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Can warmer be better? Changing production systems in three Andean ecosystems in the face of environmental change

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ABSTRACT

Andean farmers have always faced high levels of climate-related risk and have produced a wide range of resilient crops and animals to subsist under harsh ecological conditions. In recent decades, changing climatic and economic conditions have challenged farmers in the region. In response, farmers have changed their production systems. The present study outlines some of the risks farmers faced in four Andean ecosystems and examines how they have adapted production systems to changing risks over the past 20 years. Their adaptation strategies were evaluated using participatory research methods and cost benefit analysis. To date, most farmers have been able to successfully adapt to changing climatic and economic conditions in ways that usually improve their livelihoods. These improvements are largely due to their abilities to take advantage of warming trends and new markets to produce higher value crops than in the past. These strategies may not be as effective as temperatures continue to rise. Understanding farmer adaptation strategies at the micro-level can help policy makers and planners identify how they can assist adaptation in the future and will help point to challenges in the future.

Agriculture is one of the sectors most directly affected by climate change. The negative impacts of climate change on agriculture are likely to be greatest in developing countries because of weak disaster management and planning institutions, limited financial resources and a heavy dependence on rain-fed agriculture (Rockström and Falkenmark, 2000). A large number of studies, projections and reports have examined the average impact of climate change at global, regional and national levels (Jones and Thornton, 2003; Parry et al., 2004; Blázquez and Nuñez, 2013; Seo and Mendelhson, 2008). However there is limited information and effort addressing local climate change impacts and reactions to it, even though this is crucial for assisting farmer adaptation strategies. The scant amount of research may partly be due to a lack of historical and point climate data and associated problems (Thornton et al., 2010) and to site-specific constraints faced by producers which determine their actual adaptation capacities. Country-level assessments based on macroclimatic modeling need relatively modest information; micro level studies require finer more detailed data. This is even truer for mountainous areas where altitude is not the sole factor affecting the characteristics of local climates. They are also strongly shaped by solar exposure, orientation, ascendant fluxes, etc. As such, problems related to the uncertainty of climate projections and how this can be appropriately treated to obtain more realistic results are unsolved (Hallegatte, 2009; Wilby et al., 2009). This limits the value of quantitative forecasts of climate change crop yields and associated changes (Challinor et al., 2009).

Most studies of agriculture adaptation to climate change have focused on responses to disaster or promotion of actions in response to model projections. As such, climate impact studies have consistently predicted extensive effects of climate change on agriculture (Pearce et al., 1996; Tol, 2002). Other studies have indicated a reduction of crop yields when warmer temperatures occur, mainly due to average water deficits and/or the impacts of extreme events (Reilly et al., 1996; McCarthy et al., 2001). However, these studies assume that farmers are passive elements in production systems. These studies underestimate farmer's adaptive capacities by assuming they cannot change their cropping systems without significant outside help and that they have not already made significant changes to their cropping systems in response to changing environmental and market conditions. Thus, these studies predict large average yield and revenues losses due to climate change

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because they disregard how impacts are nonhomogeneous and overlook successful local adaptations.

Climate and global changes are already impacting physical, biological and social systems. Consequently, farmers have already reacted to recent climate changes (Rosenzweig et al., 2008), often in positive ways. Understanding the logics, mechanisms and effects of these farmer's actions should indicate the direction that adaptation actions should take to be successful in the future. Thus more detailed information is needed, there is need for detailed information, particularly for developing countries, on the likely impacts of and responses to climate change (Moore et al., 2009). There are relatively few publications on the specific actions farmers have taken over to adapt to climate change in recent decades. The most common practices are the adoption of drought resistant crops and better water management techniques in Ethiopia (Kelbessa, 2001), Burkina Faso (Barbier et al., 2009), and South Asia (Kumar et al., 2016). There has also been a shift to higher crops in sub-humid tropical Africa (Sanchez, 2000); in Pakistan (Rahut and Ali, 2017), and South Asia (Kumar et al., 2016). Most studies of adaptation only describe adaptation strategies, but some such as Lei et al. (2016) have shown that adaptation can lead to improved livelihoods.

The impacts of climate variability on Altiplano farming systems has been documented (Valdivia et al., 2007, 2010; Perez et al., 2010; Sietz et al., 2012). Farmers in the Altiplano have always faced recurrent droughts, floods and frosts but climate change is presenting new challenges to crop production such as increased pressure from pests and plant disease and shifts in the onset and intensity of rains. Many of these studies conclude that adaptation strategies based on farmer's own decisions could have a higher probability of success.

Some reports indicate that climate change is leading to new forms of commercial agriculture in the Andes that can be seen as local autonomous adaptations. Several studies of the Bolivian Altiplano report production system changes in the last two decades, mostly in response to climate change (Valdivia and Jetté, 1996; Valdivia et al., 2010; Taboada et al., 2014), but little is written on the logics behind these changes. It is important to consider that temperatures and precipitation are not the only driving factors affecting farming decisions in the Andes and elsewhere in the world. Market changes have also strongly affected the high Andes farm decision process. As such, the effects of climate change on crop production and, by implication, on household livelihoods are not always clear-cut nor are they always negative (Chaplin, 2009). Understanding current adaptations can help policy makers and others charged with designing and implementing adaptation strategies at the national, regional and local levels to reduce the negative consequences of climate change and to benefit from the opportunities that these changes present (Smit and Pilifosova, 2001; Agrawala and Fankhauser, 2008).

