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Farmers' Perceptions of and Adaptations to Water Scarcity in Colombian and Venezuelan *Páramos* in the Context of Climate Change

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This study examined how members of 2 water user associations in high-elevation ecosystems in Colombia and Venezuela perceive water scarcity as well as the relationship between their perception of and adaptation to it.

Among study participants, adaptation was guided not only by the perception of climate change (disturbance of the seasons, decrease in precipitation, and more extreme temperatures) but also by the perception of the socioeconomic causes of water scarcity (increase in cultivated area and population, aging irrigation infrastructure, system management problems).

Farmers in the Venezuelan study site have adopted new and more efficient irrigation technologies, restored degraded infrastructure, and undertaken various actions to preserve and conserve wetlands. In the Colombian study site, farmers created a new irrigation system that draws water from a nearby lake, creating access to an abundant resource. The study shows how perceptions of water scarcity in a climate change context are critical determinants of farmers' behavior, especially collective adaptation.

Keywords: Water shortage; high tropical Andes; ecosystem; environmental changes; local knowledge; irrigation agriculture; water user associations; local institutions; adaptive capacity.

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Introduction

The *páramo* is a neotropical alpine grassland ecosystem covering the higher elevations of the northern Andes. It plays a key role in the hydrology of South America (Célleri and Feyen 2009). Almost all river systems in Venezuela, Colombia, Ecuador, and northern Peru originate in the *páramo*. Drinking water, irrigation and hydroelectricity in these countries depend largely on the water regulation capacity of the *páramo* (Buytaert et al 2006).

Like other mountain ecosystems, the *páramo* is sensitive to climate change (Buytaert et al 2011; Anderson et al 2017). In addition to climate change, human activities, including mining, agriculture, livestock grazing, and burning, pose serious risks to its integrity and to the services it provides (Llambí et al 2012; Hofstede et al 2014; Ochoa-Tocachi et al 2016). Local communities, which have practiced intensive irrigated agriculture since the 1960s, are now particularly affected by these environmental changes, especially the increasing water scarcity.

In simple terms, water scarcity can be defined as the extent to which water demand exceeds water availability in a particular time period (Molle and Mollinga 2003; Murtinho et al 2013). It has been described as the result

not only of physical factors, such as reduced rainfall, but also of cognitive, sociocultural, and institutional factors (Aguilera-Klink et al 2000; Mehta 2003; Swyngedouw 2004; Rivière-Honegger and Bravard 2005; Noemdoe et al 2006; Buchs 2012).

The response of societies to water scarcity is now a challenge in all regions of the world, particularly in the context of climate change. Several authors (eg Turton 1999) have argued that a society's adaptive capacity—defined as its capacity to create and respond to variability and change (Adger et al 2005)—determines its water development trajectory. A wide variety of factors have been identified that determine the adaptive capacity of systems, organizations, and individuals. These include economic wealth, technology, natural resources, infrastructure, institutions, social capital, education, and access to external capital, as well as cognitive, perceptual, and social factors (Fankhauser et al 1999; Yohe and Tol 2002; Wisner et al 2004; Eakin and Lemos 2006; Smit and Wandel 2006).

Therefore, it is necessary to analyze the socioenvironmental changes that cause water scarcity in *páramos*. In addition, it is necessary to understand how the changes are perceived and integrated by rural societies: the impacts of these changes, people's vulnerabilities

(propensity or predisposition to be adversely affected—IPCC 2014a) to them, the new opportunities the changes provide, how people adapt to the changes, and what innovations they implement.

A growing body of work indicates that perceived water scarcity is an important factor in determining whether an individual or group is likely to adopt adaptive behavior, particularly in the context of climate change (Murtinho et al 2013; Alam et al 2015; Murtinho 2016; Singh et al 2018). Other studies have highlighted the link between perceptions of climate change and the ability of farmers to develop adaptation strategies for water scarcity, particularly in countries in the global South (Vedwan and Rhoades 2001; Vedwan 2006; Mertz et al 2009; Deressa et al 2011; Anik and Khan 2012; Boillat and Berkes 2013; Banerjee 2015; Smadja et al 2015; Dhanya and Ramachandran 2016; Herrador-Valencia and Paredes 2016; Sujakhu et al 2016; Sutcliffe et al 2016; Poudel and Duex 2017; Su et al 2017).

These studies can help to inform policies that reduce the vulnerability of rural communities. However, most of them focus only on climate change and underestimate other scarcity factors (eg overexploitation of water and governance problems) that shape farmers' adaptation strategies. (Notable exceptions are Kuruppu and Liverman 2011, Murtinho et al 2013, Murtinho 2016, and Singh et al 2018.)

To help fill this gap, this study analyzed perceptions of water scarcity and the ways that water user associations (WUAs) in the *páramo* cope and adapt, taking into account both climatic and nonclimatic factors. The study consisted of a comparative analysis of 2 communities that have conducted intensive irrigation farming for several years and are therefore highly dependent on water resources. While both communities are representative of the intensification of agriculture in Colombian and Venezuelan *páramos*, they also have different climatic, hydrologic, and socioeconomic characteristics. The question investigated was whether these characteristics influence their perceptions and adaptive capacity.

Study sites

The community of Misintá, Venezuela, is located in the High Chama River Valley (Valle Alto del Río Chama), in the administrative district (*municipio*) of Rangel in the province (*estado*) of Merida, at an elevation between 3000 and 3700 m (Figure 1). In 2013, its population was 517. Misintá is located in the dry zone of the High Chama Valley. The annual rainfall is 700 mm; winters are generally rainy, and summers are generally dry (Adressen and Ponte 1973; Smith et al 2007). The only climatic data available are for the High Chama Valley as a whole (Monasterio 1980) (Figure 2). Agriculture in Misintá, as in the rest of the valley, consists primarily of intensively irrigated cultivation of potatoes, carrots, and garlic, and

to a lesser extent, cauliflower and broccoli. Throughout the valley, water is collected from streams (*quebrada*, supplied with water by wetlands, springs and lagoons of the *páramo*) and transported by pipes to reservoirs managed by WUAs.

