



Research

How do Indigenous and local knowledge systems respond to climate change?

[Ruxandra Popovici](#)¹, [Andre G. de L. Moraes](#)², [Zhao Ma](#)³, [Laura Zanotti](#)⁴, [Keith A. Cherkauer](#)², [Anna E. Erwin](#)³, [Katy E. Mazer](#)⁵, [Edwin F. Bocardo Delgado](#)⁶, [José P. Pinto Cáceres](#)⁷, [Pranay Ranjan](#)³ and [Linda S. Prokopy](#)⁸

ABSTRACT. Indigenous and local knowledge (ILK) systems are critical for achieving biodiversity conservation, climate change adaptation, and other environmental goals. However, ILK systems around the world are increasingly threatened by multiple stressors. Our study assesses the effect of climate change on ILK held by crop farmers in Peru's Colca Valley. We collected qualitative data on farmers' ILK through semi-structured interviews, which we supplemented with climatological trend analysis in four Colca Valley districts. We found that shifts in the rainy season together with warmer weather affected farmers' ILK, which was less effective for informing crop planting and irrigation practices in the context of climate uncertainty and unpredictability. Changing and uncertain ILK poses obstacles to adaptation strategies that require long-term institution building from local resource users, who may prioritize short-term solutions addressing urgent needs.

Key Words: *adaptation; climate change; community-based natural resource management; coproduction; Indigenous and local knowledge; institutions; Peru*

INTRODUCTION

Adapting to climate change and addressing natural resource conservation requires the integration of scientific and Indigenous and local knowledge (ILK) systems to create effective and responsive policies (Hulme et al. 2012, Danielsen et al. 2014, Nursey-Bray et al. 2014, Tunón et al. 2015). In recent decades, the recognition and promotion of ILK systems and their integration in different governance regimes has amplified as climate change increasingly impacts rural communities around the globe. ILK can be defined as systems that are “locally or regionally maintained, adapted, and transmitted both orally and in practice, but [are] also in constant interaction with other forms of knowledge” (Tengö et al. 2014:579) and “incorporate cultural, economic, religious and pragmatic dimensions” (Hill et al. 2020:10). In contemporary, heterogeneous rural communities, ILK systems in specific regions and localities can represent a range of different types of resource users and worldviews, including Indigenous Peoples, traditional peoples, non-Indigenous local communities, and peoples with mixed heritage and ancestry (see Joa et al. 2018 for a comprehensive overview). Our research focuses our attention on heterogeneous but regionalized and localized ILK systems and adaptive decision making among rural farming communities in Peru. We explore the institutional, governance, and knowledge contexts in which farmer ILK systems respond to climate change: (1) “the informal, lay, personal, often implicit or tacit, but possibly expert, knowledge held by land managers involved in environmental decision-making” (Raymond et al. 2010:1767); (2) the institutions for managing natural resources, understood as the formal and informal rules and norms (Lam et al. 2020); and (3) the natural resource management practices regulated by these institutions (Cornell et al. 2013).

Two streams in the ILK literature are relevant to understanding farmer adaptation in climate change in Peru and their broader

decision-making contexts. The first stream emphasizes the importance of recognizing, reviving, and interweaving ILK systems into mainstream policy decisions at various scales. In small-scale agricultural communities with diverse identities (Erwin et al. 2021), ILK systems are considered essential for many reasons, including ensuring food security, fostering community well-being, and contributing to biodiversity conservation of native crop species (Lane and Jarvis 2007, Arteaga and Burbano 2018). Because rural agricultural communities are particularly vulnerable to climate change (Sanga et al. 2013), many studies have emphasized the importance of incorporating ILK systems into adaptation strategies that would increase farmer resiliency to the consequences of climate change in a way that aligns with ILK and decision-making institutions (Armitage et al. 2011, Gómez-Baggethun et al. 2013, Postigo 2014, Burnham et al. 2016).

In the last decades, we have seen these trends codified in policy and governance regimes at the national and international levels. Increasingly, national initiatives and global environmental governance platforms recognize the value of acknowledging and integrating ILK systems into policy and action. At the international level, these include the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES), the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and more broadly, the 2007 adoption of the United Nations Declaration on the Rights of Indigenous Peoples (Tengö et al. 2017, Reyes-García and Benyei 2019, Suiseeya and Zanotti 2019, McElwee et al. 2020, Stevance et al. 2020). At the national and regional levels, these include India's People's Biodiversity Registers (Gadgil 2000), Spain's CONECT-e project (Benyei et al. 2020a), and Canada's federal guidelines for including Indigenous Knowledge under the Impact Assessment Act (Eckert et al. 2020).

¹Independent Researcher, Ottawa, ON, Canada, ²Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, IN, USA, ³Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN, USA, ⁴Department of Anthropology, Purdue University, West Lafayette, IN, USA, ⁵Department of Agronomy, Purdue University, West Lafayette, IN, USA, ⁶Facultad de Ciencias Biológicas, Universidad Nacional de San Agustín, Arequipa, Peru, ⁷Facultad de Agronomía, Universidad Nacional de San Agustín, Arequipa, Peru, ⁸Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA

These platforms have been criticized because, although they explicitly state the importance of ILK systems for informing climate change adaptation and other strategies, they often fall short when it comes to specifying the processual aspects of knowledge holder involvement or the bridging mechanisms to integrate ILK systems into policy and action (Christie et al. 2019, Díaz-Reviriego et al. 2019, Obermeister 2019, Thompson et al. 2020). Diverse power-sharing approaches in complex bureaucratic landscapes, such as participatory and knowledge coproduction approaches, have emerged as inclusive processual frameworks that empower resource users, promote inclusivity in decision-making perspectives, and influence decisions (Klenk et al. 2017, Benyei et al. 2020b, Stevance et al. 2020). Although there have been great strides in acknowledging the value and importance of integrating ILK systems, the processes that address how to equitably bridge knowledge systems or short-term urgent needs in complex institutional and governance landscapes are still in the making.

The second stream of literature relevant to this study emphasizes that, although there is increased recognition of the importance of ILK systems, ILK systems are facing multiple threats and are rapidly changing because of historical legacies and contemporary political, economic, and ecological realities (Cámara-Leret et al. 2019). Threats include socioeconomic factors such as migration, integration into the market economy, technological changes, industrialization, and abandonment of traditional lifestyles (Aswani et al. 2018, Joa et al. 2018). Scholars have examined the relationship between climate change and ILK by documenting local accounts of changes in weather and biodiversity (Riedlinger and Berkes 2001, Byg and Salick 2009, Oteros-Rozas et al. 2013, Kai et al. 2014), comparing local perceptions to official climate records (Klein et al. 2014, Burnham et al. 2016, De Longueville et al. 2020), and analyzing how ILK can inform adaptation to climate change (Danielsen et al. 2014, Postigo 2014, Vogt et al. 2016, Wang et al. 2016). In addition, biodiversity loss can threaten ILK systems by causing a decline or limiting access to particular local plants and animals that have historically been important to the tacit and experiential knowledge of learning and transmitting ILK systems (Kai et al. 2014). Some studies have analyzed how ILK systems can cope with climatic changes, as well as the extent to which ILK can inform broader policies (see Galappaththi et al. 2019 for an exception).

Thus, the two literature streams indicate two complementary trends that impact adaptive decision making moving forward: (1) an increased recognition of the importance of ILK systems and their role in informing policy decisions and (2) a documented trend of increased risks and stressors to ILK systems worldwide, including climate change, which may limit how knowledge holders can integrate their knowledge systems in policy decisions. We ask, if ILK systems are essential but under threat, what does this mean for approaches to climate change adaptation that rely (or aim to rely) upon and integrate ILK to inform decisions? There is a mismatch between recommendations for building the necessary institutions to allow meaningful inclusion of ILK and the reality that ILK systems and their institutional contexts are under threat. Our study seeks to address these shifts by analyzing (1) how ILK systems have responded to climate change in agricultural communities, (2) how ILK systems might limit or facilitate farmers' ability to adapt to current and future changes in climate,

and (3) farmers' expectations regarding external partnerships to address climate change adaptation. We conducted our analysis in Peru's Colca Valley, where we studied the impact of climate change on ILK systems in four agricultural communities. In each community, we collected qualitative data through semi-structured interviews, which we corroborated with climatological data showing the climate trends in each study region. The Colca Valley has a long history of terraced agriculture, with ILK systems that can be traced to pre-Inca times (Guillet 1992). Previous studies have noted an increase in air temperature in climate observations and projection models in the Peruvian Andes (Salzmann et al. 2013, Michelutti et al. 2015). Such changes in climate can have adverse effects on Andean agricultural communities by creating economic and biodiversity losses (Arteaga and Burbano 2018), which makes the Colca Valley an ideal place for assessing the impact of climate change on ILK systems and corresponding adaptation strategies.

