Typical patterns of smallholder vulnerability to weather extremes with regard to food security in the Peruvian Altiplano[1]

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Abstract:
Smallholder livelihoods in the Peruvian Altiplano are frequently threatened by weather extremes, including droughts, frosts and heavy rainfall. Given the persistence of significant undernourishment despite regional development efforts, we propose a cluster approach to evaluate smallholders' vulnerability to weather extremes with regard to food security. We applied this approach to 268 smallholder households using information from two existing regional assessments and from our own household survey. The cluster analysis revealed four vulnerability patterns that depict typical combinations of household attributes, including their harvest failure risk, agricultural resources, education level and non-agricultural income. We validated the identified vulnerability patterns by demonstrating the correlation between them and an independently reported damage: the purchase of food and fodder resulting from exposure to weather extremes. The vulnerability patterns were then ranked according to the different amounts of purchase. A second validation aspect accounted for independently reported mechanisms explaining smallholders' sensitivity and adaptive capacity. Based on the similarities among the households, our study contributes to the understanding of vulnerability beyond individual cases. In particular, the validation strengthens the credibility and suitability of our findings for decision-making pertaining to the reduction of vulnerability.

Key words:
Climate vulnerability, Pattern approach, Cluster analysis, Tropical high mountains, Drylands, Altiplano, Peru

Introduction
As part of an Andean high plateau, the Peruvian Altiplano ranges from 3,800 to over 4,500 m in altitude. Its highly variable, semi-arid climate is closely linked to weather extremes, such as droughts, frosts and heavy rainfall, which frequently challenge people's livelihoods. In 2007, several districts in the Peruvian Altiplano declared a state of emergency caused by frosts, hail and transient droughts in the midst of the agricultural season (INDECI 2009). Despite regional development programmes to improve the smallholder systems, poverty and undernourishment remain significant (FONCODES 2006). This situation is particularly precarious since the primary sector constitutes the most important area of economic activity (INEI 2006). Given this

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situation, we aim to enhance the debate on inter-linkages between climate vulnerability and food security as a prerequisite for an adequate discussion of regional development. Therefore, we investigate as to whether there are typical characteristics of smallholder households that help to explain the causal structure of their vulnerability to weather extremes in relation to food security. Reference is made to smallholders in the administrative Region of Puno.

The smallholders living in the Peruvian Altiplano cannot be understood as one homogeneous social group. Productive resources are heterogeneously distributed and livelihood options differ among the smallholders which requires that the respective vulnerability-creating mechanisms be tackled appropriately. Addressing the heterogeneity of human-nature interactions at an intermediate functional scale, pattern approaches have been used to assess recurrent dynamics of global change and typical patterns of vulnerability at regional to global levels (e.g. Jäger et al. 2007; Manuel-Navarrete et al. 2007; Schellnhuber et al. 2002; Sietz et al. 2011). These assessments aggregate functionally similar processes to typical patterns which structure the understanding of underlying processes and provide insights into strategies that foster sustainable development.

Taking up the basic concept of pattern analysis, we assess typical vulnerability-creating mechanisms based on similarities at the household level. We extend the pattern approach in testing the validity of the identified patterns using outcomes of a specific exposure and reported mechanisms from independent information sources. Such a validated and manageable categorisation of the heterogeneous characteristics of smallholder households provides a solid basis for advancing regional development initiatives. Major initiatives have shown limited success (DRA 2005) partly because they have been based on average environmental and socio-economic conditions. Therefore, such differential insights into the vulnerability of smallholders deliver valuable information for identifying particularly critical livelihood conditions and emerging food insecurity within the social group of smallholders.

Background

Climate vulnerability and food security

Climate vulnerability is considered as a function of exposure, sensitivity and coping/adaptive capacity (IPCC 2007). To operationalise the concept, one usually asks the questions “Who is vulnerable to what impacts?” and “What property is affected by the vulnerability outcomes?”. Our analysis focuses on smallholder households being exposed to weather extremes. We assess how households are affected in their food security property. We consider the effects of weather disturbance on the agricultural systems as sensitivity. Furthermore, the adaptive capacity of smallholders (the term as used in this study encompasses the coping capacity) describes the ability to adjust to weather extremes, manage damages or explore alternative livelihood opportunities.

Food security is often discussed in terms of four dimensions: food availability, access, stability of supply/access and utilisation (FAO 2000). Weather affects the food security via crop production. While the impacts of weather on food crop production and the related building-up of reserves directly influence the availability of food, the impacts on fodder production relate to the building-up of livestock serving as savings. We consider those dimensions of food security which build the basis for nutrition and are at least partly within smallholders’ control, i.e., food availability and access.

Assessing smallholder vulnerability at the local level

Concern over the degradation of ecosystem functions and limitations of human well-being has motivated a multitude of qualitative and quantitative approaches to assess vulnerability to various stress factors, including both climatic and non-climatic factors (e.g. Eakin 2005; Eakin and Bojórquez-Tapia 2008; Eriksen et al. 2005; Hahn et al. 2009; O'Brien et al. 2004; Sallu et al. 2010;Vásquez-León et al. 2003). These assessments contribute mechanistic and quantitative knowledge for decision-making processes and the monitoring of relevant characteristics. Such knowledge is particularly important for the evaluation of smallholders' vulnerability to which integrated dynamic modelling, such as that presented by Dougill et al. (2010) as well as Krol and Bronstert (2007), is scarcely applied due to the very high data demand involved in parameterising the models. In addition, the varied objectives of different players and the uncertainties regarding the rules of human decision-making complicate an appropriate capturing of adaptation in such models.

Within the field of case study research, comparative analyses address specific mechanisms that shape the vulnerability of smallholders to climate variability and change. They employ inductive qualitative and quantitative methods including interviews, focus group discussions and statistical analysis to describe processes that determine vulnerability in particular local circumstances. The research on sustainable livelihoods (Chambers and Conway 1992; Scoones 1998) and political ecology (Blaikie 1985; Wisner et al. 2004) has contributed valuable perspectives to the investigation of the underlying processes. For example, smallholders attempted to access food and income during a severe drought in Tanzania and Kenya by collecting fruits, selling livestock and engaging in casual labour on other farms (Eriksen et al. 2005). Only very few households had access to skilled employment, received remittances or produced bricks and charcoal to generate income.

Vásquez-León et al. (2003) further extend the analysis of smallholder vulnerability in accordance with the political ecology approach in comparing rural livelihoods in similar climate conditions, but in the different socio-political and economic contexts on either side of the Mexico-USA border. They illustrate how historical inequalities in the access to natural resources and technological innovation as well as public policies, class and ethnicity determine the vulnerability of farming and ranching communities. For example, marginalised social groups, such as Hispanic farmers, smallholders and ejidatarios on communal land, were largely constrained in their access to land and irrigation systems. In addition, Hispanic farmers in the United States faced language and literacy barriers to accessing agricultural subsidies. Altogether, such studies deliver rich details about specific expressions of drivers and consequences of vulnerability in diverse livelihood contexts. Thus, they provide the necessary knowledge for a further quantitative evaluation of vulnerability as performed in this study.

Since vulnerability is not directly measurable, indicators frequently serve to quantify the underlying processes. Indicators reduce the complexity of the processes under consideration. They are mostly applied to construct indices used to compare relevant attributes at the level of households or administrative units, including smallholder-dominated areas (e.g. Hahn et al. 2009; O'Brien et al. 2004; Vincent 2007). Such indices allow particularly differentiated insights in case they keep the constituting components and underlying assumptions transparent. For example, Hahn et al. (2009) construct a Livelihood Vulnerability Index to evaluate the climate vulnerability of two smallholder-dominated districts in Mozambique. As well as aggregating 31 indicators into a final index at the district level, these authors present all sub-components at various levels of aggregation. Regionally specific indicators, such as the share of female-headed households, may thereby stimulate debate about their influence on vulnerability. Furthermore, Hahn et al. (2009) apply a monotonous relation to capture the effects of the share of family members who migrate to generate income outside the community. However, while a higher share undoubtedly contributes to decreasing vulnerability, it aggravates the HIV/AIDS prevalence, thus pointing towards another regionally specific process. This relation would be therefore an interesting point of improvement for further exploring non-monotonous relations between individual indicators and vulnerability. This links to the intrinsically nonlinear character of the cluster analysis applied in this study.

