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Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate

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ABSTRACT

Smallholder farmers continuously confront multiple social and environmental stressors that necessitate changes in livelihood strategies to prevent damages and take advantage of new opportunities, or adaptation. Vulnerability, meaning susceptibility to harm, is attributable to social determinants that limit access to assets, leading to greater exposure and sensitivity to stressors and a limited capacity to adapt. Stressors and adaptation are intertwined because stressors deplete resources available for adaptation, while adaptation may erode resources available to respond to future stressors. We present empirical evidence demonstrating the interactions of multiple stressors and adaptations over time through a case study of indigenous farmers in highland Bolivia. We examine how farmers perceive the stress on their livelihoods, their strategies for adapting to these threats, and the influence of past adaptation and exposure on vulnerability under increasing climatic change. We find that vulnerability changes over time as multiple stressors, such as land scarcity and delayed seasonal rainfall, compound, simultaneously reducing access and demanding the expenditure of household assets for adaptation, including natural capital (water and land), human capital (including labor), and financial, physical, and social capital. To reduce vulnerability over time, constraints on access to key resources must be addressed, allowing households the flexibility to reduce their exposure and improve their adaptive capacity to the multiple stressors they confront.

1. Introduction

Bolivia contributes only .04% of the world's carbon dioxide emissions (CDIAC, 2008), yet climate change is already producing observable effects on temperature, precipitation variability and seasonality, and water supply there (Barnett et al., 2005; Gilbert et al., 2010; Parry et al., 2007; Ramirez et al., 2001; Vuille et al., 2008). Some Bolivians, especially smallholder farmers, are already experiencing climate-related vulnerabilities and livelihood loss (Valdivia et al., 2010). While all individuals must manage multiple stressors on their livelihoods – climatic and otherwise – the most vulnerable are often more exposed to and least able to manage these risks (Adger et al., 2006; Sen, 1981; Watts and Bohle, 1993). Climate change exacerbates global inequalities, as those most affected are the least responsible for causing it (Barnett, 2006; Roberts and Parks, 2007). Greater attention must be paid to the social inequalities of climate-related vulnerability (Ribot, 2009).

Across a wide range of disciplines, vulnerability generally refers to susceptibility to harm (Adger, 2006; Eakin and Luers, 2006). In the climate change literature, vulnerability is often understood to be a function of exposure and sensitivity to a hazard and the ability to respond, or adaptive capacity (Parry et al., 2007; Smit and Wandel, 2006). In the biophysical conception of vulnerability, exposure and sensitivity represent the risk that a physical hazard poses to a population, and this risk is seen as exogenous to society (McLaughlin and Dietz, 2008). This risk-hazard model maintains adaptive capacity and sensitivity as fixed, mapping climate-related hazards onto a "socially static landscape"(Ribot, 2009) in order to estimate "the ultimate impacts of a hazard event . . . in terms of the amount of damage experienced by a system as a result of an encounter with a hazard" (Brooks, 2003, p. 4).

It has been widely recognized, however, that adaptive capacity, exposure, and sensitivity are not static, but vary widely over time, space, and subpopulations, as do the damages experienced (Handmer et al., 1999; Smit and Pilifosova, 2003; Turner et al., 2003). For example, smallholder farmers are often considered particularly vulnerable to climate-related food insecurity, not due to greater environmental exposure to drought than more commercial farmers, but due to limited infrastructure and inputs

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to shield them from that exposure, narrow yield margins, susceptibility to market fluctuations, and limited resources to adapt (Brown and Funk, 2008; Morton, 2007). While social variables are included in some risk-hazard models as determinants of sensitivity or adaptive capacity (Hinkel, 2011), these models do not explain *why* certain groups are more exposed or sensitive to hazards, and less able to respond, than others (Turner et al., 2003). Without identifying why and how risk and adaptive capacity are differentially distributed within a population, reducing vulnerability is difficult (Ribot, 2009).

Livelihoods approaches to vulnerability analysis attempt to identify the root causes of vulnerability to explain who is vulnerable, why, and how root causes might be addressed (Ribot, 2009). While a physical hazard is an external stressor, the *risk* of adverse consequences related to that hazard[1] is socially differentiated and is produced by processes, events, and systems internal to society (Beck, 1992; Blaikie et al., 1994). Many analysts consider vulnerability to be dependent on social variables, such as health, education, infrastructure, political participation, and poverty (Adger et al., 2004; Brooks et al., 2005; Hinkel, 2011; Vincent, 2004). All of these factors are largely manifestations of access to resources, from social to financial assets (Blaikie et al., 1994). As Adger et al. argue, vulnerability "is determined, not only by the likely responses of the resources on which individuals depend, but also by the availability of resources and, crucially, by the entitlement of individuals and groups to call on these resources" (2003, p. 181). Social processes determine resource distribution and therefore cause certain groups to be more exposed to risk (Blaikie et al., 1994; Mustafa, 1998; Watts and Bohle, 1993) and less able to adapt (Adger et al., 2004; Smit and Wandel, 2006). Vulnerability can be reduced, and adaptive capacity improved, by enabling resource access (Agrawal, 2009; Ribot, 2009).

Vulnerable households expend limited resources to respond to a changing suite of stressors, such as social, economic, political, and environmental stress (Mortimore and Adams, 2001). We define these stressors as those events, trends, policies, and processes that deplete resource stores or systematically alter resource access. Marginalized people must constantly manage stress on their livelihoods. Their attempts to minimize risk over the short-term may erode their asset base and decrease their ability to prepare for future risks, increasing vulnerability (Agrawal, 2009; Blaikie et al., 1994; Pelling, 2010; Ribot, 2009). While some communities do adapt to change over time to reduce their own vulnerability (Casale et al., 2010; Nyong et al., 2007), others experience stress that exceeds their adaptive capacity and deepens vulnerability (Tanner and Mitchell, 2008). The process of adaptation to multiple stressors, however, remains poorly understood (Belliveau et al., 2006; Bryant et al., 2000; Tschakert and Dietrich, 2010), and more insight is needed into the relationship between adaptation, assets, and multiple stressors (Prowse and Scott, 2008).

This article examines adaptation in historically marginalized agricultural communities in highland Bolivia, a region already experiencing dramatic glacial retreat and attendant shifts in water supply. We ask how these farmers experience multiple stressors and how household responses and stressors interact to reconfigure the asset base. Specifically, we explore the tradeoffs that households make when adjustments to one stressor compromise the ability to adjust to another. We begin by considering adaptation as an asset-based set of decisions and then place adaptation as part of ongoing livelihoods strategies to confront multiple stressors. This leads us to adopt a livelihoods approach to resource access as a unifying framework. We then provide empirical evidence of smallholder farmers' adaptation to multiple stressors over time, using qualitative data from sixty interviews in the Municipality of Palca in Bolivia to illustrate farmer's perceptions of the changing social and climatic stressors and corresponding adaptation. We demonstrate how heightened social stress followed by increasing climatic variability and change reconfigures households' access to key resources. Consequently, adaptation strategies compete for these limited assets. Reduced resource access compromises adaptation and further increases vulnerability, while increased access provides greater security and enhanced adaptive capacity. We suggest that vulnerability will be reduced only by ensuring sustained access to key assets, permitting households the flexibility to respond to multiple stressors.

2. Vulnerability as lack of access

Vulnerable groups are more exposed and less capable of adapting to stressors (Adger et al., 2006). Adaptation occurs in response to, and in preparation for, multiple stressors that reconfigure access to resources required for response. A livelihoods approach to access allows us to follow the process of adaptation to multiple stressors over time, by identifying how assets are obtained, constrained, and expended (Bebbington, 1999; Prowse and Scott, 2008; Ribot, 2009).

2.1. Assets as the foundation of adaptation

In the climate change literature, adaptation refers to the adjustment of socio-ecological systems to a climate stressor in order to moderate harm or take advantage of opportunity (Smit et al., 2000). Adaptation implies the reorienting of a system to avoid damages or profit from change, but also includes the ability to cope, meaning survival under temporarily constrained conditions (Cooper et al., 2008; Pelling, 2010; UNFCCC, 2003). Successful adaptation thus implies that a system can avoid damages while coping with those that do occur, without undermining the capability for future response. Most adaptation choices – either to reduce exposure and sensitivity or enhance coping ability – are constrained by the assets available to a household (Agrawal, 2009), making active adaptation an asset-based set of decisions.

