Climatic Change (2017) 145:41–55
DOI 10.1007/s10584-017-2080-3

High mountain communities and climate change: adaptation, traditional ecological knowledge, and institutions

Tenzing Ingty[1]

Received: 18 October 2016 / Accepted: 22 September 2017 / Published online: 6 October 2017

Abstract Our planet has already committed to climate change and will experience its associated impacts; thus, mitigation along with adaptation strategies cannot be mutually exclusive. Yet, international and national policies to tackle climate change have focused more on mitigation than adaptation. On the other hand, indigenous communities have been continuously adapting to environmental stresses for millennia, including more recent cascading impacts of climate change. Indigenous communities have developed a wealth of information in the form of their traditional ecological knowledge (TEK), based on their observations of the obvious linkages between changing climatic conditions and biodiversity. Here, I hypothesize that in harsh environments such as the alpine Himalaya, social systems particularly local institutions that are largely based on TEK are important in improving adaptive capacity by providing social, economic, and ecological security to the community. I provide an insight into the adaptation strategies of two communities that inhabit the alpine zones of the Sikkim Himalaya, in India. We address two broad questions: (1) How are indigenous communities in the vulnerable alpine zones of the Himalaya adapting to the complex challenges posed by climate change particularly in conjunction with their indigenous governing institution? We give examples of adaptation strategies and broadly categorize them into six groups, namely (a) Institutional capital, (b) Rationing, (c) Forecasting, (d) Mobility, (e) Economic diversification, and (f) Communal pooling. (2) How can TEK be integrated with climate change sciences for improving data availability and better policy? I conclude with a framework that uses a holistic approach complementing the rigor of science with the wealth of TEK to suggest pathways for improved policy response to climate change.

1 Introduction

The twin paths to combat climate change, firstly, mitigation by reducing greenhouse gas (GHG) emissions and increasing carbon sinks, and secondly, adaptation, cannot be mutually

✉ Tenzing Ingty
tenzingingty@gmail.com

[1] Department of Biology, University of Massachusetts , Boston, MA 02125, USA

exclusive. Nevertheless, national and international policies focus more on mitigation (Pielke et al. 2007; Measham et al. 2011), and often overlook analyses of local vulnerabilities and the need to address climate change through adaptation. (Ribot 2010; Rodima-Taylor et al. 2012). There is limited work on the impacts of climate change on the vulnerability of communities (Smit and Wandel 2006; Ribot 2010; Ford et al. 2010). However, as Urwin and Jordan (2008) stated, "*identifying what and how to adapt remain far from clear.*" The answers may lie in traditional ecological knowledge (TEK) that has been identified as an important tool in improving adaptive capacity (Salick and Byg 2007; Macchi et al. 2008, Agrawal and Perrin 2009). A greater emphasis on TEK may also result in more adaptation policy decision-oriented research (Pahl-Wostl 2009; Berrang-Ford et al. 2011; Wise et al. 2014).

Here, I follow Usher (2000) in defining TEK as "*all types of knowledge about the environment derived from experience and traditions of a particular group of people.*" There is a wealth of potentially useful information in the form of TEK of the indigenous peoples (Nyong et al. 2007; Ifejika Speranza et al. 2009; Berkes and Davidson-hunt 2010; Chaudhary and Bawa 2011; Bawa and Ingty 2012; Ingty and Bawa 2012; Kaul and Thornton 2014). Many such communities remain directly dependent on biodiversity and provisioning services of nature. Thus, they may often be the first to perceive changes in environmental conditions. The potential merits of incorporating indigenous knowledge systems into climate change adaptation policy have been recognized by the scientific community (Byg and Salick 2009; Bridges and McClatchey 2009; Turner and Clifton 2009; Chaudhary and Bawa 2011).

Additionally, TEK may be important since climate projections derived from regional- or global-scale models cannot yet be reliably downscaled to the local scale (Bridges and McClatchey 2009). In contrast, many indigenous groups have been passing down relevant information about variations in local climatic conditions over generations. Thus, Turner and Clifton (2009) suggested that TEK be treated as baseline long-term datasets developed over centuries of trial and error.

Here, I focus on the Himalaya, a region with a rich diversity of indigenous ethnicities and one of the 35 global biodiversity hotspots (Mittermeier et al. 2011). The region has been significantly impacted by changing climatic conditions. Shrestha et al. (2012) estimated that between 1982 and 2006, annual mean temperatures have increased by1.5 °C, three times the global average. Rising temperatures, leading to receding glaciers could have disastrous impacts on downstream water supplies (Yao 2004; Barnett et al. 2005; Nogués-Bravo et al. 2007), biodiversity, and livelihoods (Xu et al. 2009). Yet research in Himalaya suffers from a lack of long-term measurements. This lacuna constrains scientific capacity to assess the magnitude of climate change and its impacts on the people and biodiversity of the region.

I hypothesize that in harsh environments such as the alpine Himalaya, social systems particularly local institutions are important in improving adaptive capacity by providing social, economic, and ecological security to the community. I provide an insight into the adaptation strategies of two communities that inhabit the alpine zones of Himalaya and address two broad questions:

1. How are indigenous communities in the vulnerable alpine zones of the Himalaya adapting to complex challenges posed by climate change particularly in conjunction with their indigenous governing institution? Adaptation strategies were categorized according to commonly described adaptation processes (Agrawal and Perrin 2009; Thornton and Manasfi 2010; Gómez-Baggethun et al. 2012).
2. How can TEK be integrated with climate change sciences for improving data availability and better policy?

Although the study is local, I conclude with a framework that may be scaled up for improved policy response to climate change. The framework uses a holistic approach complementing the rigor of science with the wealth of TEK.

2 Study area

The two communities selected for our research are the Lachenpas, who practice transhumant agro-pastoralism, and the traditionally nomadic pastoralist Dokpas, or yak herders. They inhabit Lachen Valley in the North district of Sikkim on the border between India and China (Fig. 1).