In contrast to such composite indices, Vincent (2007) develops an aggregate index of adaptive capacity for assessing the ability of rural households in South Africa to deal with changing water availability related to climate change. Here, the kin and friendship ties as well as the access to traditional and formal governance structures were incorporated as important determinants of adaptive capacity. However, merging indicators into one final index does not allow one to distinguish the contribution of such sub-components and thus restricts possible conclusions. Overall, the selection, weighing and aggregation of indicators involves subjective decisions which are linked to the uncertainty of final indices. A validation is therefore a crucial requirement for indicator-based assessments. If conducted, it is often restricted to the confirmation of the implied vulnerability-creating mechanisms by using independent information sources (e.g. O'Brien et al. 2004). Vulnerability outcomes are however an equally important aspect of validation and are thus an integral part of this study.

Other indicator-based assessments account explicitly for the uncertainty inherent in the evaluation of complex domains, such as vulnerability. They integrate quantitative, indicator-based information with qualitative statements and further combine them using fuzzy logic (e.g. Cheng and Tao 2010; Eakin and Bojórquez-Tapia 2008; Krömker et al. 2008). These assessments use fuzzy classification systems to group units of analysis into categories according to linguistic values of their attributes. These categories, for example high, medium and low vulnerability, are represented by fuzzy sets (Zadeh 1965) derived from verbal statements by experts.

A difficult part of fuzzy classification is to define a set of membership functions pertaining to the specific classification problem. Units of analysis have a degree of membership in specific classes. For example, a household can belong 20% to a low vulnerability class and 80% to a medium vulnerability class. Furthermore, a rule-based system (fuzzy inference system) is required to combine the membership functions of sub-components, such as sensitivity and adaptive capacity, into an overall index. Such an approach reflects the fact that experts usually express their knowledge in the form of qualitative conditional statements. For example, if the sensitivity of a household is low and its adaptive capacity is high, then the household's vulnerability is low.

In developing their indices of sensitivity and adaptive capacity as input for a fuzzy classification, Cheng and Tao (2010) as well as Eakin and Bojórquez-Tapia (2008) employ a systematic approach to reveal the relative importance of indicators. In this way, the contribution of each indicator to the overall vulnerability becomes clear and may encourage debate. For example, Eakin and Bojórquez-Tapia (2008) suggest that financial resources are more important for the constitution of adaptive capacity of smallholders in Mexico than their education. They disaggregate the overall index of livelihood vulnerability and discuss the constituting components of sensitivity and adaptive capacity for each class. Moreover, they validate the final index by revealing that the underlying class-specific mechanisms are consistent with the relative distribution of responses to climate stress. For example, multiple adaptation strategies were more frequently employed by households in the high vulnerability class than in the other classes. This reflects the necessity of considering any available option to compensate for constraints, such as their highly limited access to insurance, irrigation and credits.

Overall, fuzzy classification has the potential to contribute to the design of appropriate intervention options since it reflects the uncertainty in available knowledge and decision-making. It enables the qualitative comparison between the results of different conceptualisations of vulnerability and types of indicators. An important difference of fuzzy classification compared to the approach applied in this study is that it prescribes the structuring characteristics for categorisation via the membership functions.

Without such a pre-selection, alternative approaches investigate the structure of the data space spanned by selected vulnerability indicators using cluster analysis. They deliver useful insights into recurrent indicator combinations based on similarities among units of analysis, in cases where such a grouping exists. For example, clustering revealed typical livelihood strategies employed by smallholders in Mexico and Botswana (Eakin 2005; Sallu et al. 2010). These livelihood strategies point out mechanisms that shape the smallholders' sensitivity and adaptive capacity. Importantly, clustering keeps the constituents visible throughout the analysis, so that their contribution to the cluster-specific vulnerability remains transparent and can be evaluated. For example, households in southwest Botswana differed significantly in terms of their agricultural assets and access to infrastructure (Sallu et al. 2010). Those who generated a significant employment income could build up their livestock and improve their access to water and transport infrastructure. The accumulated assets and enhanced water availability increased their capacity to cope with precipitation variability, related water shortage and land degradation.

Clustering provides an appropriate method of revealing typical patterns of attributes accounting for variations between the investigated units. Cluster analysis thus delivers a feasible approach to analysing vulnerability since only a limited number of indicator combinations need to be interpreted and related strategies discussed. These typical patterns add structural knowledge to the understanding of vulnerability and decision-making for vulnerability reduction.

In this study, we apply a cluster analysis to assess typical patterns of smallholder vulnerability when exposed to weather extremes and focus our analysis on the food security aspect of vulnerability. We take the cluster approach further in two aspects. Firstly, we test whether the revealed similarities of households also apply to reported damages as a result of weather extremes, without having included a damage indicator in the cluster analysis. As a second validation aspect, we test whether reported vulnerability causes are consistent with the mechanisms derived from the identified clusters.

Study region

The study was conducted in the administrative Region of Puno in southern Peru. We considered smallholder households in eight districts primarily inhabited by Quechua people (Fig. 1). Their production systems are based on rain-fed agriculture in a variety of agro-ecological zones (Circunlacustre 3,800–3,900 m, Suni Altiplano 3,830–4,500 m and Puna 4,000–4,800 m; see PISA 1993;Tapia 1991). The smallholders cultivate diverse food and fodder crops (potatoes – Solanum spp., quinua – Chenopodium quinua, broad beans – Vicia faba, barley – Hordeum spp., oat – Avena spp.) and keep livestock such as sheep, cattle and cameloids (PISA 1993). Some of the species and varieties, for example bitter potatoes, alpaca and llamas, are well adapted to the challenging mountain climate. Generally, the Altiplano is characterised by a high inter-annual climate variability. This variability is closely tied to dynamics in the tropical Pacific whereby major temperature and precipitation anomalies are associated with the El Niño Southern Oscillation (e.g. Garreaud and Aceituno 2001).

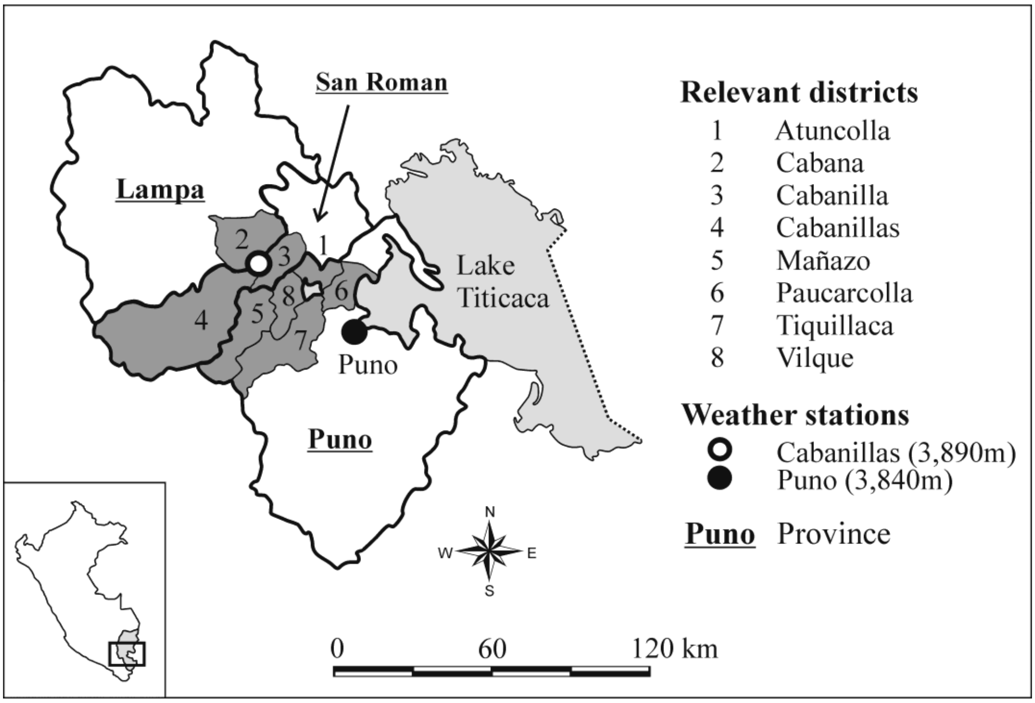

Figure 1 Location of the study region in the administrative Region of Puno (Source: Own design)