The community of Hato Laguna, Colombia, is located in the administrative district (*municipio*) of Aquitania, in the province of Sugamuxi in the department of Boyacá, at an elevation between 3000 and 3900 m (Figure 1). In 2013, its population was 535. Hato Laguna's main crop is spring onions; to a lesser extent, potatoes and beans are also grown (DNP 2014). Located on the western shore of Tota Lake, Colombia's highest lake, this watershed is relatively well watered with an average of 1187 mm of precipitation per year (as measured at the climate station La Cintas, the nearest to Hato Laguna). It, too, has dry and wet seasons (IDEAM 2014) (Figure 2). In the municipality of Aquitania, near Lake Tota, water from the lake is abundant to supply private irrigation systems. However, communities farther from the lake or at higher elevations, such as Hato Laguna, where the cultivated and inhabited areas are located up to 300 m above Tota Lake, use water from streams (supplied by wetlands, springs, and *páramo* lagoons) (Raymond 1990; Leroy et al 2018).

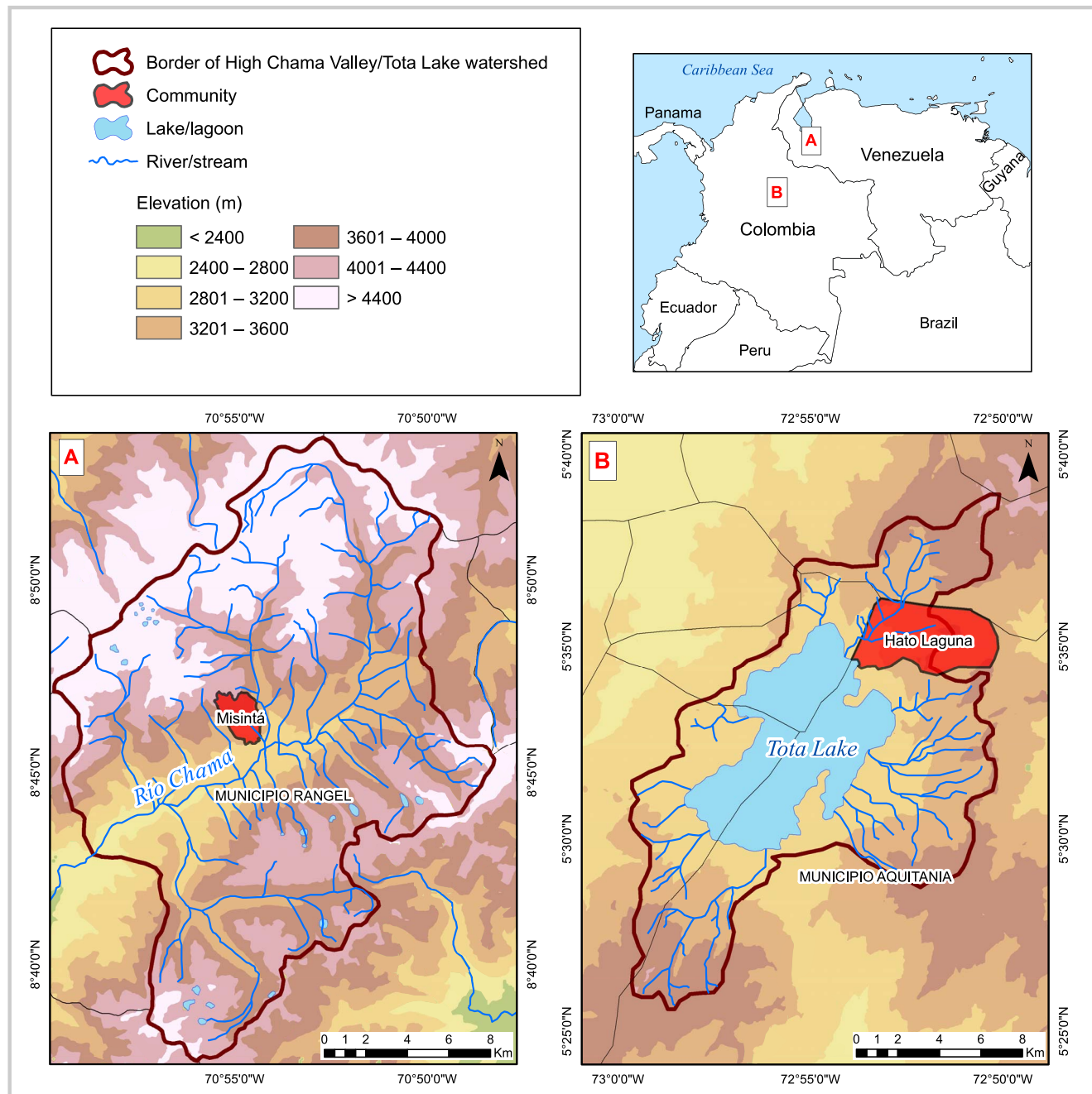
The similarities and differences between these 2 communities are summarized in Table 1. Physically, they are marked by differences in water availability, which is helpful for studying perceptions of water. They also differ in terms of water governance.

Methods

This article is based mainly on interviews with farmers and strategic actors in water, agriculture, and environmental management. Qualitative data were collected between 2013 and 2015 through semistructured interviews with 24 farmers of Misintá, 32 farmers of Hato Laguna, and 17 strategic actors, including representatives of nongovernmental organizations and public agencies and extension agents. Participatory observation was also carried out during water-related activities (eg local public meetings and water distribution and infrastructure maintenance activities).

In each community, I first talked to key members of the WUA (eg president, treasurer, and secretary), who then introduced me to other farmers (age 30 to 90 years old) who were members of the WUA. The interviews with farmers involved open-ended questions about water governance and perceptions of and vulnerability to water scarcity. Irrigators were asked about water use strategies, farmland, land under irrigation, variability in yields, the causes of this variability, and if they had experienced water scarcity. If farmers did not spontaneously mention the topic, I asked the following questions to elicit their views of climate change and its impacts on water resources: Have you seen a change in the climate in the

FIGURE 1 Location of the study communities: (A) Misintá; (B) Hato Laguna. (Maps by Efraín Porto Tapiquén and David Leroy)