Adaptive capacity, then, is "the set of resources, and the ability to employ those resources, that are prerequisites to adaptation" (Nelson et al., 2007, p. 402). To increase adaptive capacity, a household must expand its asset base, meaning both the tangible resources used to maintain livelihoods (such as natural and productive resources) and the capabilities to do so (including social and human capital) assets (Bebbington, 1999). Household decisions to improve asset allocation are important, such as by learning from exposure to past stressors (Reilly and Schimmelpfennig, 2000; Tschakert and Dietrich, 2010; Yohe and Tol, 2002). But reallocation may not be sufficient to avoid damages, and vulnerable households are often unable to expand their asset base (Blaikie et al., 1994; Tanner and Mitchell, 2008). Because social, political, and economic processes determine the distribution of assets within a society, adaptation is largely enabled or disabled by the institutions and social structures shaping these processes (Adger and Vincent, 2005; Agrawal, 2009).

2.2. Adaptation to multiple stressors from a livelihoods perspective

Adaptation is not a new concept and is not unique to climate change. Smallholder farmers have long been 'adapting' their livelihood strategies to changing stressors, from environmental degradation to market conditions (Barlett, 1980; Sabates-Wheeler et al., 2008). As Bebbington explains: "Livelihood strategies are attempts, from existing and often severe constraints, at a continuous management and modification of ... substitutions,

[1] For more on the relationship between vulnerability and risk, see Blaikie et al. (1994) and Brooks (2003).

tradeoffs and draw downs on different capital assets" (1999). Adaptation is part of these ongoing livelihood strategies to manage resources in the face of multiple stressors (Sabates-Wheeler et al., 2008).

The same resource base must be leveraged to respond to multiple stressors, and these stressors may transform assets and access to them (Blaikie et al., 1994). For example, coping with one stressor may erode or reallocate resources available to respond in the future, or increase exposure or sensitivity to other stressors (Belliveau et al., 2006; Roncoli et al., 2001; Schipper and Pelling, 2006). On the other hand, multiple stressors may compound to affect the quantity or value of one or more household resources simultaneously, compromising adaptive capacity (Belliveau et al., 2006). The adaptation process and the stressors themselves are therefore interconnected, and vulnerability analysis must reflect this entanglement.

The urban livelihoods literature has highlighted the centrality of resource access to urban poverty and vulnerability. Inequalities in access to housing, for example, multiplicatively disadvantage the poor, who are then also unable to access productive environments, services, and safe public spaces (Stretton, 1978). The urban disaster literature has shown that improving the urban poor's access to assets, from housing to education, can help households meet basic needs and buffer against stress, both reducing poverty and disaster risk (Moser and Satterthwaite, 2009; Sanderson, 2000). Rural livelihoods literature on climate change has characterized how multiple stressors affect livelihoods and how households adapt (Bryan et al., 2009; Osbahr et al., 2008; Paavola, 2008; Reid and Vogel, 2006; Tschakert, 2007). Others have pinpointed interactions between adaptation and multiple stressors, especially economic globalization and environmental change (Belliveau et al., 2006; Eakin, 2005). More insight is needed, however, into the complex asset-based relationship between adaptation and multiple stressors in rural areas (Prowse and Scott, 2008).

2.3. Access as a framework for adaptation

Multiple stressors impact the availability of assets fundamental to livelihood strategies, and also determine who can *access* these assets. Ribot and Peluso (2003) argue that while property is the *right* to benefit from things (assets also being 'things' tangible and intangible), access implies the *ability* to benefit from things. Access is not just gained through rights, which are socially enforceable claims, but is predicated on a broader bundle of powers that may also involve stealth and violence. An ability is much broader than a right. In the context of climate change, physical stressors may determine the physical quantity or quality of a given resource, like water. However, the ability to benefit from such a resource depends on a broader set of abilities or access mechanisms such as technologies, landscape configurations, social capital, violence, or theft (Ribot and Peluso, 2003). These mechanisms, including classic property, can all be enhanced or impaired by climate and other physical and social stressors. Adaptation is dependent on access to resources, and thus tied to the physical and social stressors to which a household is exposed.

The concept of adaptation has been criticized for blaming the victim, by putting the onus on the vulnerable household or social group to adjust, rather than on those social structures causing vulnerability (Ribot, 2010, 2011). Adaptation to climate change is not a choice given to vulnerable groups, but an obligation, and these same groups are often ignored in adaptation policy decisions (Adger et al., 2006). By centering analysis on access, however, the root causes of vulnerability can be ascertained, and adaptation options can be identified at both household and societal levels. This approach gives agency to vulnerable households, while putting the burden of responsibility for adaptation not on the vulnerable, but on those institutions and social structures that produce vulnerability.

Understanding adaptation to multiple stressors in terms of access to assets also allows us to address the complexity of vulnerability (Moser and Satterthwaite, 2009). Poor households are often unable to change their short-term asset use to prioritize long-term adaptation, so altering existing configurations of access has implications for both current and future livelihood strategies (Prowse and Scott, 2008; Tanner and Mitchell, 2008). Likewise, the ability to benefit from one resource, like land, may depend on access to another resource, such as labor, so some households may be unable to fully utilize the resources they *can* access (Berry, 1989; Ribot and Peluso, 2003). By focusing on such tradeoffs over time, adaptation can be conceived as a process centered on accessing and expending assets interlinked with multiple stressors. In the following sections, we present a case study of interacting multiple stressors and the tradeoffs that highland farmers in Bolivia make to sustain their livelihoods.

3. Methods and study area

3.1. Methods

We selected the Municipality of Palca for study because it depends on smallholder agriculture as its primary source of income (INE-PNUD, 2005) and on a water supply originating from glacier and snowmelt runoff that will likely diminish with climate change (Ramirez, 2008). Yet rather than presuming the potential effects of this, we followed a participatory vulnerability assessment framework, aiming to understand how farmers themselves perceive and respond to stresses on their own livelihoods (van Aalst et al., 2008). Qualitative methods allowed for a nuanced understanding of adaptation decisions and vulnerability from farmers' own perspectives (Belliveau et al., 2006; Miller et al., 2010).

We conducted sixty semi-structured interviews with heads of household in five Aymara agricultural communities at different altitudes within the Choquecota River Basin in Palca (Fig. 1) between March and August of 2008. We first interviewed key informants, including community leaders and respected elders, and then used snowball sampling (Ritchie and Lewis, 2003). The traditional system of leadership mandates that heads of all households serve as community leaders on a rotational basis, ensuring a socioeconomically diverse, though predominantly male, group of key informants. These informants then provided additional participant references, and women heads of household were specifically sought for inclusion. We ultimately included mostly landholding[2] men (32) and women (28) of various ages (18 to over 70).

Participants chose the interview language. The researcher directly interviewed Spanish speakers, while a translator conducted interviews in Aymara. Interviews began as open-ended discussions of livelihood strategies and stressors, and then focused more specifically on climate and recent changes (methods adapted from Wandel et al., 2005). Farmers were not asked to catalogue or rank their assets, but instead to discuss how their livelihoods were structured according to their priorities, which often included: who provided labor for which tasks, how much land and water farmers had, who made household and community decisions, and how income was generated, among others. Farmers augmented these themes when discussing strategies to respond to changing stressors.

[2] Only a very small number of farmers living in the communities of Palca do not own their own land. These few households tend to depend on livestock, and one was interviewed, while others depend almost solely on mining, and were not interviewed. Some younger households continue to farm parents' land until parcels are turned over to them. These households were considered to be landholding, and were also interviewed.