METHODS

Study area

For this study, we selected four agricultural districts in the Colca Canyon area of Caylloma province of Peru, namely the districts of Cabanaconde, Madrigal, Lari, and Yanque (see Fig. 1). Each of these districts is farmed by village-sized communities, with populations that range between 648 and 2117 inhabitants (see Table 1 for community-specific information). The Colca Valley is split in half by the Colca Canyon, which contributes to unequal water availability between crop farmers located on the North and South side of the canyon. Communities located on the South side, including Yanque and Cabanaconde, receive water from the Majes Canal, a government-sponsored pipeline that diverts water from the upper reach of the Colca Watershed to the Majes agricultural region on the coast (Paerregaard et al. 2016). Communities located on the North side, including Lari and Madrigal, mainly rely on rainfall, snow and glacier melt, and natural springs for irrigating their crops, which include maize, barley, broad beans, alfalfa, quinoa, and garlic. Selecting communities on both sides of the canyon allowed us to observe the impacts of climate change on ILK systems specifically related to traditional irrigation practices, as well as climate change impacts under different water scarcity conditions.

Data collection and analysis

Semi-structured interviews

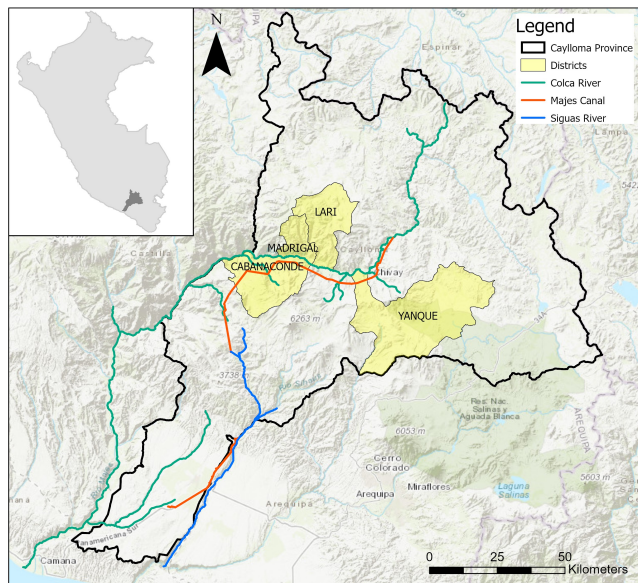
We collected data on the impact of climate change on ILK systems through semi-structured interviews with a total of 108 farmers in the four Colca Valley districts: Cabanaconde, Yanque, Lari, and Madrigal. We asked interviewees whether they had noted any changes in the climate within the last 10 years, and whether these changes had affected their agricultural institutions and practices. Interviews were conducted in Spanish and were transcribed and analyzed in Spanish. Five of the interviews were conducted in Quechua with the help of an interpreter, who also translated the interview transcripts into Spanish. Transcripts were coded in a qualitative data software analysis program (NVivo) using thematic coding and process coding strategies (Saldaña 2009). We classified the changes in climate and their consequences on ILK based on recurring themes mentioned by interviewees. Three of the authors developed the codebook, and then revised it on three

Table 1. Characteristics of study districts and number of interviewees.

District	Elevation (m above sea level)	Population	Irrigation water sources	Average annual temperature (°C)	Average annual precipitation (mm/year)	Number of interviewees
Cabanaconde	3296	2096	Glacier melt; Natural springs; Majes Canal	12.1	342.2	36
Madrigal	3271	648	Glacier melt; Natural springs	11.9	468.2	25
Lari	3358	904	Glacier melt; Natural springs	11.9	458.9	20
Yanque	3420	2117	Glacier melt; Natural springs; Majes Canal	11.1	437.5	27

separate occasions. Once the final coding framework was established and agreed upon, an inter-coder reliability test was undertaken on 10% of the total interviews, and achieved a Cohen's kappa of 0.82, indicating adequate consistency between the three researchers who coded these interviews (Viera and Garrett 2005). Quotations were translated to English for this paper.

Fig. 1. Study districts in the Caylloma Province, Peru. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), © OpenStreetMap contributors, and the GIS User Community.



Climate trend analyses

We used 30 years (1988–2017) of a daily gridded climatological data product assembled by Moraes et al. (2020) to extract climate trends for the four study districts. A suite of climate metrics was designed to quantify the types of changes that were described by local farmers. These metrics included the following: (1) annual (mm/year) and monthly (mm/month) cumulative precipitation;

(2) annual (days/year) and monthly (days/month) number of days with temperature below 0 °C. maximum (Tmax) air temperature (°C); (3) annual (mm/year) and monthly (mm/month) cumulative potential evapotranspiration (PET); (4) start of the rainy season (number of days from August 1st when cumulative precipitation reaches 10% of annual precipitation); and (5) annual (days/year) and monthly (days/month) number of days with temperature below 0 °C.

We used the Mann-Kendall test (Hirsch et al. 1982) with significance level of 0.05 to determine statistically significant trends in the data. The Mann-Kendall test has been widely used in trend analysis of time series data, for example in hydrologic and climatic data (Lettenmaier et al. 1994, Sinha and Cherkauer 2008, Kumar et al. 2009). The Theil-Sen slope estimator (Sen 1968; henceforth referred to as Sen's slope) was used to estimate the average change of the variable with time. Monthly PET was calculated according to Thornthwaite (1948) based on observed temperature data. Annual PET represents the sum of PET from all 12 months.

RESULTS

Three categories of observations emerged as critical impacts of a changing climate on crop production in the interviews. Specifically, farmer interviewees noted a shift in the rainy season, increased temperatures, and unexpected cold days. We combined qualitative interview data with climate data as a means to quantify what observed changes have occurred and to integrate climate data with farmers' ILK systems. Additional quotes from interviewees supporting the three observed climate trends are included in Table 2. These three trends have implications on farmers' ILK and their adaptation to climate change.

Shift in rainy season

"It no longer rains at the right time," expressed a farmer in Yanque. This sentiment was echoed by interviewees in all four study districts, who told us they noted a shift in the timing of the rainy season. The timing of the rainy season is particularly critical for farmers in Lari and Madrigal, who do not receive irrigation water year-round from the Majes Canal and must coordinate the planting of their crops to ensure they receive sufficient rainfall. Interviewees said that over 10 years ago, the rain began in November and ended in March. But now, the rain is starting later in December and ending in April. These statements coincide with the climate trend analysis results, which indicate that the start of the rainy season has shifted on average 13.7 days later over the period of 1998 to 2017, though this change is not statistically

Table 2. Quotations from farmers regarding observed changes in climate.

