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PERCEPTION AND RESILIENCE OF ANDEAN POPULATIONS FACING CLIMATE CHANGE

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The Andean Tropics are among the mountain systems most affected by climate change. The most conspicuous effect is glacier recession. However, little is known about how rural populations perceive climatic change impacts or about how social-ecological systems respond to the effects of change. Here, I examine perceptions of climatic change and their effects on social-ecological systems in the Peruvian Southern Andes. Data from interviews and focus groups are used to explain institutional responses to climatic variability based upon perceived effects of climate change. Results show that people perceive glaciers shrinking, more frequent and intense extreme weather events, more extreme temperatures, and shortened rainy seasons. Their responses to these perceived changes range from wetland creation to agriculture calendar modification to irrigation adjustments. Such perceptions of change rely on personal observations and local knowledge, which inform responses; knowledge-based action characterizes resilient systems. This case study supports the conclusion that the resilience of social-ecological systems in the Peruvian Southern Andes is based upon local knowledge and institutions. Thus, strengthening institutions and fostering local knowledge renewal are crucial for systems' sustainability or transformation.

Los Andes tropicales están entre los sistemas de montaña más expuestos y afectados por el cambio climático, cuyo efecto más conspicuo es el retiro glaciar. Poco se sabe aún sobre las percepciones de las poblaciones rurales respecto del cambio climático o de las respuestas de los sistemas socio-ecológicos a los efectos de dicho cambio. En este artículo, examino las percepciones sobre el cambio climático y los impactos de este último en los sistemas socio-ecológicos del sur-andino peruano. Datos de entrevistas y grupos focales son usados para explicar tanto las percepciones de los efectos del cambio climático como las respuestas institucionales a la variabilidad climática. Los resultados muestran que la población percibe el retiro glaciar, los eventos climáticos más prolongados e intensos, las temperaturas más extremas y una estación de lluvias acortada. Asimismo, las respuestas a estos cambios percibidos incluyen la creación de humedales, la modificación del calendario agrícola, y el ajuste de los turnos de riego. Las percepciones del cambio se basan en observaciones y el conocimiento local, los mismos que informan las respuestas. Los sistemas resilientes se caracterizan por responder con base en la información. Este estudio de caso sustenta la conclusión que los sistemas socio-ecológicos resilientes del sur andino peruano se basan en conocimiento local e instituciones. Por lo tanto, el fortalecimiento institucional y la promoción de la renovación del conocimiento local son cruciales para la sostenibilidad o transformacion de los sistemas.

Keywords: *local knowledge, social-ecological systems, adaptation*

Introduction

Climate change and related evidence of warmer atmosphere and oceans, shrinking ice and snow, rising sea levels, and soaring concentrations of greenhouse gases are uncontested and unequivocal (IPCC 2013; Mora et al. 2013). The impacts of climate change are widely recognized, and the international

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effort to address these impacts is growing significantly. Climate-related losses in Peruvian agriculture between 1995 and 2007 consist of 445,707 ha of crops and around $910 million USD (Ministerio del Ambiente-MINAM 2010). Between 2006 and 2007, extreme weather events triggered losses in the agriculture sector that amounted to $90 million USD. Potato, maize, barley, and fava bean were the most impacted crops (Vega and Bucher 2013).

When investigating these events it is important to consider both the impacts of an event/process as well as the probability that such an event/process will occur; these two factors comprise the ''space of risk'' (Jones and Preston 2011; National Research Council 2010). The boundaries of this theoretical space are acceptance and intolerance while the location of this space is established by the ''coordinates'' along the axis of probability and impact (Renn and Klinke 2013). One trouble with defining the space of risk is that classifying risks on the spectrum of acceptable to intolerable is a highly debated process in part because of the underlying sociocultural factors and policy consequences of any assessment (Hultman et al. 2010; Renn and Klinke 2013). Perceptions of risks' magnitude and direction (amplification or attenuation), depend on social interactions (Renn 2011) and culture (Adger et al. 2013). Further, perceptions are chiefly determined by social, institutional, cultural, and individual factors (National Research Council 2010; Oliver-Smith 1996; Renn 2011; Slovic 1987). To transition from general frameworks and concepts to concrete adaptive actions, case studies detailing specific impacts and responses are needed (Smit et al. 1999).

This paper contributes to that agenda by presenting the perceived impacts of climatic changes and responses to it by a rural population in the Peruvian Southern Andes. Responses generally occurred when the risk assessment for a perceived climatic threat was tolerable but the community wanted to lower the risk assessment to acceptable and prevent it from becoming intolerable. Responses are expected to reduce an actual or potential risk posed by the climate-related threat to culture, livelihood systems, or lifestyles (Adger et al. 2013). The focus on perceived impacts-responses suggests that perceived impacts are the most relevant for the population. This focus also avoids the contested terrain of risk classification, whereby implementing a response implies that the risk has already been classified, and the inescapable trade-offs, subjective valuation, and estimations of the responses have been sorted out (Hultman et al. 2010; National Research Council 2010).