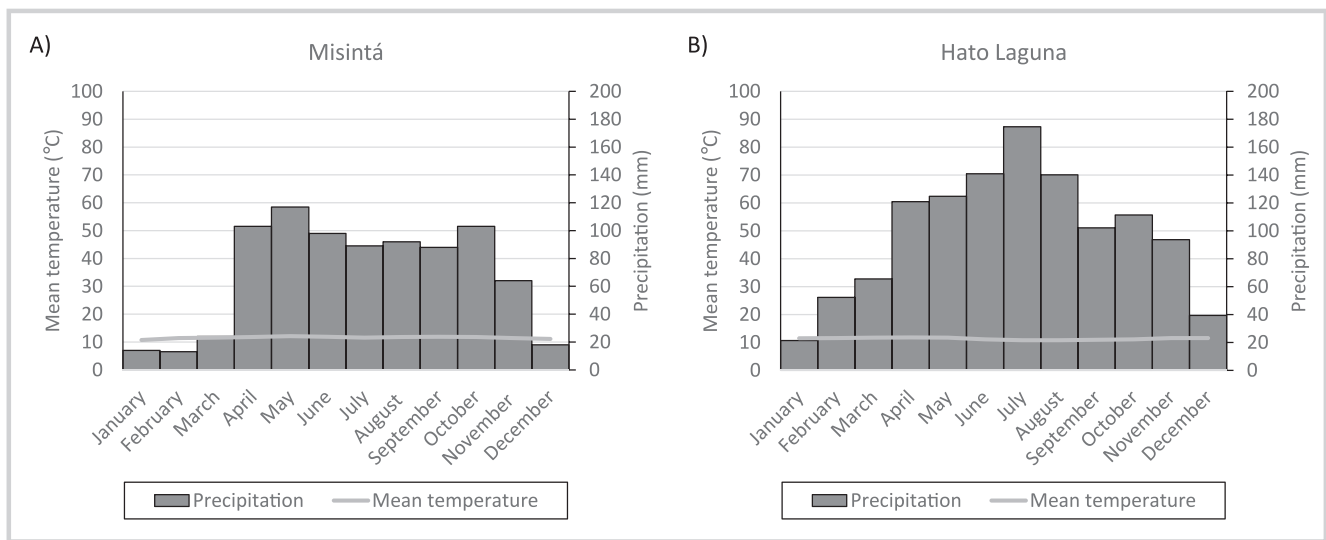
last 20–30 years? If so, what kind of change did you notice? What are the impacts of these phenomena on water resources? These questions were answered by all 24 farmers interviewed in Misintá but only by 26 of the 32 farmers interviewed in Hato Laguna.

Past, present, and planned adaptations to water scarcity were identified by asking interviewees to describe any changes they had made in their agricultural and irrigation practices (eg investment in infrastructure,

improvements to governance, or changes in planted area) and by directly observing farmers' practices.

The interviews generally lasted between 1 and 1.5 hours. They were transcribed verbatim. The assessment was mainly qualitative, but it was supplemented by a quantitative analysis (response frequencies) for perceptions of scarcity and climate change. The data were coded using relevant themes in an iterative manner following an inductive approach. Tables 2 and 3 provide

FIGURE 2 Precipitation and temperature trends in (A) Misintá (based on data from Monasterio 1980) and (B) Hato Laguna (based on data from IDEAM 2014).



examples of coding regarding perceptions of water scarcity and climate change.

Irrigation systems and governance

Two state-run irrigation systems

The irrigation systems of the Venezuelan and Colombian Andes, as well as their infrastructure and governance principles, are of recent development compared with the rest of the northern Andes (Peru, Ecuador). They are associated with market gardening production systems that have been grafted onto traditional family systems (potatoes, wheat, beans) (Robineau et al 2010; Angélique-Descamps and Gutiérrez-Malaxecharría 2014; Leroy 2017).

In the Venezuelan Andes, collective irrigation systems have been promoted by the state’s development programs (Programa Subsidio Conservacionista [Conservation Grant Program] 1959–1974; Programa Valles Altos [High Valleys Program] 1974–1992) since the 1960s (Tulet 2002). This is the case of the Misintá irrigation system (Figure 3), which was built in 1968 by Ministry of Agriculture and Land (Ministerio de Agricultura y Tierra). This system has 84 members. The water comes from a stream in the community but also from 2 transfers from the La Musuy and La Toma watersheds because of the water deficit in the Misintá watershed.

In the Colombian Andes, irrigation practices are generally more informal (Gutiérrez-Malaxecharría 2013). However, the state has promoted some irrigation systems, such as the Hato Laguna irrigation system, which

TABLE 1 Main characteristics of the study areas.

	Misintá, Venezuela	Hato Laguna, Colombia
Elevation (m)	3000–3700	3000–3900
Average annual precipitation (mm)	700	1187
Mean annual temperature (°C)	11.6	11.2
Available water resources	Streams	Streams and Tota Lake
Population	517	535
Year WUA was established	1968	1997
Type of irrigation	Gravity	Gravity
Terms of water governance	Community participation	Hired specialist (<i>aguadier</i> or water-guardian)
Crops	Potatoes, carrots, garlic; to a lesser extent, cauliflower and broccoli	Spring onions; to a lesser extent, potatoes and beans

TABLE 2 Causes of water scarcity as perceived by farmers.

Coded category	Sample comment from study participant
Dry season/summer (n = 48)	“The main factor is the summer itself, that in summer the soil dries faster, evaporates, dry winds blow and dehydrate the soil, the springs lower their flow because there is little rain; these are the reasons.” Onias R., 45 years old, Misintá, Venezuela, July 2013
Increase in water use (n = 19)	“About 20 or 15 years ago spring onion was not grown, so there was not much consumption of water. And now, for the spring onion, we have to pour water almost every other day” Carlos V., 48 years old, Hato Laguna Colombia, November 2014
Governance issue (n = 16)	“Water has been stolen for two or three families . . . They are the same as the board of the WUA . . . Then, the <i>aguadier</i> pours the water for them and it’s up to us to go on enduring.” Myriam A., 52 years old, Hato Laguna, Colombia, January 2015
Inadequate water supply (n = 14)	“The water is terribly scarce; that reservoir that you saw full of water is going to dry up; it is only supplied by an 8-inch pipe. In 3 months, the water will dry up and there will be no more water.” Alvaro B., 39 years old, Hato Laguna, Colombia, November 2014
Aging infrastructure (n = 5)	“Another factor is that there may be breaks in pipes; the water is wasted; it goes the other way.” Amanda. P., 55 years old, Misintá, Venezuela, August 2013