Both groups inhabiting the region are directly dependent on the biodiversity of their surroundings for livestock husbandry and the collection of medicinal, aromatic, and edible plants (Singh and Chauhan 1997; Tambe and Rawat 2009). They are of interest to the study because

1. Both communities practice seasonal transhumance. Although both communities live in the same valley, their grazing pastures seldom overlap. The Lachenpas occupy a lower elevation, between 2000 and 3800 m above mean sea level (amsl), and the Dokpas occupy altitudes between 3800 m to about 6000 m amsl. In the summers, the Lachenpas move to higher altitude pastures and retreat to mid-montane altitudes in the winter. The Dokpas do the opposite, moving up in winter to the Tibetan Plateau where they find wind-

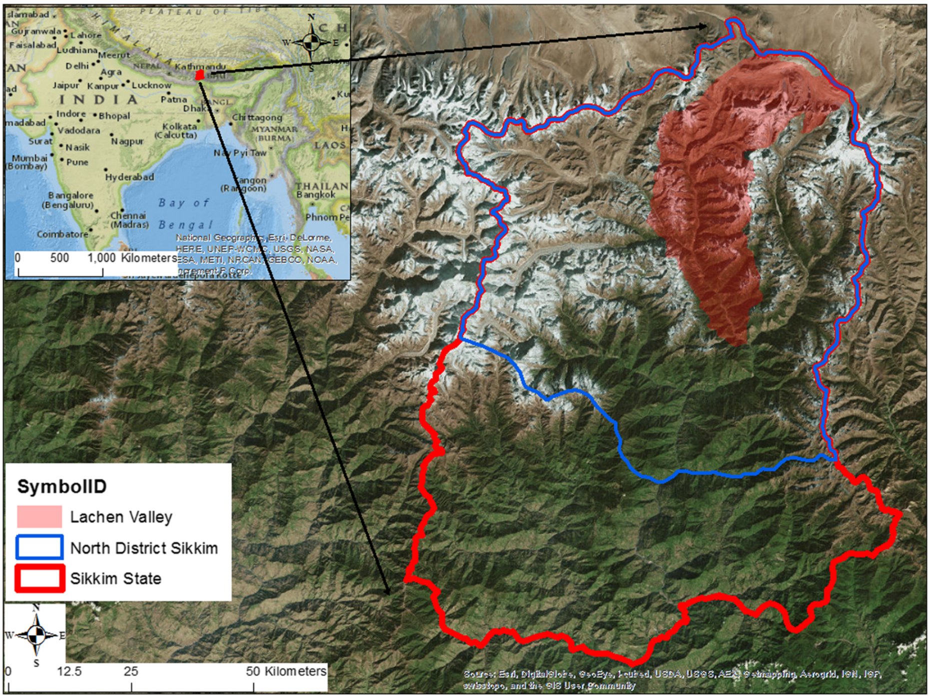

Fig. 1 Study site

blown, snow-free pastures. This migratory practice, employing the rhythm of the seasons, has produced a wealth of TEK based on their observations of the links between changing climatic conditions and biodiversity.
2. Dokpas and Lachenpas follow a traditional system of self-governance known as the *Dzumsa*, which was developed in the early nineteenth century (Bourdet-Sabatier 2004). The *Dzumsa* is an annually elected assembly with the primary responsibility of managing natural resources for the community. It thus forms an important link between social structures and natural systems. Over two centuries, this institution has helped the community adapt to numerous changes in their social and environmental surroundings. These include major socio-economic and socio-political transformations, alterations in the national security landscape (Bourdet-Sabatier 2004), and natural calamities like earthquakes, landslides, and most recently due to the cascading effects of climate change.

3 Methods

The research, a part of a larger project to understand the impacts of climate change on the region, was based on ethnographic field-work over 3 years (2011–2013). I used a participatory rural appraisal approach, including use of semi-structured questionnaires, focus group discussions, and informal interviews. Participant and non-participant observations were also used that immensely improved the research. All interviews were conducted in the local Lachenpa dialect with the help of a local field assistant.

The *semi-structured questionnaire* included open- and closed-ended questions centering on (1) the respondent's perceptions, observations, and interpretations of changing climatic conditions, and (2) their beliefs, and adaptation strategies, and coping mechanisms, if any. I conducted a total of 44 interviews with 35 Lachenpa households (about 15% of the population) and nine Dokpa families (60% of the population). All respondents were household heads above the age of 40. Household heads tended to be men with only six Lachenpa household interviewed with women as household heads.

Focus group discussions and informal interviews: A total of six focus group discussions were conducted:

a. Members of the *Dzumsa* Council (primarily village elders; group size = 6)
b. Government agencies (Forest Department, Primary Health Sub-Center, Veterinary Center, and Tourism Information Center; group size = 8)
c. Two groups of Lachenpas (practicing traditional agriculture and pastoralism; group sizes = 6 and 9, respectively)
d. Two groups of Dokpas (yak herders; group sizes = 5 and 4, respectively)

Informal interviews and participatory and independent observations greatly enriched the field data.

4 Results

Based partly on classifications by Agrawal and Perrin (2009), Thornton and Manasfi (2010) and Gómez-Baggethun et al. (2012), I grouped adaptation strategies into six broad categories: (1)

Institutional capital, (2) Rationing, (3) Forecasting, (4) Mobility, (5) Diversification, and (6) Communal pooling. I placed the observed adaptation strategies under the six broad cognitive categories. Cognitive categories as used here aids communication with decision makers, and enhances ease of policy design. Although the six categories have been described independently, adaptation strategies show much interdependency and overlap especially with respect to the local self-governing system or institutional capital. The *Dzumsa* plays an essential role in social, environmental, and economic characteristics of the community thus cutting across the different categories described.

4.1 Institutional capital

Institutional capital is the governance structure that enhances adaptive capacity and encourages efficient allocation systems and sustainability (Platje 2008). In the unforgiving environmental conditions of alpine Himalaya, traditional institutions like the *Dzumsa* play a vital role by partitioning resources to prevent overuse, maintaining resource buffers, and provide social, environmental, and economic security.