The research presented here was conducted in four ecosystems in Bolivia's Northern and Central Altiplano. Its goals were to understand the changing conditions and risks small holders face in these ecosystems in Bolivia's Central and Northern Altiplano, describe changes in their production systems taken in response to these changes and to evaluate the efficiency of some adaptive strategies by using cost-benefit analysis (CBA). The research is based on participatory research processes designed to link local and scientific knowledge.

1. Background

Bolivia is a typical tropical mountainous country, where the Andean slopes dominate climate and topography. The Andes extend vertically from the highlands (6500–3500 m.a.s.l.) to the valleys (3500–800 m.a.s.l.) towards the lowlands (<800 masl.). The high Andes include a very important agricultural region and is home of most of Bolivia's rural population. This area is highly affected by the temperature changes related to altitudinal differences and exposure to sun radiation. The high altitude increases air transparency and reduces energy retention. Thus, direct sunlight strongly shapes daily maximum temperatures (Tmax); likewise, air humidity determines minimum nighttime temperatures (Tmin). Areas with higher humidity have higher Tmin, because they retain more energy during the night. Precipitation gradients are also of importance; on average, there is a rainfall gradient from North to South and from East to West. However, many inter-Andean valleys are prevented from receiving humid air from the East and are drier than nearby open western slopes. Consequently, high Andes locations at the same altitude but with different exposure may have different climates.

Previous studies have examined the processes of long term temperature and rainfall change in the Altiplano. García et al. (2004) and Valdivia et al. (2010) analyzed historical trends using a long term homogenous data set of monthly Tmax, Tmin, daily precipitation (PP) and Reference Evapotranspiration (ETo). We compared these trends to qualitative results coming from surveys conducted in several rural communities in the area. Trends in Tmax and Tmin (Fig. 1 Annex 1) indicated some general warming over the last 50 years. Interestingly, the spatial structure of these trends varies; some cooling in terms of Tmin occurred in the Southern Altiplano, while significant increases in Tmax and Tmin were found in the Central and Northern Altiplano. The cooling trends in Tmin in the Southern Altiplano may be related to the clearing of lands for quinoa production in response to booming quinoa prices which has increased the bare soil area and has reduced natural vegetative cover. This could be reducing relative humidity which would lead to increased radiative cooling at night. These phenomena are not observed in the Central and Northern areas where land use has not changed dramatically.

In contrast to Tmin, the authors report that Tmax has increased more uniformly across the entire region. Seiler et al. (2013) also analyzed Tmax trends over the past 30 or more years. They also found some cooling close to the Titicaca Lake. The overall warming trend in Tmax may be related to greenhouse warming. Finally, annual precipitation exhibited little total historical change in the entire area. As a result of increasing Tmax, a trend of rising values of ETo was found for the entire region, although the impacts are larger in the Southern and Northern Altiplano and less significant in the Central region. Unchanging rainfall tied to increasing atmospheric demand rates (ETo) results in increasingly drier air over the high Bolivian Andes (Fig. 1b annex), which could affect the water availability for crops in the soil.

Valdivia et al. (2010) and Garcia et al. (2013) also evaluated the results of 12 General Circulation Models for the Altiplano region. These results were similar to those obtained from analyzing historical temperature data. The projections show mean temperature increases of 1.5 °C by 2020–2030 and even greater increases by the end of the century. These models also show negligible changes in mean precipitation are projected (see Figs. 1 and 2). However, when seasonality was analyzed, the early rainy season (Sept. through Nov.) was projected to be drier and the peak rainy season (Jan. through Mar.) to be wetter than at present, suggesting that the dry season could extend into what is now the early rainy season. This could be due to the weakening of the tropical circulation (Seth et al., 2010) and implies a shift toward a later and stronger rainy season (Thibeault et al., 2010). A previous long term analysis of the rainy season duration in the Altiplano (García et al., 2007) suggests that a delayed onset of the rainy season would result in increased crop water stress during and after the planting period.