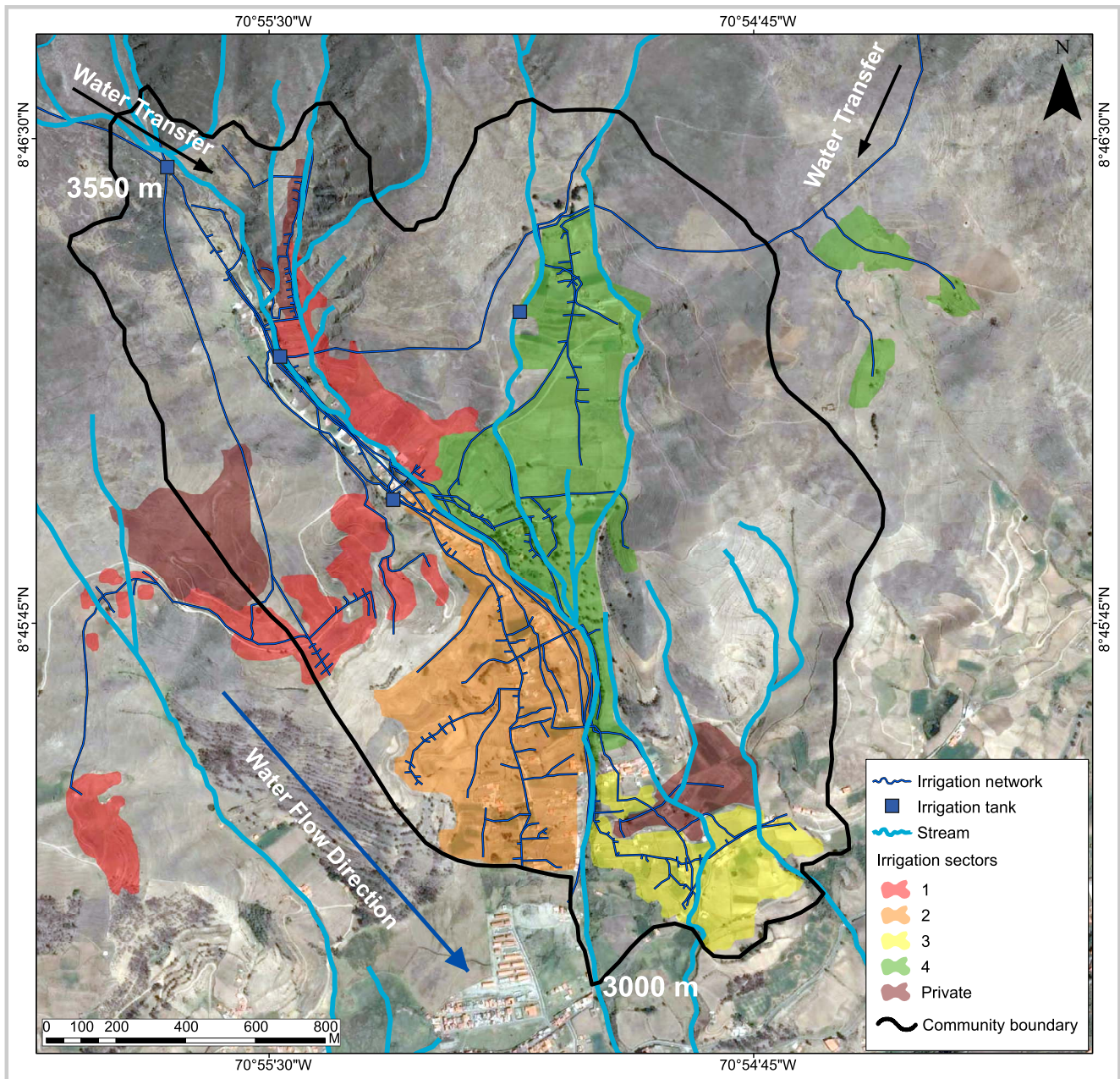
was built in 1997 by the National Institute of Land Adjustment (Instituto Nacional de Adecuación de Tierras). This system has 186 members. Water from several streams on the *páramo* is conveyed through 2 small canals to a 350,000 m³ reservoir at an elevation of 3310 m (Figure 4). The reservoir is supplied with water

throughout the rainy season, but during the dry season, according to farmers, it receives no water. In both cases of these gravity irrigation systems in Misintá and Hato Laguna, the state was fully responsible for planning and designing the infrastructure and for the construction costs.

TABLE 3 Climate change indicators as perceived by farmers.

Coded category	Sample comment from study participant
Disruption of the seasons (n = 24)	“Winters and summers are no longer so regular. That’s the difference. What we lived 30 years ago was very regular; before, if we started summer it was summer, winter [was] winter. Now there are 15 days of rain in the middle of summer or 15 days of strong summer in the middle of winter.” Lucio T., 50 years old, Hato Laguna, Colombia, November 2014
Decrease in precipitation (n = 19)	“It rained more a few years ago, 30 years ago, 25 years ago. I was a child, but I remember that there were heavy rains, and now it almost doesn’t rain anymore; it doesn’t rain at all. I noticed this change . . . Who knows why the climate is changing, but it doesn’t rain as much; before there were many winter months, day and night it rained.” Sara M., 40 years old, Hato Laguna, Colombia, December 2014
Increase in temperature (n = 13)	“I noticed that the sun is warming more . . . It always has an impact because, as I say, the water diminishes more; the same amount of water does not arrive, so it always has an impact on the springs that there are in the <i>páramos</i> , and the same amounts of water [does] not flow as a few years ago.” Carlos C., 55 years old, Hato Laguna, Colombia, January 2015
Decrease in snow (n = 6)	“Climate change has had a great influence because before the mountain was snow-covered in June, July, and August. This whole mountain was covered with snow. Now it is very rare for snow to fall due to climate change.” Carlos R., 42 years old, Misintá, Venezuela, September 2013
Decline of springs (n = 6)	“We went through a situation of strong climate change in the region. The springs had no water for the crops; the drinking water was also scarce.” Ligia P., 65 years old, Misintá, Venezuela, October 2013
More extreme summers (n = 5)	“The summer is more intense, stronger. Before at least in summer the temperatures rose in the <i>páramo</i> to 18°C; now it rises to 20°C or more.” Dionisio S., 43 years old, Misintá, Venezuela, October 2013

FIGURE 3 Irrigation system in Misintá. “Water transfer” indicates transfer from the watersheds of La Musuy and La Toma. Data sources: field surveys 2013–2014; Smith et al 2007. (Map by Efraín Porto Tapiquén and David Leroy. Data: Google, DigitalGlobe)