In the 1970s when the *panchayat* system was introduced into Sikkim, India, it was not imposed upon the two valleys of Lachen and Lachung. Eventually, the *Dzumsa* was officially recognized by the government of India in 1985. The *Dzumsa* consists of an annually elected body of 12 village representatives. It is composed of 2 *pipons* (headmen), 6 *gembos* (headmen's assistants), 2 *tsipos* (accountants), and 2 *gyapons* (messengers). This body represents the people of Lachen and manages resource utilization, conservation, pasture management, conflict resolution, social and community mobilization, traditions, and local governance.

Some resource management strategies of the *Dzumsa* are summarized in Table 1 along with their implications.

These examples show that the traditional role of the *Dzumsa* has been to reduce social, economic, and environmental stressors and risks. The *Dzumsa* thus forms an important institutional link between natural systems and social structures. It has helped to maximize the benefits from ecosystem services while minimizing the threats from ecosystem *dis*-services. These measures provide a sense of resilience to the multifarious impacts of climate change.

4.2 Rationing and storage as a response to common shortages

Our survey revealed that both communities perceived a decrease in the amount of snowfall (Fig. 2a). All Dokpas interviewed and 94% of Lachenpas agreed that average snowfall has decreased over time (a minimum of 25 years). Respondents reported that the lowest elevation that received snowfall had increased from a village at an average of 1700 m amsl to a higher elevation village at about 1950 m amsl. Dokpas revealed that shallower snow pack, shorter winters, and erratic rainfall (heavier but shorter spells), are leading to drying and deteriorating pasture conditions. These observations conform to other studies in the Himalaya that detect declining biomass, lower forage quality, and shortened periods of growth under the influence of experimental warming (Dorji et al. 2013). Pastoralists assert that inferior pasturage has resulted in many sheep fatalities. To increase sheep numbers and prevent cost escalation, the *Dzumsa* banned the slaughter and sale of sheep for 3 years, lifting the ban only in 2011 after sheep stocks had increased. This is another example of the *Dzumsa*'s willingness to make an "adaptive" administrative decision to ration resources in response to apparent cascading impacts of climate change.

Table 1 Role of Dzumsa in natural resource management

Actions	Effects
Resource related	
Sets dates for communal transhumance movements, as well as lower altitudinal grazing limits	Ensures availability of winter grazing resources by setting enough summer fallow time for pasture regrowth
Proposes dates for fodder collection along an altitudinal gradient	Provides equal opportunity to all to build their winter reserves
Suggests sowing and harvesting dates and prescribes crop selection for villages along the altitudinal gradient	Co-ordinates the community effort, giving everyone time to repair fences to protect crops from freely roaming livestock; also increases the potential for optimal yield
Imposes up to 3-year restrictions on agriculture in plots showing low productivity; allows grazing in fallow plots	Maintains soil fertility by replenishing soil nutrients through manure, and ensures alternative income to landowner from grazing rights, and
Social and economic well-being	
Regulates prices for livestock and livestock products	Protects poorer members of society from price shocks and swings
Collects money (fees, fines, government contract work, and other sources) and is responsible for their equitable redistribution among members	Provides financial safety net to member households
Organizes fuel wood for funeral by requiring each member to bring one bundle of wood to the house of the deceased and one log for the funeral pyre; logs are checked for size with a bamboo ring	Reduces economic stresses at times of crisis

Storage Historically, both communities stocked up on food and fodder for the winter season.

Storage is an important strategy to reduce risk and vulnerability. Grain provided by the State Government's targeted public distribution system is stored in a public warehouse. During the earthquake of 2015, due to damage to the road networks, there were no rations coming into the valley. This stocked up grain was then distributed, with families receiving 40 kg of rice each.

Another form of storage is the practice of winter fodder collection. Besides rotational grazing that allows pasture regrowth over a season, certain areas are permanently fenced off to allow for hay formation. The grass and herb cover is allowed to grow till just prior to the snow season (October) when the vegetation cover is removed and stocked as fodder for the winter.

4.3 Forecasting

Many indigenous communities have devised intricate systems of weather forecasting by taking note of changes in their biophysical surroundings (Ifejika Speranza et al. 2009; Gómez-Baggethun et al. 2012). The two communities in our study have also developed methods for predicting the weather based on responses of a range of species. Both Lachenpas and Dokpas use an intricate system of forecasting seasons based on the phenological stages of particular species in their surrounding biodiversity.

Our survey revealed that both communities have noticed shifts in seasons. Spring and summer are perceived to have begun earlier, while autumn and winter have been delayed (Fig. 2b). Dokpa respondents unanimously reported delayed winters and autumns, while 85 and 95% of Dokpas interviewed reported advancing summer and spring seasons, respectively