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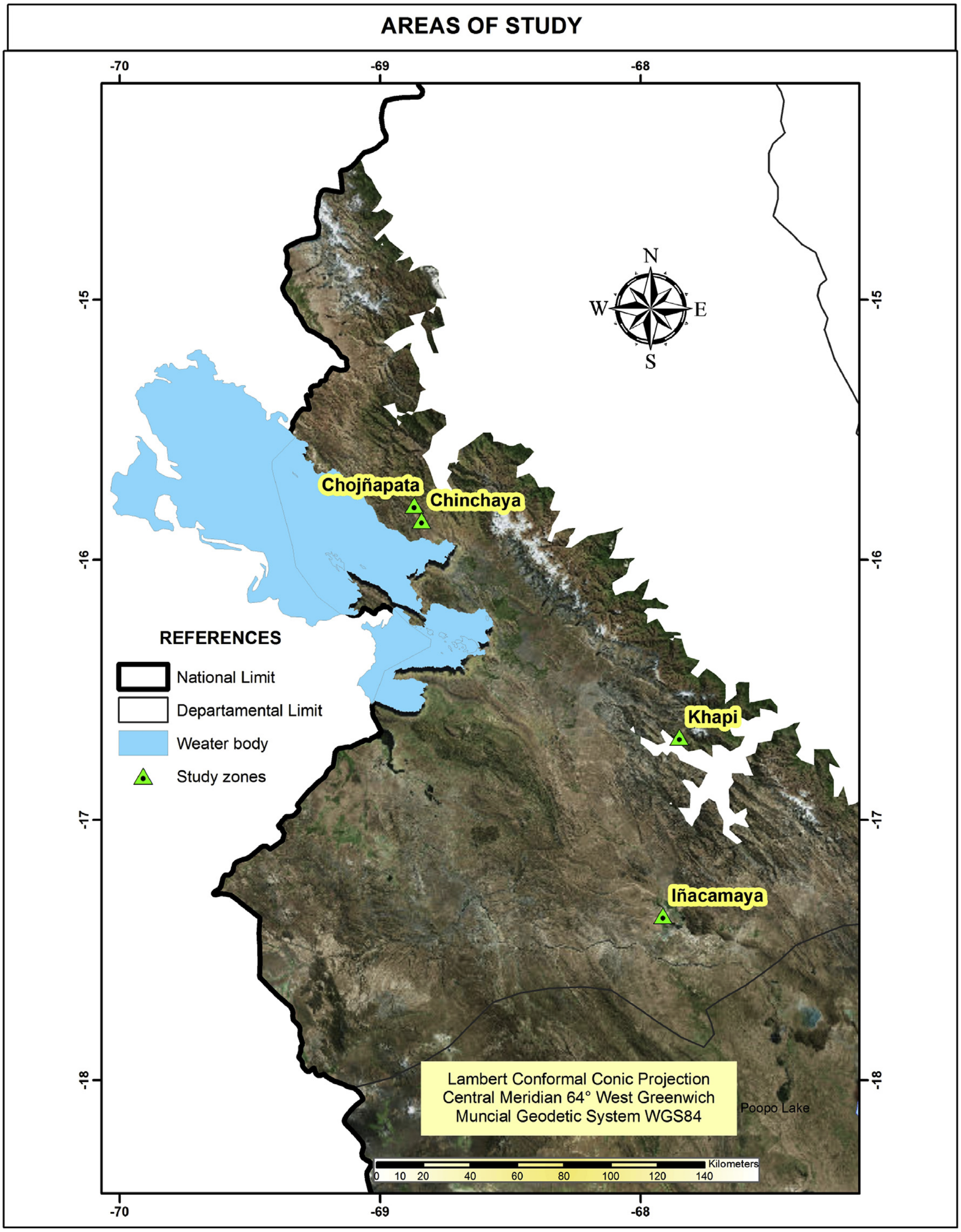

Fig. 1. Location of study communities. Northern and Central Altiplano and Lake Titicaca.

1.1. *Research location*

Our research was carried out in four communities with distinct agro-ecosystems where the authors have worked for around a decade. Although all four are above 3600 m.a.s.l., each has a unique ecosystem and climate (see Table 1). A description of each community is found in Table 2 and their locations in Fig. 1. Two, Chinchaya and Chojñapata, the sites of Valdivia et al. (2010) study, are located in a watershed near Lake Titicaca in the Northern Altiplano. Chinchaya is located near the shore of Lake Titicaca while Chojñapata is higher, wetter and cooler. Chojñapata generally experiences warmer nights because of frequent cloud cover. The Northern Altiplano sites have higher annual precipitation. Iñacamaya is adjacent to San Jose Llanga, one of Valdivia et al.'s Central Altiplano communities and has similar ecological conditions. Iñacamaya is characterized by higher Tmax and lower Tmin than the other study communities because it does not have the moderating effect of the lake or cloud cover. The last community,

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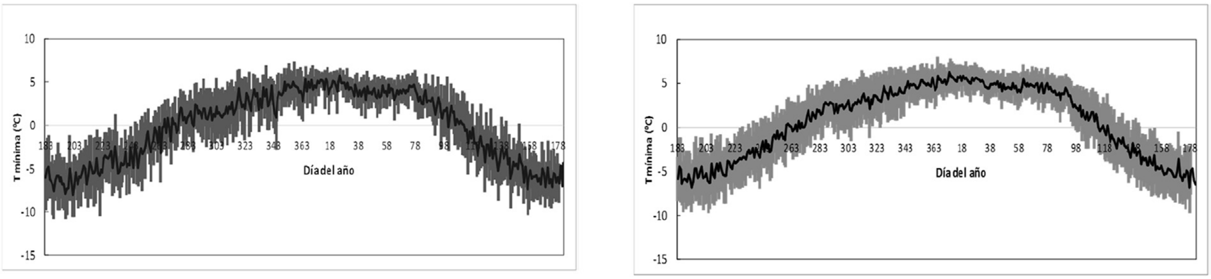

Fig. 2. (Adapted from Garcia et al., 2013). Daily mean Tmin (black lines) showing one standard deviation range for the historic record and the same for the LARS-WG projected record for 2020–2030 for the A2 scenario under the ECHAM5 boundary conditions for the location of Patacamaya in the Central Altiplano.

Table 1
Geographic and climatic characteristics of the communities included in the study.