The purpose of this paper is neither to critically analyze local perceptions nor to judge their accuracy; other work has examined the accuracy and relevance of such perceptions in Peru and the region (Valdivia et al. 2010; Vega and Bucher 2013). Instead, I address how herders and farmers in the Peruvian Southern Andes perceive and respond to climatic changes. Additionally, this paper evaluates the role of local knowledge in the responses collected within the study region—specifically, people's knowledge of ecosystem dynamics, resources, and management practices (Folke 2004; Folke et al. 2005; Kronik and Verner 2010).

Indigenous and local populations are responding to climate change, manifested as increasing climatic intra- and inter-annual climate perturbations, through dynamic knowledge systems (Adger et al. 2013; Nelson et al. 2007). The importance of local responses is enhanced by the fact that climate change impacts are not evenly distributed over landscapes and rural populations (Boillat and Berkes 2013). These responses rest upon localized traditional knowledge systems and experience (Kronik and Verner 2010). Existing local knowledge may be recognized and incorporated into policies to enhance local peoples' adaptive capacity (Leclerc et al. 2013). Thus, local knowledge systems are active elements of peasants' adaptive capacity to environmental change (Boillat and Berkes 2013; Kronik and Verner 2010). These adaptations are based on past experience but also interpreted in light of current events through new generations (Bustamante Becerra 2006; Erickson 1999; Rhoades 2006; Valdivia et al. 2010; Vos 2010). For example, elder members of communities in the study region are recognized as knowledge keepers; they identify and interpret signals in the natural world to provide forecasts of weather and climate conditions (Boillat and Berkes 2013; Valdivia et al. 2010). These signals are a combination of astronomical features such as position and brightness of constellations and the moon (Cane et al. 2000), wind directions, and cloud shapes. In addition to local knowledge, social and landscape capital are key components of such adaptations (Adger et al. 2007; Agrawal 2010; Bebbington 1999; Blaikie and Brookfield 1987; Valdivia et al. 2010).

The effects of more frequent and severe extreme events have led to government assessments as well as policies to mitigate such effects and to adapt to change (e.g., Adger et al. 2007; Easterling et al. 2007; IPCC 2013). Government evaluations of climate change impacts inform national and regional measures to mitigate at the local level. These measures and local responses usually overlap on the ground. Thus, the local landscape can become a space for contestation between traditional-local and scientific non-local knowledge. Moreover, these knowledge systems do not only embody contestation of who has a better understanding of environmental change at the landscape level, but also who will guide decisions about how to respond. In this type of context, knowledge and landscape become political. Another perspective sees these knowledge systems as complementing each other, suggesting that both should be integrated in order to generate robust adaptive responses to climate change (Folke 2004; Kronik and Verner 2010). This paper contributes to this knowledge-complementarity perspective by focusing on the local knowledge (and responses) of a rural population in the Peruvian Southern Andes. In doing so, it highlights key elements that would have been included in climate-related adaptive management policies had they been elaborated by synergistically integrating knowledge of all stakeholders for sustainability (National Research Council 2010).

The social-ecological systems (SES) of the Peruvian Southern Andes are examples of landscapes that have become politicized by climatic variability and change. Further, these changes have constituted external disturbances to the SES. The interactions between SES and disturbance—including the role played by change in the development, maintenance, and transformation of the Peruvian Southern Andes—represent a case that can be analyzed within the conceptual framework of resilience thinking (Folke et al. 2010). In this framework, adaptive capacity is crucial for SES resilience through the dynamic interactions between continuity and development related to disturbance (Folke 2006). In SES, adaptive capacity is increasingly part of the social sub-system because humans manage much of the system (Berkes et al. 2003). As a result, in the context of climate change impacts, sustainability of SES relates directly to adaptive capacity (Boillat and Berkes 2013). Perceptions of climate change and responses to climate change impacts discussed in this paper are clearly expressions of such capacity. Thus, the research presented here enriches understanding of the adaptive capacity-vulnerability trade-offs in local SES, which may help improve environmental stewardship of global-scale SES (Janssen et al. 2007).

Study Area

This research was conducted in the departments of Puno, Arequipa, and Cusco in the Peruvian Southern Andes. Specifically, fieldwork was conducted in three provinces within these departments: 1) Carabaya (Puno); 2) Caylloma (Arequipa); and 3) Canas (Cusco) (Figure 1). This complex Andean landscape combines diverse biophysical characteristics with long-term human occupation, resulting in a heterogeneous mosaic of spatially and temporally dynamic land covers and uses (Maxwell 2011; Vos 2010; Young 2009; Young et al. 2007; Zimmerer 1999). For instance, in the highlands, glaciers and ice fields dominate the landscape wherein pastoralists have used dry alpine vegetation (i.e., *puna*) to herd alpaca, llama, and sheep.