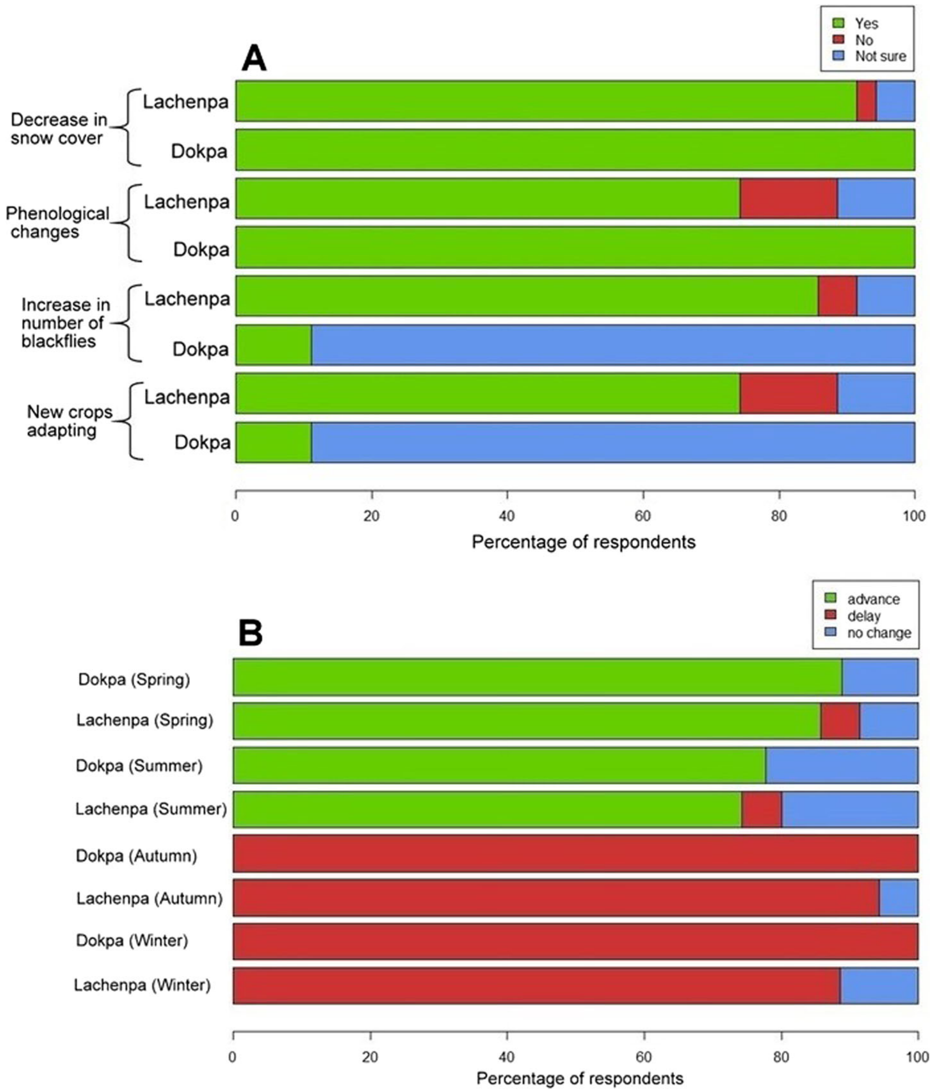

Fig. 2 Perceptions of the two communities: (**a**) On indicators of climate change other than timing of seasons. (**b**) On change in timing of seasons

(Fig. 2b). Among the Lachenpas, 95% reported delayed autumns and 90% delayed winters. Similar trends, i.e., 85 and 75%, respectively, were seen with reports on advancing springs and summers (Fig. 2b). Our survey revealed that with shifts in seasons, phenological responses of species too have shifted. Seventy-five percent of Lachenpas and 100% of Dokpa respondents reported phenological changes (Fig. 2a). Some examples of are:

a. *Flowering of prominent plants:* The Dokpas traditionally mark the start of winter, defined as when snow covers the lower altitude pastures, by the flowering season of *Gentiana ornata*. Respondents noticed that with delayed winters, the flowering of this species has been delayed. Likewise, the first flower to bloom, *Primula denticulata* has been used to mark change in seasons, marking the end of winter and the onset of spring. It was reported that advancing spring inception dates coincide with early flowering of *P. denticulata*.

b. *Species migration:* The migration of the bird, Ruddy Shelduck (*Tadorna ferruginea*), both arrival and departure from the high-altitude riparian systems, mark the start and end, respectively, of the monsoons. Respondents brought to light changing migration patterns of the bird in response to altered rainfall patterns. These observations are in concordance with studies from around the world related to shifts in distribution ranges and altered phenology of numerous species in response to climate change (Parmesan and Yohe 2003; Primack et al. 2004; Menzel et al. 2006; Yu et al. 2010; Chen et al. 2011).

4.4 Mobility: transhumance and nomadic migration to reduce exposure and manage resources

Mobility in the form of migration is a long-established strategy to reduce vulnerability to difficult environmental conditions such as droughts, soil erosion, and heat or cold stress, as well as stressors on resources (McLeman and Smit 2006; Ifejika Speranza et al. 2009). In Africa, studies have documented migration as a common adaptation strategy in response to drought, famines, and land degradation (Henry et al. 2005; Ezra 2005; Ifejika Speranza et al. 2009). In China, historical records document migration of human populations, particularly nomadic pastoralists in response to changes in climate (Smit and Cai 2005). Similarly, Yeh et al. (2014) identify mobility among pastoral communities in Tibet as an essential strategy to cope with snowstorms. Similar mobility is seen among the two target communities that practice transhumance and nomadic migration.

Transhumance timing Transfer of the livestock to summer pastures allows regrowth of winter pastures during the summer months and vice versa. This traditional practice, not a direct response to climate change, has reduced both exposure and sensitivity to climate change thus reducing vulnerability. The dates for migration to summer pastures are decided upon by the *Dzumsa* using a combination of indicators, including dates from the religious calendar as well as dates for the season when blackflies reappear and irritate the livestock. With the advent of the blackfly season, livestock are taken to higher altitudes outside the upper distribution range of the flies. Eighty-five percent of Lachenpa respondents agreed that blackfly season has expanded over the years (Fig. 2a), while 90% of Dokpa respondents had no opinion on the matter. This is explained by the fact that the Dokpas live all year at altitudes outside the upper distributional range of blackflies, hence are unaware of changes.

4.5 Diversification

Agricultural diversification Some of the impacts of climate change on the agricultural patterns of these high-altitude villages have been economically beneficial. About 80% of Lachenpa respondents reported growing crops that had previously been unable to survive at such high altitudes (Fig. 2a), (only 10% of Dokpa respondents were able to respond to this question, since most Dokpas, being nomadic, do not practice agriculture). Based on various local factors, as mentioned earlier, the *Dzumsa* selects the crops to be sown. The *Dzumsa* has recently introduced a number of crops at high altitudes including maize, cabbages, and pumpkins at Lachen (2700 m amsl), carrots at Thangu (4100 m amsl), and potatoes at Gochung (4750 m amsl).

As discussed in the section on rationing, shallower snow packs, shorter winters, and erratic rainfall have led to deteriorating pastures resulting in numerous sheep fatalities. Consequently, though sheep have traditionally played an important role in Dokpa life, Dokpas are diversifying livestock by replacing sheep with yaks, which are more tolerant to poor-quality pasturage.