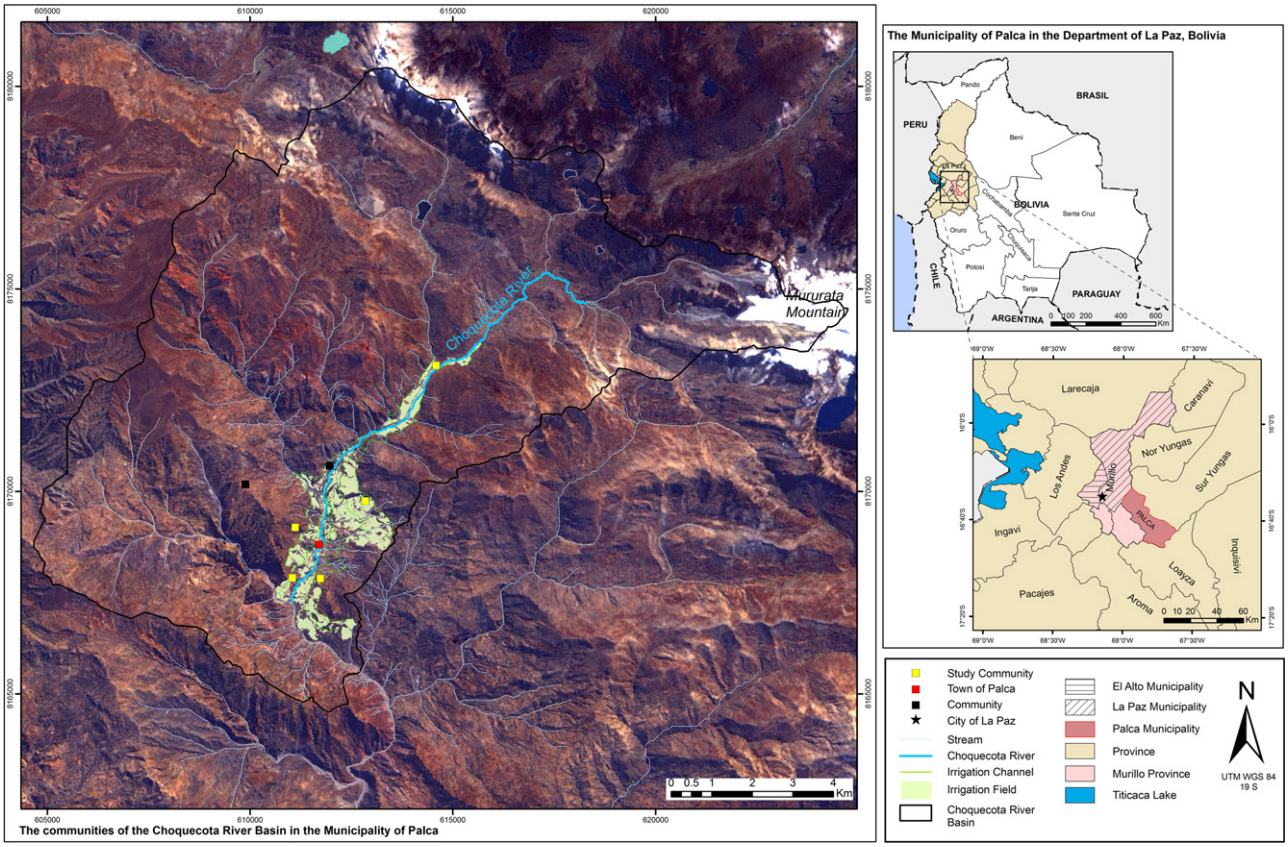

Fig. 1. Map of the agricultural communities of the Municipality of Palca (Castel, 2008). The farmers in Palca irrigate land with water that descends from the Mururata Mountain via the Choquecota River. They also farm rain-fed plots in the hills above the irrigated areas.

Structured participant observation (Emerson et al., 1995) in the fields, homes, and community meetings complemented interviews. Additionally, institutional actors were interviewed, including government officials and representatives from aid organizations, to provide a perspective on available institutional assets for adaptation, though most were not accessible to Palca's farmers. While we focus on farmers' experiences in our analysis here, institutional factors are discussed in greater detail elsewhere (Diaz et al., 2011).

3.2. Study area

The Choquecota River Basin is located in the Municipality of Palca, approximately 20 km southeast of the capital city of La Paz, Bolivia in a valley at the western base of the Cordillera Real Range in the Andes. About 14,000 people live in the 740 km^2 municipality (INE-PNUD, 2005). Approximately 140 km^2 of this area fall within the Choquecota River Basin. The river originates in the peaks of the Mururata Mountain (5628 m) descending to supply the valley below (down to 3400 m) (Castel, 2008).

The Municipality of Palca is rural, with almost 70% of the population depending on agriculture for its income. Nearly 80% of Palqueños live in extreme poverty (INE-PNUD, 2005) and many suffer from high food insecurity (WFP, 2008). Infrastructure is limited—only one-fifth of arable lands are irrigated, and there are no paved roads (Ontiverios, 2007). Over 90% of Palca's inhabitants self-identify ethnically as Aymara, and 84% claim Aymara as their first language, while only half is bilingual in Spanish (INE-PNUD, 2005).

Much of Palca's indigenous population once worked on the haciendas. In this semi-feudal farming system, Spanish or mixed Indian-Spanish (mestizo) descendents were granted land to create enormous plantations using labor supplied by the land's displaced inhabitants. In Palca, the hacienda prospered during the colonial period and even following Bolivia's independence from Spain in 1825 (Barragán, 1982). A popular revolution in 1952 lead by the National Revolutionary Movement finally brought universal suffrage (though subsequently interrupted by military coups and questionable elections) and an agrarian reform that dismantled haciendas, redistributing land to indigenous communities, campesinos (peasants), and displaced miners (Flores, 1954; Sanabria, 1999). Today, Palca's farmers live mostly in campesino communities (Fig. 1) governed by agrarian unions that oversee quotidian social, economic, and spiritual life. This system of governance coexists with formal state structures including the municipal, prefectural, and national governments.

Palca is characterized by a sub-tropical, high-altitude climate. The town of Palca (3400 m), the seat of the municipal government, has a yearly average high temperature of 22.4 °C, average low temperature of 5 °C (Ontiverios, 2007), and average rainfall of 557 mm (SENAMHI, 2006). However, precipitation in the region is highly variable both inter-annually (Garreaud et al., 2003), and seasonally (most of the rain falls between November and March (SENAMHI, 2006). Frosts are also common (François et al., 1999). The Andean region has experienced a decadal temperature increase of 0.1 °C over the past 70 years (Vuille et al., 2008), and more recent increases in frost events and variable, intense precipitation (Thibeault et al., 2010). Like most Andean glaciers, the Mururata glacier that sustains the Choquecota River is shrinking, having lost nearly 18% of its surface area since 1983, and is likely to disappear before 2040 (Ramirez, 2008).

3.3. Andean agriculture and climate

Andean farming systems have endured for centuries under the region's highly variable climate (Dillehay and Kolata, 2004;

Erickson, 1999). In Palca, farmers indicated several long-standing practices for withstanding climate variability and extreme events. In addition to religious practices to ward away climatic hazards, strategies focus on assuring year-round availability of foodstuffs through crop diversification, spatial distribution of fields, food storage, communal land and labor, and animal husbandry.

The use of different altitudinal levels and corresponding microclimates (*pisos ecológicos*) is one indigenous technique for assuring diversified food production (Murra, 2002). In Palca, hardy crops, like tubers, barley, and quinoa, are often cultivated in rain-fed mountain fields, while lower-altitude, irrigated plots also produce corn, beans, and peas. Families often farm small parcels scattered throughout the valley at different geographic and altitudinal locations. As one farmer says of his fields: we have "lots, like confetti—one over here, another over there ..." In this way, households ensure a varied diet in good years and diversify their risk in bad years across locations and crop varieties. Hail, for example, is often a quick, spatially isolated event that damage crops in one area while sparing others nearby (Valdivia and Dunn, 1996). In dry years when high-altitude fields produce little, farmers depend on limited irrigated crops and food stores to sustain them.

Assuring reserves is a key objective of many Andean agriculture systems (Rist, 2000). Many traditional crops can be dried and/or stored. One farmer explained survival when yields were low: "That's how we made it that year, with the small amount of produce we saved." *Kaya* and *Chuño*, dehydrated tubers that keep for years, are staple foods in Palca. Livestock represents another asset store. Small animals like guinea pigs and poultry supplement household diets, or provide a small source of income. Most families have a few large animals, like sheep, cows, or llamas, which they slaughter in times of serious need for food or cash (Valdivia, 2004).

Communal land and shared labor are essential components of indigenous Andean agricultural systems (Guillet, 1980, 1981). The *Aynoqa*, a traditional crop rotation scheme on rain-fed communal land, requires farmers to switch plots annually on a predetermined, rotational basis to alternate specified crops with fallowing to maintain fertile soils (Orlove and Godoy, 1986). Risk sharing through reciprocity is also common (Valdivia and Dunn, 1996). These practices include the *ayni* (shared work between families and/or neighbors), *la partida* (a type of sharecropping), and *trueque* (customary exchange of agricultural products, usually across distinct ecological levels). One mid-altitude community member in Palca explains *trueque* with a high-altitude community: "We exchange for food. They usually bring *kaya*, and *chuño* ... we usually give them onions." In recent years, changing social and climatic stressors have prompted the abandonment of some practices, while others have become more important.

4. Multiple exposures and adaptation in Palca

Palca's agricultural households experience various stressors on their livelihoods, some of which have increased in recent decades. Relying on farmers' perceptions of stressors and corresponding adaptation strategies, we present observations in two periods: one period of mounting social and economic stress, followed by the current period of intensifying climatic stress. We focus on assets that participants identified as most affected by multiple stressors and needed for adaptation, including land, water, labor, financial resources, and human and social capital.