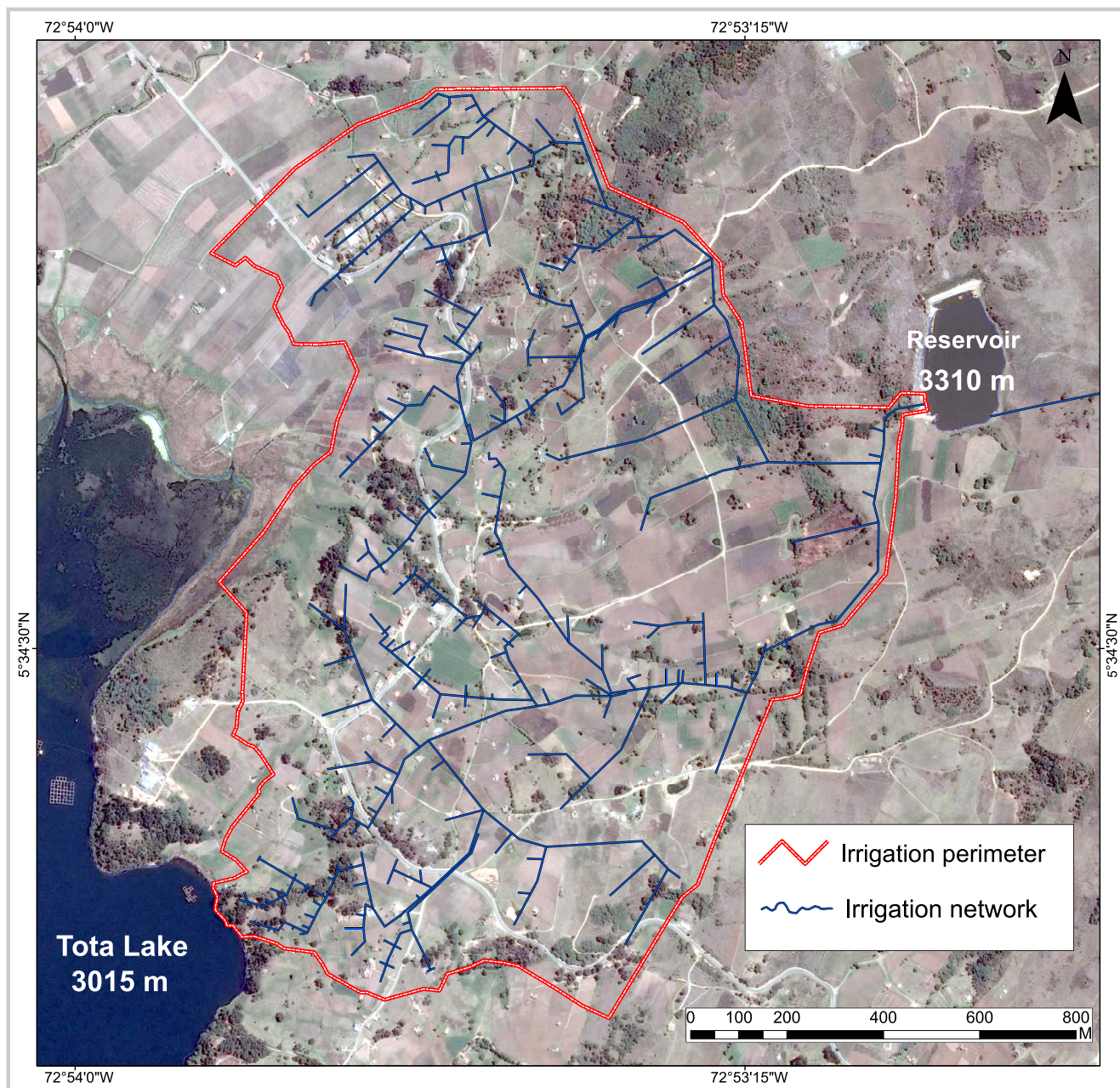
Different forms of governance

The construction of irrigation systems was related to the creation of WUAs with an institutional framework (eg set of rules, monitoring mechanism, sanctions). These WUAs are called Comité de riego de Misintá (Misintá Irrigation Committee) and Asohatolaguna (Asociación de Usuarios del Distrito de Riego de Hato laguna [Association of Users of the Hato Laguna Irrigation District]). During interviews, staff members from several state institutions said that the objective of governments at that time was to

organize farmers so that they could collectively and sustainably manage the irrigation system, notably through the establishment of a standard institutional framework, articulating the following rights and obligations:

- Right to water
- Attendance at meetings and participation in decision making
- Payment of fees
- Participation (through money or work) in infrastructure maintenance

FIGURE 4 Irrigation system in Hato Laguna. Data sources: field surveys 2014–2015; data of National Institute of Land Adjustment (Instituto Nacional de Adecuación de Tierras). (Map by Efraín Porto Tapiquén and David Leroy. Data:Google, DigitalGlobe)

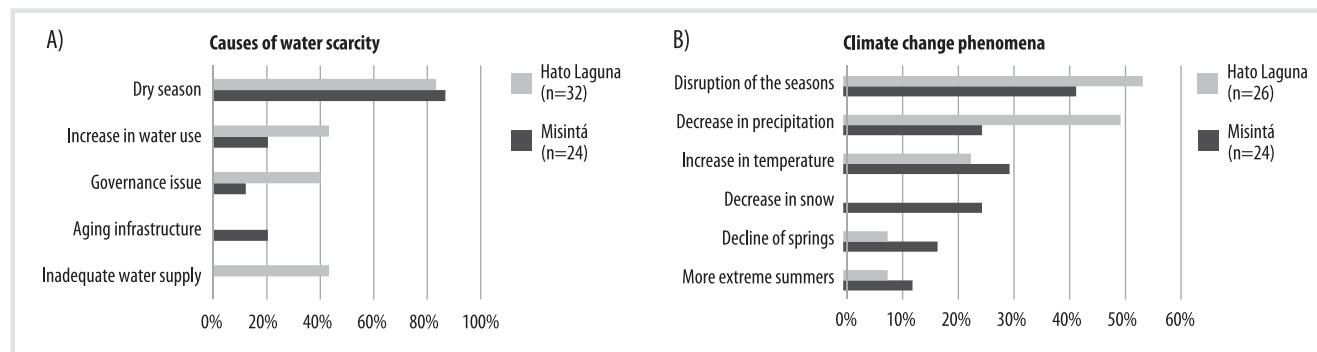


- Compliance with established distribution rules
- Payment of fines for violations of established rules

Although both WUAs are based on these principles, there is a crucial difference between them in terms of farmer participation. In Misintá (Venezuela), community members participate directly in water distribution and infrastructure maintenance, while in Hato Laguna (Colombia), participation is indirect, since 1 person (known as the *aguadier* or water guardian) is hired to do this work.

Distribution arrangements are also different. The Misintá irrigation system is divided into 4 sectors, each with its own rules for sharing, distribution, and collective organization. The distribution rules are based on the principle of the water turn, in which water is allocated to each plot for a fixed period of time so that each farmer can benefit from the same quantity of water. Thus, in each sector, 1 turn of water is allocated to an irrigation district (between 3 and 10 individual farms) for 24 hours. Despite the management rules, conflicts are frequent, especially

FIGURE 5 Perception in the study communities of causes of water scarcity (A) and of climate change phenomena (B).



during the dry season. They point to serious problems of water scarcity.