Community	Ecologicalzone	Elevation (m.a.s.l.)	Latitude	Longitud	Annual Tmin (°C)	Annual Tmax (°C)	Annualrainfall (mm)
Chinchaya	Northern altiplano (low)	3815	15°59′	68°50′	1,5	16,5	510
Chojñapata	Northern altiplano (high)	4150	15°55′	68°45′	2	11	580
Iñacamaya	Central Altiplano	3770–3805	17°05′	67°57′	−0,2	17,5	410
Khapi	Upper basin valley	3500–3800	16°38′	67°46′	1,2	18,3	350

Table 2
Household descriptive statistics (averages) for study communities.

Variables	Chinchaya	Chojñapata	Iñacamaya	Khapi
Ecological zone	North Altiplano (low)	North Altiplano (high)	Central Altiplano	Upper valley
Age head of household (years)	60	57	50	47
Family size	5	5	6	5
Education head of household	9	8	10	8
Area planted annual crops (Has.)	1,38	0,91	4,5	0,74
Area in alfalfa (Has.)	0,15	0	4	0
Sheep	17	35	15	NA
Cattle)	3	5	16	NA
Camelids (head)	0	16	0	NAN

Khapi, at the lowest elevation, is the highest community in a valley where agriculture is based on irrigation from glacier runoff.

2. Materials and methods

Data for this paper came from three sources: 1) historical climate data from the Patacamaya experiment station—the only weather station with reliable historical data that is adjacent to one of our study communities, 2) participatory workshops with farmers conducted in 2009 and 2010 and 3) household surveys conducted in 2006. Data from Patacamaya (a station 15 km from Iñacamaya) was used to assess the likelihood of increased extreme events and increased climate-related risks. Due to the need for daily data for this type of analysis, the stochastic generator LARS –WG (Semenov 2008) was utilized to produce downscaled daily site-specific A2 scenarios of the near future climate (2020–2030) using the ECHAM5 general circulation model developed by the Max Planck Institute for Meteorology (Stevens et al., 2013) specifically to analyze expected frost-free days and the return period for high Tmax and PPmax in the future.

Participatory research methods were used to describe the changes in the production systems in each community over the previous three decades. Participants were asked to recall how the production system was at the time of the strong drought in 1983 and to use participatory mapping techniques to describe land use in the 1980s and now and the producers' explanations for the changes in land use since that time (IFAD, 2009). We recorded their answers and explanations and then used data from the INE (the National Statistics Institute) was used to validate farmer recollections. The principal crops identified were the subject of the cost benefit analysis. We used 203 household interviews to assess risk perceptions and as the source of data for the cost benefit analysis (CBA). Eighty-four of these interviews were from a 2006 database constructed by Valdivia et al. (2010) and the rest were from interviews conducted in 2009 and 2010 (see Table 3) using the same questions related to risk perceptions. In all cases, a representative sample of households based on a list provided by community leaders were interviewed. The principal agricultural activities in our study communities at present and in the 1980s in the communities of Chojñapata and Khapi evaluated using conventional CBA. These production systems require significant input investment; so the use of CBA is appropriate. Since all expenditures and benefits occur during the year, with reduced capitalization of farmers, this technique can be applied annually. In spite of some limitations, the careful application of CBA can greatly improve decision-making by providing information to agricultural decision makers (Bekele, 2003; Bojö, 1992; Ekbom, 1995; De Graaf, 1996). Input and output prices for all communities were first obtained in 2010 and updated annually until 2013. The dominant crops before 1983 are still being produced in each community so the CBA could be calculated at present values.

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Table 3
Households surveyed.

Community	Ecological zone	Households Interviewed/year		
Community (# households)		2006 SANREM Database (Valdivia et al., 2010)	2009	2010
Chinchaya (287)	'Northern altiplano (low)	57	51	
Chojñapata (118)	Northern altiplano (high)	27	23	
Iñacamaya (138)	Central Altiplano		25	
Khapi (36)	Upper basin valley			20

3. Results

Fig. 2 shows that the frost-free periods in the Central Altiplano will be longer in the 2020–2030 period. Reduced frost risk will lengthen the crop production period. However, the frost risk does not disappear during the winter, early spring and late fall. The analysis also shows that the average return period (the time of recurrence of extreme events) for extreme temperatures may be strongly reduced by 2020–2030 but the return period for extreme rainfall will not significantly change (Fig. 3). The results confirm the findings from a similar study by Thibeault et al. (2010) related to extreme temperatures; the number of warm nights, the length of heat waves and the number of frost-free days are increasing. Their study also projects more frequent heavy rain fall events and longer dry spells during the growing season. Historical trends and the projection of the mean climate variables and extreme events suggest that temperatures will keep increasing (especially Tmax), while precipitation may have a more stable behavior. Under this scenario, soil moisture will likely be substantially reduced in the future because water deficits will steadily increase (Thibeault et al., 2012) and put more stress on crops (see Fig. 4).