4.1. Social stressors and adaptation

"There isn't much profit in agriculture."—Farmer from Palca

Farmers identified numerous social and economic stressors that have been growing over time, most notably land scarcity, uncertainties in agricultural and labor markets, and institutional marginalization, which limit access to assets. In response, farmers have adapted their livelihoods by intensifying production of cash crops, incorporating more off-farm income, and relying on community institutions (agrarian unions).

4.1.1. Land scarcity

The agrarian reform following the 1952 Revolution reordered the land tenure system of both haciendas and traditional indigenous landholding practices (Andersson and Haarstad, 2009). In Palca, individual titles were granted for small parcels in the valley, while most hillsides remained communal. While freedom from the hacienda is celebrated, access to land is recognized as a problem once more. One participant explains that his land belonged to "my father from before, from the time of the hacienda when [President] Victor Paz Estenssoro mandated [the reform] ... to my grandfather, then my father, and now we are here ... we split it between us, piece by piece, with my sister, and now it is all divided." After several generations, most families now have less than one hectare of land, while some have as little as 500 m^2 (Ontiverios, 2007). The tiny holdings are known as "minifundios." A select few farmers have purchased land outside of Palca, but most participants could not access more land due to insufficient economic resources.

Minifundios prevent the practice of traditional methods of crop diversification and rotation, which require some plots of land to rest fallow each year, instead planting irrigated parcels twice annually. Though only one community still practices the *Aynoqa*, some highland communal areas are still available for household use. A few households have shifted to greater dependence on livestock, grazed on communal lands. Many households have responded by prioritizing crops that yield the most produce per hectare, like potatoes, or that bring a high profit, like vegetables, which fulfill growing cash needs. One farmer assessed his most profitable crops: "It could be the peas, but also the onions. Or maybe the lettuce—in one year it comes up twice." Some families have switched almost entirely to cash crops, then purchasing cheap commercial foods for household consumption.

Farmers have strategically intensified production to increase yields. Subsistence crops are grown on rain-fed land, while irrigated land is dedicated to market-quality produce, including water-intensive vegetables and higher quality traditional crops: "Irrigated potatoes, we sell. Those from the hills are for eating, you know, we store them ..." Intensified production requires greater expenditure on inputs. As irrigated fields are rarely rotated or left fallow, soils become deficient, making fertilizers necessary. Some noticed a greater presence of pests in cash crops, which requires more pesticides. Some cash crops also require farmers to purchase seed, rather than reuse, seed each year. This intensified system demands more labor to irrigate, fumigate, and fertilize parcels, and take goods to market, while inputs perpetuate the need for cash, creating further dependence on the market.

4.1.2. Market uncertainties

Reliance on cash crops creates greater exposure to agricultural market prices, while the need for income to supplement and sustain agriculture has fueled the need for more paid, off-farm work. As one farmer explains of the market for produce: "It goes up, sometimes, it goes down. It is not a fixed price." Some farmers have responded by staggering planting and then harvesting over several weeks, smoothing income under volatile market prices and saving labor costs by keeping work within the household. Another strategy is timing: "One plants early sometimes in order to earn a little more ... so that it is ready in December, and it sells a little better." Farmers' access to markets was limited even when prices where good, because the "intermediaries take it away from us," and farmers earn a fraction of the profits.

Insufficient land, income, and rural work opportunities, countered by a greater need for cash, push community members to migrate to nearby urban areas or mines. Work options are often limited to low-paying day labor, as one farmer explained: "To be a worker, [you are] only just a worker. Only the owners always earn more, you see?" Off-farm work is, nonetheless, an important household income source, but with consequences—migration deprives families of their loved ones and most productive members, putting greater strain on the remaining women, children, and elderly to run the farms. Some households now depend on off-farm income to cover the costly inputs for intensified agriculture. One farmer explains when she could not buy seeds in time to plant: "We get behind because we do not have money ... My husband went to work, but he did not earn much, and that's why we are behind."

The shift to cash crops thus introduces greater exposure to the labor market, as human resources are strained to respond to various stressors. At the same time, land scarcity and cash needs have changed traditional labor practices. Some farmers with land or cash shortages seek paid work on neighbors' farms, rather than participating in traditional reciprocal labor. Still, the *ayni* remains an important coping strategy for tough times: "Today, they are going to help me, tomorrow I have to help them. We do it this way because sometimes there is no money." Such sources of social capital prove essential substitutes for negligent formal institutions.

4.1.3. Institutional marginalization

Bolivia's long history of racism continues, even with the ascension of indigenous President Evo Morales (Kohl, 2010). Many public and private sector institutions are inaccessible to Palca's farmers due to systemic discrimination against indigenous people. For example, decades of intentional exclusion followed by years of bureaucratic negligence have left many rural dwellers without the official identity cards or land titles required to access services and capital. One participant explained of the bank: "We cannot borrow. There are [loans], but one needs documentation—they ask for a lot of things. We applied to the bank for a sum, but it went nowhere, it resulted in nothing." Other participants feared being tricked or losing their belongings to creditors. Some cited their lack of formal education prevented them from accessing and managing loans.

The quality of rural schools is very poor, made worse by culturally inadequate curricula. Rural schools are taught in Spanish, seen by Aymara farmers as an essential skill, but few bilingual resources are available to ease this linguistic transition. Rural students are then denied opportunities for higher education and job training: "Schooling here in the provinces is not good—they go to La Paz and then they cannot enroll – in vain, you know?" Consequently, options to gain the human capital necessary to improve terms of labor in the urban market are limited.

Institutional failure to provide access to physical capital, including infrastructure, was highlighted by participants. Farmers attributed Palca's washed-out roads and bridges, collapsing irrigation canals, and patchy provision of drinking water to the misuse of funds, because the municipal politicians "take the money for themselves!" Yet addressing these failures through formal political channels requires costly trips to La Paz, knowledge of bureaucracy, and Spanish literacy. Even the agrarian unions were often unable to procure assistance: "We go to the municipality and the prefecture, but there is no way to get help. They offer, but they never follow through."

On the other hand, the agrarian unions continue to fulfill primary institutional roles in the communities, from settling disputes to overseeing infrastructure maintenance. As one union leader who oversees irrigation explains: "In the dry season, [I] see how everything is, if it's good or bad. One has to check to see if it needs work, or does not need work." Leaders organize days of communal labor to clean and repair canals, as well as roads, clinics, and school buildings, though lack of economic resources frequently prohibits the purchase of basic construction materials. While these community institutions are important for mobilizing existing assets, changes in climate are presenting additional challenges.

4.2. Changing climatic stressors and adaptation

> "It has changed. Sometimes the rain does not fall in its season; sometimes the frost does not come right in its season. Before it was later, but now the frost arrives early, like a punishment. Now the rain falls like it is saying 'I am not going to come anymore.' Already, the sun is very strong. Before, it was not like this."—Farmer from Palca.

In recent years, many interviewees have observed changes in the climate evidenced by water shortages, rising temperatures, and increased climatic variability, which have been substantiated in the climate science literature (Bradley et al., 2006; Magrin et al., 2007; Thibeault et al., 2010; Vuille et al., 2008). Farmers have responded by changing cropping and water use strategies, but limited economic resources and institutional support stymie further action. Climate-related adaptation is further constrained because market-oriented production is often highly climate-sensitive, but necessary to address social stressors.

4.2.1. Water shortages

Over the past one to two decades, farmers noted a trend toward a delayed rainy season with less precipitation overall (Thibeault et al., 2010; Vuille et al., 2003) and reductions in stream flow, likely partly attributable to diminishing glaciers (Barnett et al., 2005; Bradley et al., 2006; Ramirez, 2008)[3]. Recently, the rainy season has started in late October, instead of September, and many farmers noticed that less rain fell overall. The decreased precipitation, and increased temperatures that favor rain over snow, correspond with farmers' observation of diminished snowfall in the mountains (Barnett et al., 2005): "Before, when it used to rain, it used to snow [on the mountain] and everything used to be white, but now, no. Now it does not snow." With the Mururata glacier shrinking each year and a reduction in new snow cover (Ramirez, 2008), there is less dry season runoff into the Choquecota River, and less water to fill farmers' irrigation canals. One farmer explains: "Not as much water runs now ... Sometimes there is no water at all ... so we are almost fighting over the water." This physical water scarcity is likely exacerbated by the increased water demand of cash crops.