Below the zone of exclusive livestock herding, in the Altiplano and intermountain valleys, farming has taken place since 1600 BC (Jackson et al. 2007; Moseley 2001), and raised field agriculture started 3000 years ago in the area surrounding Lake Titicaca (Erickson 1992; Kolata 1986). Recent transformations (in the last quarter of the twentieth century) driven by changing farming practices include major conversion of dry lands into farmland through irrigation projects (Ertsen et al. 2010; Mayer 2002; Young 2008). These projects have had major impacts on the landscape. For example, between 1985 and 2001, the desert of Arequipa shrank 12%, while urban and agriculture areas grew by 12% and 34% respectively (Polk et al. 2005).

Diverse land tenure systems and institutions regulating access and control of resources (i.e., land and water) also characterize the study region. In the high elevation zone of exclusive pastoralism, though land tenure is characterized by formal communal property, extended families within the community are the social institutions that control grazing areas, often over centuries. Below this zone, agropastoralism is the dominant type of land use. Within the higher elevation zone, a communal, sectoral fallow system takes place: cultivation of potatoes (first year) and barley (second year), with livestock grazing in the fallowing fields (e.g., Orlove and Godoy 1986; Zimmerer 1991). Lower-elevation lands are dedicated to cultivating rain-fed cash crops that are sometimes also irrigated. The lower the elevation the more dominant agriculture becomes—below agropastoral lands the cultivation of maize, wheat, and barley is prevalent. In the lowest zone, small (<5 ha) and medium-sized (5–20 ha) farms, which are privately owned, are engaged in irrigated commercial agriculture of fruits, onions, and paprika as well as alfalfa for the dairy industry. Farmers are

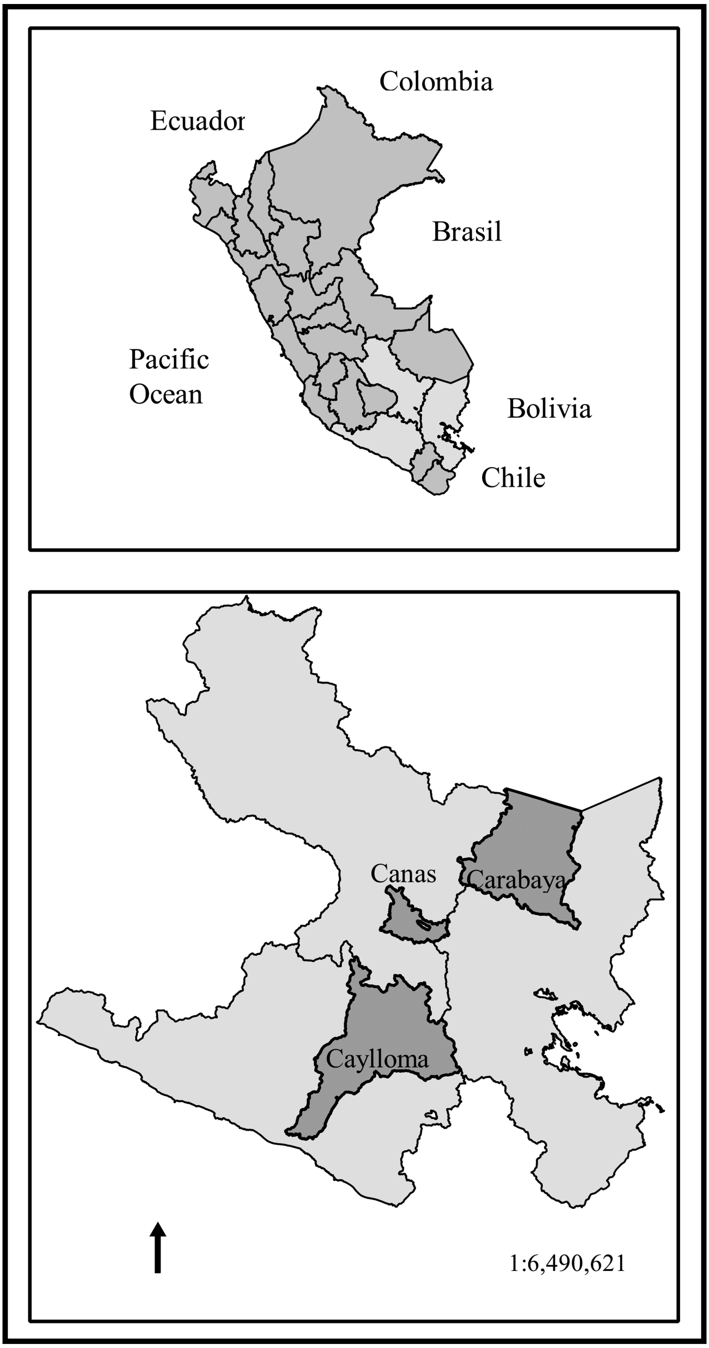

Figure 1. Top: Peru (dark grey) and the Peruvian Southern Andes (the three departments are in lighter grey). Below the three departments (in lighter grey) and the three provinces (dark grey).

organized into water boards (*juntas de usuarios*) that regulate water access and maintain irrigation systems (e.g., channels and gates).