Despite the marginality of the Altiplano, three historical approaches permitted the development of ancient civilisations: elaborate irrigation and drainage systems, domestication of cameloids and freeze-drying of crops as a means of food security (e.g. Erickson 1992; Kolata 1993; Troll 1943). Ensuring food security is thus possible, but requires a sophisticated management of available resources. Freeze-drying of tuber crops and cameloid husbandry are still commonly practised throughout the Altiplano. The freeze-drying process takes advantage of the main frost period from June to August. The resulting products, for example dark chuño and white tunta (moraya), can be stored over a long period due to the dry climate. However, the poorly developed irrigation systems, highly fragmented land properties as well as insufficient capacity building and technical assistance (DRA 2005) significantly hamper the adequate management of natural resources. Moreover, traditional adaptation measures, such as cultivation on terraces and raised fields (waru waru, sukacollo), have been substantially eroded since smallholders often cannot afford them or consider them to be inefficient. In addition to this, collectively determined rotation systems (aynoka, laymi; see Canahua et al. 2002) have often been replaced by individual decision-making.

Data

Vulnerability-generating mechanisms

This section sets the basis for the following analysis and discussion by outlining important mechanisms that generate vulnerability. Since empirical evidence about vulnerability has been scarcely reported for our study region, we draw our information from systematic community assessments performed in the Peruvian Altiplano as part of a larger assessment of climate resilient development in Peru (Sperling et al. 2008). These assessments cover parts of our study region.

Sperling et al. (2008) capture the perspectives of communities on their vulnerability to climate variability and change. The assessments involved focus group discussions including smallholders who are affected by extreme weather events and covered a range of smallholder systems in representing the diversity of vulnerability-generating mechanisms. They focused on the people's perceptions concerning the exposure to climate risks as well as their sensitivity and their adaptive capacity to those risks. Based on a qualitative evaluation of the vulnerability-related attributes, the team revealed the relevant underlying mechanisms.

Mechanisms that relate to climate vulnerability and food security in our study region concern the location, size and quality of land resources as the basis for agricultural production and livestock resources as savings accounts. Furthermore, the level of education and the access to alternative income sources give insights into the climate sensitivity of food security. These processes provide a useful entry point for our analysis since they specify a generic pattern of vulnerability discussed in an analysis of global drylands (Sietz et al. 2011) in a local context. The vulnerability pattern identified for our study region reflects medium poverty and severely degraded water and soil resources compared to the global situation. The poverty dimension relates to the size of land and livestock as well as the alternative income in the local context, while the degradation of resources is linked to the quality of land. The location of land in our study however describes a locally specific aspect of climate vulnerability. In addition, the community assessments display the land ownership, access to credits, crop diversity as well as changes in climate and water availability as further vulnerability dimensions.

We briefly summarise the relevant processes identified by Sperling et al. (2008) and specify their relation to climate vulnerability and food security. As the first dimension, the high climate variability in the Altiplano is linked to the risk of harvest failure. The community assessments suggest the lack of opportunities to plant in different altitudes as an important aspect of vulnerability. While some pasture land at higher altitudes is located further away, most land in our study region is cultivated in close vicinity to the households. Therefore, the location of land in relation to production zones that sub-divide the broad agro-ecological zones becomes important. In our study region, three production zones exist to spread the risk of harvest failure, namely plains, hillsides and hills. The plains are more prone to frosts since cold air accumulates in the low-lying areas, whereas the hillsides and hills are more drought-prone due to water drainage. Importantly, if production is damaged in one production zone, the other zones may still provide sufficient yield. Access to more production zones hence increases a household's adaptive capacity.

Besides the harvest failure risk, the size of land resources, as the second vulnerability dimension, further determines the basis for food and fodder production. Cultivating on less land makes households more susceptible to completely losing the harvest. In addition, they are less able to accumulate food reserves for the coming year. Overall, the cultivated area may be constrained due to population pressure as well as a production loss in the previous year and a related seed shortage. As another important part of the production systems, the third vulnerability dimension refers to the livestock constraint. Livestock constitutes a savings account which can be used to buy food during emergencies. A greater stock size thus compensates, to some extent, for limited monetary assets. It also induces a higher capacity to maintain a critical number of livestock throughout an exposure time to rebuild the stock numbers afterwards.

Adding to the characteristics of the production systems, the fourth dimension relates to the productivity of natural resources. Households relying on less productive resources are less able to produce sufficient food and fodder from a given area. The productivity mainly reflects the quality of land, management practices and weather conditions. Productivity constraints are hence considered as an aggregate vulnerability dimension.

Educational effects on vulnerability constitute the fifth dimension. A lack of education decreases the household's coping and adaptive capacity. In emergencies, educationally deprived households are forced to accept poorly-paid work. They can then generate only limited income to cope with a food shortage. The education deprivation also limits the access to skilled climate-independent work and related alternative income as a long-term adaptation option. As the sixth dimension, a lack of alternative income, i.e., climate-independent income, reduces the capacity of households to obtain food when production fails. A strong tie to on-farm activities thus implies a high climate sensitivity of food security.

Finally, some pasture land is rented in our study region. Challenges in the tenancy due to unreliable agreements or high rents entail consequences that accumulate in the size of livestock, so that they are observable in the livestock constraint. As a further dimension, the access to credits is generally constrained in our study region and thus does not reveal a distinction between households. Moreover, the smallholders investigated here commonly cultivate a diversity of food and fodder crops, so that this aspect does not distinguish well between the households. Lastly, changes in climate and water availability relating to the onset and duration of rain, for example, point to dynamic aspects of exposure. These need to be analysed over a longer period and thus go beyond the scope of our study.

Overall, the described sensitivity and adaptive capacity mechanisms together determine whether smallholders are able to maintain their food situation when the production systems are disturbed by weather extremes. To capture the disturbance, weather anomalies are considered as exposure components (see "Climate exposure" Section).

Taken together, the processes revealed by Sperling et al. (2008) lay out important determinants of the climate vulnerability of smallholder systems in our study region. However, it remains unknown as to whether they occur in characteristic combinations. Therefore, we apply a cluster analysis to investigate whether typical patterns exist in these processes.

Quantitative indication of sensitivity and adaptive capacity

The mechanisms generating sensitivity and adaptive capacity outlined in the previous section are quantitatively indicated at the household level. Another regional assessment, the ALTAGRO project, provides the respective data. Starting in 2005, the project established a data base (ALTAGRO 2006) to monitor development progress in 25 communities.

The ALTAGRO (2006) data base contains detailed quantitative information for 527 smallholder households collected through household questionnaires. The data refer to the 2005/2006 agricultural campaign. Ten categories describe the smallholder households covering personal information about the family members (e.g. occupation, education level, age), production systems (e.g. crop and livestock assets, labour input, processing and commercialisation of produce), weather conditions, food reserves, income, some expenses and credits. The households were randomly selected in four areas across the administrative Region of Puno reflecting representative smallholder livelihood conditions.