Water shortages have begun to compromise agricultural production, as climatic stressors interact with social stressors to increase both exposure and sensitivity. For example, in the hills, "if the rain does not arrive, then one has to plant the rain fed plot in October," at the risk of losing crops to an early frost before harvest. As rain becomes undependable, and labor becomes increasingly valuable for off-farm work, farmers hesitate to invest in hillside fields with lower, less certain yields. Many have therefore abandoned or reduced highland production, an important subsistence food source, to focus on irrigated cash crops and off-farm activities. Decreased precipitation and market pressures thus compound land scarcity, decreasing the utility and value of some land, and intensifying pressure on irrigated parcels and their water supply.

Yet farmers do not have the mechanisms to access more water or make more efficient use of the existing supply. Nearly all

[3] While receding glaciers will initially increase stream flow, as they diminish in size they lose storage capacity and no longer buffer seasonal changes in water supply (Bradley et al., 2006).

farmers wanted to replace their earthen irrigation canals, which lose substantial water to seepage and evaporation, and are labor intensive to maintain. Others suggested larger infrastructure investments: "A reservoir should be put up there [below the glacier], that way there will be no water shortages." Farmers also desired improved inputs, such as short cycle or drought resistant crop varieties. Farmers cited lack of knowledge, economic resources, and institutional support as principle barriers to such improvements. One community, through exceptional leadership by the agrarian union, did obtain a piped irrigation system from an international aid organization.

Without increased access to water or improved efficiency, adaptive strategies to confront water scarcity may increase sensitivity and exposure to social and economic stressors. For example, some farmers have responded to the delayed rainy season and dry season water shortages by waiting until there is sufficient irrigation water to plant: "If we plant without irrigation, it is not going to produce [anything]." However, a late harvest exposes farmers to low selling prices at the peak of the season. Others have adapted by reallocating labor, such as by irrigating at night. While this adds hours to their work day, there is less competition: "At night there is more water, one has to do nocturnal irrigation." Community-selected irrigation committees help distribute water equitably by rationing water during the dry season *por turno*, or in assigned shifts, to users that help maintain the canal collectively. Some canals continue to function on a 'first come, first served' basis, however, to the detriment of downstream users.

4.2.2. Rising temperatures

An increase in temperature (Vuille et al., 2008) was observed by most participants over approximately the past two decades in a variety of ways: the physical sensation of increased air temperature, changes in cultivars, proliferation of pests, and rapid evaporation of irrigation water. Many equated temperature increase with stronger solar radiation, as one farmer indicated: "It is very hot, very sunny. Look, it's burning us. It did not use to be like this." Others noted the change in vegetation (Cannone et al., 2007; Fischlin et al., 2007). While ten or twenty years ago fruit trees only grew in the lowest parts of the basin, now "the sun is very strong. For that reason, even peaches can grow! Before, peaches were not known to thrive, but now, even the *tuna* [cactus fruit] grows." A few farmers at the lower altitudes have been growing fruit for some time and are able to take advantage of these changing conditions. Others wanted to invest in orchards, but cited insufficient economic resources and technical knowledge as obstacles. In this way, adaptive capacity of the poor and marginalized is limited by the inability to take advantage of opportunities to profit from risk (Zimmerman and Carter, 2003), and is another way in which multiple stressors compound to limit the resources available for adaptation.

Not only plants are surviving at higher elevations—pests that damage crops may also thrive as temperatures increase (Bale et al., 2002; Easterling et al., 2007; Hodkinson, 2005). As one farmer from a higher altitude community explained: "There are too many worms in the potato . . . in the lower parts [of the basin] there are usually worms, and not so much here, but this year almost everything got worms . . . it is a little hotter, maybe that is the reason." A few farmers acknowledged that adopting less pest resistant crops, purchasing seeds from elsewhere, and giving up crop rotation and fallowing, may enable pest proliferation. In this way, climate stressors compound upon social stressors to doubly affect households' resources, while adaptation strategies may be incompatible across these different stressors as access to needed resources is increasingly restricted. In response to the pests, farmers applied more pesticides, at significant cost. This further strained limited economic resources and increases the need for cash, even more tightly coupling households' agricultural production with the market. Once again, the most marginalized are least able to profit from their investment, as many farmers were unsure of which chemicals to use or how to apply them most effectively, and depended on advice from neighbors or pesticide vendors. While some NGO's provided technical assistance, no government extension services were known to be available.

The accelerated evaporation of irrigation water is also seen as an indication of increased heat. As one producer lamented: "Today I irrigate, the day after tomorrow it is already dry . . . I have to work all the time—before, it lasted a week." Increased production of water-intensive cash crops and greater dependence on irrigated land require even more water and labor for irrigation under these new conditions. As in dealing with water shortages, improved irrigation systems were seen as out-of-reach, and irrigating at night was a solution of last resort, as it helped avoid rapid loss of soil humidity: "In the morning we have to irrigate, from three or four in the morning. We irrigate until the sun comes out."

4.2.3. Extreme events

Farmers reported that in recent years rainfall, hail, and frost events had become more extreme and less predictable, as substantiated by the climate science literature (Magrin et al., 2007; Thibeault et al., 2010). For example, some participants have noticed an increase in rainfall intensity, while others say it falls in shorter intervals. A farmer explains that while the rain "fell nice and slowly before, now it is very strong, and it even hails." In the past several years, flash floods have swept away plots of cropland and caused the collapse of irrigation canals, further compromising infrastructure and uncertain agricultural production: "It carried away everything, it entered houses, when the flood water came. Below I had planted corn and peas, and it washed all of this away." Because irrigated land is of increasing importance to the household economy in Palca, losses from these flash floods are felt even more acutely than before—another instance where social and climate stressors compound on the same resource, in this case land.

Many farmers noted that hailstorms have become even more intense (Magrin et al., 2007), frosts more frequent (Thibeault et al., 2010), and both less predictable. One farmer explained: "[The frost] is increasing. It is not usually like this in this season, it is usually cloudy now. The frost is already here a little bit and it is getting worse." Likewise, hail has begun to fall outside its normal season: "Before, it was in August, September, October, November. In these months the hail came. But now it comes all the time." When frosts are expected, bonfires are set near fields or straw is laid over crops, but unpredictability has made these strategies less feasible. Some deal with unexpected hail and frost by gradually planting their fields, exposing only some plants, rather than the whole field, to late frosts. This risk smoothing measure also protects against low market prices at harvest and reduces the need for extra-familial labor, making it one of few strategies compatible with both climatic and economic stressors. At the same time, delayed rains shorten the growing season, and may limit the yield that can be achieved through this method.

Cash crops, like vegetables, are especially sensitive to hail, which "destroys the lettuce. The leaves are fragile and everything destroys them." Even when crops are only aesthetically damaged, ". . . then in La Paz they only want it for cheap," reducing farmers' income. Given limited stores of traditional foodstuffs, sacrificed in order to plant cash crops, a decline in agricultural prices or an adverse weather event greatly compromises household income and food security.

Many expressed a lack of adaptation options: "When the frost or the hail comes, one cannot do a thing. With what can we defend ourselves? It beats down on the quinoa as it wishes, and destroys it all." Greenhouses were seen as one potential solution, though no

community members had access to this type of physical capital. Instead, many drew on existing asset stores to buffer rapid and/or unexpected agricultural losses, including food stores and livestock. When crops are lost or yield is low, livestock provides an important wealth store, as one farmer explains of losing crops to a flash flood: "Selling livestock, selling that, we bought corn or beans, or a little bit of rice and noodles and bananas. With that we made it through that year." Yet because most households only have a few heads of livestock, this resource can be quickly exhausted, and an eroded asset base may reduce households' ability to respond to subsequent shocks (Moser and Satterthwaite, 2008; Roncoli et al., 2001). Such difficult tradeoffs in the short-term led made some farmers interested in switching primarily to livestock rearing as an alternative under increasingly uncertain growing conditions, as livestock can be less susceptible to climatic conditions, require less labor than agriculture, and are usually grazed on communal land, relieving pressure on small landholdings. However, the poorest were least able to take advantage of this opportunity, as few could access enough financial resources to acquire larger herds.

5. Discussion and conclusions

Farmers in Palca perceive changes in climate that are consistent with other farmers in the region (Valdivia et al., 2010; Young and Lipton, 2006) and with physical science observations (Bradley et al., 2006; Thibeault et al., 2010; Vuille et al., 2008). Farmers also identified numerous non-climatic stressors on their livelihoods, many of which preceded climate change. Key assets for adaptation included: land, water, labor and human capital, social capital, and financial capital (which enables access to infrastructure, fertilizer, land, etc.), which have proved similarly important to smallholder farmers elsewhere (Bryan et al., 2009; Eakin, 2005; Osbahr et al., 2008; Reid and Vogel, 2006). Yet social stressors limited access to these assets before climate change became evident, and farmers shifted to more market-oriented livelihoods, only to increase sensitivity to later climatic stress. As stressors compounded, the ability to mobilize assets became constrained, making adaptation choices highly interdependent, and sometimes contradictory.

