be repaid after harvesting. Intermediaries set the local maize prices at their lowest after harvesting and at their highest during the growth period. Since the prices of Peruvian products are lower, smallholders' products are less competitive in local markets. Participants claimed that they can hardly cover their expenditures and debts make them more vulnerable to climatic changes. In addition, financial income generation has become more important due to increasing household costs (eg electricity, health care, education, transport). Local stakeholders also expressed the importance of site-specific conditions and changes in agricultural practices, forest resources, infrastructure and technical equipment, governance, and organization, as well as human mobility (Figure 5).

Discussion

Addressing our research questions

Climate change observations reported by our participants coincide with the main climate risks underlined in the Tropical Andes (eg Kronik and Verner 2010; IPCC 2014b; Aguirre et al 2015; UNEP 2016). There has been an intense warming trend in Ecuador since the 1960s (Bendix 2004; Peters 2016a), but no homogenous precipitation trends could be found (Urrutia and Vuille 2009; Peters et al 2013; Morán-Tejeda et al 2016). The changes in rainfall patterns described by participants were confirmed by local data from Sabiango climate station only to a small extent by the Era-Interim data. As shown in other case studies in rural settings (eg Below et al 2012; Rankoana 2016; Barrett and Bosak 2018; Paerregaard 2018), our local stakeholders experience impacts of climatic changes and extreme events that concern, for example, agricultural production, infrastructure, and health. However, they have also developed in situ and ex situ strategies to cope with them, for example, alternative means for income generation, adjustments in agricultural production, and alimentation. While internal outmigration to live in other areas was reported during the drought in the 1960s (Temme 1973), it was not stated as a common strategy during heavy rainfall events. Gray (2009) shows that agrarian and environmental conditions particularly influence local mobility and internal migration. The practices listed by participants are gradually adjusted to the severity of extreme events, the impacts on rural livelihood systems, and the coping capacities of the local population. Our dialogue partners consider climatic conditions, such as rainfall patterns, crucial for agricultural production, which is the principal means of livelihood in the study area. Nonetheless, further challenges and ongoing transformations affect their livelihoods (see context of vulnerability below). According to Stadel (2008: 15), "Andean rural livelihoods always had to adapt to new developments, to threats and challenges, as well as to opportunities and alternative potentials."

Merging climate experiences and measurements

Climate perceptions cannot simply be wrong because they are socially constructed, even if they do not correlate to climate data (Meze-Hausken 2004). We consider climate observations to be historically laden experiences of everyday life and lifetimes. Our participants use site-specific indicators to evaluate climatic conditions, and these observations are strongly interconnected with the impacts on rural livelihoods. Thus, local stakeholders may be affected differently depending on site-specific conditions, the severity of trends or events, and their adaptive capacity.

Climate change awareness is influenced by biophysical parameters and livelihood characteristics in which "visual changes tend to be more easily observed compared to less tangible long-term changes" (Barrett and Bosak 2018: 14). When talking about climatic changes, the participants discussed what they consider to be the "normal situation," which may contrast with scientific views (Meze-Hausken 2004). Normal, as well as optimal, rainfall not only refers to quantity, but also to timing, duration, amount, intensity, and region-specific distribution. In our study area, rainfall varies substantially in time and space, as in many other semiarid zones and mountain regions. The analysis of two differently scaled datasets (Era-Int and InaSab) demonstrates that climate trends vary according to the resolution of measurement. Local observations agree with the InaSab dataset for a single measuring point in Sabiango. The Era-Int data calculated for an area of 1.5° × 1.5° shows less agreement. Climate observation sites are often limited to single-point locations in well-populated areas and/or regions that are easy to access (eg coastal areas), and the existing spatial gaps between ground climate monitoring sites are often filled by reanalyzing regional climate data (Peters 2016b). Our findings highlight that different scaling of datasets can produce different results, especially in mountain areas with different climates.