Methods

In the fall of 2009, 17 peasant communities were sampled in the provinces of Carabaya, Caylloma, and Canas in the departments of Puno, Arequipa, and Cusco, respectively (see Figure 1). I use the term peasant deliberately, following the lead of extensive research on the Andes (e.g., Boillat and Berkes 2013; Crabtree 2002; Mayer 2002; Sendón 2001). Peasant (i.e., *campesino*) is an official category created during the Agrarian reform to overcome the discrimination and pejorative meaning of indigenous (i.e., *indio*) in the Peruvian Andes.

Information about rural population responses to climate change was obtained through 29 semi-structured interviews with community authorities, leaders, water board officials, and key informants, as well as three focus groups with peasants in Cabanaconde (Arequipa; 12 people), Tinta (Cusco; 20 women only) and Quelcaya (Puno; ten herders). Interviews addressed the themes of (1) perceptions of climatic changes and their effects, and (2) responses to perceived changes and effects. Data were analyzed through descriptive statistics and textual analysis, the goal of which was to find patterns among perceptions of climate change and shared responses to it.

The selected communities cover the range of Andean farming systems from mainly agriculturalist to exclusively pastoralist, from land tenure regimes of communal property to individual private property, and from farming systems with traditional technologies (e.g., terraces) to modern systems (e.g., drip irrigation). This diversity of systems of Andean farming allowed for observations on the full array of adaptive responses by peasants to climate change impacts and how such responses vary by system (e.g., pastoralists vis-à-vis farmers).

Results

Data gathered through focus groups and interviews reveal rural peoples' perceptions of climate change in the Peruvian Southern Andes. While glacier shrinkage is quite visible (particularly as perceived among elders who have been observing the glaciers for more time), participants also highlighted shorter rainy seasons and warmer days and colder nights as noticeable changes in the region. The modified patterns are perceived to negatively impact important agrarian resources such as soils and livestock. More intense but irregular rainfall—interrupted by dry and warmer periods—degrades the soil, increases the likelihood of pests, and produces ponds of stagnant water that affect livestock health. Similarly, delayed onset of the rainy season has proven detrimental to crops. Further, herders and peasants explained that effects of climatic change on the landscape are impacting wetlands, resulting in less water available in both river flow and runoff, and a wider altitudinal range of pests across the study area.

Responses to change have used local ecological knowledge, adjustment of agricultural activities, and institutional capacity. The following section summarizes the effects of climate change from the highlands to the lowlands as perceived by herders and peasants.

Perceived Climatic Change Effects in the Peruvian Southern Andes

The findings from my research suggest that rural people in the Peruvian Southern Andes have noticed climate change through glacier shrinkage and shifts in precipitation patterns over the seven to nine years preceding the study. Glacier retreat was stated as one of the most conspicuous effects of climate change. Most elder herders remember that glacier tongues extended downward for hundreds of meters, reaching the location of their huts in the past. Nowadays, however, these same herders see that glacier tongues have withdrawn to higher elevations while all herders complained about pasture and wetland shrinkage and/or displacement. This effect is significant because of the importance of pasture and wetlands for high Andean livestock husbandry and other ecosystem functions. Consequently, the vast majority of herders have created wetlands through irrigation for a long time. Initially, this was done to expand the available area of wetlands; more recently, according to the survey data, it is a response to the decreasing area and amount of wetlands.

In addition to glaciers receding, all participants noted that (1) the rainy season has become shorter through a delayed onset and an earlier end, and (2) precipitation has become more irregular during the rainy season, with a higher intensity when it rains but with more dry days. In Cabanaconde (Arequipa) a peasant said that ''the weather is changed … the rainy season has shortened and has become more irregular'' (el clima está cambiado…la época de lluvias se ha acortado, y llueve disparejo). The same pattern was found in Cusco, where a peasant from the community of Rosasani said:

> La época de lluvias ha reducido su duración, antes empezaba en octubre/noviembre para el sembrío y duraba hasta abril/mayo, ahora las lluvias se inician en diciembre/enero y se acaban en marzo/abril. La lluvia se ha vuelto irregular, antes llovía parejo, ahora cae una lluvia intensa tipo chaparrón por uno o dos días y luego está seco por varios días.
> The rainy season has shortened in its duration; it used to start in October/November—for sowing season—and last until April/May; now the onset of rainy season is December/January and ends in March/April. Rain has become irregular—it used to rain a constant amount, but now it rains heavily—like pouring rain for one or two days and then it is dry for several days (translation by the author).