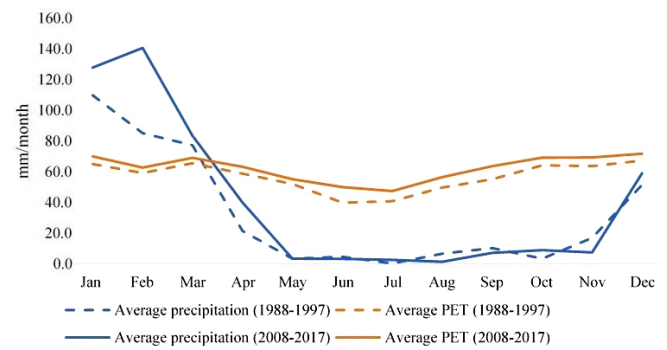
Observed changes in climate	Quotations
Shift in rainy season	“In December, it should be raining already.” (Interviewee in Cabanaconde)
	“Hopefully it arrives, we are waiting for the rain to arrive.” (Interviewee in Madrigal)
	“We are waiting for the rain to arrive [...]. If the rain doesn’t come, with the little water we have now, we will not have a good harvest.” (Interviewee in Lari)
Increased temperatures	“Because of the changes in climate, we no longer have a good harvest. Sometimes it rains on time and sometimes it doesn’t.” (Interviewee in Yanque)
	“We will need to irrigate not even a week from now because it is very hot.” (Interviewee in Cabanaconde)
	“Before, it was not as warm. Now there is too much heat, and we have less water.” (Interviewee in Madrigal)
Unexpected cold days	“Because it is quite hot, [water] evaporates quickly. Irrigation does not last long, it dries, and often the crops must be thrown away.” (Interviewee in Lari)
	“The climate has changed a lot. Now there is much more heat. Before, you could work in the field all day [...] but now the heat burns and burns [...] It has become unbearable. Now we need to find shade and to cover up.” (Interviewee in Yanque)
	“Now, there can be frost at any time. Before, we had a frost season.” (Interviewee in Cabanaconde)
	“It’s not supposed to be so cold now. It is damaging our crops.” (Interviewee in Madrigal)
	“Unexpected frost burns the crops.” (Interviewee in Lari)
	“We used to know the winds. There are winds that announce rain, and winds that announce cold weather. When we see the winds that announce rain, we are happy. But when the winds change and announce frost then we become worried.” (Interviewee in Yanque)

significant (see Table 3). Signs of a shift at the start of the rainy season were found in all four study districts, ranging from a delay of 5.5 days in the Lari District to 24 days in the Madrigal District. We also found that total annual precipitation (mm/year) is increasing (see Table 3). However, this increase is mostly observed during the months of January and February (see Fig. 2 and Appendix 1). It is important to note that an increase in precipitation does not necessarily translate into more water available to farmers. The soil can only hold a limited amount of water, resulting in percolation and runoff of excess water. Therefore, farmers can only take advantage of the precipitation increase if they store it in reservoirs. At the time of this study, all four districts had at least one small-scale reservoir; however, interviewees expressed the need to build additional ones.

Increase in average temperature and potential evapotranspiration

In all four study districts, farmers made comments such as, “Before, [the weather] was more temperate. Now, it’s becoming much warmer” and “The heat is stronger.” Our climate data analyses show a significant increase in annual average daily maximum (average increase of 1.74 °C in 30 years) and minimum (2.19 °C in 30 years) air temperature in all four districts (see Table 3). There is also an overall increase in monthly average values for daily minimum and maximum air temperatures throughout the year. The largest observed temperature increases were found in the months from April to September for minimum temperature and from June to September for maximum temperature, both periods that coincide with Austral wintertime (see Fig. 3 and Appendix 1). Temperature increases were also found to be larger at higher altitude districts (e.g., Yanque) and smaller at lower altitudes (e.g., Cabanaconde).

Fig. 2. Monthly average precipitation and potential evapotranspiration (PET) for the periods of 1988 to 1997 and 2008 to 2017 in the Lari District.



Farmer interviewees expressed concern about the warmer temperatures because they had to irrigate their crops more frequently during the growing season. Older farmers told us that 40 years ago, they irrigated their maize every 60 days. Interviewees said that now, they must irrigate at least every 35 days otherwise the crops die. Warmer air temperatures result in annual potential evapotranspiration (PET) rates increasing by between 77.5 mm to 94.7 mm depending on location over the period 1988 to 2017 (see Table 3). Monthly PET is also increasing, with months from June to September experiencing the greatest increase, although summer increases are still substantial (see Fig. 2 and Appendix 1). This means that despite receiving more rain during the months of January and February, crops in the Colca Valley now require

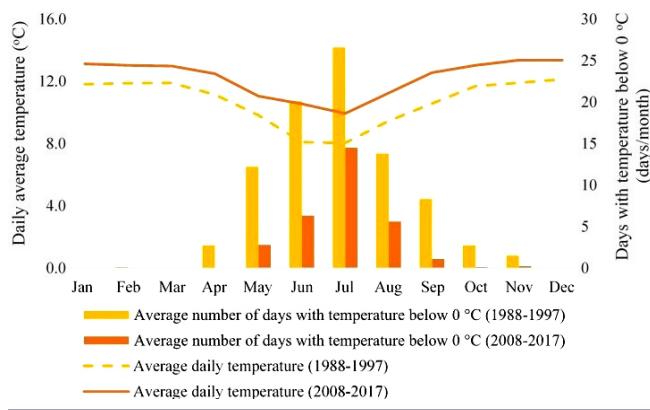
Table 3. Change in the evaluated climatic variables over the period of 1988 to 2017 for the study districts.

Climatic variables	Districts				
	Cabanaconde	Madrigal	Lari	Yanque	Average
Annual Tmax (°C)	1.46*	1.72*	1.82*	1.98*	1.74
Annual Tmin (°C)	1.82*	2.13*	2.23*	2.59*	2.19
Annual precipitation (mm)	69.7	142.1*	93.0	92.8	99.4
Annual PET (mm)	77.5*	83.2*	94.7*	89.7*	86.3
Days below 0 °C per year (days)	-45.7*	-68.2*	-82.5*	-106.7*	-75.8
Start of the rainy season (days after Aug. 1)	16.2	24	5.5	9.2	13.7

Values represent the total change for the period 1988 to 2017 based on the Sen's slope trend analysis; * indicates that a statistically significant trend was found using Mann-Kendall analysis with a significance level of 0.05; Tmax = average daily maximum air temperature; Tmin = average daily minimum air temperature; PET = potential evapotranspiration.

more water from irrigation because of increased PET. Figures 2 and 3 show the 10-year average of monthly precipitation and PET and average daily temperature for the periods of 1988 to 1997 and 2008 to 2017 for the Lari District. These differences between the averages of the two periods for each climatic variable represent the general climate change pattern for the Colca Valley region; however, there are subtle differences in each of our four study districts that can be seen in the Appendix.

Fig. 3. Monthly average temperature and number of days with temperature below 0 °C for the periods of 1988 to 1997 and 2008 to 2017 in the Lari District.



Reduced frost days

That unexpected frost “burns the crops” was a concern for farmers in all four study districts. During cold days with air temperatures below 0 °C, farmers’ crops can be severely damaged by frost, and many farmers reported losing their entire harvest. Our climate trend analysis found that, because of warmer temperatures, frost days are in fact decreasing but still happening. There is a significant decrease of between 45.7 and 106.7 days per year when air temperature is at or below 0 °C for the study districts in the 30-year evaluation period (see Table 3). Although the number of days with temperatures below freezing is decreasing, farmers attribute great significance to frost events, which they are unable to anticipate. Indeed, many farmers we interviewed told us that frost is “unexpected.” This confusion could be caused by the rising temperatures mentioned above, where farmers may not expect frost to occur once it starts to get warmer. Farmers may see

warming air temperature as an indication to plant some of their crops early. For example, one community leader told us that farmers in his district started to plant corn earlier in August instead of later in October, as was customary in previous decades. However, planting in August would be risky in all four districts, because although the average temperature is now favorable for planting earlier in the year, frost days still occur through November, especially in the higher elevation districts (see Fig. 3 and Appendix 1), although they are less common than in the past. Even one frost episode can be devastating for farmers, causing them to lose their entire harvest.

Implications for adaptation to climate change

Our results indicate that farmers’ ILK systems are changing and reflect new observations and patterns because of perceived changes in temperatures and precipitation. They were also concerned about unexpected frost days because frost no longer followed predictable patterns and could happen following warm days. Nevertheless, farmers’ awareness of changes in the climate was not, on its own, sufficient to devise effective strategies for adapting to climate change. Although farmers were aware of shifting climate patterns, they were not always able to access the kinds of resources they needed in order to adapt accordingly. Existing institutions were not able to keep up with these changes and were not able to help farmers meet their needs because of bureaucratic, financial, and legal conditions that were not in place or that were not able to respond effectively to the time-sensitivity of agricultural cycles. Farmers identified two specific limitations to institutional responsiveness to the effects of climate change.