Perhaps farmers' most important asset was land, as larger landholdings provide flexibility in production options (Eakin, 2005; Reid and Vogel, 2006). Shrinking landholdings and lack of economic resources to access additional land prompted intensified production of cash crops. This adaptation increased household sensitivity to concurrent market and climatic stressors, including increased pests and extreme events that harmed the value and quantity of produce, similar to market-climate interactions observed on commercial Canadian farms (Belliveau et al., 2006). However, Palca's farmers are losing not only their income but also their food security, as the minifundio prohibits the extensive farming of resilient traditional food crops. Though communal property may reduce vulnerability (Adger and Kelly, 1999; Kelly and Adger, 2000), most communities no longer have sufficient land to practice communal management systems. Some communal pasturelands exist, but lack of access to financial assets prohibited most households from acquiring enough livestock for subsistence. While accessing additional land is economically prohibitive, *benefiting* from existing land is increasingly difficult with climate change.

Access to water is influenced by both climatic and social factors that shape adaptation (Liu et al., 2008; Young et al., 2010). Water stress is growing in Palca, in part attributable to changes in rainfall, rapid evaporation, and decreased snowmelt, but also due to greater demand for intensified year-round production of cash crops. Yet as rain-fed plots become unsustainable, irrigation water is even more essential. Poor irrigation infrastructure, unattainable credit, and absent technical assistance all limit access by reducing farmer's ability to benefit from the water that *is* available. The delay in rainfall also challenges adaptation strategies, as it becomes more difficult to plant early, while planting late puts crops at risk of frost.

Human capital, including labor and the capacity to make it meaningful and fruitful (Sen, 1997), is essential to adaptation (Moser and Satterthwaite, 2008). In Palca, labor is overtaxed by increased off-farm work coupled with intensified production, while changes in climate require increased labor to irrigate and manage pest. Institutional racism restricts access to human capital inputs that could improve terms of labor, education and technical assistance. Indigenous knowledge can provide human capital important to adaptation (Berkes et al., 2000; Kronik and Verne, 2009), but social and climate stressors sometimes interact to exceed the coping range provided by indigenous strategies. For example, land scarcity has limited altitudinal crop diversification, which is further restricted as decreased rainfall makes high altitude rain fed lands unproductive.

Social capital can both help households leverage resources for adaptation and organize collectively to change resource access (Adger, 2003; Duarte et al., 2007). Palca's key social capital asset is its strong community institutions, which have been shown to be important to adaptive resource governance (Agrawal, 2008, 2009). For example, without formal state support to improve water access, community appointed irrigation committees distribute increasingly strained water resources among users. Agrarian unions mobilize community labor for minor infrastructure improvements, and have successfully appealed for external support. Communities have been unable, however, to hold local government accountable.

Access to financial capital, especially credit, is essential to smallholder agricultural adaptation (Bryan et al., 2009; Howden et al., 2007), but institutional marginalization restricts access. Market-oriented livelihoods provide some income, made insecure by market uncertainties. Cash crops require investment, but without access to credit and with little flexibility to save, households are increasingly dependent on these unreliable incomes to begin each agricultural cycle. Small landholdings and financial needs limit some adaptation options, as more resilient crops cannot provide sufficient food or replace the income from cash crops. New income-generating opportunities, like fruit trees and vegetables at higher altitudes, have appeared, but scarce financial resources prohibit the initial investment needed to seize these opportunities. Similarly, lack of access to financial assets limits farmers' ability to benefit from existing resources, such as by increasing livestock herds to graze on communal land.

Stress on these assets will likely increase in coming years. Climate stress is expected to increase in highland Bolivia as temperatures continue to rise, rain falls later and more erratically (Thibeault et al., 2010), glaciers disappear (Vuille et al., 2008), and crop yields decline (Parry et al., 2005). Land scarcity is increasing, while market stress and institutional neglect do not show signs of diminishing in the near term. The establishment and financing of carefully considered adaptation options are therefore essential (Adger et al., 2003; Howden et al., 2007). However, vulnerability will only be reduced if farmers' have the flexibility to manage changing stress on their livelihoods on an ongoing basis (Duarte et al., 2007; Reilly and Schimmelpfennig, 2000). This means expanding the livelihood choice set available to vulnerable farmers by increasing access to resources and to the social and human capital to make optimal use of them (Prowse and Scott, 2008).

This asset-based perspective on adaptation is consistent with longstanding development objectives, like poverty reduction (Golkany, 2007; Pielke et al., 2007). Adaptive development can help improve access to key resources through investment in mechanisms of access including technology, infrastructure, and

technical assistance, but must be accompanied by institutional reform to protect and expand access for the poor (Agrawal, 2008; Mearns and Norton, 2009). Ensuring sustained access to assets, rather than designing interventions solely to protect against a specific stressor, will allow households and communities to confront multiple stressors according to their own priorities, improving current livelihoods and reducing vulnerability in the long term.