Table 4 presents the perceived risks of various hazards farmers face in the study communities. It shows that the perception of threats to agricultural livelihoods differ in intensity according to community and topography. In general, climate-related risks were perceived to be the lowest in Khapi, the valley community, and highest in Iñacamaya in the Central Altiplano. The Central Altiplano has less ground water and is colder than the other areas. Of the perceived threats, frost risk had the highest divergence between communities. Frost was perceived to be the highest risk in each of the three Altiplano communities and the lowest risk in Khapi. Khapi is located in a warmer valley and irrigation permits its producers to plant when there is less risk of frost. Frost risk was greater in Chinchaya and Iñacamaya, which have large expanses of flat land. Hail was viewed as a moderate risk in all of the study communities. The region's tropical location, arid conditions and strong convective movements favor hail development. The risk of flooding was a moderate risk in all communities but it was highest in Chinchaya and Iñacamaya, which have large expanses of flat land, and lower in the two communities which are steeply sloped. Crop pests were a moderate risk in the Altiplano and the risk is perceived to be increasing. The increased pest pressure is probably due to warming trends and agricultural intensification.

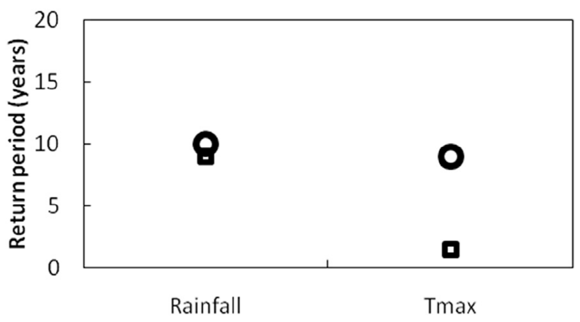

Fig. 3. (Adapted from Garcia et al., 2013). Projected return periods (years) for the maximum rainfall event and the daily maximum temperature that was exceeded on average once during a 33-year period in the late 20th century (1967–2000) (circles) for the location of Patacamaya in the Central Altiplano. A decrease in return period implies more frequent extreme temperature or rainfall events (i.e., less time between events on average). The squares show results for the projection for 2020–2030 with the LARS-WG for the A2 scenario under the ECHAM5 boundary conditions.

Climate change was viewed as moderate risk but it was of more concern in the three Altiplano communities. They are more dependent on rain-fed agriculture than in Khapi where irrigated production predominates. Farmers in all communities felt that temperatures had increased since the strong El Niño event of 1983 (Center for Ocean and Atmosphere Prediction Studies, 2017) and said that they had made modifications in their cropping systems in response to changing environmental and market conditions. Table 5 summarizes the major changes in these production systems over three decades. Three communities, Chojñapata, Chinchaya and Khapi, changed their cropping systems to take advantage of higher temperatures. This was done by producing higher value crops using more intensive management. In the case of Iñacamaya, warming did not significantly reduce the risks of frosts so there was a shift to dairy and forage production.

Both of the communities in the Northern Altiplano modified their cropping systems to take advantage of warming temperatures. Chojñapata (the highest community) reacted to rising temperatures by moving to replace the bitter frost-resistant potatoes with commercial varieties of white potatoes. Farmers are well aware that summer frost risks have greatly reduced and commercial potatoes can be cultivated with less risk of crop failure. In Chinchaya, farmers responded to warming trends by shifting the agricultural calendar and by moving to higher valued crops Rising temperatures and the availability of irrigation water led to the cultivation of high value winter crops (especially onions) This adaptation was well suited to new climate conditions as well as to demographic pressures that have reduced farm and plot sizes. Families cannot support themselves through potato production, so they cultivate higher value vegetables for market in nearby cities to increase incomes because the CBA is significantly higher (Taboada et al., 2014).

In Khapi, the new production system was not based on a change in crops produced but was based on a change in the agricultural calendar (Table 5). A decline in frost risk in late winter, allowed potato planting to occur earlier if they were irrigated. Farmers began constructing irrigation systems in the 1990s and were able to take advantage of warming conditions. As a result farmers could harvest in December instead of April. Potato prices generally reach their peak in December and January and are at their lowest in April and May. Irrigation has increased yields and many farmers are able to double crop potatoes. Because it is the highest community in a watershed dependent on glacier melt, they have not experienced water shortages. However, there has been an increase in conflicts over water with communities lower in the watershed. In addition to warmer temperatures, the construction of a road and a bridge in