First, farmers told us they had insufficient funds to build additional reservoirs for water storage, which would enable them to take advantage of increased precipitation during the months of January and February. In all four districts, farmers made comments such as, “building more reservoirs is our top priority” for dealing with observed changes in climate. Local irrigation commissions were not well equipped for requesting funds because, at the time of our study, these local institutions had no legal personhood, which is required when requesting government funding. In response, irrigation commission leaders had submitted written requests for funding through their municipality, and some had also looked into getting assistance from the regional Water Users’ Association, which is supposed to assist Colca Valley irrigation commissions with the building of new irrigation infrastructure. Leaders, however, told us that municipalities were highly bureaucratic and slow-paced in

processing their requests. Moreover, the municipalities and the Water Users' Association had very limited access to funds. Interviewees told us that, even if they received funding, it would not cover the full costs of building a reservoir.

Second, farmers told us that their traditional irrigation practices were no longer as effective with the advent of warmer temperatures. At the time of the study, farmers in the Colca Valley practiced furrow irrigation, a practice that can be traced to pre-Inca times (Guillet 1992). To address water scarcity caused by the increased temperatures, some farmers had begun experimenting with water-saving irrigation methods such as sprinklers. However, water-saving irrigation was incompatible with the rules inherited by the local irrigation commissions, which were originally designed to manage furrow irrigation. In Lari, for example, farmers using sprinklers were allotted the same amount of irrigation time as the farmers that practiced furrow irrigation. Even though sprinklers used less water, they were still subjected to the same irrigation schedule as the farmers who flooded their fields. Furthermore, farmers said they often had issues with sprinkler technology because the water in sprinklers' tubes froze in the mornings and evenings, which further limited their ability to irrigate. Using sprinklers was also more time consuming and cumbersome than practicing furrow irrigation because it required farmers to transport the sprinklers to their various plots that were scattered across the district. Faced with the limitations posed by their traditional rules for furrow irrigation and by inefficiencies in sprinkler technology, leaders expressed the need for experts outside their community to help them design an improved irrigation system. One irrigation commission president said, "We need capacity-building. According to experts, water-saving irrigation leads to more efficient water use. But we lack the infrastructure and a plan [for transitioning]."

DISCUSSION AND CONCLUSION

Our results indicate that existing ILK systems for crop planting and irrigation are becoming less effective at managing agricultural practices because of climate change, despite farmer observations that documented shifts and proposed strategies to address changes. With shifts in temperature, farmers experienced a decline in their perceived ability to anticipate frost days. Although farmers were aware of a shift in the rainy season and of increased temperatures, institutions and practices that have been followed since pre-Inca times were experiencing stress, and were not able to respond rapidly to manage crops and irrigation water.

Farmers' ILK systems reflected the perceived changes in climate; however, simply observing these changes did not necessarily help them manage their effects. Farmers expressed the need for additional support in terms of infrastructure, capital, and specialized information to help implement local environmental and institutional management practices (Sanga et al. 2013). Even though farmers were beginning to adapt their practices by applying for funding to build reservoirs through their municipality and Water Users' Association, as well as by experimenting with water-saving irrigation methods, these changes may not be happening fast enough to avoid the negative consequences of climate change. Scholars have shown that governance systems and infrastructure that were successful in the past may no longer be effective in the context of a rapidly changing climate with increased uncertainty (Dietz et al. 2003, Hallegatte

2009, Fernández-Llamazares et al. 2015). Our study indicates that climate change can create tensions within ILK systems and across observations, institutional practices, and the contexts in which ILK systems operate. In the Colca Valley, there is a tension between knowledge of climate change and the local institutions and practices that, because of a wide variety of internal and external stressors, are unable to adapt fast enough.

Our study contributes to the literature on ILK systems in the context of climate change in two ways. First, we explored the diverse ways in which knowledges, institutions, and practices were integrated and organized in heterogeneous rural farming communities. In exploring these arenas separately, we analyzed how climate change can impact different components of ILK systems unevenly. Specifically, we showed that new types of knowledge can develop in response to climate change, but that they may be at odds with the long-standing institutions and practices that shift more slowly. This gap between new and old components of ILK systems should be an area of focus in future studies and initiatives geared toward climate change adaptation. Breaking down the different components of ILK systems could help inform more specific guidance for designing possible strategies for climate change adaptation in localized contexts with complex governance regimes.

Second, our study stresses the need to integrate ILK systems into both short- and long-term policy decisions when they are under threat. We identified some local priorities in an area where ILK systems were eroding because of external drivers of change, which can provide insights for devising targeted solutions that meet local needs. Specifically, the stressors identified by local farmers point to the need to understand local priorities in the context of their local institutions, the specificities of the agricultural cycles in the region, and the broader bureaucratic, technical, and legal conditions in which local institutions operate. Although scholars and practitioners are increasingly emphasizing the importance of ILK systems in informing larger scale conservation initiatives, interlocking factors of ILK systems need to be taken into account (Hallegatte 2009, Hulme et al. 2012, Nursey-Bray et al. 2014, Tunón et al. 2015). For example, to enhance resilience and adaptive capacity for natural resource management, Dietz et al. (2003) advocate building nested institutions at various governance levels in a way that accurately reflects local issues and priorities for natural resource management. Scholars also recommend including ILK in regional, national, and international environmental policies (Lee et al. 2019). However, institution building and policy making are often lengthy processes that require much iteration and back-and-forth deliberation (Ostrom 1990). Although this type of institution building might be ideal in the long term, it is not clear how it can help local resource users adapt to climate change in the short term.

Nor is it clear how, to what extent, and for what purpose ILK systems should be involved in climate change adaptation strategies. Our study found that ILK systems were under threat in Peru's Colca Valley, which supports previous studies conducted in other parts of the world that reported the same phenomenon (Kai et al. 2014, Aswani et al. 2018, Joa et al. 2018, Cámara-Leret et al. 2019). We argue that designing institutions for climate change adaptation is a context-specific process, which may or may not derive from local demand for knowledge coproduction. The

farmers interviewed for our study conveyed a sense of urgency in needing quick solutions to their concrete problems, such as a predictable window for crop planting and an effective system for water-saving irrigation. Our research indicates that farmers might prefer non-local assistance for quick and targeted problem solving (Popovici et al. 2021), at least in the short term, but may not have the power-sharing structures in place that coproduction processes promote. In contrast, approaches such as knowledge coproduction that are lengthy and time-intensive may not be able to keep up with the urgency at which changes are needed. Nor do they acknowledge the difficulties that arise in situations where local resource users have reduced capacity or prefer not to engage in initiatives that require extensive in-person and verbal participation (Cleaver 1999, Popovici et al. 2021). To be effective, long-term institution-building initiatives should be paired with short-term solutions such as targeted consultations that address specific and immediate local needs while continuing to address overall processual and power-sharing features of integrating ILK into policy decisions.

Responses to this article can be read online at:
<https://www.ecologyandsociety.org/issues/responses.php/12481>

Acknowledgments:

Funds to support research in the Arequipa Nexus Institute for Food, Energy, Water, and the Environment were provided by the Universidad Nacional de San Agustín. We thank our research participants in the districts of Cabanaconde, Madrigal, Lari, and Yanque.

Data Availability:

The data code that support the findings of this study are available on request from the corresponding author, Ruxandra Popovici. The data code are not publicly available because of restrictions enforced by the Institutional Review Board, because the data contains information that could compromise the privacy of research participants.