Agronomists with sound field experience conducted the household surveys. They had been engaged in participatory work with agricultural communities over a long period, some of them in the area in which ALTAGRO intervenes. Moreover, they had a good command of the local indigenous languages Quechua and Aymara. The surveys were mainly conducted at the smallholder domiciles (95%) and in some cases at the location of grazing areas or other on-going activities. Overall, surveyors reported that the smallholders thoughtfully responded to the questions despite the length of the questionnaire. They observed further that recalling the requested aspects was feasible since the survey was carried out in August 2006, that is to say at the end of the agricultural campaign 2005/2006. Finally, the collected data were reviewed and consolidated by ALTAGRO personnel based at the collaborating non-governmental organisation Centro de Investigación de Recursos Naturales y Medio Ambiente (CIRNMA) in Puno. They checked the collected data base for consistency in ranges and logic relations of variables. In particular, incorrectness biases could arise in the surveys through enumerating, counting or measuring errors. Incorrect values were detected and corrected, where it was reasonable, by cross-checking various observations, such as the total cultivated area against the sum of crop and pasture land. This review of the survey and processing conditions reveals that the data are reliable.

The following data are taken from the ALTAGRO (2006) data base to indicate the mechanisms relevant in this study. As the first dimension, the harvest failure risk is indicated by the number of production zones used for crop and pasture cultivation. The indicator considers plains, hillsides and hills. The second dimension of the area constraint is measured by the crop area as an important prerequisite for food production. The pasture area highly correlates to livestock keeping and is therefore reflected in the livestock measure. The third dimension, the livestock constraint, is characterised by the number and types of animals. To compare various animal species, we calculated standardised livestock units in relation to an improved cattle variety based on the livestock-specific metabolism (Kleiber 1961). Average livestock weights were estimated using 20 representative animals of each species in the study region. Since fodder production is an essential condition for livestock keeping, the respective indicator contains a reference to the area and productivity of pasture land. Furthermore, the productivity constraint as the fourth dimension is provided for the major food crops potatoes and quinua. It averages the household's productivity across species, varieties and production zones for each crop. Again, we concentrate on food crops since the productivity of pastures is already included in the livestock measure. The fifth dimension of education deprivation relates to the number of years that a household head attended school. School attendance is classified according to the four levels: no formal education, primary, secondary and higher education. Finally, the lack of alternative income as the sixth dimension is quantified by the sum of annual monetary income from local off-farm activities and remittances. People usually receive remittances from household members who migrate for climate-independent labour, for example mining and commerce. Table 1 summarises the indicators used to assess vulnerability.

The data given in Table 1 describe the attributes of 268 smallholder households located in our study region. In preparing the further analysis, we adjusted data sets with only a few extreme values to increase the influence of these data sets on the cluster partitions. For example, the majority of households possess eight or fewer units of livestock. The few households with up to 39 livestock units can be formally interpreted as single outliers which skew the overall data distribution of this indicator. To deskew such data sets and thus adequately focus on the majority of households, we winsorised the data sets, i.e., replaced the outlying observations (4%) with the next available less extreme observation (Barnett and Lewis

1994). This procedure was applied to the area and livestock constraints as well as the alternative income. All indicators were then normalised to a 0-1 range using the minimum–maximum values.

Table 1 Indicators of households' sensitivity and adaptive capacity. The range of the area and livestock constraints as well as lack of alternative income is provided following winsorisation, see description in text. (Data source: ALTAGRO 2006)

Dimension of sensitivity and adaptive capacity	Indicator	Range
Harvest failure risk	Number of production zones used for cultivation	1-3
Area constraint	Crop area	0.1-1.3 ha/person*
Livestock constraint	Livestock units	0.1-8.0 livestock units/person
Productivity constraint	Potato productivity Quinua productivity	0.1-10.0 t/ha 0.2-1.8 t/ha
Education deprivation	Education level of household head	1-4
Lack of alternative income	Local off-farm income and remittances	0-2,400 Soles/year∗person

*) Average: 4 persons per household

Prior to the cluster analysis, we determined correlations between the selected indicators and the variance distribution in the data space. Firstly, the correlation coefficients reached average absolute values of 0.11. The crop area and livestock units correlate most strongly here (0.46) reflecting the mixed production systems. Furthermore, variables showing a large variance may be intuitively expected to contain most of the structure information. Therefore, we explored the variance of the selected indicators using a principal component analysis (PCA). The PCA was performed using the open source statistics package R (RDCT 2009) following standard procedure based on Pearson correlations. The PCA shows minor loadings for both productivity indicators, whereas each of the remaining data sets has a significant loading (absolute values >0.53) in the first three components explaining 66% of the total variance. The productivity indicators have significant loadings only in the last two components. This finding would encourage a clustering without the productivity indicators given the above expectation. However, variables that contribute little to the overall variance of the data space may still contain important structure information (e.g. Chang 1983; Yeung and Ruzzo 2001). To test the relevance for our clustering, we compared the cluster results obtained by including and excluding the productivity indicators (see Section "Outcome-oriented validation and ranking of vulnerability clusters"). Finally, we inverted all indicator values, so that now high values point to climate-relevant constraints in the smallholder systems contributing to vulnerability.

Climate exposure

The climate exposure is determined by precipitation and temperature conditions as main natural production factors. We refer to both the 2005/2006 and the preceding agricultural campaign. Weather conditions during these two campaigns influenced food production and available reserves in the campaign under investigation. Furthermore, we use a well-documented additional campaign to identify the conditions for drought and water stress. The necessary weather information is available in good quality for the 1996–2006 period for two stations located in Puno and Cabanillas (see Fig. 1). Table 2 shows the average precipitation and temperature for both stations.

Table 2 Mean precipitation and temperature for 1996–2006 at Puno and Cabanillas Stations (Data source: Servicio Nacional de Meteorología e Hidrología del Perú, SENAMHI)

		Mean values for 1996-2006												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)														
	Puno	201	161	138	60	7	3	4	14	27	51	48	88	801
	Cabanillas	166	165	112	56	6	1	3	11	19	54	55	91	738
Mean temperature (°C)														
	Puno	10.8	10.7	10.6	9.7	8.1	6.8	6.8	7.9	9.3	10.4	11.0	11.5	9.5
	Cabanillas	10.6	10.5	10.5	9.8	8.6	7.3	6.9	8.1	9.6	10.6	11.1	11.3	9.6
Minimum temperature (°C)														
	Puno	5.7	5.8	5.4	3.8	0.8	-0.9	-1.1	0.4	1.9	3.6	4.3	5.4	2.9
	Cabanillas	5.3	5.5	5.2	3.7	1.1	-0.8	-1.5	0.3	2.1	3.7	4.2	5.1	2.8

Physiological modelling of production stress is not feasible in this study because appropriate data on evapotranspiration and soil conditions, for example, do not exist. Instead, in a first step, we calibrated observed precipitation anomalies against reported production damage. To make the two stations comparable, we determined relative anomalies compared to the average precipitation course over the period 1996–2006 through precipitation ranking. This ranking was then used to identify driest and wettest periods which caused production damage. Since soil water content integrates previous precipitation events to some extent, we cumulated the daily precipitation records in a 20-day window. This window was moved as a running mean by steps of one decade (10 days). This choice is supported by the calibration campaign 2003/2004 described below. Covering the rainy season from December to March, we obtained cumulated precipitation values for 12 time segments (Fig. 2). This number of time segments still allows for sufficient resolution of intra-seasonal anomalies.

The 2003/2004 campaign serves to calibrate the anomalies in the light of production damage (INDECI 2010; Revista Agraria 2004). At the beginning of 2003/2004, the relevant provinces Puno and San Roman reported 490 ha and 306 ha of affected agricultural land and some 70 ha lost in each province due to torrential rainfall. These damages correlate with the relative precipitation anomalies given in Figure 2 (lower part). Here, the wettest time segments are found in late December for both stations and an additional segment at Cabanillas Station in early January. At the end of the campaign, an early harvest was reported in both provinces due to a lack of precipitation. This emergency concurs with the driest segments identified in late February in Cabanillas and in early March at both stations. To facilitate comparison with other regions, Figure 2 includes absolute precipitation values in the upper part.

		December			January			February			March		
		21.11.-10.12.	1.12.-20.12.	11.12.-30.12.	21.12.-9.1.	31.12.-19.1.	10.1.-29.1.	20.1.-8.2.	30.1.-18.2.	9.2.-28.2.	19.2.-10.3.	1.3.-20.3.	11.3.-30.3.