In the community of Yanque Hurin Saya in Arequipa a peasant explained the change in precipitation as follows:

> …antes las primeras lluvias se iniciaban en noviembre, hacia el 25 de diciembre empezaban las lluvias más intensas, poco interrumpidas y bastante parejas, que duraban hasta abril. Ahora, las lluvias empiezan en enero, duran 30 días y se terminan, e incluso en ese tiempo la lluvia es interrumpida con días secos.
> …the first rains used to start in November, then around December 25 the heavier rains began, which were barely interrupted and pretty consistent until April. Now, the rainy season starts in January, lasts 30 days and it is

> over and during those 30 days rain is interrupted by dry days (translation by the author).

Twenty women from one focus group in Cusco explained that they had modified the agricultural calendar in order to adjust tasks to changes in the rainfall regime; they replaced maize with wheat and fava beans because these crops are more resistant to cold spells.

Drier conditions lead to indirect effects such as increasing abundance of pests. In the women's focus group in Cusco, they explained that higher temperatures have increased diseases in animals and plants, noticing for instance the exacerbated presence of *rancha* (*Phytophthora infestans* [Montagne] Bary) in the potatoes. Some peasants perceived that the altitudinal range of pests is expanding as they follow rising temperatures to higher elevations. In the community of Pampahuasi (Cusco), previously unknown pests are attacking the crops. Moreover, in Yanque Hurin Saya, broad beans were attacked by ''chocolate spot''—*Botrytis fabae* Sardiña. Prior to this attack, the peasants from Yanque Hurin Saya had only seen this pest at lower elevations. They attributed the pest's range expansion to increased temperatures at higher elevations. The pest's presence has led to increased pesticide use in summer by the majority of peasants, adding to production costs. A perceived side-effect of increased pesticide use is that water pollution levels have also increased. However, some peasants stated in the interviews that they also use biological pesticides and ash against worm pests.

Pests are not expanding their altitudinal range exclusively in agricultural areas. Some informants stated that there are previously unknown pests in the wetlands and that they affect grazing livestock. It is possible that increased presence of mosquitos is related to ponds of stagnant and warm water where they develop. Five herders mentioned that these mosquitos infect the animals with various blood-borne diseases, which are perceived to have increased in prevalence. Many herders stated that the incidence of pneumonia, blindness and mucosity in alpacas—and coughing, swollen hearts, and death in sheep—has increased due to harsher climatic conditions.

Four members of the water board '*Chili no Regulado*' (Arequipa) have noticed diminished runoff from springs as well as reduced river flow, which they attribute to the fact that some small springs have dried up. Less runoff hampers aquifer recharge, which when added to decreased river flow and shortened rainy season, compromises water availability for irrigation. These members mentioned that water management is more difficult when there is less water. In order to face decreased water availability, the water board curtailed the number of irrigation turns per farmer, which stresses crops.

Water boards (*juntas de usuarios*) have been responding to water scarcity. For instance, in some areas of Arequipa, the traditional system of irrigation formerly allocated water by alternating turns between high- and low-elevation community sectors. This, however, has been changed to a system that allocates water first to all the irrigators at higher elevations, and then plots at lower elevations are irrigated. This modification in water allocation was designed to improve efficient distribution of water.

Most peasants from the focus groups and interviews explained that their responses to insufficient water span from changing to cash crops with shorter growing periods and higher tolerance to water stress, to cultivating in furrows. The furrows make water distribution more manageable because they slow down and direct flow.

The vast majority of interviewees in the highlands also noted changes in snowfall, which has become almost nonexistent in some areas, erratic in others, and lasting for several days in other parts of the region. In July, two months before my fieldwork in Arequipa, many alpaca (*Vicugna pacos* Linnaeus) died because of a substantial snowfall that covered the pastures for several days, which prevented grazing. Almost all peasants from Arequipa remembered an unusual freezing night in early September, 2009; one farmer stated that, ''…it was as if the cold spell had feet and chose its path leaving a wave-like pattern on the ground impacting this crop but not the one next to it'' (''era como si la helada tuviera pies y escogiera por donde ir haciendo curvas, le afectaba a la planta aquí y no a la de su costado'').

All peasants indicated that they perceive changes in the average daytime and nighttime temperatures, which they express as having warmer days and colder nights. Moreover, this perceived change in temperature was consistently reported by herders and peasants across the study area. In the Cabanaconde community, a peasant from the Villa Colca water commission said, ''…both heat during day and cold at night have increased'' (''los dos, el calor en el día y el frío en la noche han aumentado''). In the community of Yanque Hurin Saya, peasants perceived the same pattern of intensified extreme temperature. It was observed that, ''the intense cold at dawn hampers crop growth'' (''el intenso frío del amanecer impide el crecimiento de los cultivos'').