LITERATURE CITED

Armitage, D., F. Berkes, A. Dale, E. Kocho-Schellenberg, and E. Patton. 2011. Co-management and the co-production of knowledge: learning to adapt in Canada's Arctic. *Global Environmental Change* 21(3):995-1004. <https://doi.org/10.1016/j.gloenvcha.2011.04.006>

Arteaga, N. L. E., and N. J. E. Burbano. 2018. Efectos del cambio climático: una mirada al Campo. *Revista de Ciencias Agrícolas* 35(2):79-91. <https://doi.org/10.22267/rcia.183502.93>

Aswani, S., A. Lemahieu, and W. H. H. Sauer. 2018. Global trends of local ecological knowledge and future implications. *PLoS ONE* 13(4):e0195440. <https://doi.org/10.1371/journal.pone.0195440>

Benyei, P., A. Guadalupe, and V. Reyes-García. 2020b. Storing and sharing: a review of Indigenous and local knowledge

conservation initiatives. *Ambio* 49:218-230. <https://doi.org/10.1007/s13280-019-01153-6>

Benyei, P., M. Pardo-de-Santayana, L. Aceituno-Mata, L. Calvet-Mir, M. Carrascosa-García, M. Rivera-Ferre, A. Perdomo-Molina, and V. Reyes-García. 2020a. Participation in citizen science: insights from the CONECT-e case study. *Science, Technology, & Human Values* 46(4):755-788. <https://doi.org/10.1177/0162243920948110>

Burnham, M., Z. Ma, and B. Zhang. 2016. Making sense of climate change: hybrid epistemologies, socio-natural assemblages and smallholder knowledge. *Area* 48(1):18-26. <https://doi.org/10.1111/area.12150>

Byg, A., and J. Salick. 2009. Local perspectives on a global phenomenon: climate change in Eastern Tibetan villages. *Global Environmental Change* 19(2):156-166. <https://doi.org/10.1016/j.gloenvcha.2009.01.010>

Cámara-Leret, R., M. A. Fortuna, and J. Bascompte. 2019. Indigenous knowledge networks in the face of global change. *PNAS* 116(20):9913-9918. <https://doi.org/10.1073/pnas.1821843116>

Christie, M., B. Martín-López, A. Church, E. Siwicka, P. Szymonczyk, and J. M. Sauterel. 2019. Understanding the diversity of values of "Nature's contributions to people": insights from the IPBES Assessment of Europe and Central Asia. *Sustainability Science* 14:1267-1282. <https://doi.org/10.1007/s11625-019-00716-6>

Cleaver, F. 1999. Paradoxes of participation: questioning participatory approaches to development. *Journal of International Development* 11(4):597-612. [https://doi.org/10.1002/\(SICI\)1099-1328\(199906\)11:4<597::AID-JID610>3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1099-1328(199906)11:4<597::AID-JID610>3.0.CO;2-Q)

Cornell, S., F. Berkhout, W. Tuinstra, J. D. Tabara, J. Jäger, I. Chabay, B. de Wit, R. Langlais, D. Mills, P. Moll, I. M. Otto, A. Petersen, C. Pohl, and L. Kerkhoff. 2013. Opening up knowledge systems for better responses to global environmental change. *Environmental Science & Policy* 28:60-70. <https://doi.org/10.1016/j.envsci.2012.11.008>

Danielsen, F., E. Topp-Jørgensen, N. Levermann, P. Løvstrøm, M. Schiøtz, M. Enghoff, and P. Jakobsen. 2014. Counting what counts: using local knowledge to improve Arctic resource management. *Polar Geography* 37(1):69-91. <https://doi.org/10.1080/1088937X.2014.890960>

De Longueville, F., P. Ozer, F. Gemenne, S. Henry, O. Mertz, and J. Ø. Nielsen. 2020. Comparing climate change perceptions and meteorological data in rural West Africa to improve the understanding of household decisions to migrate. *Climatic Change* 160:123-141. <https://doi.org/10.1007/s10584-020-02704-7>

Díaz-Reviriego, I., E. Turnhout, and S. Beck. 2019. Participation and inclusiveness in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Nature Sustainability* 2:457-464. <https://doi.org/10.1038/s41893-019-0290-6>

Dietz, T., E. Ostrom, and P. C. Stern. 2003. The struggle to govern the commons. *Science* 302(5652):1907-1912. <https://doi.org/DOI:10.1126/science.1091015>

Eckert, L. E., N. X. Claxton, C. Owens, A. Johnston, N. C. Ban, F. Moola, and C. T. Darimont. 2020. Indigenous knowledge and

- federal environmental assessments in Canada: applying past lessons to the 2019 impact assessment act. *FACETS* 5(1):67-90. <https://doi.org/10.1139/facets-2019-0039>
- Erwin, A., Z. Ma, R. Popovici, E. P. Salas O'Brien, L. Zanotti, E. Zeballos Zeballos, J. Bauchet, N. Ramirez Calderón, and G. R. Arce Larrea. 2021. Intersectionality shapes adaptation to social-ecological change. *World Development* 138:105282. <https://doi.org/10.1016/j.worlddev.2020.105282>
- Fernández-Llamazares, Á., I. Díaz-Reviriego, A. C. Luz, M. Cabeza, A. Pyhälä, and V. Reyes-García. 2015. Rapid ecosystem change challenges the adaptive capacity of local environmental knowledge. *Global Environmental Change* 31:272-284. <https://doi.org/10.1016/j.gloenvcha.2015.02.001>
- Gadgil, M. 2000. People's biodiversity registers: lessons learnt. *Environment, Development and Sustainability* 2(3):323-332. <https://doi.org/10.1023/A:1011438729881>
- Galappaththi, E. K., J. D. Ford, E. M. Bennett, and F. Berkes. 2019. Climate change and community fisheries in the Arctic: a case study from Pangnirtung, Canada. *Journal of Environmental Management* 250:109534. <https://doi.org/10.1016/j.jenvman.2019.109534>
- Gómez-Baggethun, E., E. Corbera, and V. Reyes-García. 2013. Traditional ecological knowledge and global environmental change: research findings and policy implications. *Ecology and Society* 18(4):72. <https://doi.org/10.5751/ES-06288-180472>
- Guillet, D. 1992. *Covering ground: communal water management and the state in the Peruvian highlands*. University of Michigan Press, Ann Arbor, Michigan, USA. <https://doi.org/10.3998/mpub.10159>
- Hallegatte, S. 2009. Strategies to adapt to an uncertain climate change. *Global Environmental Change* 19(2):240-247. <https://doi.org/10.1016/j.gloenvcha.2008.12.003>
- Hill, R., Ç. Adem, W. V. Alangui, Z. Molnár, Y. Aumeeruddy-Thomas, P. Bridgewater, M. Tengö, R. Thaman, C. Y. Adou Yao, F. Berkes, J. Carino, M. Carneiro da Cunha, M. C. Diaw, S. Díaz, V. E. Figueroa, J. Fisher, P. Hardison, K. Ichikawa, P. Kariuki, M. Karki, P. O. B. Lyver, P. Malmer, O. Masardule, A. A. Oteng Yeboah, D. Pacheco, T. Pataridze, E. Perez, M. M. Roué, H. Roba, J. Rubis, O. Saito, and D. Xue. 2020. Working with indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. *Current Opinion in Environmental Sustainability* 43:8-20. <https://doi.org/10.1016/j.cosust.2019.12.006>
- Hirsch, R. M., J. R. Slack, and R. A. Smith. 1982. Techniques of trend analysis for monthly water quality data. *Water Resources Research* 18(1):107-121. <https://doi.org/10.1029/WR018i001p00107>
- Hulme, M., J. Vogel, and B. Wynne. 2012. Listen to the voices of experience. *Nature* 488:454-455. <https://doi.org/10.1038/488454a>
- Joa, B., G. Winkel, and E. Primmer. 2018. The unknown known: a review of local ecological knowledge in relation to forest biodiversity conservation. *Land Use Policy* 79:520-530. <https://doi.org/10.1016/j.landusepol.2018.09.001>
- Kai, Z., T. S. Woan, L. Jie, E. Goodale, K. Kitajima, R. Bagchi, and R. D. Harrison. 2014. Shifting baselines on a tropical forest frontier: extirpations drive declines in local ecological knowledge. *PLoS ONE* 9(1):e86598. <https://doi.org/10.1371/journal.pone.0086598>
- Klein, J. A., K. A. Hopping, E. T. Yeh, Y. Nyima, R. B. Boone, and K. A. Galvin. 2014. Unexpected climate impacts on the Tibetan Plateau: local and scientific knowledge in findings of delayed summer. *Global Environmental Change* 28(1):141-152. <https://doi.org/10.1016/j.gloenvcha.2014.03.007>
- Klenk, N., A. Fiume, K. Meehan, and C. Gibbes. 2017. Local knowledge in climate adaptation research: moving knowledge frameworks from extraction to co-production. *WIREs Climate Change* 8(5):e475. <https://doi.org/10.1002/wcc.475>
- Kumar, S., V. Merwade, J. Kam, and K. Thurner. 2009. Streamflow trends in Indiana: effects of long term persistence, precipitation and subsurface drains. *Journal of Hydrology* 374 (1-2):171-183. <https://doi.org/10.1016/j.jhydrol.2009.06.012>
- Lam, D., E. Hinz, D. Lang, M. Tengö, H. von Wehrden, and B. Martín-López. 2020. Indigenous and local knowledge in sustainability transformations research: a literature review. *Ecology and Society* 25(1):3. <https://doi.org/10.5751/ES-11305-250103>
- Lane, A., and A. Jarvis. 2007. Changes in climate will modify the geography of crop suitability: agricultural biodiversity can help with adaptation. *Journal of SAT Agricultural Research* 4(1):1-12. [online] URL: <http://ejournal.icrisat.org/SpecialProject/sp2.pdf>
- Lee, L. C., J. Thorley, J. Watson, M. Reid, and A. K. Salomon. 2019. Diverse knowledge systems reveal social-ecological dynamics that inform species conservation status. *Conservation Letters* 12(2):e12613. <https://doi.org/10.1111/conl.12613>
- Lettenmaier, D. P., E. F. Wood, and J. R. Wallis. 1994. Hydroclimatological trends in the continental United States, 1948-88. *Journal of Climate* 7(4):586-607. [https://doi.org/10.1175/1520-0442\(1994\)007<0586:HCTITC>2.0.CO;2](https://doi.org/10.1175/1520-0442(1994)007<0586:HCTITC>2.0.CO;2)
- McElwee, P., Á. Fernández-Llamazares, Y. Aumeeruddy-Thomas, D. Babai, P. Bates, K. Galvin, M. Guèze, J. Liu, Z. Molnár, H. T. Ngo, V. Reyes-García, R. R. Chowdhury, A. Samakov, U. B. Shrestha, S. Díaz, and E. Brondízio. 2020. Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: reviewing the experience of the IPBES Global Assessment. *Journal of Applied Ecology* 57 (9):1666-1676. <https://doi.org/10.1111/1365-2664.13705>
- Michelutti, N., C. A. Cooke, W. O. Hobbs, and J. P. Smol. 2015. Climate-driven changes in lakes from the Peruvian Andes. *Journal of Paleolimnology* 54:153-160. <https://doi.org/10.1007/s10933-015-9843-5>
- Moraes, A. G. L., L. C. Bowling, C. R. Z. Velarde, and K. A. Cherkauer. 2021. *Arequipa climate maps normals*. Version 2.0. Center for Sustainable Watershed Management of the Arequipa Nexus Institute, Purdue University, West Lafayette, Indiana, USA. <https://doi.org/10.4231/JNBNK-ZK34>
- Nursey-Bray, M. J., J. Vince, M. Scott, M. Haward, K. O'Toole, T. Smith, N. Harvey, and B. Clarke. 2014. Science into policy? Discourse, coastal management and knowledge. *Environmental Science and Policy* 38:107-119. <https://doi.org/10.1016/j.envsci.2013.10.010>