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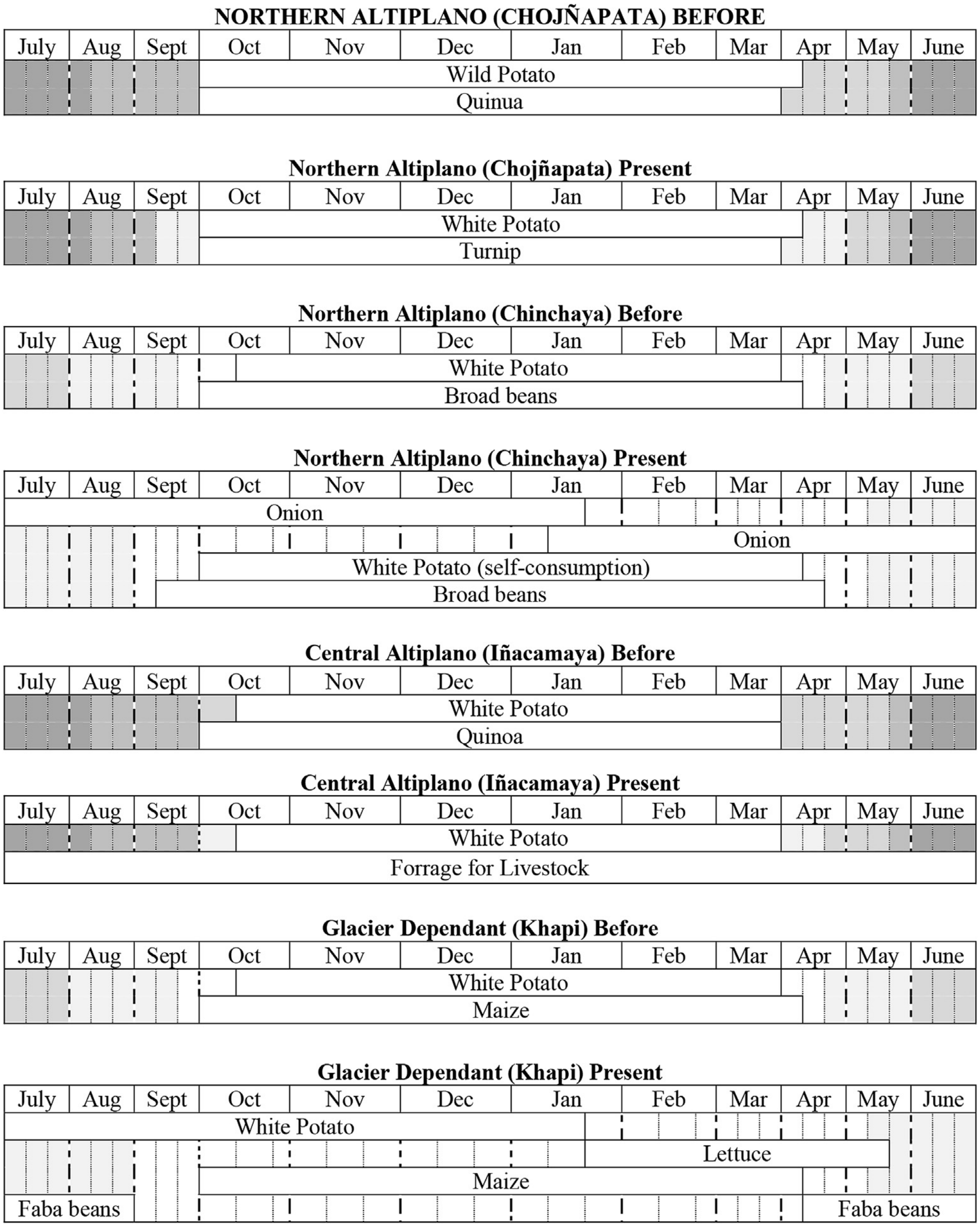

Fig. 4. Representative cropping structure in the surveyed communities before 1983 and in 2013. The shaded graded grey areas represent the frost intensity, as darker shadow means higher frost risks.

the 1990s connecting Khapi to the capital city motivated farmers to intensify production to take advantage to new market opportunities.

In Iñacamaya (Central Altiplano), where frost risk was not reduced significantly in spring and fall and irrigation is an expensive and less reliable option, farmers also changed their production systems. In this case they shifted away from potato production and towards dairy and forage production. This community had larger landholdings and a secure market for dairy products beginning in the 1990s as a result of a joint project of the Bolivian and Danish governments (Markowitz and Valdivia, 2001).

In Table 6A, the CBA of the production of the most important cash crop in Chojñapata and Khapi is presented. In Chojñapata, the high altitude community which previously had extremely high frost risks, increasing temperatures have permitted farmers to shift from highly frost resistant bitter potatoes to white potatoes. In this case, the cropping calendar was not modified and rainfed agriculture remained the dominant form of production but the switch from bitter potatoes led to higher incomes. Bitter potatoes not only fetched a lower price and but required much more labor as they had to processed into chuño (freeze dried) before they could be sold or consumed Completion of a road in the 1990s gave farmers access to urban markets which increased the profits from white potatoes. The benefit to cost ratio increased from 1.3 to 2.0 with these changes. In the case of Khapi the benefit-to-cost ratio increases from 1.3 to 2.7.

Table 6B presents the results of the CBA for Chinchaya and Iñacamaya. In Chinchaya farmers took advantage of warmer weather, new market opportunities and a high water table to switch from potato production to irrigated onion production. The benefit to cost ration increased from 1.23 to 1.82. In the case of Iñacamaya the benefit cost ratio did not increase but incomes

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Table 4
Risk Perceptions Average Index[a], in the Bolivian upper Andes by landscape (2006–2010).

Type of Risk/	Northern Altiplano Ancoraimes Municipality	Central Altiplano Umala Municipality	High valley Palca Municipality		Average
	Chinchaya	Chojñapata	Iñacamaya	Khapi	
Number of household respondents (N)	108	50	25	20	
Perceptions (index)					
Frost	4.2	4.0	4.4	1.5	3.5
Floods	3.8	3.3	4.4	3.6	3.8
Drought	3.4	3.5	3.0	2.6	3.1
Hail	3.8	3.7	3.9	3.3	3.7
Changing climate	4.0	4.0	3.9	2.6	3.6
Crop pests	4.0	3.8	3.1	3.4	3.6
Soil fertility loss	3.9	3.7	3.4	3.7	3.7
Low livestock prices	3.8	3.3	3.7	1.6	3.1
Adult unemployment	3.8	3.7	2.3	4.1	3.5

[a] The index is the average of responses to the question with 1 = it is not a threat, 2 = it is a minimal threat; 3 = it is a moderate threat; 4 = it is a very strong threat, 5 = it is an extreme threat.