Colder nights differently impact crops depending on their location. Some peasants pointed out that the crops in the valley bottoms are more exposed and sensitive to nightly frosts than crops on the slopes. The latter exposes less area to frost; there is less wind blowing, and longer exposure to the sun. Additionally, all peasants have noticed that the longer exposure to the sun melts the frost faster. Furthermore, runoff from melted frost clears ice on slopes faster than it does in valley bottoms.

To prevent nighttime frosts, some peasants burn shrubs, grass, and manure to generate smoke. Additionally, most peasants pay respect to Mother Earth and the sacred mountains by detonating fireworks and miniature explosives to prevent hailstorms. All the communities have also responded to nightly frosts by delaying the sowing season, thus avoiding freezing temperatures. The downside of this practice is twofold: first, the sowing season is concentrated in a shorter period of time, which entails a large demand for water that is not always available; and second, a shorter sowing season limits the seed development period, resulting in a smaller harvest.

In addition to their effects on crops, colder nights are perceived by some peasants as indirectly related to frog extinction. In the community Urinsaya Llalla (Cusco), the linkage starts with the fact that nightly frost freezes crops after they have been irrigated. To cope with nightly frosts, some peasants said, ''…después de la helada fumigamos la papa para que reaccione'' (''after the nightly frost we fumigate the potatoes to make it react''), which prevents freezing. However, the use of pesticides has increased water pollution, which in turn might have decimated the frog population. Most peasants have noticed that rats, in contrast to the frogs, seem to have increased as they thrive in the presence of stored crops (which the pastoralists are increasingly relying on).

Livestock is severely impacted by freezing nights and extended snowfalls. According to all the herders I interviewed, freezing nights are particularly harmful for newborns, while extended snowfalls prevent alpacas from eating because they do not dig in the snow. Herders explained that lack of available fodder threatens starvation for alpacas. Moreover, undernourished and weakened livestock becomes more vulnerable to harsh weather events related to shifting climate. This perceived effect was confirmed during the prolonged snowfalls registered since late August 2013 that caused the death of thousands of South American camelids in the Peruvian highlands. In spite of this extreme event, pastoralist households have responded by increasing livestock mobility within their pastures, creating and expanding wetlands through irrigation, limiting the allocation of wetlands to new households, and (for some) cultivating grasses.

Irrigated agriculture has also been affected, though in an unexpected way, by extreme cold temperatures. According to water board members and several interviewees, frozen water during part of the morning delays the beginning of irrigation, thus shortening the period of irrigation and the number of farmers that irrigate their fields. This delay has prompted an institutional response from the water board in the form of a new irrigation schedule in the highlands of Arequipa.

Information from the focus groups and interviews indicates that peasants expect institutional solutions to the problem of reduced water availability, including policies and infrastructure to improve water management. Such solutions would include fair and rigorous water authorities that enforce rules and a flexible irrigation scheduling tailored for times when less water is available and when the number of hours for irrigating is reduced because water is frozen. These expectations are consistent with the institutional response in some communities, which rule that water access is granted only to those who fulfill their duties (e.g., payment of water rates or completion of work in infrastructure maintenance).

My research found that actions taken by the majority of peasants to cope with climatic events rely on local knowledge of environmental and biological signals. These signals improve peasants' abilities to forecast weather or to anticipate seasonal changes. The following examples were explained and confirmed by many informants. If the Southern Cross constellation is descending in April it means the onset of the nightly frost season. Southern winds indicate nightly frost while northern winds indicate rain. Biological indicators are also part of these signals. For instance, flowering of plum and apple trees in August indicates a good year to cultivate broad beans, and grass in the river in June to August signals a good year for agriculture. Animal behaviors (e.g., certain birds in rivers or streams) are used to foresee how crops will perform during the year: if *Vanellus chilensis* Molina (*leque leque*) nests are at high elevations it means that it will be a rainy year; however, if the nest is at lower elevations, the year will be dry. In addition, an abundance of fish signals a productive year for agriculture. Other biological signals described in the interviews included the presence of flamingos, fish jumping in the headwaters of the basins, and the eyes of cats changing to black color, meaning that it will be a good rainy year.

Discussion

Perceptions of Climatic Change

The relevant characteristics of perceptions for this research are that they guide and inform decisions regarding how to respond to the effects of climatic change. Peasants' perceptions on changes in precipitation rates are consistent with the findings of research using multi-scenario modeling to examine climate change in the Altiplano region. This latter research has projected increasing precipitation extremes, where the rainy season will intensify and start later in the year, and dry spells (during the rainy season) will be longer and more frequent (Thibeault et al. 2010). Furthermore, Valdivia and colleagues (2010) analyzed the models employed in the Intergovernmental Panel on Climate Change (IPCC) using the Coupled Model Intercomparison Project (CMIP3) and projected that precipitation changes in the region will result in (1) a drier and earlier rainy season (September–November), and (2) higher precipitation at the peak of the rainy season (January–March).