Precipitation (mm) 1996-2006

Wettest segment	Puno	95	87	128	148	199	214	167	182	181	182	185	143
	Cabanillas	110	126	127	163	190	190	155	235	215	158	134	107
Median	Puno	30	39	62	93	120	141	115	133	99	92	82	92
	Cabanillas	34	58	80	83	107	102	102	134	94	77	73	34
Driest segment	Puno	7	26	25	39	91	79	87	50	41	49	54	40
	Cabanillas	17	27	24	23	49	48	51	61	70	35	20	46

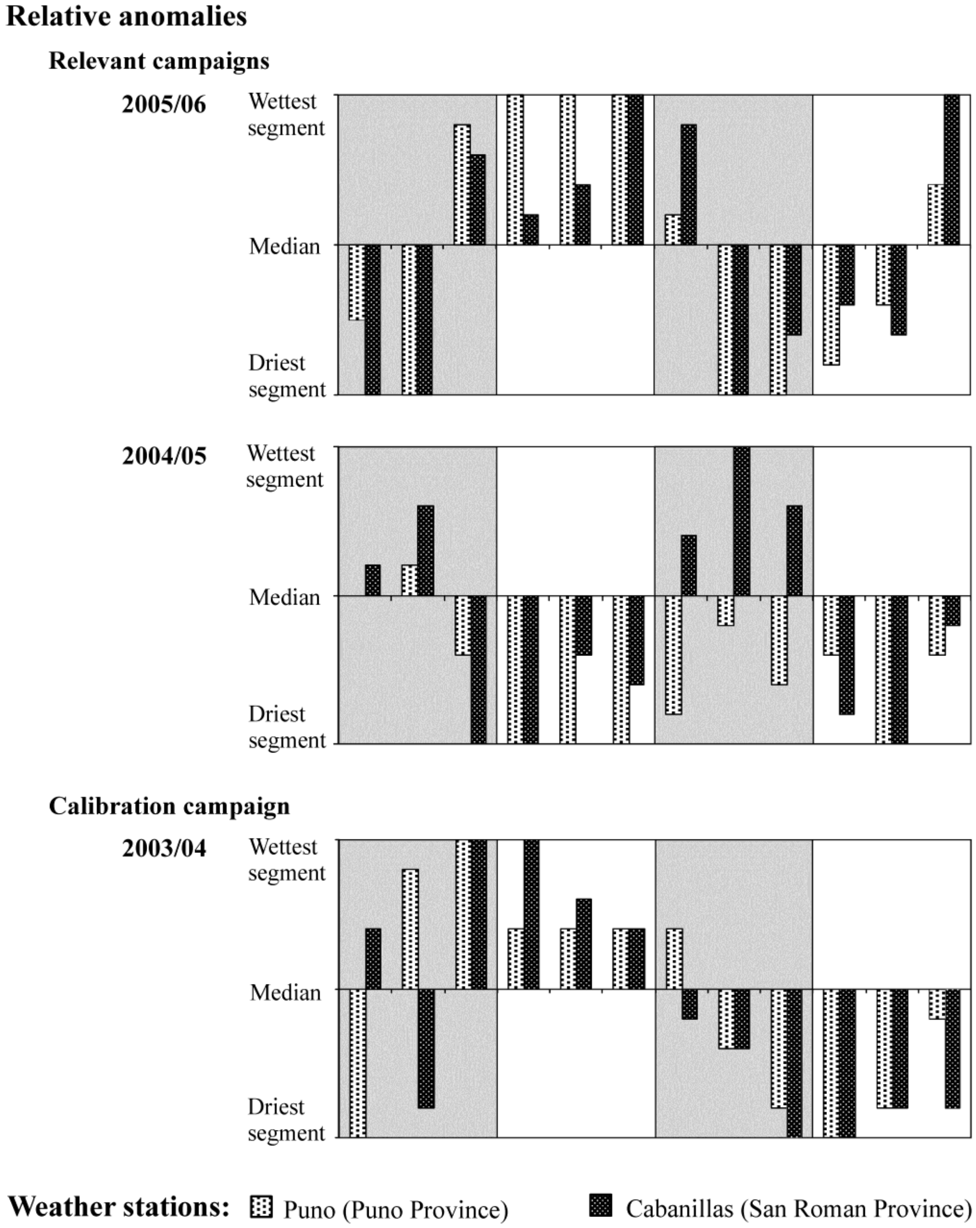

Figure 2 Precipitation anomalies during the rainy season December to March in 1996–2006. The upper part presents precipitation records for the wettest, median and driest segment of 12 time segments. These segments result from the cumulation of precipitation records in a 20-day window moved as a running mean by one-decade steps. In the middle and lower parts, the abscissa refers to these 12 time segments. The ordinate indicates the ranking of the 1996/1997–2005/2006 cumulated precipitation values. (Note: For missing values in 2004, the first segment in Puno refers to nine campaigns. Data source: SENAMHI)

To describe the exposure in the campaigns relevant for our study, we use the above information. In 2005/2006, we find the driest time segments in December and February at both stations, while the wettest segments are found in January and March (Fig. 2, middle part). In 2004/2005, the driest segments occurred during December/January and mid-March, with an additional wettest segment in mid-February at Cabanillas Station. Overall, both stations recorded precipitation anomalies in the same magnitude as the calibration campaign. The study region was thus also exposed to drought and water stress during the 2005/2006 and the previous agricultural campaign. Climate exposure was similar throughout the study region since the number of precipitation anomalies at the two stations is comparable in each campaign.

Contrary to the precipitation conditions, no general frost exposure was identified for the relevant campaigns as the minimum temperature did not fall below 0°C at the two stations (Data source: SENAMHI). Considering that temperature is measured 1.5 m above ground and that the air may be around 1°C colder at canopy height (Morlon 1987), the 0°C threshold refers to a general frost sensitivity. Commonly grown bitter potato and quinua species are however more frost resistant withstanding temperatures as low as -3°C to -8°C (e.g. Bois et al. 2006; Canahua et al. 2002).

In conclusion, climate exposure was precipitation-driven during the relevant campaigns. Similar precipitation and temperature conditions at both stations indicate a similar climate exposure throughout the study region. Therefore, a potential spatial variation in the exposure does not have to be considered in the further vulnerability analysis.

Methods

Cluster analysis

The cluster analysis was performed using a sequence of a common hierarchical and exchange algorithm, i.e., hclust and k-means, using the statistics package R (MacQueen 1967; RDCT 2009). Based on stochastic initialisation, we calculated the reproducibility of partitions for a pre-given number of clusters to determine whether the algorithm detects stable or unstable (inappropriate) partitions. The share of households that were categorised in the same cluster in two partitions is expressed as “consistency measure”. The higher this measure, the more reliable the cluster results. We calculated the consistency measure as the average of 200 pairwise comparisons of partitions with a given number of clusters. Ultimately, the consistency measure enables us to identify the optimal number of clusters to be analysed. Further methodological details are outlined in a previous application of the cluster approach to dryland vulnerability on a global scale (Sietz et al. 2011).

Applying this procedure, the partitions with two and four clusters present local optima in the consistency measure among partitions with 2–10 clusters (Fig. 3, left-hand side). Though partitions with two clusters yield the highest consistency, they only differentiate between the clusters according to the harvest failure risk. The other dimensions do not differ much, meaning that the discussion would be rather limited. Moving on to partitions with four clusters, the algorithm separates groups of households that clearly differ in five dimensions. Such a categorisation contributes interesting aspects to the interpretation of vulnerability clusters. In addition, the ratio of the between-cluster and inner-cluster variance is a measure of the dissimilarity between clusters and their compactness. It increases more strongly for partitions with up to four clusters than for partitions with higher cluster numbers (Fig. 3, right-hand side). Therefore, we base our analysis on four clusters.