Income diversification One form of climate adaptation and vulnerability reduction is income diversification, which spreads risk (Kelly and Adger 2000; Howden et al. 2007). Historically, both Lachenpa and Dokpa communities practiced transhumant pastoralism and conducted small trade between Tibet to the north and India to the south of their region. Due to both external constraints and the benefits of urbanization, they have diversified toward other sectors, particularly the tourism industry. The most immediate reason for this change was the complete closure of the international border after the war of 1962 between India and China. Closure meant loss of trade with Tibet, but also loss of vast areas of winter pastures. The communities gradually found new sources of income with tourism, starting just a little over a decade ago, now playing a major role. Roughly 60% of the total households are involved in tourism as hotel owners, tourist taxi drivers and owners, porters, and guides. The tourism industry in Lachen is rapidly specializing to cater to the diverse needs of different tourist groups, be they religious pilgrims (Lachen Valley is home to one of the most sacred lakes for the Sikh and Buddhist religions i.e., the Gurudongmar Lake), or adventure tourists, or the "mass tourists" who prefer shorter visits and have greater commercial and comfort-based expectations. Entrepreneurship in construction, hospitality, and transport has opened numerous job opportunities. The number of lodges has increased from just 1 in the year 2000 to 33 lodges and eight home-stays in 2013. The number of locally-owned taxis too has increased from 15 to 52 from 1998 to 2012 and forms an integral part of the local economy. While the reasons discussed here are not directly a response to impacts of climatic change, they demonstrate the diverse sources of income for the people of the region and underline the adaptive capacity with respect to income diversification.

4.6 Communal pooling: communities and markets communal pooling

Until quite recently, the *Dzumsa* has functioned by common consent as a significant counter-balance to the power and influence of markets. By controlling agrarian schedules, the institution has restricted the ability of individuals within the community to maximize short-term agricultural productivity at the risk of sacrificing long-term sustainability. By pooling and redistributing fees, the *Dzumsa* has constrained the possibilities for elite capture and rent-taking. In an agrarian economy poised between subsistence and regional markets, these mechanisms have worked toward greater security, particularly by providing an economic floor for the least well-off and by drawing the "marginalized" into a community.

5 Discussion and conclusion

Across the world, pastoral communities have used their TEK on climate variability, grassland ecosystem, and livestock dynamics, and strong social institutions to manage their natural resources and reduce vulnerability (Ifejika Speranza et al. 2009; Marin 2010; Aryal et al. 2014), underlining the importance of documenting TEK in the development and implementation of adaptation policy.

Although documentation of the ways a community experiences climate change and the decision-making processes involved at both agent and agency level can contribute to mechanisms to improve adaptive capacity (Ford et al. 2004; Smit and Wandel 2006), one must be cautious of TEK data as: "*unquestioning acceptance of TEK is as foolish as its unquestioning rejection*" (Huntington 2000). It is thus not surprising that more recently people have used a Bayesian belief network (BBN), a model-based parametric estimation, that combines quantitative data with qualitative information. Studies such as Pesek et al. (2009) and McGregor et al. (2010) used BBN to harness non-quantifiable data as an important predictive parameter in conjunction with quantitative data. TEK also shows immense potential in complementing geographical information systems (GIS) data that uses non-continuous representation and relies on categorical data (Calamia 1999; Pesek et al. 2009; Benthel et al. 2014).

Availability of knowledge is one thing, and its use for adaptation to climate change is another. I have shown that both communities not only have considerable knowledge about their environment but also have an effective institution to use and apply this knowledge. These institutions are in tune with local dynamics, allowing for a rapid response. As a result, Dokpas and Lachenpas have and continue to adapt to environmental changes through strong local governance. Similar responses have been documented in other regions. In Ethiopia, Virtanen et al. (2011) discuss how local institutions play an important role in preventing forest fires, reintroducing controlled range burning, constructing earth dams and ponds for domestic use, and rehabilitating traditional deep wells in collaboration with local state authorities. Yeh et al. (2014) show how pastoralists in Tibet are coping with snowstorms. Interestingly, they note that the government projects that focus largely on emergency aid and shelter have disrupted informal institutions of reciprocity that allowed for communal pooling and mobility to cope with snowstorms.

Our second question about integration of climate change adaptation strategies and TEK must be addressed in two parts. First, is that rapid environmental and economic change may bypass local institutions. The second is how TEK (on which local institutions are largely based) can be integrated with climate change sciences to improve policy response to climate change at the level of both local and state institutions.

5.1 TEK and rapid economic and developmental changes

Local communities such as Dokpas and Lachenpas are in a state of flux and so is TEK and their social institutions. The major economic activity in the area is tourism that is regulated by the state government and travel agencies based in the state capital, Gangtok, or in other major cities in the country. The Dzumsa has responded by developing several new rules to encourage and facilitate tourism in the valley. For example, to maintain the cleanliness of the village, it has banned free-ranging cattle inside the village and plastic mineral water bottles. By discouraging logging of attractive trees like Rhododendrons and sea buckthorns (*Hippophae salicifolia*), the Dzumsa hopes to entice tourists with the valley's natural beauty.

However, the Dzumsa has been slow to respond to other challenges brought about by the fast growing tourism industry that is putting tremendous pressure on forests (fuelwood use), land (diversion of pristine areas for construction), air (emissions), and water (sewage). As the influence of commercial markets in North Sikkim has grown, increasing numbers of individuals and families have chosen to work outside the community social system and to invest their efforts and wealth into private enterprises. There has been some fragmentation of the "community" into individual families, acting in their own interest and outside the influence of the *Dzumsa*, which has little control over tourism-related developments. Interestingly, there has been no overall reduction in the number of people that identify themselves as members of *Dzumsa*-led communities. In fact, in the immediate aftermath of the massive earthquake of September 2011, social capital was cited as one of the most useful resources during a time when the state seemed to have been hobbled by confused responsibilities and unclear lines of authority.

Although the Dsumza has found sound means to prepare communities for climate change, there is little integration of local priorities and state-level responses. Sikkim has a State Action Plan on Climate Change (SAPCC) with a strong development agenda (Jogesh and Dubash 2014) and has adaptation as a focal area. Yet it lacks the discourse on developing institutional arrangements for integrating local institutions in policy formulation and implementation. In fact, SAPCC identifies hydro-power projects in the region, opposed strongly by the Dzumsa, as a source of clean energy and a significant revenue generation.

