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Research

Perception matters: an Indigenous perspective on climate change and its effects on forest-based livelihoods in the Amazon

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ABSTRACT. Indigenous and subsistence-oriented people are particularly sensitive to the impacts of climate change. Strategies to cope and adapt to those changes may rely on traditional ecological knowledge (TEK), which can play an important role for understanding global environmental change at the local level. We aim to provide insights regarding perceptions of climate change, traditional ecological knowledge, and the coping strategies forest-dependent Indigenous people in the Amazon adopt when faced with climate change impacts. The outcomes are based on a mixed set of methods: comprising semi-structured interviews, meteorological data, and photovoice in a case study approach of 49 households of the Indigenous Territory TCO Tacana I in lowland Bolivia. Data were collected in 2013 and 2015; meanwhile, the study area was hit by a severe extreme weather precipitation event and resulting flood in 2014. The results demonstrate that Tacana's perception of weather trends and those of Western science-trained specialists complement each other because they provide different sets of details. The study revealed 38 traditional weather-related short-term indicators that underline the close interaction of Tacana with the environment. However, their current reliability has been questioned, indicating a need for further observation and research for potential long-term environmental change. Photovoice outcomes suggest that most of the negative effects during the extreme weather event were reported on natural capital in subsistence farming households. Indigenous households relied more on strong bonding and networking social capital (intracommunal and external), less on other capitals to cope with the flood event. Acknowledging TEK insights and changing local ecological indicators contributes information to assist sustainable ecosystem management and build corresponding resilient social systems. Local knowledge can support the understanding of climate and environmental change and local and regional risk management planning, interventions, and policy recommendations. This can considerably enhance the effectiveness and robustness of such strategies while counteracting the loss of traditional ecological knowledge.

Key Words: *forest communities; coping; methodology; social-ecological system; traditional ecological knowledge*

INTRODUCTION

Climate change and its projected adverse ecological and socioeconomic impacts disproportionally affect Indigenous people in vulnerable regions (Savo et al. 2016, Bose 2017). Evidence suggests that Indigenous and subsistence-oriented people are especially vulnerable to the impacts of climate change. This may be related to their living in regions exposed to rapid changes in weather patterns, their often high reliance on natural resources, and unfavorable economic, social, and political conditions (Ford 2012, Wildcat 2013, Savo et al. 2016, Belfer et al. 2017). This is particularly relevant for the Plurinational State of Bolivia, given that 36 recognized Indigenous groups represent 41% of the population (INE 2013), and 85% of Bolivia's food is produced by small-holder and subsistence farmers (FAO 2015).

Climate-induced extreme weather events, such as floods, droughts, and bushfires, are becoming more frequent worldwide and also in Bolivia (Seiler et al. 2013, Cai et al. 2014, Marengo and Espinoza 2016). The way Indigenous groups cope with and adapt to environmental changes is likely to depend on how they perceive and interpret change (Boillat and Berkes 2013). Understanding the impacts of climate change on subsistence and forest-dependent lowland Indigenous communities and the way they cope can be a crucial first step to identify possible adaptation measures (Seppälä et al. 2009, FAO 2017).

This study was part of a broader research to understand the socioeconomic impacts of climate change on three forest-dependent Indigenous Tacana communities in Bolivia and their resilience to those impacts. We aim to reveal the perspectives of households living in these three communities on climate change and their experiences with extreme precipitation events. Local experiences and perceptions of global environmental change among small-scale societies and how traditional knowledge is mobilized to respond are important for related decision making (Pyhälä et al. 2016). Understanding how people cope with climate change and its consequences helps academic debates, policy responses, and mustering practical support to facilitate long-term adaptation strategies. A holistic view of local households' perspectives on climate change can also lead to an improved two-way communication among actors and thus support suitable policy measures.

We, therefore, sought to answer the following research questions:

1. What are the changes in weather patterns perceived by the Tacana, and how do these relate to meteorological data?
2. What are the traditional indicators used by the Tacana to forecast the weather, and are these still considered reliable?
3. From Tacanas' perspectives, which livelihood capitals were most affected during extreme weather events?
4. From Tacanas' perspectives, which livelihood capitals contributed most to cope with the extreme weather event?