In Hato Laguna, each user is allocated 2 water turns per week. However, since all farmers irrigate at the same time, which implies a decrease in pressure in the pipes, they can only use 1 sprinkler at a time, which is a substantial restriction.

Perceived causes of water scarcity

Farmers who participated in the interviews pointed to 2 main causes of water scarcity (Figure 5). A large majority (88% in Misintá and 84% in Hato Laguna) attributed it to the dry summer season (*el verano*)—that is, to purely biophysical phenomena, lack of rainfall, and rising temperatures. Farmers also described scarcity as an anthropogenic phenomenon caused by human factors, such as governance problems, increased water use, aging infrastructure, or inadequate water supply due to poor access or lack of infrastructure.

The perception of water scarcity as a biophysical phenomenon is understandable given the climatic conditions (alternating wet and dry seasons) in these areas. For farmers, the summer (November to April) corresponds to a period of low rainfall, which causes a water deficit for irrigation. During this season, not only is streamflow reduced but springs and *páramo* wetlands—the main water reserves in these areas—dry up.

Farming societies have always adapted their agricultural calendar and crop cycle to annual rainfall patterns, but in recent years, the increase in water scarcity is often perceived in Misintá and Hato Laguna as a manifestation of climate change. Farmers in the 2 study sites perceived similar climate change phenomena (Figure 5).

Taking farmers' perceptions into account is important when designing local adaptation strategies. However, as some studies have pointed out, perceived changes do not always reflect reality, and climate events can be misinterpreted for a variety of reasons. Hence, it is important to compare perceptions with meteorological data (Meze-Hausken 2004; Imran et al 2018).

Unfortunately, there is very little quantitative information on this phenomenon in the tropical Andes, including on the high-elevation *páramo* (Buytaert et al 2010; Buytaert and de Bièvre 2012; Hofstede et al 2014). However, the climate models presented by the Intergovernmental Panel on Climate Change project reflect important changes in Colombia and Venezuela, such as a temperature increase of 3°C or 6°C by 2100 as well as a probable change in rainfall patterns (IPCC 2014b).

Disruption of the seasons

Some farmers in Misintá and Hato Laguna say they have perceived a major disruption in the seasonal cycle in recent years, and in particular the rainy season. These changes have created many uncertainties. Farmers no longer know when to plant because they do not know if they can expect dry or rainy weather. Rural communities fear droughts during the rainy season. They directly affect the most water-intensive crops, causing a significant drop in production, especially when they occur during the germination phase.

The perception of seasonal unpredictability is relatively similar among farmers in Misintá (42%) and Hato Laguna (54%). This result can be partly explained by the importance of the rainfall cycle for the agricultural calendar. Although the *páramo* study sites are climatically and hydrologically different, their relationships with seasonal cycles are essentially the same. This perception is consistent with some results at the *páramo* scale, which show more frequent and intense rainfall interrupted by longer dry periods (Anderson et al 2017).

Decrease in precipitation

It is difficult to identify a general trend in precipitation, as results differ by location and are sometimes contradictory (Buytaert et al 2010). Buytaert et al (2010) and Marengo et al (2011) measured a decrease in rainfall in the Colombian and Venezuelan Andes. A decrease in precipitation was also perceived in both study sites. Several farmers reported less frequent and less abundant rainfall. They

FIGURE 6 Annual precipitation in Hato Laguna, 1971–2013. (Based on data from IDEAM 2014).



also mentioned a decrease in stream and spring flows that complicates water supply for collective irrigation systems. The decrease in rainfall is forcing farmers to revise their production targets as it increases the likelihood of short-term crop failure and a long-term drop in production.

This perception is particularly marked among producers in Hato Laguna (50%), who are probably less used to water stress than farmers in Misintá (25%). However, a comparison with historical rainfall data in Hato Laguna (Figure 6—Misintá's data are unavailable) shows that farmers' perceptions do not match reality as there has been no significant decrease in rainfall in recent years in this area. It is therefore possible that participants' perceptions may have been influenced by other factors (eg increased consumption) or recent events (decreased precipitation from 2011 to 2013).

Warming of the páramo

Several studies have identified a warming trend in the tropical Andes, as highlighted in the Intergovernmental Panel on Climate Change report (IPCC 2014b). Data show an increase of 0.1°C–0.2°C per decade in the last century, but a greater increase (up to 0.5°C per decade) in the last 25 years (Marengo et al 2011; Magrin et al 2014; Anderson et al 2017). Numerous studies, including 3 fairly recent in-depth reviews (Vuille et al 2008; Rabatel et al 2013; Vuille et al 2018), have reported a rapid retreat and melting of the tropical Andean glaciers in Bolivia, Colombia, Ecuador, Peru, and Venezuela. Ruíz (2010) indicated that the average air temperature in Colombia is increasing at an average rate of 0.12°C–0.31°C per decade.

Thus, in recent decades, some farmers have experienced a marked increase in temperatures that has had a direct impact on their way of life. For older farmers, there is no doubt: the páramos are warming. Beyond the rise in temperatures, mentioned by 30% of farmers in Misintá and 23% in Hato Laguna, a few farmers mentioned longer and more intense summers (13% in Misintá and 8% in Hato Laguna).

Rising temperatures and strong sunlight considerably increase water loss through evapotranspiration. Some

farmers associated the warming process with a decrease in water resources: 17% in Misintá and 8% in Hato Laguna perceived water-loss phenomena, such as a decrease in the flow of streams and lagoons, as well as the drying up of several wetlands and the disappearance of several water sources. Farmers who participated in the study also made other observations related to rising temperatures, including a decrease in snow on the highest peaks of the mountains (less frequent and less abundant snowfalls and shorter duration of snow cover). This phenomenon was only observed by farmers in Misintá (25%), as snow is absent from the municipality of Aquitania (the mountain peaks are lower than those of the High Chama valley) and therefore are not observable by farmers in Hato Laguna. Snow is indeed a good indicator of climate change (IPCC 2014a). Misintá farmers' perceptions confirm the recent study by Vuille et al 2018, which highlighted a rapid decline in snow in the tropical Andes.

The perceptions of farmers in Misintá integrate a number of elements related to global warming: increase in temperatures, decrease in snow, drying of wetlands, and more intense summers. This result can be partly explained by the water deficit in Misintá, which makes agriculture, and consequently rural communities, more vulnerable to warming.