The Dzumsa's opposition to dam construction was expressed through a strong cultural approach, citing the wrath of local deities, who reside in the surrounding mountains, and an imbalance between short-term economic gains and long-term sustainable development (of which tourism is a vital part) (Bhutia 2012; Huber and Joshi 2015).

5.2 Integrating TEK with climate change policy

TEK produces meticulous site-specific information, developed over the long term while science usually works over larger spatial scales and relatively shorter temporal scales.

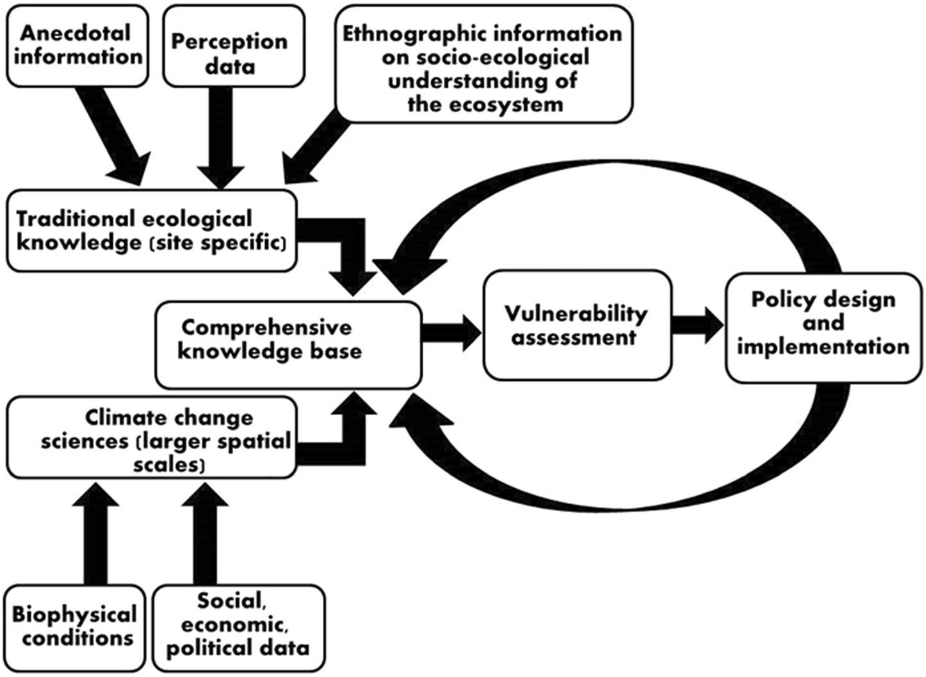

Fig. 3 Framework for climate change adaptation policy design integrating TEK-based local institutions and climate change sciences

The two knowledge systems can thus be complementary rather than being mutually exclusive. Some novel approaches have been used to integrate information from TEK with scientific data. One approach used Zadeh's (1965) "fuzzy logic" or "fuzzy models" (Zadeh 1965; Moller et al. 2004; Berkes and Berkes 2005) that use approximate information and is modeled on being similar to human thinking and natural language (Lee 1990). Berkes and Berkes (2005) point out that the holistic approach of "fuzzy models" shows immense potential for integrating TEK and science but also warn of taking out indigenous knowledge from its cultural context.

Local institutions, with their foundations in TEK, must be integrated with state-level institutions, in policy development and implementation to reduce vulnerability of communities living in the alpine zones of the Himalaya. However, this remains a challenge given the top down approach of state and federal governments that limits government engagement with indigenous institutions to being primarily prescriptive (Howitt et al. 2012; Leonard et al. 2013). I propose a framework in Fig. 3 that aims to overcome this challenge and propose a more holistic approach to policy design and implementation.

As a first step, we need to document perceptions of indigenous communities who have a wealth of knowledge, including anecdotal information, based on their experiences in the region. Local perspectives of how socio-ecological systems function result not only in larger and richer data sources but also contribute to a process that may contribute to the empowerment of communities for protecting and managing their resources. Second, robust climate change science could then integrate environmental and socio-economic indicators to create a comprehensive knowledge base. Downscaling models and projecting climate change scenarios is essential. Validation of perception data where possible should be continuously explored.

This comprehensive knowledge should form the basis of vulnerability assessments that would include downscaling of models, and validation of data. Vulnerability is a function of exposure (e.g., climate data), sensitivity (e.g., physiographical and socio-economic characteristics, dependency on farming, natural hazards) and adaptive capacity (e.g., social, economic, and environmental indicators) (IPCC 2007). Particular importance should be given to natural resources at risk: water, biodiversity, and agriculture. Vulnerability assessments should then lead to the formulation and implementation of pragmatic climate change policy.

Policies should undergo periodic evaluation of interventions and have explicit feedback loops to register signals to allow modifications of future interventions as social and environmental conditions change. These feedback loops would also enrich the comprehensive knowledge base. Overall, the exchange of knowledge, not just between TEK and science but among different communities and different sites, would be vital to devise efficient adaptation policies.

Acknowledgments I would like to thank Dr. Kamaljit Bawa for offering vital comments and edits. I would also like to acknowledge the contribution of the two anonymous reviewers.

References

Agrawal A, Perrin N (2009) Climate adaptation, local institutions and rural livelihoods. In: Adger N, Lorenzoni I, O'Brien K (eds) Adapt. to Clim. Chang. Threshold. Gov. Cambridge University Press, New York, pp 350–367

Aryal S, Cockfield G, Maraseni TN (2014) Vulnerability of Himalayan transhumant communities to climate change. Clim Chang 125:193–208. https://doi.org/10.1007/s10584-014-1157-5