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References

Adger, W.N., 2003. Social capital, collective action, and adaptation to climate change. Economic Geography 79, 387–404.
Adger, W.N., 2006. Vulnerability. Global Environmental Change 16, 268–281.
Adger, W.N., Brooks, N., Bentham, G., Agnew, M., Eriksen, S., 2004. New Indicators of vulnerability and adaptive capacity. Technical Paper. Tyndall Center for Climate Change Research, Norwich, U.K.
Adger, W.N., Huq, S., Brown, K., Conway, D., Hulme, M., 2003. Adaptation to climate change in the developing world. Progress in Development Studies 3, 179–195.
Adger, W.N., Kelly, P.M., 1999. Social vulnerability to climate change and the architecture of entitlements. Mitigation and Adaptation Strategies for Global Change 4, 253–266.
Adger, W.N., Paavola, J., Huq, S., 2006. Toward justice in adaptation to climate change. In: Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), Fairness in Adaptation to Climate Change. The MIT Press, Cambridge, Massachusetts, pp. 1–19.
Adger, W.N., Vincent, K., 2005. Uncertainty in adaptive capacity. Comptes Rendus Geoscience 337, 399–410.
Agrawal, A., 2008. The role of local institutions in adaptation to climate change. Working Paper. International Forestry Resources and Institutions Program. School of Natural Resources and Environment, University of Michigan, Ann Arbor.
Agrawal, A., 2009. Local institutions and adaptation to climate change. In: Mearns, R., Norton, A. (Eds.), Social Dimensions of climate Change: Equity and Vulnerability in a Warming World. The World Bank, Washington, DC.
Andersson, V., Haarstad, H., 2009. Citizenship and state-building in contemporary Bolivia; politization of cultural identity. In: Studies, G.D. (Ed.), Global Development Studies Research Series. Aalborg University, Aalborg, Denmark.
Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K., Butterfield, J., Buse, A., Coulson, J.C., Farrar, J., Good, J.E.G., Harrington, R., Hartley, S., Jones, T.H., Lindroth, R.L., Press, M.C., Symrnioudis, I., Watt, A.D., Whittaker, J.B., 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology 8, 1–16.
Barlett, P.F., 1980. Adaptive strategies in peasant agricultural production. Annual Review of Anthropology 9, 545–573.
Barnett, J., 2006. Climate change, insecurity, and injustice. In: Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), Fairness in Adaptation to Climate Change. The MIT Press, Cambridge, Massachusetts, pp. 115–130.
Barnett, T.P., Adam, J.C., Lettenmaier, D.P., 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438, 303–309.
Barragán, R., 1982. El acceso vertical y el nacimiento de la hacienda en Palca (1596–1644). Avances de Investigación Museo Nacional de Etnografía y Folklore, La Paz, Bolivia.
Bebbington, A., 1999. Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. World Development 27, 2021–2044.
Beck, U., 1992. Risk Society: Toward a New Modernity. Sage Publication, London.
Belliveau, S., Smit, B., Bradshaw, B., 2006. Multiple exposures and dynamic vulnerability: evidence from the grape industry in the Okanagan Valley Canada. Global Environmental Change 16, 364–378.
Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10, 1251–1262.
Berry, S., 1989. Social institutions and access to resources A. Journal of the International African Institute 59, 41–55.
Blaikie, P., Cannon, T., Davis, I., Wisner, B., 1994. At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, London.
Bradley, R.S., Vuille, M., Diaz, H.F., Vergara, W., 2006. Threats to water supplies in the tropical Andes. Science 312, 1755–1756.
Brooks, N., 2003. Vulnerability, risk, and adaptation: a conceptual framework. Working Paper. Tyndall Centre for Climate Change Research, Norwich, U.K.
Brooks, N., Neil Adger, W., Mick Kelly, P., 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change 15, 151–163.
Brown, M.E., Funk, C.C., 2008. Climate food security under climate change. Science 319, 580–581.
Bryan, E., Deressa, T.T., Gbetibouo, G.A., Ringler, C., 2009. Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environmental Science & Policy 12, 413–426.
Bryant, C.R., Smit, B., Brklacich, M., Johnston, T.R., Smithers, J., Chjotti, Q., Singh, B., 2000. Adaptation in Canadian agriculture to climatic variability and change. Climatic Change 45, 181–201.
Cannone, N., Sgorbati, S., Guglielmin, M., 2007. Unexpected impacts of climate change on alpine vegetation. Frontiers in Ecology and the Environment 5, 360–364.
Casale, M., Drimie, S., Quinlan, T., Ziervogel, G., 2010. Understanding vulnerability in southern Africa: comparative findings using a multiple-stressor approach in South Africa and Malawi. Regional Environmental Change 10, 157–168.
Castel, A.P., 2008. Cuenca del Rio Choquecota, Proyecto DANIDA Bolivia.814-2: Vulnerabilidad al cambio climatico en regiones afectadas por el retroceso de los glaciares tropicales en Bolivia. Agua Sustentable, La Paz, Bolivia.
CDIAC, 2008. Carbon Dioxide Emissions (CO_2), Thousand Metric Tons of CO_2 Millennium Development Goals Indicators, 07 July 2011 ed. United Nations Statistics.
Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferaw, B., Twomlow, S., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? Agriculture, Ecosystems & Environment 126, 24–35.
Diaz, H., Gary-Fluhmann, R., McDowell, J., Montaña, E., Reyes, B., Salas, S., 2011. Vulnerability of Andean communities to climate variability and climate change. In: Leal Filho, W. (Ed.), Climate Change and the Sustainable Use of Water Resources. Springer-Verlag, Berlin, pp. 209–224.
Dillehay, T.D., Kolata, A.L., 2004. Long-term human response to uncertain environmental conditions in the Andes. Proceedings of the National Academy of Sciences of the United States of America 101, 4325–4433.
Duarte, M., Nadelman, R., Norton, A., Nelson, D., Wolf, J., 2007. Adapting to Climate Change: Understanding the Social Dimensions of Vulnerability and Resilience. Environment Matters at the World Bank. June 2006–July 2007. World Bank.
Eakin, H., 2005. Institutional change, climate risk, and rural vulnerability: cases from central Mexico. World Development 33, 1923–1938.
Eakin, H., Luers, A., 2006. Assessing the vulnerability of social-environmental systems. Annual Review of Environment and Resources 31, 365–394.
Easterling, W., Aggarawal, P., Batima, P., Brander, K., Erda, L., Howden, M., Kirilenko, A., Morton, J.F., Soussana, J.-F., Schmidhuber, J., Francesco, T., 2007. Food, fibre and forest products. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J.v., Hanson, d.C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., pp. 581–615.
Emerson, R.M., Fretz, R.I., Shaw, L.L., 1995. Writing Ethnographic Fieldnotes. Sage Publications, Thousand Oaks, California.
Erickson, C.L., 1999. Neo-environmental determinism and agrarian 'collapse' in Andean prehistory. Antiquity 73, 634.
Fischlin, A., Midgley, G.F., Price, J., Leemans, R., Gopal, B., Turley, C., Rounsevell, M., Dube, P., Tarazona, J., Velichko, A., 2007. Ecosystems, their properties, goods and services. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J.v., Hanson, d.C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., pp. 581–615.
Flores, E., 1954. Land reform in Bolivia. Land Economics 30, 112–124.
François, C., Bosseno, R., Vacher, J.J., Seguin, B., 1999. Frost risk mapping derived from satellite and surface data over the Bolivian Altiplano. Agricultural and Forest Meteorology 95, 113–137.
Garreaud, R., Vuille, M., Clement, A.C., 2003. The climate of the Altiplano: observed current conditions and mechanisms of past changes. Palaeogeography Palaeoclimatology Palaeoecology 194, 5–22.
Gilbert, A., Wagnon, P., Vincent, C., Ginot, P., Funk, M., 2010. Atmospheric warming at a high-elevation tropical site revealed by englacial temperatures at Illimani, Bolivia (6340 m above sea level, 16 degrees S, 67 degrees W). Journal of Geophysical Research-Atmospheres 115 .
Golkany, I.M., 2007. Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. Mitigation and Adaptation Strategies for Global Change 12, 755–786.
Guillet, D., 1980. Reciprocal labor and peripheral capitalism in the Central Andes. Ethnology 19, 151–167.
Guillet, D., 1981. Land tenure, ecological zone, and agricultural regime in the Central Andes. American Ethnologist 8, 139–156.
Handmer, J.W., Dovers, S., Downing, T.E., 1999. Societal vulnerability to climate change and variability. Mitigation and Adaptation Strategies for Global Change 4, 267–281.