It seems clear that climate change has shaped perceptions of water scarcity, in particular biophysical water shortages. The comparison of farmers' perceptions with the results of several studies (Vuille et al 2008; Buytaert et al 2010; Ruíz 2010; Marengo et al 2011; Rabatel et al 2013; IPCC 2014b; Magrin et al 2014; Anderson et al 2017; Vuille et al 2018) shows that perceived changes often do reflect reality. However, some perceptions, such as the decrease in rainfall in Hato Laguna, show that local knowledge is sometimes misinterpreted. Moreover, because of the subjective nature of this knowledge, it is difficult to assess the real impact of climate change on water scarcity.

Water scarcity: a social construction

Water scarcity linked to new agricultural practices

Although biophysical phenomena, such as climate change, are frequently cited as causes of scarcity, some farmers are aware that “in general, as production increases and the agricultural frontier expands, water resources diminish,” as a small-scale farmer from Misintá said. Other farmers also referred to water scarcity as not only a meteorological but also a socioeconomic phenomenon, defined by the imbalance between available water resources and current consumption.

Introduced in the 1950s–1960s, the market garden crops now found in the páramos are particularly dependent on a regular supply of water, unlike traditional crops (eg wheat and potato), which are considered more resistant. Beyond the intrinsic sensitivity of new crops to

water scarcity, springs have become insufficient to meet water demand due to the increase in cultivated areas and populations. This perception was more pronounced among farmers in Hato Laguna (44%) than in Misintá (21%). This difference can be explained by the dynamics of agricultural intensification in the district that is home to Hato Laguna—Aquitania, Colombia—which has led to a significant increase in water consumption in recent years.

Aging irrigation infrastructure in Misintá

Water scarcity is related not only to agricultural intensification but also to economic and institutional problems. For example, in Misintá, the irrigation infrastructure is very old and degraded, which causes considerable water losses. This problem is not topical at the moment in Hato Laguna because the infrastructure is more recent and uses highly durable plastic pipes. Some Misintá farmers (21%) denounced the government's shortcomings in terms of supervision, financing, and technical monitoring. From the early 1990s, the state, pushed by the structural adjustment program of the International Monetary Fund and the World Bank, completely disengaged from the management of irrigation systems (Llambí and Arias 1997). In addition, interviewees in Venezuela stated that since 2012, due to that country's economic and political crisis, the human, logistical, and technical resources of public institutions were reduced to almost nothing, and farming communities have essentially been abandoned.

Irrigation governance problems in Hato Laguna

Although Misintá farmers perceive water scarcity as an economic and institutional phenomenon, for Hato Laguna farmers it is also a technical and governance problem. Use restrictions imposed by the Hato Laguna WUA (Asohatolaguna) do not allow farmers to irrigate their plots effectively. In particular, farmers cannot irrigate more than twice a week, whereas spring onion needs 3 weekly waterings to develop well. In addition, farmers are only allowed to use 1 sprinkler at a time during irrigation turns, which requires more work, as they have to rotate the sprinkler to irrigate their entire plot.

Despite the use restrictions imposed by the WUAs, total exhaustion of water reserves during the dry season is inevitable—a vulnerability that is inherent in this irrigation system but is exacerbated by dysfunctions in the WUA and its mode of governance. This view is held by more than 40% of the Hato Laguna farmers interviewed for this study.

Unlike Misintá's irrigation system, which relies on direct participation by all members, the Hato Laguna system is managed by a single person (the *aguadier*). However, it is impossible for a single person to control and monitor the entire irrigation perimeter. This

encourages opportunistic behavior, which leads to conflicts. In addition, fraud and corruption are frequent because it is tempting for an *aguadier* to use the power over the allocation of resources to derive benefits.

In addition to governance issues, several farmers from Hato Laguna (44%) see water scarcity primarily as the result of inadequate water supply due to poor access or lack of infrastructure. These farmers are located near one of the most abundant water sources in Colombia, but they say that they do not have access due to a lack of investment.

Adaptation to water scarcity

Adaptation strategies can be seen as manifestations of adaptive capacity, actions taken to adjust the system to address the impacts of climate, social, and environmental change to which the system is vulnerable (Smit and Wandel 2006).

Misintá: collective action

Developing irrigation institutions: In recent decades, numerous studies of forest governance, water management, and pastoral migration (Tompkins and Adger 2004; Young and Lipton 2006; Agrawal 2008; Engle and Lemos 2010; Gupta et al 2010; Upton 2012) have demonstrated that local institutions are a key determinant of adaptation. Institutions can be understood as sets of rules that make collective action possible (Ostrom 1990) or as the rules of a game played by organizations (North 1990).

For Ostrom (1992), institutions are essential to the proper functioning of an irrigation system because they enable farmers to work toward a common objective. But the establishment of institutions is a long and sometimes difficult process. For example, the Misintá WUA's (Comité de riego de Misintá) first rules governing water distribution and use were ineffective due to the WUA's lack of legitimacy and authority. Water turns were little respected, maintenance was sporadic, and fee payments were highly irregular. But in recent years, as water scarcity and conflict have increased, farmers have become aware of the importance of defining precise rules and allowing an institution to establish and enforce them.

Thus, in the early 2000s, farmers focused their efforts on establishing an equitable distribution of the resource. They experimented with different options and regularly made small adjustments to make the system effective and ensure that it was respected by a majority. For Misintá, implementing a control and sanction system has been essential. This system has made it possible to limit opportunistic behavior, but above all, it has strengthened the legitimacy of the WUA.

In addition to better water distribution, the WUA has also decreased the area that can be planted during the dry

season. Farmers have also adopted new water-saving irrigation technologies—including the *bailarina* (dancing girl), a micro-sprinkler that limits water waste and is now mandatory within the WUA. Finally, faced with increasing problems related to the degradation of irrigation infrastructure, farmers in Misintá decided to replace deteriorated steel pipes with plastic pipes. This required not only heavy financial investment but also unprecedented collective work.

Arguably, disengagement by state institutions since the 1990s has pushed the WUAs of Venezuela to better self-management, which in turn has facilitated adaptive capacity.

Protecting wetlands: While the evolution of irrigation water management rules has greatly strengthened the adaptation of Misintá farmers, protection of wetlands is another form of collective action that has, according to farmers, considerably improved water supply, especially during the dry season. Beginning in 1999, a severe drought and the lack of water, which farmers interpret as a consequence of climate change, directed the eyes of the Misintá community toward the wetlands of the *páramo*. The degradation of these fragile areas by the presence of livestock was obvious. Repetitive trampling by livestock leads to soil degradation and compaction and thus reduces the capacity of wetlands to retain and regulate water (Valero Lacruz 2010; Angélieume-Descamps et al 2013; Sarmiento et al 2015).