Barnett TP, Adam JC, Lettenmaier DP (2005) Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438:303–309. https://doi.org/10.1038/nature04141
Bawa KS, Ingty T (2012) Climate Change in Sikkim: A synthesis. In: Arrawatia ML, Tambe S (eds) Clim. Chang. Sikk. Patterns, Impacts Initiat. Information and Public Relations Department, Government of Sikkim, Gangtok, pp 413–424
Benthel MB, Brien LF, Esposito MM et al (2014) Sci-TEK: a GIS-based multidisciplinary method for incorporating traditional ecological knowledge into Louisiana's coastal restoration decision-making processes. J Coast Res 30:1081–1099. https://doi.org/10.2112/JCOASTRES-D-13-00214.1
Berkes F, Berkes MK (2005) Ecological complexity, fuzzy logic, and holism in indigenous knowledge. Futures 41:6–12. https://doi.org/10.1016/j.futures.2008.07.003
Berkes F, Davidson-hunt IJ (2010) Innovating through commons use: community-based enterprises. Int J Commons 4:1–7
Berrang-Ford L, Ford JD, Paterson J (2011) Are we adapting to climate change? Glob Environ Chang 21:25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012
Bhutia DT (2012) Independent people's tribunal on dams, environement and displacement. Human Rights Law Network, New Delhi
Bourdet-Sabatier S (2004) The Dzumsa of lachen: an example of a Sikkimese political institution. Bulletion Tibetol 40:93–104
Bridges KW, McClatchey WC (2009) Living on the margin: ethnoecological insights from Marshall Islanders at Rongelap atoll. Glob Environ Chang 19:140–146. https://doi.org/10.1016/j.gloenvcha.2009.01.009
Byg A, Salick J (2009) Local perspectives on a global phenomenon — Climate change in Eastern Tibetan villages. Glob Environ Chang 19:156–166. https://doi.org/10.1016/j.gloenvcha.2009.01.010
Calamia MA (1999) A methodology for incorporating traditional ecological knowledge with geographic information systems for marine resource management in the Pacific. SPC Tradit Mar Resour Manag Knowl Inf Bull 10:2–12
Chaudhary P, Bawa KS (2011) Local perceptions of climate change validated by scientific evidence in the Himalayas. Biol Lett 7:767–770
Chen I-C, Hill JK, Ohlemüller R et al (2011) Rapid range shifts of species associated with high levels of climate warming. Science 333:1024–1026. https://doi.org/10.1126/science.1206432
Dorji T, Totland O, Moe SR et al (2013) Plant functional traits mediate reproductive phenology and success in response to experimental warming and snow addition in Tibet. Glob Chang Biol 19:459–472. https://doi.org/10.1111/gcb.12059
Ezra M (2005) Demographic responses to environmental stress in the drought- and famine-prone areas of northern Ethiopia. Int J Popul Geogr 7:259–279. https://doi.org/10.1002/ijpg.226
Ford JD, Ford JD, Smit B, Smit B (2004) A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. Arctic 57:389–400. 10.14430/arctic516
Ford JD, Pearce T, Duerden F et al (2010) Climate change policy responses for Canada's Inuit population: the importance of and opportunities for adaptation. Glob Environ Chang 20:177–191. https://doi.org/10.1016/j.gloenvcha.2009.10.008
Gómez-Baggethun E, Reyes-García V, Olsson P, Montes C (2012) Traditional ecological knowledge and community resilience to environmental extremes: a case study in Doñana, SW Spain. Glob Environ Chang 22:640–650. https://doi.org/10.1016/j.gloenvcha.2012.02.005
Henry S, Piché V, Ouédraogo D et al (2005) Descriptive analysis of the individual migratory pathways according to environmental typologies. Popul Environ 25:397–422
Howden SM, Soussana J-F, Tubiello FN et al (2007) Adapting agriculture to climate change. Proc Natl Acad Sci U S A 104:19691–19696. https://doi.org/10.1073/pnas.0701890104
Howitt R, Havnen O, Veland S (2012) Natural and unnatural disasters: responding with respect for indigenous rights and knowledges. Geogr Res 50:47–59. https://doi.org/10.1111/j.1745-5871.2011.00709.x
Huber A, Joshi D (2015) Hydropower, anti-politics, and the opening of new political spaces in the Eastern Himalayas. World Dev 76:13–25. https://doi.org/10.1016/j.worlddev.2015.06.006
Huntington HP (2000) Using traditional ecological knowledge in science: methods and applications. Ecol Appl 10:1270–1274
Ifejika Speranza C, Kiteme B, Ambenje P et al (2009) Indigenous knowledge related to climate variability and change: insights from droughts in semi-arid areas of former Makueni District, Kenya. Clim Chang 100:295–315. https://doi.org/10.1007/s10584-009-9713-0
Ingty T, Bawa KS (2012) Climate change and indigenous people. In: Arrawatia ML, Tambe S (eds) Clim. Chang. Sikk. Patterns, Impacts Initiat. Information and Public Relations Department, Government of Sikkim, Gangtok, pp 275–290
IPCC (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