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This study will help fill the gap of primary research on Indigenous knowledge and climate change adaptation in South America, recognized by Petzold et al. (2020). In Bolivia, only a few studies on forest-dependent people in the context of climate change exist. They focus on climate change adaptation (Ruiz-Mallén et al. 2015a) or anticipated adaptation strategies (Ruiz-Mallén et al. 2015b, 2017). The present study provides the first evidence of actual climate change coping strategies of forest-dependent households by analyzing short-term responses to extreme weather events in Bolivia. In a systematic literature review, Pyhälä et al. 2016 found that studies on local perceptions of global environmental change provided little methodological explanation on the definition of "local" and whether reported perception is actually about individual's or community's perception. So far, the question of possible heterogeneity within a community was largely unaddressed in the literature on global environmental change (Pyhälä et al. 2016), while it has been shown that heterogeneity within and across social groups in perception, knowledge, and practices is important to consider for sustainable management practices (Ghimire et al. 2005). Our study acknowledges explicitly intra-communal heterogeneity of livelihood strategies and its relevance in climate change coping by focusing on responses of households.

THEORETICAL FRAMEWORK

We use the social-ecological systems (SES) framework to investigate local perspectives of forest households in three Tacana communities regarding climate change, epitomized by a specific extreme weather event. The SES framework conceptualizes feedback and linkages between elements of interacting social and ecological systems (Folke and Berkes 1998). The local perspective comprises perceptions of changing weather patterns, related traditional ecological knowledge (TEK), and experiences of an extreme precipitation event, which all influence local decision making in natural resource management matters (Pyhälä et al. 2016). They influenced coping with the weather event and longer term adaptation strategies (Alam et al. 2017, Mekonnen et al. 2018).

In-situ perceptions of changing weather patterns can be important for understanding climatic anomalies at a local scale, especially where weather stations are scarce, historical data are incomplete or non-existent, or disagreements exist between observed and simulated climatic trends (Onyekuru and Marchant 2014). The perception of climatic variability and change might determine household responses (McDaniels et al. 1996, Adger et al. 2009, Djoudi et al. 2013, Harvey et al. 2014). For instance, in response to perceived changing weather patterns, farmers might adapt their agricultural practices, such as changing the time of planting or harvesting and the use of seeds that are planted (Harvey et al. 2014, Verschuuren et al. 2014).

Ex-situ perspectives held by researchers or policy makers can complement and validate or contradict local weather perceptions. Possible conflicting views, such as a difference between locally perceived risk and risk assessments based on measurements of weather data, can result in an under or overinvestment in adaptive responses (Williamson et al. 2012). Lately, there has been growing interest in integrating Indigenous perceptions of climate and climatic change into scientific studies (Petzold et al. 2020). Bringing local perceptions and Western scientific research together is increasingly being recognized as a way to enhance the understanding of climate change and possible adaptation strategies. Evidence from different knowledge systems can enrich understanding, triangulation, and assessment. Cross-fertilization can also lead to new evidence and insights and potentially improve the capacity to interpret causal relationships in the dynamics of SES (Tengö et al. 2014).