Table 5
Change direction and driving factors for the adapted production structures in the studied communities.

Community	Main farming activities before 1983	Main farming activity at present	Reason for change	Driving factor for the change
Chojñapata	Bitter potato, camelids,	White potato, turnips,camilids	Rising prices, reduced frost risk	Increasing temperatures, better roads to connect with markets
Chinchaya	Rain-fed white potato, sheep, (Andean tubers)	Onions, white potato,	Rising prices, reduced frost risk, small plots, non suitable for other crops, available water for irrigation	Increasing temperatures, better prices
Iñacamaya	Common white potato, sheep	Dairy, commercial potatoes	Better and more stable prices, large plots, better extension and support service for dairy.	All year open market, large plots availability
Khapi	Rain-fed white potato, Andean tubers	Irrigated white potato, maize, lettuce and broad beans	Rising prices, reduced frost risk, available water for irrigation	Increasing temperatures, better roads to connect with markets, better prices

increased substantially do to the higher levels of investment that are required for dairy production and the fact that considerable state investment was made to support a change to dairy production. However, the Iñacamaya CBA was only done for dairy production and does not include income from the sale of calves.

4. Discussion

Climate and weather related risks have been the main shapers of Andean agriculture for millennia, but increasingly rapid changes in climate are modifying these systems more rapidly than previous changes. Analyses of farmers' risk perceptions presented here suggest that researchers should revise some of their assumptions about climate risk. Experts have paid particular attention to increasing risks of drought. This is due to the fact that higher temperatures and higher rates of evapotranspiration have led to a drying trend even though precipitation rates have not change. However this analysis suggests that, even though farmers recognize that their soils are getting drier, they feel that their greatest meteorological hazards are floods, frost hail and climate change. Only the latter is related to the observed drying trends.

Drought is only seen as a moderate risk because farmers use traditional risk management strategies to deal with drought and because they have changed their production systems to manage this risk to date. Traditional production systems have a number of ways to deal with drought including the sale of livestock and temporary migration. Farmers also can invest less in agricultural inputs when conditions are unusually dry. The shift to irrigation or to more intensive livestock production in some study communities also manages this risk. Even though the frequency of frost has been declining because of rising minimum temperatures, the risk associated with frost has not declined as much. Farmers have taken advantage of temperature increases by shifting from extensive production based on resilient crops to short season higher valued crops such as onions and irrigated potatoes. These high value crops are less cold resistant and require more investment in inputs so the potential losses to hail and frost have increased. The Central Altiplano community shifted from extensive potato production to intensive animal production.

Although Tables 4,5 and 6 show that farmer decisions in response to changing conditions have led to more efficient cropping systems, the sustainability of these adaptations may be threatened. In the Northern Altiplano and in glacier-dependent communities, farmers are subdividing their plots and people are now planting throughout the growing season. Subdivision is due to population pressures and the fact that agriculture has remained economically attractive so there has been a desire to inherit land. Subdivision has led to shorter fallow periods and has contributed to lower soil fertility. These changes have also increased the pressure on limited supplies of irrigation water and have increased the possibility of water conflicts. These changes have resulted in an increase in the portion of the year dedicated to agricultural production and more demand for labor throughout the year This has interfered with past practices of seasonal migration in search of wage labor during the winter. New hazards are emerging as result of changing production systems. Changes in soil fertility are already a concern while salinization, loss of agrobiodiversity and the appearance of new pests are emerging threats.

In the drier Central Altiplano, the later onset of the rainy season has created more severe risks for farmers due to the lack or limited

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Table 6A
CBA results for the communities of Chojñapata y Khapi.

Community	Chojñapata			Khapi		
PRODUCTION COSTS	Wild potato (cultivated before 1983)	White potato (cultivated at present)	Remarks	Rain-fed white potato (cultivated before 1983)	Irrigated white potato (cultivated at present)	Remarks
Rent of machinery	0	820	Wild potato does not use tractor	0	0	The topography of the area does not permit to use tractor
Production Inputs	2.590	3.370	Difference lies in the price of the seeds	5.700	5.700	No difference
Hand labor	2.400	2.000	Hand labor differs in the transformation of wild potato to chuño	7.180	7.610	Differences lie on the hand labor for irrigation
Community labor	180	180	No difference	180	500	Differences lie on the hand labor to periodically maintain earth irrigation channels
Other costs (especially commercialization costs)	0	500	Wild potato is produced for household consumption, and then post harvest and commercialization costs are not included.	1.000	1.500	Rain-fed white potato produces lower yields, therefore the commercialization costs are lower
Total Production costs	**5.170**	**6.870**		**14.560**	**15.310**	
BENEFITS						
Commercialization (fresh)	0	10.000	Wild potato is not sold in fresh	16.000	39.040	Irrigated potato produces more and is sold when the prices are higher (December)
Derivatives (Chuño: dry freeze potato)	5.000	2.000	Wild potato is commercialized as chuño	0	0	In this area, only fresh products are sold
Seed	1.400	2.800	Farmers sell seeds and wild potato seeds are cheaper	1.560	1.560	No differences
Home consumption	400	900	The quantity of consumed white potato has a higher price.	1.000	1.000	No differences
Total Benefits	**6.800**	**13.700**		**18.560**	**41.600**	
PROFITS	**1.630**	**6.830**		**4.000**	**26.290**	
C/B	**1.3**	**2.0**		**1.3**	**2.7**	

Table 6B
CBA results for the communities of Chinchaya and Iñacamaya.