- Obermeister, N. 2019. Local knowledge, global ambitions: IPBES and the advent of multiscale models and scenarios. *Sustainability Science* 14:843-856. <https://doi.org/10.1007/s11625-018-0616-8>
- Ostrom, E. 1990. *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press, Cambridge, UK.
- Oteros-Rozas, E., R. Ontillera-Sánchez, P. Sanosa, E. Gómez-Baggethun, V. Reyes-García, and J. A. González. 2013. Traditional ecological knowledge among transhumant pastoralists in Mediterranean Spain. *Ecology and Society* 18(3):33. <https://doi.org/10.5751/ES-05597-180333>
- Paerregaard, K., A. B. Stensrud, and A. O. Andersen. 2016. Water citizenship: negotiating water rights and contesting water culture in the Peruvian Andes. *Latin American Research Review* 51(1):198-217. <https://doi.org/10.1353/lar.2016.0012>
- Popovici, R., A. Erwin, Z. Ma, L. S. Prokopy, L. Zanotti, E. F. B. Delgado, J. P. P. Cáceres, E. Z. Zeballos, E. P. S. O'Brien, L. C. Bowling, and G. R. A. Larrea. 2021. Outsourcing governance in Peru's integrated water resources management. *Land Use Policy* 101:105105. <https://doi.org/10.1016/j.landusepol.2020.105105>
- Postigo, J. C. 2014. Perception and resilience of Andean populations facing climate change. *Journal of Ethnobiology* 34(3):383-400. <https://doi.org/10.2993/0278-0771-34.3.383>
- Raymond, C. M., I. Fazey, M. S. Reed, L. C. Stringer, G. M. Robinsong, and A. C. Evely. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management* 91(8):1766-1777. <https://doi.org/10.1016/j.jenvman.2010.03.023>
- Reyes-García, V., and P. Benyei. 2019. Indigenous knowledge for conservation. *Nature Sustainability* 2:657-658. <https://doi.org/10.1038/s41893-019-0341-z>
- Riedlinger, D., and F. Berkes. 2001. Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record* 37(203):315-328. <https://doi.org/10.1017/S0032247400017058>
- Saldaña, J. 2009. *The coding manual for qualitative researchers*. Sage, London, UK.
- Salzmann, N., C. Huggel, M. Rohrer, W. Silverio, B. G. Mark, P. Burns, and C. Portocarrero. 2013. Glacier changes and climate trends derived from multiple sources in the data scarce Cordillera Vilcanota region, southern Peruvian Andes. *Cryosphere* 7(1):103-118. <https://doi.org/10.5194/tc-7-103-2013>
- Sanga, G. J., A. B. Moshi, and J. P. Hella. 2013. Small scale farmers' adaptation to climate change effects in Pangani River Basin and Pemba: challenges and opportunities', *International Journal of Modern Social Sciences* 2(3):169-194. [online] URL: <http://www.modernscientificpress.com/journals/ViewArticle.aspx?YTDXIpb35qABc+2BV/0oMPFf5GIHuxxQgImfIPePJJu99-FZfJgvxNUkRjQ9LQ6>
- Sen, P. K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* 63(324):1379-1389. <https://doi.org/10.1080/01621459.1968.10480934>
- Sinha, T., and K. A. Cherkauer. 2008. Time series analysis of soil freeze and thaw processes in Indiana. *Journal of Hydrometeorology* 9(5):936-950. <https://doi.org/10.1175/2008JHM934.1>
- Stevance, A. S., P. Bridgewater, S. Louafi, N. King, T. D. Beard Jr., A. S. Van Jaarsveld, Z. Ofir, R. Kohsaka, K. Jenderedijan, M. R. Benites, K. J. Mulongoy, K. L. Chaudhari, J. Painter, and A. Meter. 2020. The 2019 review of IPBES and future priorities: reaching beyond assessment to enhance policy impact. *Ecosystems and People* 16(1):70-77. <https://doi.org/10.1080/263-95916.2019.1702590>
- Suiseeya, K. R. M., and L. Zanotti. 2019. Making influence visible: innovating ethnography at the Paris climate summit. *Global Environmental Politics* 19(2):38-60. https://doi.org/10.1162/glep_a_00507
- Tengö, M., E. S. Brondizio, T. Elmqvist, P. Malmer, and M. Spierenburg. 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio* 43(5):579-591. <https://doi.org/10.1007/s13280-014-0501-3>
- Tengö, M., R. Hill, P. Malmer, C. M. Raymond, M. Spierenburg, F. Danielsen, T. Elmqvist, and C. Folke. 2017. Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability. *Current Opinion in Environmental Sustainability* 26-27:17-25. <https://doi.org/10.1016/j.cosust.2016.12.005>
- Thompson, K.-L., T. Lantz, and N. C. Ban. 2020. A review of Indigenous knowledge and participation in environmental monitoring. *Ecology and Society* 25(2):10. <https://doi.org/10.5751/ES-11503-250210>
- Thorntwaite, C. W. 1948. An approach toward a rational classification of climate. *Geographical review* 38(1):55-94. <https://doi.org/10.2307/210739>
- Tunón, H., M. Kvarnström, and P. Malmer. 2015. Indigenous and local knowledge in a scoping study for a Nordic IPBES assessment. Technical report 96. Swedish Biodiversity Centre, Uppsala, Sweden. <https://doi.org/10.13140/RG.2.1.4030.6004>
- Viera, A. J., and J. M. Garrett. 2005. Understanding interobserver agreement: the kappa statistic. *Family Medicine* 37(5):360-363. [online] URL: <https://fammedarchives.blob.core.windows.net/imagesandpdfs/fmhub/fm2005/May/Anthony360.pdf>
- Vogt, N., M. Pinedo-Vasquez, E. S. Brondizio, F. G. Rabelo, K. Fernandes, O. Almeida, S. Riveiro, P. J. Deadman, and Y. Dou. 2016. Local ecological knowledge and incremental adaptation to changing flood patterns in the Amazon delta. *Sustainability Science* 11(4):611-623. <https://doi.org/10.1007/s11625-015-0352-2>
- Wang, G., S. Mang, H. Cai, S. Liu, Z. Zhang, L. Wang, and J. L. Innes. 2016. Integrated watershed management: evolution, development and emerging trends. *Journal of Forestry Research* 27(5):967-994. <https://doi.org/10.1007/s11676-016-0293-3>