Hinkel, J., 2011. Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface. Global Environmental Change 21, 198–208.
Hodkinson, I.D., 2005. Terrestrial insects along elevation gradients: species and community responses to altitude. Biological Reviews 80, 489–513.
Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H., 2007. Adapting agriculture to climate change. Proceedings of the National Academy of Sciences of the United States of America 104, 19691–19696.
INE-PNUD, 2005. Bolivia: Atlas estadístico de municipios. Instituto Nacional de Estadística y el Programa de las Naciones Unidas para el Desarrollo. Plural, La Paz.
Kelly, P.M., Adger, W.N., 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Climatic Change 47, 325–352.
Kohl, B., 2010. Bolivia under Morales. Latin American Perspectives 37, 107–122.
Kronik, J., Verne, D., 2009. The role of indigenous knowledge in crafting adaptation and mitigation strategies in Latin America. In: Mearns, R., Norton, A. (Eds.), Social Dimensions of climate Change: Equity and Vulnerability in a Warming World. The World Bank, Washington, DC, pp. 145–172.
Liu, C., Golding, D., Gong, G., 2008. Farmers' coping response to the low flows in the lower Yellow River: a case study of temporal dimensions of vulnerability. Global Environmental Change 18, 543–553.
Magrin, G., Gay Garcia, C., Cruz Choque, D., Gimenez, J.C., Moreno, A.R., Nagy, G.J., Nobre, C., Villamizar, A., 2007. Latin America. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J.v., Hanson, d.C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., pp. 581–615.
McLaughlin, P., Dietz, T., 2008. Structure, agency and environment: toward an integrated perspective on vulnerability. Global Environmental Change-Human and Policy Dimensions 18, 99–111.
Mearns, R., Norton, A., 2009. Equity and vulnerability in a warming world: introduction and overview. In: Mearns, R., Norton, A. (Eds.), Social Dimensions of climate Change: Equity and Vulnerability in a Warming World. Washington, DC, The World Bank.
Miller, F., Osbahr, H., Boyd, E., Nelson, D., 2010. Resilience and vulnerability: complementary or conflicting concepts? Ecology & Society 15.
Mortimore, M.J., Adams, W.M., 2001. Farmer adaptation, change and 'crisis' in the Sahel. Global Environmental Change 11, 49–57.
Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences of the United States of America 104, 19680–21968.
Moser, C., Satterthwaite, D., 2008. Towards pro-poor adaptation to climate change in the urban centres of low- and middle-income countries. In: Human Settlements Discussion Paper Series, International Institute for Environment and Development, London.
Moser, C., Satterthwaite, D., 2009. Toward pro-poor adaptation to climate change in the urban centers of low- and middle-income countries. In: Mearns, R., Norton, A. (Eds.), Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World. The World Bank, Washington, DC.
Murra, J.V., 2002. El Mundo Andino: Población, Medio Ambiente y Economía, 1st ed. Lima: Instituto de Estudios Peruanos: Pontificia Universidad Católica del Perú, Lima, Peru.
Mustafa, D., 1998. Structural causes of vulnerability to flood hazard in Pakistan. Economic Geography 74, 289–305.
Nelson, D.R., Adger, W.N., Brown, K., 2007. Adaptation to environmental change: contributions of a resilience framework. Annual Review of Environment and Resources 32, 395–419.
Nyong, A., Adesina, F., Osman Elasha, B., 2007. The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. Mitigation and Adaptation Strategies for Global Change 12, 787–797.
Ontiverios, O., 2007. Plan de Desarrollo Municipal: 2007–2011. Departamento de La Paz, Municipality of Palca, La Paz, Bolivia.
Orlove, B., Godoy, R., 1986. Sectoral fallowing systems in the Central Andes. Journal of Ethnobiology 6, 169–204.
Osbahr, H., Twyman, C., Neil Adger, W., Thomas, D.S.G., 2008. Effective livelihood adaptation to climate change disturbance: scale dimensions of practice in Mozambique. Geoforum 39, 1951–1964.
Paavola, J., 2008. Livelihoods, vulnerability and adaptation to climate change in Morogoro Tanzania. Environmental Science & Policy 11, 642–654.
Parry, M., Rosenzweig, C., Livermore, M., 2005. Climate change, global food supply and risk of hunger. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences 360, 2125–2138.
Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J., Hanson, C.E., 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 7–22.
Pelling, M., 2010. Understanding adaptation. In: Pelling, M. (Ed.), Adaptation to Climate Change: From Resilience to Transformation. Routlege, London.
Pielke, R., Prins, G., Rayner, S., Sarewitz, D., 2007. Climate change 2007: lifting the taboo on adaptation. Nature 445, 597–598.
Prowse, M., Scott, L., 2008. Assets and adaptation: an emerging debate. IDS Bulletin-Institute of Development Studies 39, 42–52.
Ramirez, E., 2008. Deshielo del Nevado Mururata y su impacto sobre los recursos hidricos de la Cuenca de Palca. Proyecto DANIDA Bolivia.814-2: Vulnerabilidad al cambio climatico en regiones afectadas por el retroceso de los glaciares tropicales en Bolivia. Agua Sustentable, La Paz, Bolivia.
Ramirez, E., Francou, B., Ribstein, P., Descloitres, M., Guerin, R., Mendoza, J., Gallaire, R., Pouyaud, B., Jordan, E., 2001. Small glaciers disappearing in the tropical Andes: a case-study in Bolivia: Glaciar Chacaltaya (16oS). Journal of Glaciology 47, 187–194.
Reid, P., Vogel, C., 2006. Living and responding to multiple stressors in South Africa – glimpses from KwaZulu-Natal. Global Environmental Change 16, 195–206.
Reilly, J., Schimmelpfennig, D., 2000. Irreversibility, uncertainty, and learning: portraits of adaptation to long-term climate change. Climatic Change 45, 253–278.
Ribot, J.C., 2009. Vulnerability does not fall from the sky: toward multiscale, pro-poor climate policy. In: Mearns, R., Norton, A. (Eds.), Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World. The World Bank, Washington, DC.
Ribot, J.C., 2010. God Culture and Adaptation – Social Cause and Responsibility for Un-Natural Disasters. University of Illinois, Urbana-Champaign, p. 3.
Ribot, J.C., 2011. Vulnerability before adaptation: toward transformative climate action. Global Environmental Change 21, 1160–1162.
Ribot, J.C., Peluso, N.L., 2003. A theory of access. Rural Sociology 68, 153–181.
Rist, S., 2000. Linking ethics and the market: campesino economic strategies in the Bolivian Andes. Mountain Research and Development 20, 310–315.
Ritchie, J., Lewis, J., 2003. Qualitative Research Practice: A Guide for Social Science Students and Researchers. Sage Publications, Thousand Oaks, California.
Roberts, T.J., Parks, B.C., 2007. A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy. MIT Press, Cambridge.
Roncoli, C., Ingram, K., Kirshen, P., 2001. The costs and risks of coping with drought: livelihood impacts and farmers[1] responses in Burkina Faso. Climate Research 19, 119–132.
Sabates-Wheeler, R., Mitchell, T., Ellis, F., 2008. Avoiding repetition: time for CBA to engage with the livelihoods literature? IDS Bulletin 39, 53–59.
Sanabria, H., 1999. Consolidating states, restructuring economies, and confronting workers and peasants: the antinomies of Bolivian neoliberalism. Comparative Studies in Society and History 41, 535–562.
Sanderson, D., 2000. Cities, disasters and livelihoods. Environment and Urbanization 12, 93–102.
Schipper, L., Pelling, M., 2006. Disaster risk, climate change and international development: scope for, and challenges to, integration. Disasters 30, 19–38.
Sen, A., 1981. Poverty and Famines: An Essay on Entitlement and Deprivation. Clarendon Press, Oxford.
Sen, A., 1997. Editorial Human capital and Human Capability, 25. World Development, pp. 1959–1961.
SENAMHI, 2006. Estacion Meterologica de Palca: 1973–2006. La Paz.
Smit, B., Burton, I., Klein, R.J.T., Wandel, J., 2000. An anatomy of adaptation to climate change and variability. Climatic Change 45, 223–251.
Smit, B., Pilifosova, O., 2003. From adaptation to adaptive capacity and vulnerability reduction. In: Smith, J., Klein, R., Huq, S. (Eds.), Climate Change, Adaptive Capacity, and Development. London, UK, Imperial College Press.
Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282–292.
Stretton, H., 1978. Urban Planning in Rich and Poor Countries. Oxford University Press, Oxford.
Tanner, T., Mitchell, T., 2008. Entrenchment or enhancement: could climate change adaptation help to reduce chronic poverty? IDS Bulletin 39, 6–15.
Thibeault, J.M., Seth, A., Garcia, M., 2010. Changing climate in the Bolivian Altiplano: CMIP3 projections for temperature and precipitation extremes. Journal of Geophysical Research 115, D08103.
Tschakert, P., 2007. Views from the vulnerable: understanding climatic and other stressors in the Sahel. Global Environmental Change 17, 381–396.
Tschakert, P., Dietrich, K.A., 2010. Anticipatory learning for climate change adaptation and resilience. Ecology & Society 15, 1–18.
Turner, B.L., Kasperson 2nd, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A., 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America 100, 8074–8079.
UNFCCC, 2003. Workshop on Local Coping Strategies and Technologies for Adaptation. United Nations, New Delhi.
Valdivia, C., 2004. Andean livelihood strategies and the livestock portfolio. Culture & Agriculture 26, 69–79.
Valdivia, C., Dunn, E.G., 1996. Diversification as a risk management strategy in Andean agropastoral community. American Journal of Agricultural Economics 78, 1329.
Valdivia, C., Seth, A., Gilles, J.L., García, M., Jiménez, E., Cusicanqui, J., Navia, F., Yucra, E., 2010. Adapting to climate change in Andean ecosystems: landscapes, capitals, and perceptions shaping rural livelihood Strategies and linking knowledge systems. Annals of the Association of American Geographers 100, 818–834.
van Aalst, M.K., Cannon, T., Burton, I., 2008. Community level adaptation to climate change: the potential role of participatory community risk assessment. Global Environmental Change 18, 165–179.
Vincent, K., 2004. Creating an index of social vulnerability to climate change in Africa. Working Paper. Tyndall Center for Climate Change Research, Norwich, U.K.
Vuille, M., Bradley, R.S., Werner, M., Keimig, F., 2003. 20th century climate change in the tropical Andes observations and model results. Climatic Change 59, 75–99.
Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B.G., Bradley, R.S., 2008. Climate change and tropical Andean glaciers: past, present and future. Earth-Science Reviews 89, 79–96.

Wandel, J., Smit, B., Young, G., Diaz, P., Salas, S., 2005. Field guide: for community-based assessment of vulnerabilities and adaptive capacities related to water and institutions in the context of climate change, elqui and south saskatchewan river basins. In: Change, I.A.t.C. (Ed.), IACC Summary Field Guide. University of Regina, Regina, Saskatchewan.

Watts, M.J., Bohle, H.G., 1993. Hunger, famine and the space of vulnerability. GeoJournal 30, 117–125.

WFP, 2008. Diagnóstico, modelo y atlas municipal de seguridad alimentaria en Bolivia. Sistem de Informacion Gerencial de Seguridad Alimentaria. World Food Program. Ministry of Planning for Development of Bolivia, Bolivia.

Yohe, G., Tol, R., 2002. Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. Global Environmental Change 12, 25–40.

Young, G., Zavala, H., Wandel, J., Smit, B., Salas, S., Jimenez, E., Fiebig, M., Espinoza, R., Diaz, H., Cepeda, J., 2010. Vulnerability and adaptation in a dryland community of the Elqui Valley, Chile. Climatic Change 98, 245–276.

Young, K., Lipton, J., 2006. Adaptive governance and climate change in the tropical highlands of western South America. Climatic Change 78, 63–102.

Zimmerman, F.J., Carter, M.R., 2003. Asset smoothing, consumption smoothing and the reproduction of inequality under risk and subsistence constraints. Journal of Development Economics 71, 233–260.