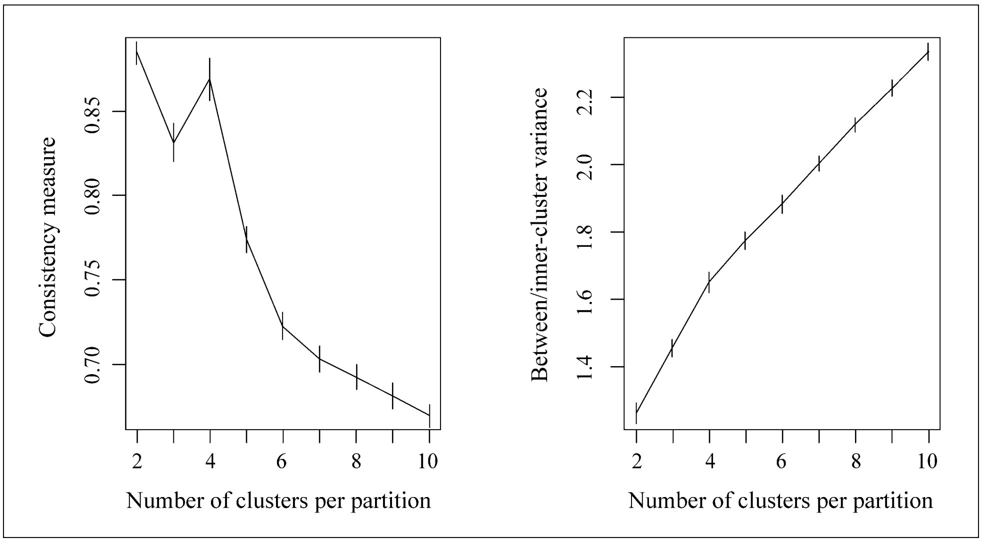

Figure 3 Consistency measure and ratio of between/inner-cluster variance for partitions with 2–10 clusters. Whiskers indicate standard deviations of 50 repetitions of 400 cluster runs, that is to say 200 pairwise comparisons for the consistency measure.

As the severity of vulnerability does not automatically result from the cluster analysis, an additional step was necessary. Here, we used outcomes of vulnerability to test the four identified clusters for validity and rank them as described in the Section "Outcome-oriented validation and ranking of vulnerability clusters". Thereafter, these typical combinations of household attributes were interpreted and the implied vulnerability-creating mechanisms tested against empirical evidence. Both the outcomes and underlying mechanisms were collected in a household validation survey as described in the following section.

Household validation survey

The identified vulnerability clusters were tested for validity based on both outcomes resulting from the exposure to weather extremes and reported causes of vulnerability. The two regional assessments used to describe and quantify the vulnerability-creating mechanisms did not provide sufficient details for such a validation. Therefore, we conducted a Household Validation Survey (HVS) in collaboration with CIRNMA technicians. It was carried out in 33 randomly chosen households (12%) in February 2009. The engagement of local smallholders is a key component of this study. They are considered a necessary information source for providing details on the local conditions of climate sensitivity as well as constraints and opportunities for coping with adverse effects.

For the outcome-oriented aspect of validation, we assume that an increased purchase of food and fodder indicates damage since it forces the household to mobilise resources which may have been earmarked for other purposes. We collected data on the purchase of food and fodder in 2005/2006 including monetary and in-kind exchange. The purchase was considered in relation to an average year to compare households in a standardised way. The average year indicates the necessary purchase which complements the household's production and reserves to maintain the average nutritional status. We assume that changes in 2005/2006 were primarily caused by the identified weather extremes given that the productive resources and agricultural management are relatively stable over time.

As smallholders do not maintain records of their purchase, the data collection drew on their memory recall. This approach provides good estimates in the absence of other reliable data sources, though some limitations need to be considered. Most importantly, this method does not account for memory biases. To reduce such biases, the survey referred to the purchase of a specific crop in a given year. Firstly, smallholders were asked to reflect on the crop they harvested last, starting with the previous campaign and successively moving backwards to the 2005/2006 campaign. This part of the survey was conducted with the aid of an abacus. Starting with the given number of 10 beads indicating the average purchase, household heads or other adult family members removed or added beads to quantify their relative purchase in 2005/2006. The survey considered the five major food and fodder crops: potatoes, quinua, broad beans, barley and oat.

The second part of the HVS focused on information about aspects of the smallholder livelihoods that help explain important causes for differences in purchase to support the interpretation and validation of the vulnerability clusters. This part involved semi-structured interviews exploring effects of weather extremes on the smallholders' livelihoods, access to land, production zones and income, availability of labour as well as social and economic opportunities to cope with production failure. Overall, each interview took around 45 min and was carried out in Spanish or Quechua according to the native language of the interviewees.

To test the consistency, we triangulated the responses with informal surveys conducted in the same smallholder households in 2007/2008 and a recall of CIRNMA technicians who had engaged in long-term field work with the respective smallholders. As a result, we had to repeat two surveys for contradictory responses in the households initially selected. The information for the households finally surveyed was consistent.

Results and discussion

Outcome-oriented validation and ranking of vulnerability clusters

In this section, we consider the identified vulnerability clusters firstly as formal entities without regarding their contents; these will be discussed in the following section. Before going into the details of validation, we will review the results of the different cluster analyses, including and excluding the productivity indicators.

The initial cluster analysis considering all seven vulnerability indicators demonstrates that neither the productivity of potatoes nor that of quinua significantly differ between the households (maximum difference 0.09 and 0.03 for the normalised potato and quinua productivity, respectively). The limited contribution of the productivity indicators to the overall variance of the data space as described in Section "Quantitative indication of sensitivity and adaptive capacity" may partly explain this similarity. Furthermore, the comparison of clustering with and without the productivity indicators reveals an identical number of four clusters with a relative maximum in the consistency measure and a significant increase in the variance ratio for partitions with up to four clusters. Clustering without the productivity indicators yields very small differences of -0.03 for the respective consistency measure and 0.2 for the variance ratio as well as comparable indicator combinations at the cluster centres (average difference 0.01, maximum difference 0.03 in absolute terms). In addition, the cluster membership of almost all households (99%) persists. Therefore, the productivity is non-informative for our clustering, meaning that we will concentrate our discussion on the remaining five discriminating dimensions.

Recognising the sensitivity of any vulnerability analysis to the choice of indicators, we empirically examine whether the formal entities provide specific evidence about damages under the identified climate exposure. For this, the data on households' purchase collected in the HVS are related to the cluster membership of households. Figure 4 shows that each cluster corresponds to a relatively small range of the damage measure. Therefore, the similarities among the households revealed by the cluster analysis hold true with regard to the outcomes of the climate exposure. These similarities prove that the clusters provide specific information on climate vulnerability with regard to food security. Furthermore, the clusters clearly distinguish between the households in terms of the amount of purchase. The purchase ranges from above- to below-average values pointing to the severity of vulnerability. The severity is used to rank the clusters.

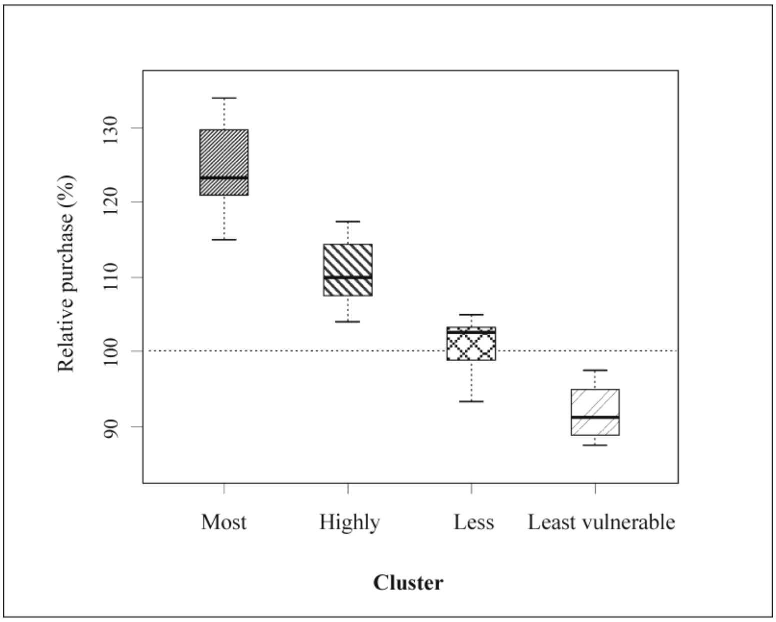

Figure 4 Relation between the vulnerability clusters and relative purchase in 2005/2006. Clusters are ranked according to the severity of vulnerability as shown by the relative purchase. The dotted line indicates an average year. The box plots give the 50% range of households including median values (bold line), while the whiskers show minima and maxima.