Appendix 1

Table A1.1. Trends in Monthly Cumulative Precipitation (mm) over the Period of 1988 to 2017 for the Different Districts

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cabanaconde	16.0	56.4*	-9.5	12.4	0.0	0.0	0.0	0.0	0.0	1.6	-3.8	-0.8
Madrigal	7.4	76.8	12.1	12.6	0.0	0.0	0.0	0.0	0.0	3.6	-5.0	8.4
Lari	9.1	75.9	10.2	19.3	0.0	0.0	0.0	0.0	0.4	4.6	-6.3	8.3
Yanque	21.3	85.6*	20.7	25.8*	0.0	0.0	0.0	0.0	1.0	1.2	-8.3	10.9

OBS: Values represent the total change for the period 1988 – 2017 based on Sen's slope trend analysis; * indicates that a statistically significant trend was found using Mann-Kendell analysis with a significance level of 0.05

Table A1.2. Trends in Monthly Potential Evapotranspiration (mm) over the Period of 1988 to 2017 for the Different Districts

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cabanaconde	4.4*	4.7*	4.1*	4.6*	2.7*	11.1*	8.5*	7.5*	10.8*	5.1*	6.4*	6.9*
Madrigal	5.3*	5.2*	4.4*	5.1*	2.7	12.8*	9.8*	8.0*	11.5*	5.0*	7.2*	7.9*
Lari	5.1*	5.1*	4.6*	5.2*	2.9	13.3*	9.9*	8.2*	11.8*	5.2*	7.4*	8.1*
Yanque	6.0*	5.2	5.3*	5.3*	2.9	15.3*	10.0*	8.9*	12.4*	6.0*	7.0*	8.5*

OBS: Values represent the total change for the period 1988 – 2017 based on Sen's slope trend analysis; * indicates that a statistically significant trend was found using Mann-Kendell analysis with a significance level of 0.05

Table A1.3. Trends in Monthly Average Maximum Daily Air Temperature (°C) over the Period of 1988 to 2017 for the Different Districts

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cabanaconde	1.1	0.6	0.8	1.0*	0.6*	2.4*	2.1*	1.9*	1.6*	0.9*	1.7*	1.4*
Madrigal	1.5*	0.9	1.0	1.1*	0.5	2.8*	2.3*	1.9*	1.9*	1.0*	2.1*	1.8*
Lari	1.6*	0.9	1.0	1.2*	0.5	2.8*	2.3*	1.9*	1.8*	1.0*	2.1*	2.0*
Yanque	1.9*	1.0	1.2	1.3	0.3	3.0*	2.5*	2.0*	1.9*	1.2*	2.3*	2.5*

OBS: Values represent the total change for the period 1988 – 2017 based on Sen's slope trend analysis; * indicates that a statistically significant trend was found using Mann-Kendell analysis with a significance level of 0.05

Appendix 1

Table A1.4. Trends in Monthly Average Minimum Daily Air Temperature (°C) over the Period of 1988 to 2017 for the Different Districts

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cabanaconde	1.4*	1.7*	1.6*	1.7*	2.0*	2.8*	2.3*	1.8*	2.7*	1.5*	1.1*	1.8*
Madrigal	1.6*	1.8*	1.9*	2.2*	2.4*	3.5*	2.7*	2.2*	3.0*	1.7*	1.3*	2.0*
Lari	1.7*	1.8*	2.0*	2.3*	2.6*	3.7*	2.9*	2.5*	3.2*	1.9*	1.4*	2.1*
Yanque	2.2*	2.4*	2.4*	2.9*	3.0*	4.4*	3.2*	3.0*	3.7*	2.1*	1.6*	2.3*

OBS: Values represent the total change for the period 1988 – 2017 based on Sen's slope trend analysis; * indicates that a statistically significant trend was found using Mann-Kendell analysis with a significance level of 0.05

Table A1.5. Trends in the Number of Days under 0 °C per Month over the Period of 1988 to 2017 for the Different Districts

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cabanaconde	0	0	0	0	-3*	-15*	-20*	-1.5	-2.1*	0	0	0
Madrigal	0	0	0	0*	-10*	-20*	-19.6*	-10*	-6.5*	0	0	0
Lari	0	0	0*	0*	-12.3*	-20*	-16*	-15*	-9.5*	0	0	0
Yanque	0*	0*	0*	0	-18*	-16.7*	-10*	-22.5*	-15*	-3.6*	0	0*

Obs: Values represent the total change for the period 1988 – 2017 based on Sen's slope trend analysis; * indicates that a statistically significant trend was found using Mann-Kendell analysis with a significance level of 0.05; a 0 followed by * means: Man-Kendal found a significant trend but Sen's slope could not measure the magnitude of the trend, all trends in this table are negative.

Appendix 1

Fig. A1.1. Monthly average Temperature and Number of Days with Temperature Below 0°C for the Periods of 1988 to 1997 and 2008 to 2017 in the Cabanaconde District

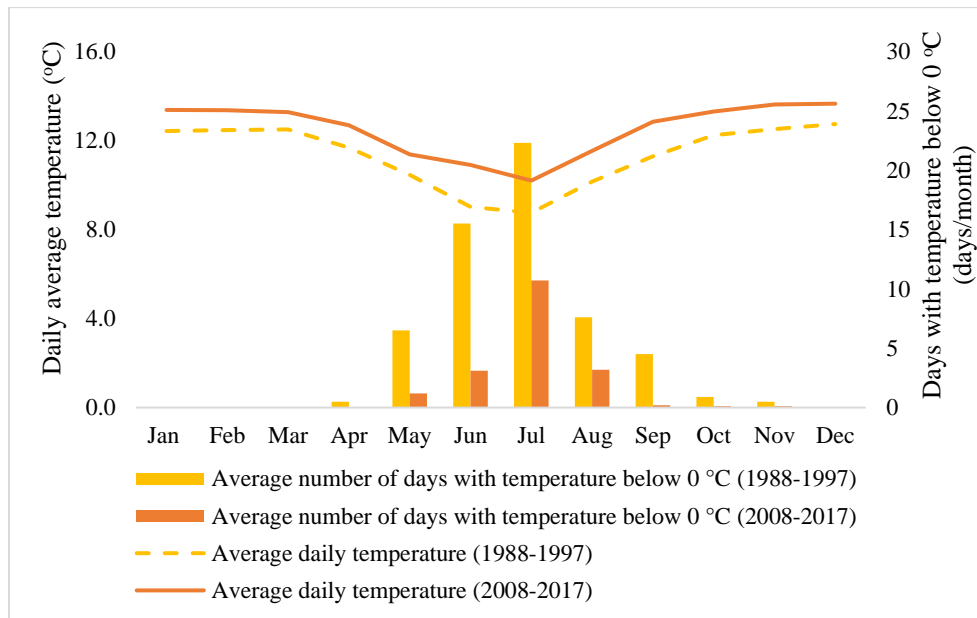
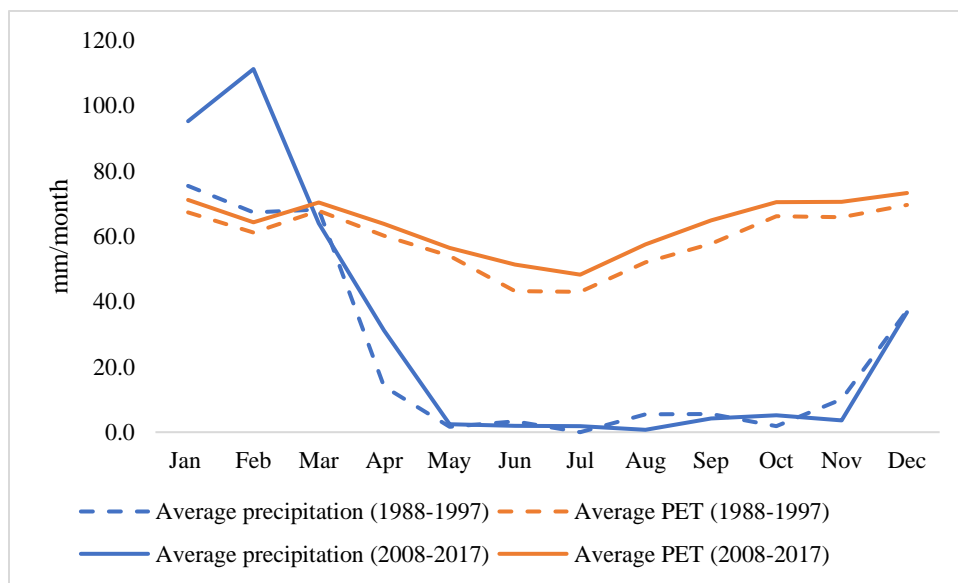