Climate variability is not a new disturbance for the social-ecological systems in the Peruvian southern Andes, although anthropogenic climate change in the past few decades is. How are the disturbance-response interactions playing out in the continuity and change dynamic of the SES? If instability is increased, what is needed to improve the systems' stability and sustainability? This section addresses these questions from the highlands to the lowlands of my Peruvian study area.

In the highlands, the current extent and pace of glacier recession are among the most conspicuous effects of climate change in several millennia (Lemke et al. 2007; Orlove et al. 2008; Rhoades 2008; Thompson 2000; Thompson et al. 2006). For instance, the retreat of ice of the Quelccaya Ice Cap has exposed paleobotanical wetland plant remains, allowing radiocarbon dating of deposits indicating, first, that the glacier is smaller than it was 6000 years ago and second, that its current rate of retreat (~300 m/25 yrs) is faster than its rate of advance approximately 6000 years ago (~300 m/~1600 yrs; Thompson et al. 2013). This glacier shrinkage has led directly to increased glacier runoff due to ice melting, which in turn has modified the extent of wetlands (Postigo et al. 2008). However, in some areas of the Andes, the increased runoff has already peaked; therefore, wetland expansion may reverse when, or if, melting stops (Bury et al. 2013).

Changes in precipitation patterns are impacting livestock herding in the region. Lower surface volume of runoff hampers aquifer recharge. In turn, diminished aquifer recharge leads to drying springs, which compromises pasture irrigation and the amount of water available for livestock, thereby jeopardizing the resilience of pastoralism in the region. Pastoralists have been extending wetlands and pastures through irrigation as a response to climatic changes and environmental conditions. However, long-term assessment of the sustainability and robustness of these responses requires asking whether this response would match the needs for grazing areas, and whether the irrigation network would be able to supply drying pastures and wetlands. In addition to the herders' capacity to generate enough forage, the fate of this SES will be determined by the interactions with species and land uses as they are driven upslope by climate change. For instance, vegetation expanding its altitudinal range may modify an ecosystem's composition and structure, which may compromise feeding livestock. Similarly, expansion of agriculture to higher elevation will increase the pressure on land and water, which might withdraw some of the labor force from livestock herding. What will herders lacking wetlands and water do? How will communities accommodate their households under new water, land, and labor constraints?

Responses to issues of resource availability often require institutionalization. For instance, institutional household cooperation can increase available grazing areas and community decisions may diminish the uneven allocation resulting from climate change and pressures from other land uses (Postigo et al. 2008). Whereas solutions like new rotation systems and use of grazing areas of kinfolk in other communities help to maintain the organization and functionality of the system, responses like cultivation of vegetables in some areas where previous climatic conditions prevented agriculture may transform the system.

Concatenations of climate impacts and human actions generate outcomes, which lead to improving or decreasing the vulnerability of SES. For instance, on the one hand, more suitable climatic conditions at higher elevations may be driving crops' altitudinal range expansion (e.g., Ertsen et al. 2010; Gelles 2000; Loayza 2006; Maos 1985). On the other hand, rising temperatures and precipitation changes in farming areas have increased water stress due to increasing evapotranspiration and lower water levels in local reservoirs, respectively. Additionally, decreased water supply coupled with leaking irrigation infrastructure and insufficient water storage capacity increases the vulnerability of these SES to water stress. Moreover, water stress may have long-lasting effects or push the system to change crops when the yield of crops sensitive to water stress (e.g., maize, barley, and alfalfa) diminishes and fails to regain former levels. In the study area, this research has found peasants who have improved their productive systems (probably diminishing their vulnerability by diversifying the productive area and crops) with crops such as maize, broad beans, green peas, and sweet granadilla (*Passiflora ligularis* Juss) whose altitudinal limits have shifted upward. However, cases of increasing vulnerability were also found where some communities planned to convert pastures into alfalfa fields. This conversion would not only replace pasture with a water-demanding crop (alfalfa) but also displace the alpacas that previously grazed there to pastures located at higher elevations. Further research is needed to assess whether this change will lead to multi-scale resilience such that traditional practices may shift locations while also creating both local and regional resilience (e.g., Folke et al. 2010; Walker et al. 2004).

The results of this study indicate the importance of institutional responses such as regulating irrigation turns; however, there are also cases in which institutional responses to former disturbances may be inadequate to account for emergent variability in environmental impacts (Janssen et al. 2007). This is illustrated by the land tenure system of small and dispersed household fields in the community. Though dispersing fields decreases the risk that an extreme event will impact all fields of a single household, it hampers moving modern irrigation systems wanted by peasants and farmers from field to field in order to irrigate pastures and crops. Thus, land tenure institutions implemented to respond to climatic variability in the Andes (a chronic disturbance) may hinder innovative farming responses to emergent variability in water availability and irrigation scheduling.