The above-average purchase in the most and highly vulnerable households (Fig. 4) indicates that these households were sensitive and ill-adapted to the weather extremes. The less vulnerable households were not affected much and the least vulnerable households purchased even less than average.

Interpretation of vulnerability clusters

We interpret the identified vulnerability clusters based on the indicator values at the cluster centres. These indicator values are representatives for all households categorised as a given cluster. The cluster profiles show that the specific sum of indicators (Fig. 5, upper part) reproduces exactly the cluster ranking according to the damage measure (see Fig. 4). This correspondence provides a bridge to vulnerability metrics (e.g. Hahn et al. 2009; O'Brien et al. 2004).

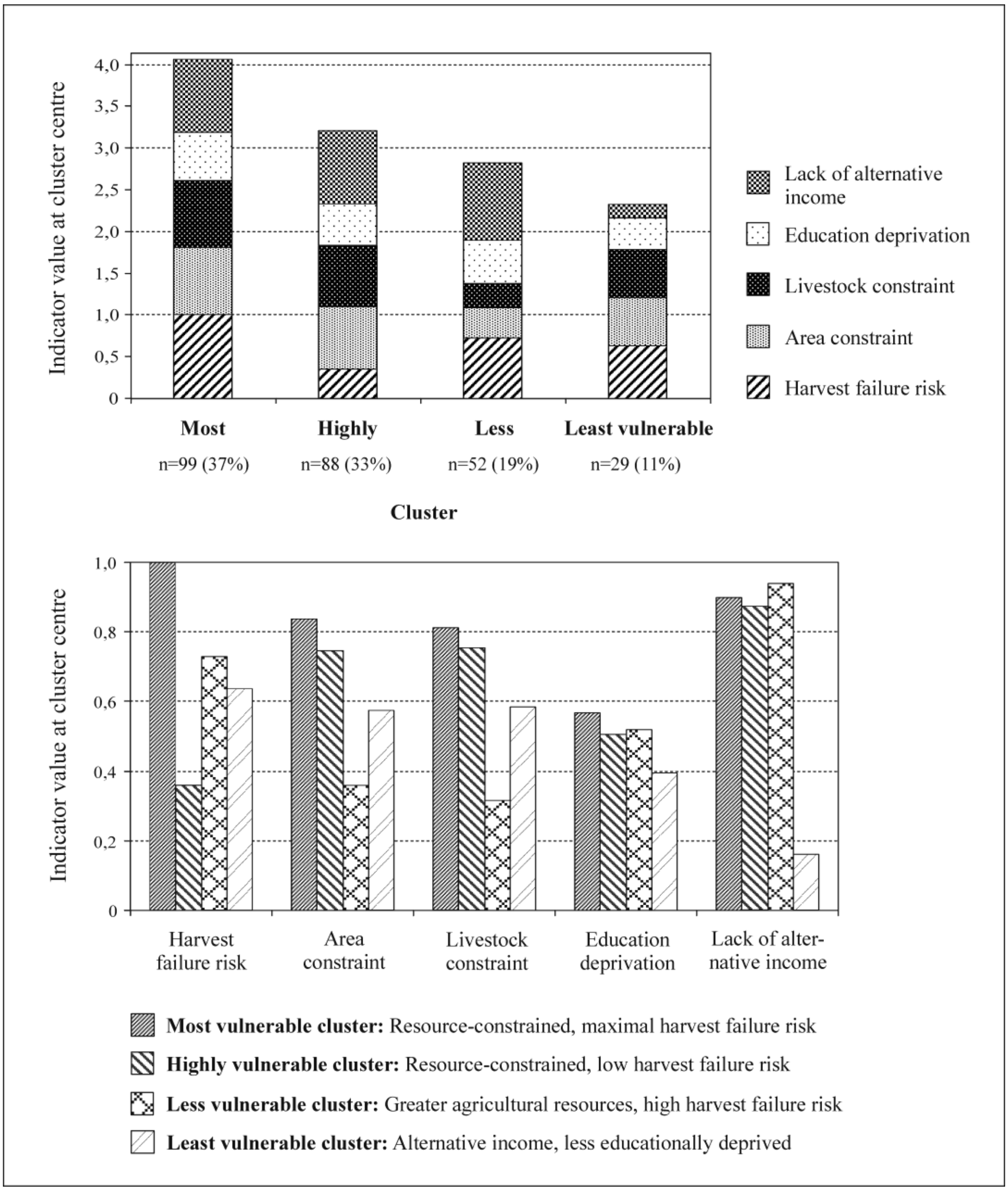

Figure 5 Vulnerability profiles with indicator values at cluster centres. Indicators are normalised according to their minimum and maximum, whereby high values contribute to vulnerability.

Table 3 Households' total income and involvement in extension services provided by CIRNMA (Data source: ALTAGRO 2006)

Cluster	Total income (Soles/year∗person)	Extension involvement ≤ 4 years (% of households)	Extension involvement > 4 years (% of households)
Resource-constrained, maximal harvest failure risk	1,065	61	39
Resource-constrained, low harvest failure risk	965	56	44
Greater agricultural resources, high harvest failure risk	1,503	38	62
Alternative income, less educationally deprived	3,972	67	33

The clusters roughly divide the households into two broad types (Fig. 5, lower part). Either they rely on subsistence indicated by the higher education deprivation and lack of alternative income (most to less vulnerable clusters) or they integrate both on-and off-farm activities (least vulnerable cluster). Focusing on subsistence, the most and highly vulnerable clusters depict particularly resource-constrained households. The clusters however differ with regard to the harvest failure risk. The less vulnerable cluster assembles households with greater agricultural resources, but poorly distributed harvest failure risks. In contrast, the least vulnerable cluster indicates less educationally deprived households that generate a high alternative income. This means their food security is less sensitive to weather conditions.

In the remainder of this section, we will describe and interpret the identified vulnerability clusters in more detail. The empirical evidence independently gained in the HVS serves to validate the underlying mechanisms. The smallholders reported causes of climate vulnerability which deliver rich details that improve the understanding of particular mechanisms in the local context.

Resource-constrained households with maximal harvest failure risk

The most vulnerable cluster describes the maximal harvest failure risk together with pronounced area and livestock constraints. These households are educationally deprived and lack an alternative income. To specify the constraints, we cite two farmers from the Mañazo district who belong to this cluster. The competition for land resources greatly restricts their access to different production zones. Land still available is located far from their living places and sometimes has to be rented at high costs. Despite owning at least some land in plains and hills, they could not distribute the production risks well in the respective campaign. One of them followed his crop rotation which assigned the limited available area in the hills to fallow. The other farmer faced a labour shortage during sowing since he fell ill and his wife alone could not sow the rather distant intended area. They had no monetary assets to hire labourers for this task.

For the highly constrained area coinciding with a maximal harvest failure risk, the agricultural production fell short as result of the precipitation anomalies and related insect attacks (e.g. Gorgojo de los Andes). This causal relation was reported by the majority of interviewed smallholders that belong to this cluster. The purchase subsequently increased more than in the other clusters (see Fig. 4). However, although the households' expenses are unknown in detail and the purchase identified reflects both monetary and in-kind exchange, the generally limited income (Table 3) and livestock savings indicate that the most vulnerable households had a lower capacity to afford the increased purchase. The wife of one of the farmers mentioned above sought to overcome the deficit by knitting sweaters. But she was forced to compete with the saturated market supplying tourists in the city of Puno and could only negotiate a weak position. Within the family, one daughter living in Puno supported the parents financially.