Community	Chinchaya			Iñacamaya		
PRODUCTION COSTS	Rainfed White potato (cultivated before 1983)	Irrigated Onion (cultivated at present)	Remarks	Rainfed white potato (cultivated before 1983)	Dairy Production (at present)	Remarks
Rent of machinery	0	90		240	0	For Dairy, machinery cost is included In feeding cost.
Production Inputs	2.500	2.800	Difference lies in the price of the seeds	5.794	49714,20	
Hand labor	3.600	2.546	Hand labor differs because potato sowing and harvest requires more labor.	4.480	9500	Differences lie on the hand labor for grazing and other daily cost as milking
Community labor	180	180	No difference	180	0	Dairy's producers are organized as producer's association.
Other costs (especially commercialization costs)	1000	1000	.No difference	800	0	The community has its own gathering center.
Total Production costs	**7.100**	**6.236**		**11.494**	**59214,20**	
BENEFITS						
Commercialization	6125	9120		9.310	69120	
Self consumption	2.625	2.280	The quantity of consumed onion has a higher price.	3.990	0	100% of darity's production is for sale
Total Benefits	**8.750**	**11.400**		**13.300**	**69120**	**Producers receive a biweekly payment in cash**
PROFITS	**1.630**	**5.164**		**1.806**	**9905,80**	
C/B	**1.23**	**1,82**		**1.16**	**1.17**	

potential for irrigation. This means that the few crops that can grow in this region must be planted later. Even with rising temperatures, planting later significantly increases the risk of killing fall frosts that can occur before crops reach maturity. Increasing the area devoted to more resilient forage crops and intensifying livestock production have been efficient responses to these risks. However, changes to dairy production have increased market-related risks; there is only a single buyer of milk and dairy production in Bolivia is subject to international competition.

The changes in production systems observed in Chojñapata Khapi and Chinchaya Iñacamaya have been local adaptations driven by climate change and market opportunities while those in Iñacamaya were largely the result of state intervention. Despite being very efficient in responding to new market and climate structures, these adaptations may not be able to respond to ever increasing temperatures. For example in Khapi and Chinchaya there is a limit to the ability of these communities to expand irrigation, and there are already conflicts between water users. These tensions are exacerbated by the subdivision of already small parcels. Intensification has placed pressure on fragile soils and the threat of pests and diseases is increasing. Thus far, farmers have been able to adapt to changing conditions without any outside help. In the future, they may need it to create a menu of adaptation options and to minimize the risks of rising temperatures. Participatory collaboration between farmers, researchers and extension agents is likely the best way to enhance local knowledge, provide farmers with important technical knowledge and improve their decision-making (Slovic and Weber, 2011). This process could create a common language and enhance the adaptive capacity of Andean smallholders by creating better linkages between farmers and scientists.

5. Conclusions

Over the centuries, Andean farmers have demonstrated their capacity to modify production systems and livelihood strategies in response to climate signals. To reduce risks, they have modified the varieties and the crops they produces as well as the locations and times they plant. In addition, they have used migration, trade and livestock to buffer climate-related shocks and sustain themselves and their families. They have developed a number of indicators to help them predict weather (Gilles and Valdivia, 2009. Given these traditions, it is not surprising that farmers have continued to adapt to rising temperatures caused by climate change. Farmers have made dramatic shifts in the past 30 years and we expect that they will continue to modify their production systems. However, as temperatures continue to rise, options available for responding to climate pressures may be declining. Current strategies may be inadequate to respond to steadily increasing temperatures if farmers do not receive external support. Therefore, agencies and scientists interested in adaptation to climate change should give more consideration to understanding the dynamics of local adaptation strategies so that we can reinforce them rather than to develop general strategies for regions and nations. One area that shows considerable potential would be to strengthen local agricultural forecasts by linking meteorological and local knowledge systems. Currently, farmers do not use meteorological forecasts (Gilles and Valdivia, 2009) and the use of traditional forecast methods is declining (Gilles et al., 2013). In addition to this, locally appropriate insurance and credit schemes might speed farmer adaptation.

However, we must put climate change into perspective. Climate change is not the only force that is threatening the sustainability of agriculture in the Altiplano. Increased dependence on markets, the risks inherent in reducing agro-biodiversity, migration and population pressure also pose significant threats. While Andean farmers

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have developed many tools to deal with climate-related risk over centuries, they do not have many cultural tools to deal with these other challenges. These challenges may undermine farmers' abilities to manage climate-related risks. It is important that governments and the scientific community develop adaptation strategies that include local climate knowledge and take into account these other drivers of change.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2017.08.005.

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