Local people's observations are very useful to indicate appropriate datasets for climatological analysis or supply missing data. We argue that more sophisticated analyses are necessary to understand changes in local rainfall patterns and to compare them with local observations. Timescales, analysis, and threshold levels of climate data should also be considered. While the calculated duration of the seasons based on different monthly precipitation threshold levels was not supported by participants' observations, the analysis of daily time series regarding monthly precipitation amounts was supported.

Since climate change is likely to have economic, social, and environmental repercussions, local knowledge of impacts and adaptation strategies is necessary to develop reliable measures for climate action and sustainable mountain development (Pohle et al 2010). Thus, our findings highlight the need for inter- and transdisciplinary knowledge coproduction by equally considering social and natural sciences, as well as locally situated knowledge in climate change research and action (Stock and Burton 2011; IPCC 2017: 22; López et al 2017). In particular, more "bottom-up" approaches that include local knowledge right from the beginning should be implemented (van Aalst et al 2008).

Examining the context of vulnerability in climate change research

The information about how local stakeholders evaluate and experience their own living situations shows that there are other interrelated social, economic, and ecological challenges (eg rural livelihood characteristics and strategies, agricultural practices, and human mobility) that should be considered within the context of vulnerability to climate change. These insights indicate how impacts of climate change, as well as adaptation capacities and actions, are related to sustainable development in general (IPCC 2017: 4) and to specific regional and local contexts (eg in mountain areas). "The Andes are characterized by a mosaic of niches of sustainability and patchworks of vulnerable spaces, [whereby] a principle objective of agriculture is to cope with ecological, economic and social crisis situations" (Stadel 2008: 20–21). Stadel (2008) and Mathez-Stiefel et al (2017) suggest research priorities for rural livelihoods, agriculture, governance, and sustainable development in the Andes. Local stakeholders' perspectives indicate a need for more research on factors affecting socioeconomic, cultural, and environmental conditions and transformations to comprehend and adequately interpret climate observations (Meze-Hausken 2004; Aldunce et al 2017; Paerregaard 2018).

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There is a need to address vulnerability in climate change research as a phenomenon of climate–society interactions—a phenomenon that is multidimensional, place and context specific, dynamic, and different across scales (O'Brien et al 2007; Roman et al 2011). A promising approach is to unpack and interpret local people's climate observations considering social meanings of climate change and to develop measures for climate action and sustainable mountain development. This is in line with the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (2014a: ix), acknowledging that "risks of climate change unfold in environments with many interacting processes and stressors." Furthermore, our findings support the need for context-specific approaches that consider regional, sectoral, and actor-specific perspectives and incorporate different knowledge sources, indicated by the Scoping Document of IPCC AR6 (2017).

Conclusion

We applied an inter- and transdisciplinary research perspective with a mixed-methods approach, using participatory research tools, qualitative interview techniques, and climate data analysis. This showed that merging different sources of knowledge from social and natural sciences, as well as local stakeholders, is challenging but important to provide reliable results in climate change research and develop measures for climate action. Extended local climate measurements and sophisticated data selection and analysis are particularly needed in areas with high climatological variability, such as mountain areas or semiarid zones.

While data from the local weather station in Sabiango confirmed the precipitation trends described by our participants, Era-Interim data did not capture their observations adequately. Thus, we suggest using local knowledge to select and verify datasets, timescales of records, analysis procedures, and threshold levels. Locally situated climate observations could also bridge knowledge gaps in areas where data are missing.

By focusing on the priorities of local stakeholders, we uncovered the main factors that shape vulnerability of rural livelihoods in our study area. These encompass environmental and socioeconomic conditions and transformations, such as rainfall patterns and seasonality, extreme climatic events, livelihood characteristics and strategies, agricultural production, forest resources, infrastructure and technical equipment, governance, and organization. Since local perspectives are highly influenced by the impacts of climatic changes and extreme events on livelihoods, and local strategies already exist, these experiences should be used to develop adaptation measures and policies. In particular, the role of human mobility in the context of climate change adaptation needs to be further elaborated. Further, climate risks, impacts, and adaptation actions must also be addressed in the wider context of sustainable mountain development.

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Supplemental material

FIGURE S1 Annual duration of the rainy season. (Data source: INAMHI, Era-Interim)

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