Resource-constrained households with low harvest failure risk

Households in the highly vulnerable cluster are constrained in agricultural resources, education and income, similar to the most vulnerable cluster. But they distribute the harvest failure risks better. Farmers from this cluster in Cabana pointed out that their cultivation area consists of a high number of small parcels (8–13) located in various production zones. They prioritise the distribution of production risks when planning a campaign. This means that the area constraint is not necessarily a barrier for the balanced use of production zones. This finding contradicts the hypothesis on ample land resources as an implicit requirement for adequate risk distribution as mentioned by Sperling et al. (2008). Overall, the only slight increase in purchase in 2005/2006 required rather small additional efforts. Some farmers exchanged parts of their cereal surplus harvested in the investigated campaign and remaining chuño reserves for quinua and beans which they did not produce in sufficient quantity.

Greater agricultural resources with high harvest failure risk

In contrast, the less vulnerable cluster indicates greater agricultural resources. Here, the longer involvement in CIRNMA's extension services compared to all other clusters has probably facilitated the accumulation of resources and income generation (Table 3). As a part of this, financial support and consulting services to improve cattle breeding and organic quinua production receive special emphasis. A female farmer in Cabana explained that the extension service helped to improve her cattle stock by controlling breeding conditions and diseases. The well-developed cattle stock now supplies her with plenty of milk that she processes to cheese to sell at the local market. The income she generates with this allows her to increase her livestock further and acquire new land holdings. The female farmer however added that the labour-intensive animal husbandry absorbs a great part of the available labour force inducing labour shortages for the cultivation in different production zones. Generally, if households in this cluster lost parts of their harvest due to the identified precipitation anomalies, this was not a problem. They had enough reserves from the previous campaign.

Alternative income in less educationally deprived households

The least vulnerable cluster describes somewhat better educated people who more easily explore opportunities for skilled alternative income. Here, the alternative income contributes to the limited risk distribution. Some farmers from this cluster living in Cabanilla indicated that they engage less in agriculture and related reduction of harvest failure risk because they give more priority to skilled off-farm activities, including teaching and capacity building. They said that the resulting alternative income facilitates necessary purchase when their production fails. The below-average purchase (see Fig. 4) points to the opportunity that people use their higher income (Table 3) to meet changing family demands. For example, they sometimes substitute potatoes and quinua, as traditional foods, with rice and wheat products. Being widely considered modern food, people like to include them in the diet. In addition, people who increasingly engage in off-farm activities sometimes reduce their agricultural assets, for example labour-intensive livestock. Under these circumstances, fodder requirements and the related purchase may slowly decline.

The prevalence of most and highly vulnerable households (Fig. 5) points to the urgent need to reduce climate vulnerability for improved food security. These households could not sustain their production even under the relatively modest exposure in the investigated campaign. Being limited by resources and income, the most and highly vulnerable households would benefit from extending the cultivated area and building-up of livestock. It would be helpful to identify further supportive conditions for well-distributed production risks and income generation. Under the given conditions, these households face substantial difficulties in innovating their systems. Increasing the livestock or the production of organic quinua, for example, demands a restructuring of the production systems to allocate the necessary labour and follow specific guidelines for organic growing. By organising in associations, individual households can negotiate a better market position to reduce costs for new inputs and receive more for their outputs. Capacity building and technical assistance would be important to support these processes with a simultaneous focus on building climate-robust production systems.

Considering the extreme El Niño events recurrently disturbing the Altiplano, the majority of the investigated households are probably unable to meet their food requirements during such periods as their capacity to deal with moderate stress is already low. Without major improvements, the undernourishment currently prevalent could unfold further and have adverse consequences for labour productivity and related income. As the undernourishment of mothers is linked to critical child malnutrition and higher rates of child mortality, it can transmit disadvantages across generations (Harper et al. 2003).

Summary and conclusions

This study has analysed climate vulnerability with regard to food security based on a cluster approach. Capturing multiple attributes of 268 smallholder households in the Peruvian Altiplano, we identified four vulnerability clusters. The typical patterns of vulnerability identified were validated against independently reported damages under climate exposure. At the same time, the damage measure allowed for a ranking of the clusters according to the severity of vulnerability. Given the similarities of both the vulnerability characteristics and the outcomes of the observed climate exposure, the clusters provide appropriate indication of climate-related causes of food insecurity in the smallholder households investigated. Moreover, independent empirical evidence about causes of climate vulnerability validated the cluster-specific mechanisms. This elaborate validation strengthens the credibility of our findings and the assumption that they are suitable for decision-making.

Our findings concur with previous studies on the consequences of resource scarcity, diversification of activities and income restrictions for climate vulnerability in smallholder households. For example, Valdivia and Quiroz (2003) report that livestock assets, the sale of dairy products and off-farm employment significantly increased the coping capacity of smallholders in the Bolivian Altiplano. They conclude that poor households deplete rather than accumulate assets, even with average precipitation conditions. As another example, smallholders in Mexico with limited land resources rather dedicated their land to maize production to meet subsistence needs (Eakin 2005). Though the price for maize was higher than for wheat and barley, the production of maize is more sensitive to frosts and droughts than mixed cropping systems. This links to a higher climate vulnerability. Adding to these findings, our results further differentiate within the group of resource and income-constrained households. Among them, we identified households that managed the risk of harvest failure better by extending their agricultural production into diverse production zones, thus improving their food self-sufficiency. Overall, the Peruvian Altiplano compares to other dryland regions in which ancient cultures evolved based on a sophisticated management of natural resources, but whose current inhabitants are poor and rely on over-used water resources, frequently in combination with degraded soils, such as in central Mexico and the Middle East (Sietz et al. 2011).

The vulnerability patterns describe typical combinations of household attributes that translate into specific sets of strategies for reducing vulnerability. Entry points here for overcoming cluster-specific constraints include interventions that concern both the household level, such as climate risk management or the building-up of agricultural assets, and the context in which people live, including access to education and alternative livelihoods. The management of climate risks in this case is an essential area of intervention. It strongly relies on weather information, expected consequences and available livelihood alternatives. In the context of risk management, the application of weather forecasts to adjust agricultural management has been intensively discussed. Their potential to positively influence decision-making depends on technical, institutional and cultural conditions as well as their legitimacy and credibility (e.g. Dilling and Lemos 2011; Howden et al. 2007;Patt etal. 2007). Important aspects include their spatial and temporal resolution, accessibility, the lead times, communication of uncertainties, their specificity to the users' needs and the users' perceptions of risks and benefits.

In the Peruvian Altiplano, forecast information has scarcely been integrated into the agricultural decision-making of smallholders, partly due to a lack of comprehension and mistrust of governmental institutions (Sperling et al. 2008). The smallholders rely more on the observation of local indicators, for example plants, animals and stars. However, only the precise observation of the brightness of the Pleiades stars is recognised as being able to provide quite reliable results in predicting rainfall variability in extreme periods associated with El Niño events (Orlove et al. 2000). Therefore, an improved communication of forecast information would be essential for better management of climate risks. For example, continued participatory workshops with smallholders in Zimbabwe demonstrated that iterative interactions with potential users can provide significant benefits by jointly interpreting the weather forecasts and translating them into specific management decisions (Patt et al. 2005).

The validation outlined in our study complements newer studies that test the consistency of indices of vulnerability against independent data sets of observed or perceived vulnerability outcomes (e.g. Alcamo et al. 2008; Fekete 2009; Krömker et al. 2008). Being the first iteration of the cluster approach to analyse climate vulnerability at the household level, the secondary data set already provides an opportunity for validation. In a future assessment, it would however ideally cover a greater share of households. By testing the approach under different livelihood conditions and climate exposure, further damage dimensions may come to be meaningful. Finally, in view of newly arising stresses related to a stronger market integration, the food security of smallholders who increasingly engage in cash-crop production, such as organic quinua, or off-farm activities should be further examined under the influence of multiple stress factors, including demand, price and wage fluctuations.

Acknowledgments

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