Fig. A1.2. Monthly Average Precipitation and Potential Evapotranspiration (PET) for the Periods of 1988 to 1997 and 2008 to 2017 in the Cabanaconde District



Appendix 1

Fig. A1.3. Monthly Average Temperature and Number of Days with Temperature below 0°C for the Periods of 1988 to 1997 and 2008 to 2017 in the Madrigal District

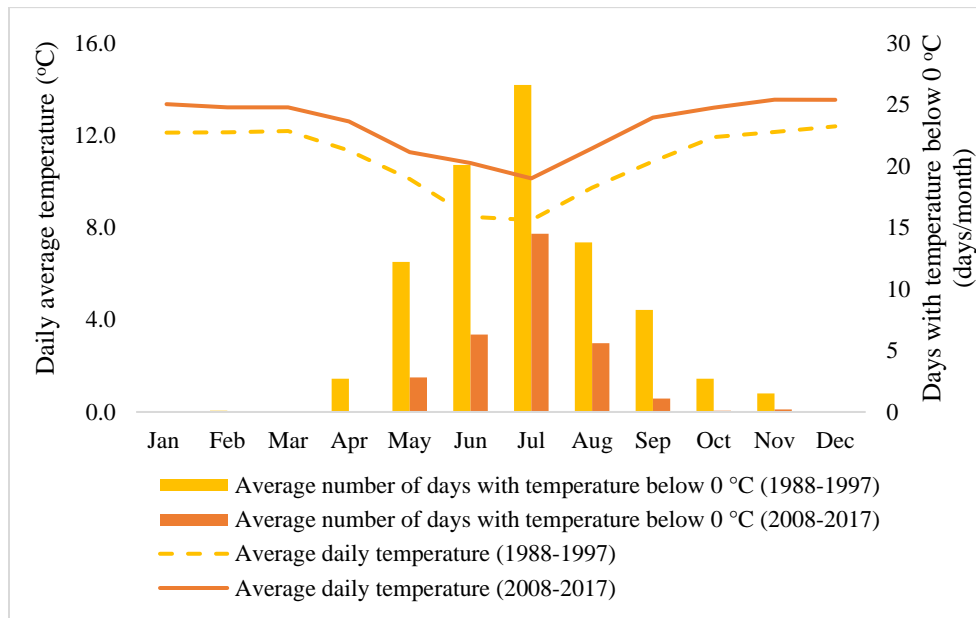
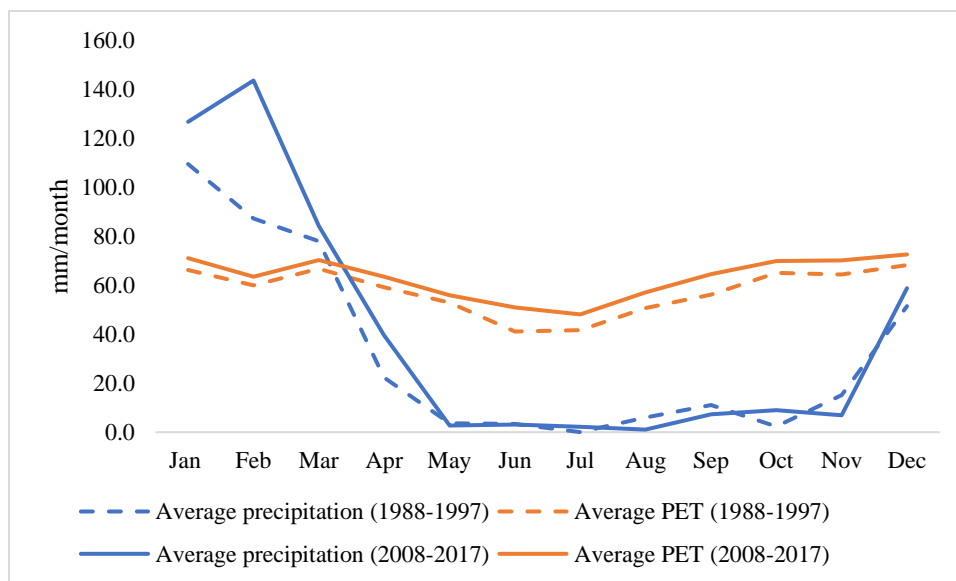


Fig. A1.4. Monthly Average Precipitation and Potential Evapotranspiration (PET) for the periods of 1988 to 1997 and 2008 to 2017 in the Madrigal District



Appendix 1

Fig. A1.5. Monthly Average Temperature and Number of Days with Temperature Below 0°C for the Periods of 1988 to 1997 and 2008 to 2017 in the Yanque District

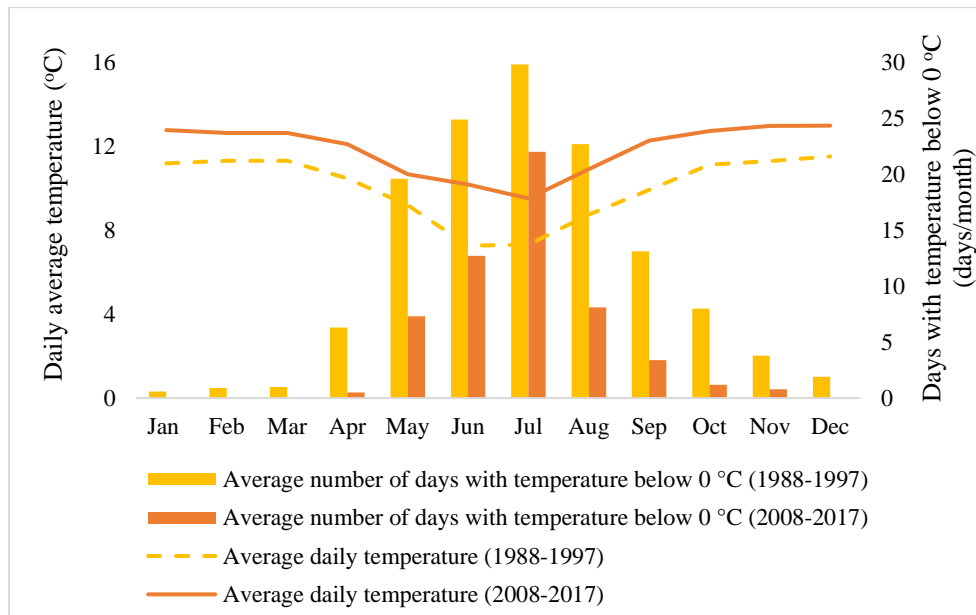


Fig. A1.6. Monthly Average Precipitation and Potential Evapotranspiration (PET) for the Periods of 1988 to 1997 and 2008 to 2017 in the Yanque District