During this time a person from the Misintá community decided to create an association for the protection of wetlands: the Association of Environmental Coordinators for Farmers of the *Municipality of Rangel* (Asociación de Coordinadores del Ambiente por los Agricultores del municipio Rangel). The association's objective is to preserve wetlands through restoration and establishing protection perimeters. This is a large-scale collective effort that mobilizes all farmers in the community. The association holds work days for stream cleanup and the reforestation of springs and banks with native plants (Angélieume-Descamps et al 2013).

The beneficial effects of protection measures are now unanimously stressed by farmers and by some scientists, who stress the regeneration of vegetation, the decrease in soil compaction, and the increase in water retention capacity in protected areas (Valero Lacruz 2010; Sarmiento et al 2015). As a result, participation in the protection of wetlands is now compulsory within the Misintá WUA and has spread to the rest of the communities in the High Chama Valley.

As these examples show, the farmers of Misintá have been able to modify their rules related to irrigation to adapt to water scarcity by reorganizing the water turn, adopting more efficient irrigation technologies, restoring aging infrastructure, and undertaking wetland conservation projects. While these strategies were

developed in the context of climate change, they were also guided by the perception of scarcity as an anthropogenic phenomenon.

Hato Laguna: individual and collective action

Individual adaptation—pumping water from Lake Tota: Since the mid-2000s, many farmers in Hato Laguna have improved their access to water by pumping water from Lake Tota. For a long time, this practice was limited to flat areas and areas near Lake Tota in the municipality of Aquitania due to the cost of infrastructure. But faced with water scarcity problems, many farmers have decided to invest in access to this abundant water resource. Initially, this practice was carried out by individuals or small groups of farmers, but their success did not go unnoticed in Hato Laguna. It led to a common will to organize to have access to lake water, thus inspiring a new form of collective action in Aquitania: the creation of a new irrigation system.

Collective adaptation—creating a new irrigation system: Asomohán's irrigation system, started in 2006, is in line with the dynamics of water exploitation in Lake Tota. It is guided by the perception of the lake as an unlimited resource that must be exploited. Unlike the Hato Laguna irrigation system, built in 1997 by the state, this irrigation system is financed completely by farmers. This is an innovative project because pumping water from the lake was previously reserved for very wealthy farmers, and private irrigation systems had only 2 or 3 members at most.

The Asomohán irrigation system is based on expensive hydraulic infrastructure. Water is pumped from Tota Lake, then transported through pipes to a small reservoir at higher elevations. This irrigation system, which brings together about half of Hato Laguna's farmers, is considered a real success in this region. Unlike the irrigation system managed by Asomohán, farmers can irrigate at will and without any limit on the number of sprinklers, which represents a considerable time saving.

Asomohán's irrigation system has created marginality among farmers who have not had the economic capacity to invest and who therefore cannot use it. Today, these farmers feel particularly vulnerable to water scarcity and denounce the Asomohán system's principle of exclusion.

In Hato Laguna, farmers have been able to adapt to water scarcity by creating new water infrastructure. Adaptation has thus not only been guided by the perception of scarcity as a result of climate change or poor WUA governance but also results from the perception of water as a production tool that only needs to be exploited.

Discussion and conclusion

The objective of this study was to analyze perceptions of and adaptations to water scarcity by WUA members in the

páramo, taking into account both climatic and nonclimatic factors. Results show that climate variability has shaped perceptions of water scarcity. This is consistent with most studies on the perception of climate change in mountain areas, which highlight a perception of seasonal changes, temperature increases, and lower rainfall and snowfall (Vedwan and Rhoades 2001; Vedwan 2006; Byg and Salick 2009; Chaudhary and Bawa 2011; Boillat and Berkes 2013; Smadja et al 2015; Herrador-Valencia and Paredes 2016). Nevertheless, the interdependence and complexity of how farmers define water scarcity and the direct and indirect indicators they point to when expressing their knowledge about it show that climate change is not the only cause of water scarcity.

Like several recent studies (Kuruppu and Liverman 2011; Murtinho et al 2013; Wheeler et al 2013; Murtinho 2016; Singh et al 2018), I argue that while climate is an important factor shaping farmers' perceptions of water scarcity, it is essential to take into account nonclimatic factors in order to truly understand community adaptation strategies. Otherwise, researchers run the risk of wrongly attributing farmers' adjustments to climate stimuli that are sometimes misinterpreted, while ignoring other more important factors, such as increased water demand, infrastructure degradation, or poor governance of the resource.

The causes of water scarcity are multiple and interdependent and shape a wide variety of adaptation strategies. The example of Misintá confirms the results of several studies, which show that local institutions are a key determinant of adaptation (Tompkins and Adger 2004; Young and Lipton 2006; Agrawal 2008; Engle and Lemos 2010; Gupta et al 2010; Upton 2012) and, more particularly, those that highlight a link between

adaptation and better water governance (Murtinho et al 2013; Wheeler et al 2013; Birkenholtz 2014; Murtinho 2016; Villamayor-Tomas and García-López 2017). The example of Hato Laguna shows improvement in infrastructure, allowing individual as well as collective adaptation, as has also been shown by several other studies (Murtinho et al 2013; Murtinho 2016; Villamayor-Tomas and García-López 2017).

Thus, this study shows how perceptions of water scarcity in a climate change context are critical determinants of farmers' behavior, especially collective adaptation. It also shows the importance of taking into account local knowledge in the implementation of adaptation strategies (Grothmann and Patt 2005; IPCC 2014a) and demonstrates that certain factors—such as modes of governance, access to capital, public aid, or access to water—can influence the perception and adaptation of individuals and groups. One could argue that farmers tend to collaborate better when the resource is perceived as scarce (Misintá) than when it is perceived as abundant (Hato Laguna). These 2 case studies therefore offer some suggestions for better encouraging and stimulating adaptive behaviors in rural communities and, more specifically, in WUAs.

The adaptation of the Misintá WUA is essentially based on institutional evolution that made it possible to preserve and better develop the water resource. That of Hato Laguna is based on a logic of exploitation of lake water and has marginalized the small-scale farmers excluded from the system. It is only through strengthening and improving the rules that adaptation is truly effective, equitable, and sustainable. In other words, reducing vulnerabilities is above all a collective challenge based on the effectiveness of local institutions.

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