Water availability is inversely related to socioeconomic tensions amongst users and the pressure they will likely put on institutions. Therefore, weakening institutions constitute positive feedback loops that can reduce the resilience of farming systems. For example, a weakened water board is less able to regulate water use and to organize the maintenance of irrigation infrastructure, thereby enhancing the flaws of the irrigation system. However, institutional responses through more strict rules for water allocation and tariff collection have been successful in some water systems in the Andes (Gelles 2000; Vos 2010). These activities strengthen institutions' legitimacy with local people, which allow them to consolidate their position within the system and bolster their role in adaptation. Therefore, strengthening local organizations that manage water with technical capacity to monitor infrastructure and consolidate management, may improve systems' resilience during times of crisis (Hendriks 2002; Rosegrant and Cline 2003). Further, institutional arrangements during periods of change eliminate much of the pressure through solving conflicts, allocating scarce resources, and generating conditions for self-organization of the system (Boelens et al. 2002; Meinzen-Dick 2007; Postigo et al. 2008). Thus, strengthening of institutional aspects will enhance the adaptive capacity and resilience of a SES (Kronik and Verner 2010).

Water provisioning is crucial for farming and livestock herding. Highlands and lowlands, upper, middle, and low basins are interconnected by biophysical characteristics, above and underground water flows, and social networks; there is a mutual dependency, which has to be represented in the institutional framework of resource governance. By using an interconnected and democratic network, water management institutions may be better equipped to address potential conflicts due to water scarcity. In this way, the legitimacy of the governance body may increase in concert with the likelihood of a more sustainable system.

Local Knowledge

Local population knowledge of its ecosystem and resources is a key component of adaptive systems (Folke et al. 2005). Reported perceptions of climate change documented in this study for Andean populations are consistent not only with perceptions in other parts of the region (Kendall and Chepstow-Lusty 2006; Milan and Ho 2013; Sperling et al. 2008) but also with research findings of increased variability and timing shifts of rain for the Peru-Bolivia Altiplano (Boillat and Berkes 2013; Hoffmann and Requena 2012; Seth et al. 2010; Valdivia et al. 2010).

Similarly, reports of colder nighttime and warmer daytime temperatures are consistent with research on temperature changes arising from shifts in evapotranspiration (Sperling et al. 2008; Thibeault et al. 2010; Valdivia et al. 2010). Higher daytime temperatures could be driving increased incidence of pests such as three potato tuber moth species (*Phthorimaea operculella* Zeller, *Tecia solanivora* Povolny, and *Symmetrischema tangolias* Gyen) in the Andes (Dangles et al. 2008) and elsewhere (Sutherst et al. 2011), as well as changes in the distribution of pest and crop species (Young 2009). More intense heat and longer dry spells will likely desiccate pastures, which become more easily uprooted by the winds (which are also blowing with increasing strength), causing soil exposure and land degradation.

Although local knowledge is a long-term asset for adaptive capacity, research elsewhere has shown that prevalent socioeconomic disturbances such as poverty and illiteracy may undermine the institutions and social capital supporting such capacity (Kronik and Verner 2010). Social and economic conditions and institutions are important components of a population's adaptive capacity and resilience to climate change (Boillat and Berkes 2013; Valdivia et al. 2010). The poverty levels of peasant populations in the study region make them more vulnerable to acute climate change impacts and to more intense and extended extreme events (Adger et al. 2007; Agudelo et al. 2003; Alley et al. 2003; Ribot 2010; Swinton and Quiroz 2003; Valdivia et al. 2010). Emerging vulnerabilities coupled with prevalent socioeconomic disturbances, enhanced climatic variability, and extreme events may push this SES over its threshold. Thus, programs to enhance adaptive capacity and resilience of the most vulnerable populations must be part of policies for poverty alleviation within a larger framework of sustainable and equitable development (Rhoades 2006; Valdivia et al. 2010). Similarly, investigation on multicausal vulnerability should be a major focus of this research agenda.

Conclusion

Rural people perceive climate change, which impacts ecosystems and a mosaic of social formations along an altitudinal gradient in the Peruvian Southern Andes. These impacts diminish the adaptive capacity of vulnerable groups and, therefore, further increase their vulnerability. This research shows that these perceived social-environmental impacts raise tensions and may create feedbacks in the SES. Herders responded to perceived modification in the extent and location of pastures and wetlands through irrigation. Farmers responded to perceived diminished water availability by limiting irrigation, which in turn, raises the stress on crops and water management institutions. Drier conditions and higher temperatures are driving pests and diseases to higher elevations. This research has also shown that change stimulated responses from the SES. Wetlands have been created, agriculture calendar and irrigation turns have been adjusted to new climatic conditions, and traditional responses continue to be implemented. These stresses, pushes and pressures on the SES have driven social formations to battle for control of increasingly limited resources that are necessary to protect communities and individuals from bearing the full brunt of a changing climate. However, local knowledge and institutions have been crucial in the adaptive responses of local populations to social-environmental disturbances. Further, local knowledge strengthens institutions and constitutes a vital element of adaptive policies in the face of climate change.

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