Jogesh A, Dubash NK (2014) Mainstreaming climate change in state development planning: an analysis of the Sikkim action plan on climate change. Centre for Policy Research (CPR), Climate Initiative, Working Paper (New Delhi)
Kaul V, Thornton TF (2014) Resilience and adaptation to extremes in a changing Himalayan environment. Reg Environ Chang 14:683–698. https://doi.org/10.1007/s10113-013-0526-3
Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change andfacilitating adaptation. Clim Chang 47:325–352. https://doi.org/10.1023/A:1005627828199
Lee CC (1990) Fuzzy logic in control systems: fuzzy logic controller—part I. IEEE Trans Syst Man Cybern 20: 404–418. https://doi.org/10.1109/21.52552
Leonard S, Parsons M, Olawsky K, Kofod F (2013) The role of culture and traditional knowledge in climate change adaptation: insights from East Kimberley, Australia. Glob Environ Chang 23:623–632. https://doi.org/10.1016/j.gloenvcha.2013.02.012
Macchi M, Oviedo G, Gotheil S, et al (2008) Indigenous and traditional peoples and climate change. Issues Paper. International Union for Conservation of Nature
Marin A (2010) Riders under storms: contributions of nomadic herders' observations to analysing climate change in Mongolia. Glob Environ Chang 20:162–176. https://doi.org/10.1016/j.gloenvcha.2009.10.004
McGregor S, Lawson V, Christophersen P et al (2010) Indigenous wetland burning: conserving natural and cultural resources in Australia's World Heritage-listed Kakadu National Park. Hum Ecol 38:721–729. https://doi.org/10.1007/s10745-010-9362-y
McLeman R, Smit B (2006) Migration as an adaptation to climate change. Clim Chang 76:31–53. https://doi.org/10.1007/s10584-005-9000-7
Measham TG, Preston BL, Smith TF et al (2011) Adapting to climate change through local municipal planning: barriers and challenges. Mitig Adapt Strateg Glob Chang 16:889–909. https://doi.org/10.1007/s11027-011-9301-2
Menzel A, Sparks TH, Estrella N et al (2006) European phenological response to climate change matches the warming pattern. Glob Chang Biol 12:1969–1976. https://doi.org/10.1111/j.1365-2486.2006.01193.x
Mittermeier RA, Turner WR, Larsen FW et al (2011) Global biodiversity conservation: the critical role of hotspots. In: Zachos FE, Habel JC (eds) Biodivers. Hotspots Distrib. Prot. Conserv. Prior. Areas. Springer Berlin Heidelberg, Berlin, pp 3–22
Moller H, Berkes F, Lyver POB, Kislalioglu M (2004) Combining science and traditional ecological knowledge: monitoring populations for co-management. Ecol Soc 9:2
Nogués-Bravo D, Araújo MB, Errea MP, Martínez-Rica JP (2007) Exposure of global mountain systems to climate warming during the 21st century. Glob Environ Chang 17:420–428. https://doi.org/10.1016/j.gloenvcha.2006.11.007
Nyong A, Adesina F, Osman Elasha B (2007) The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. Mitig Adapt Strateg Glob Chang 12:787–797. https://doi.org/10.1007/s11027-007-9099-0
Pahl-Wostl C (2009) A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob Environ Chang 19:354–365. https://doi.org/10.1016/j.gloenvcha.2009.06.001
Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42. https://doi.org/10.1038/nature01286
Pesek T, Abramiuk M, Garagic D et al (2009) Sustaining plants and people: traditional Q'eqchi' Maya botanical knowledge and interactive spatial modeling in prioritizing conservation of medicinal plants for culturally relative holistic health promotion. EcoHealth 6:79–90. https://doi.org/10.1007/s10393-009-0224-2
Pielke R, Prins G, Rayner S, Sarewitz D (2007) Climate change 2007: lifting the taboo on adaptation. Nature 445:597–598. https://doi.org/10.1038/445597a
Platje J (2008) "Institutional capital" as a factor of sustainable development-the importance of an institutional equilibrium. Technol Econ Dev Econ 14:144–150. https://doi.org/10.3846/1392-8619.2008.14.144-150
Primack D, Imbres C, Primack RB et al (2004) Herbarium specimens demonstrate earlier flowering times in response to warming in Boston. Am J Bot 91:1260–1264
Ribot JC (2010) Vulnerability does not fall from the sky: toward multi-scale 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, pp 47–74
Rodima-Taylor D, Olwig MF, Chhetri N (2012) Adaptation as innovation, innovation as adaptation: an institutional approach to climate change. Appl Geogr 33:107–111. https://doi.org/10.1016/j.apgeog.2011.10.011
Salick J, Byg A (2007) Indigenous peoples and climate change. Tyndall Center for Climate Change Research, Oxford

Salick J, Ross N (2009) Traditional peoples and climate change. Glob Environ Chang 19:137–139. https://doi.org/10.1016/j.gloenvcha.2009.01.004
Shrestha UB, Gautam S, Bawa KS (2012) Widespread climate change in the Himalayas and associated changes in local ecosystems. PLoS One 7:e36741. https://doi.org/10.1371/journal.pone.0036741
Singh P, Chauhan A (1997) Plant diversity in Sikkim Himalaya. In: Hajra P, Mugda V (eds) Plant divers. Hotspots India. BSI, Calcutta, pp 137–162
Smit B, Cai Y (2005) Climate change and agriculture in China. Glob Environ Chang 6:205–214. https://doi.org/10.1016/0959-3780(96)00018-0
Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang 16:282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008
Tambe S, Rawat GS (2009) Ecology, economics, and equity of the pastoral systems in the Khangchendzonga National Park, Sikkim Himalaya, India. Ambio 38:95–100
Thornton TF, Manasfi N (2010) Adaptation—genuine and spurious: demystifying adaptation processes in relation to climate change. Environ Soc 1:132–155. https://doi.org/10.3167/ares.2010.010107
Turner NJ, Clifton H (2009) "It's so different today": climate change and indigenous lifeways in British Columbia, Canada. Glob Environ Chang 19:180–190. https://doi.org/10.1016/j.gloenvcha.2009.01.005
Urwin K, Jordan A (2008) Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. Glob Environ Chang 18:180–191. https://doi.org/10.1016/j.gloenvcha.2007.08.002
Usher PJ (2000) Traditional ecological knowledge in environmental assessment and management. Arctic 53:183–193
Virtanen P, Palmujoki E, Dereje TG (2011) Global climate policies, local institutions and food security in a pastoral society in Ethiopia. Cons J Sustain Dev 5:96–118
Wise RM, Fazey I, Stafford Smith M et al (2014) Reconceptualising adaptation to climate change as part of pathways of change and response. Glob Environ Chang 28:325–336. https://doi.org/10.1016/j.gloenvcha.2013.12.002
Xu J, Grumbine RE, Shrestha A et al (2009) The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conserv Biol 23:520–530. https://doi.org/10.1111/j.1523-1739.2009.01237.x
Yao T (2004) Recent glacial retreat in High Asia in China and its impact on water resource in Northwest China. Sci China Ser D 47:1065. https://doi.org/10.1360/03yd0256
Yeh ET, Nyima Y, Hopping KA, Klein JA (2014) Tibetan pastoralists' vulnerability to climate change: a political ecology analysis of snowstorm coping capacity. Hum Ecol 42:61–74. https://doi.org/10.1007/s10745-013-9625-5
Yu H, Luedeling E, Xu J (2010) Winter and spring warming result in delayed spring phenology on the Tibetan Plateau. Proc Natl Acad Sci U S A 107:22151–22156. https://doi.org/10.1073/pnas.1012490107
Zadeh LA (1965) Fuzzy sets. Inf Control 8:338–353. https://doi.org/10.1016/S0019-9958(65)90241-X