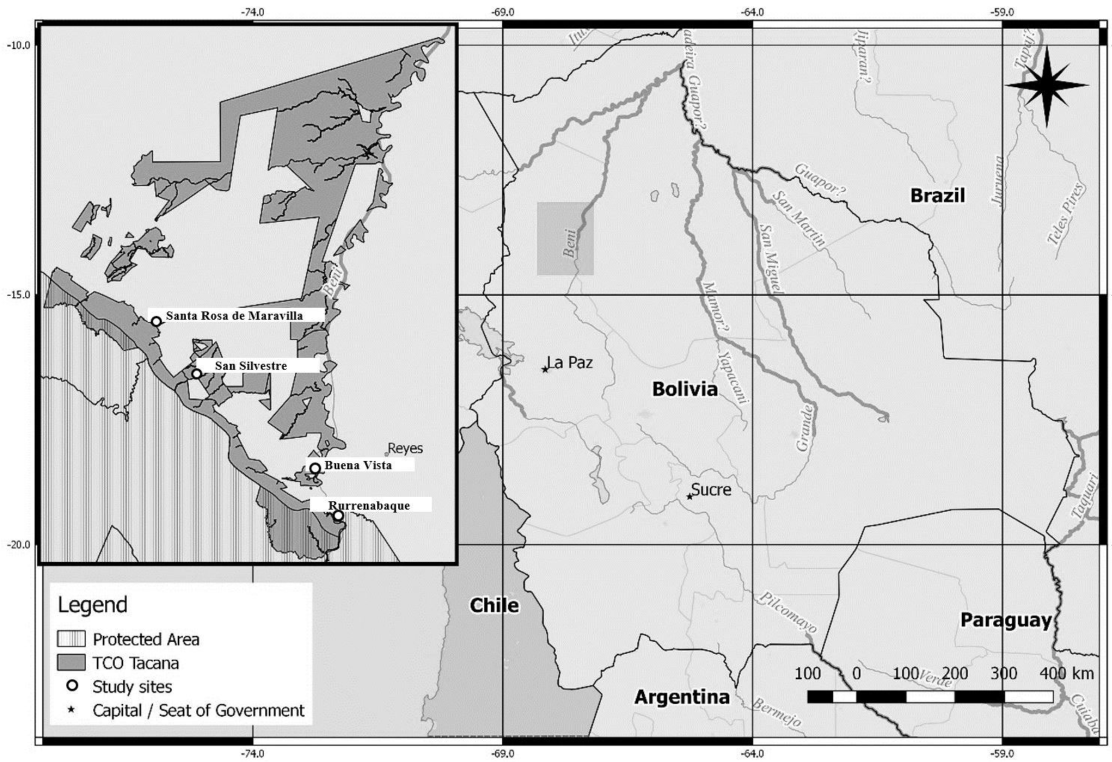
The role of Indigenous and local knowledge and its contribution to climate change coping and adaptation is increasingly being researched and discussed (Petzold et al. 2020). In this study, we combine the often interchangeably used terms Indigenous local knowledge (ILK) and traditional ecological knowledge (TEK) using Berkes (1993:3) definition: "... the cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment." Generally, TEK includes traditional knowledge of both Indigenous and non-Indigenous holders, while ILK refers to Indigenous knowledge holders only. The TEK referred to in this study is largely knowledge held by Indigenous people.

TEK is an important concept in understanding traditional and natural-resource-dependent societies with detailed knowledge about their natural environment. It enables TEK-holders, such as local communities, to estimate possible risks and changes related to the environment and to apply mitigation and resilience mechanisms to cope with well-being undermining nature events (Nishida et al. 2006a, b, Bose 2017, Alves and Barboza 2018).

Since ancient times, climatic events' prediction using biotic indicators, such as animals, plants, algae, or fungi, and astronomical observations are firmly established in many human cultures (Orlove et al. 2002, Alves and Barboza 2018). The observation of animals, their behavior, physiology, and reproduction as climate ethno-zooindicators, is among the oldest and most prevalent forms of human-animal interaction (Parrotta and Agnoletti 2012, Alves and Barboza 2018). Based on TEK, local forest-based communities also develop adaptation strategies to cope with global environmental change (Fernández-Llamazares et al. 2015). At the same time, however, evidence shows that TEK related to agricultural practices, calendars, and bioindicators is eroding (Kronik and Verner 2010, Garteizgogeascoa et al. 2020), and biocultural diversity is declining (Loh and Harmon 2014). The adaptive capacity of TEK may be challenged by the decreased intergenerational sharing (Aswani et al. 2018), the extinction or migration of indicator species (Alves and Barboza 2018), and the unprecedented rates at which societal and environmental change occurs (Fernández-Llamazares et al. 2015). Alves and Barboza (2018) and Bose (2017) claim the need to document TEK and recognize its role in climate change adaptation strategies to prevent further loss. Interdisciplinary and participatory research may play a pivotal role in halting the ongoing erosion of TEK and customary practices and social institutions, which may jeopardize Indigenous adaptive capacity (Williamson et al. 2012).

The role of vulnerability or livelihood insecurity is defined by the exposure of the livelihood to particular trends, shocks, or seasonality and its sensitivity to those. In this context, we choose the sustainable livelihood approach (SLA; Scoones 1998), which offers a guiding set of tools to analyze the contextual situation

Fig. 1. TCO Tacana I. Study communities Santa Rosa de Maravilla, San Silvestre, Buena Vista, and Rurrenabaque (weather station site) on the left, location in Bolivia on the right. Modified from Bauer et al. (2018).



and capitals of the livelihood in the specific case of the 2014 Bolivian extreme weather event. A sustainable livelihood is regarded as being able to cope with and recover from stresses and shocks while maintaining or enhancing the capabilities and capitals without undermining the next generation's natural resource base (Chambers and Conway 1992). Capitals can be tangible (natural, physical, financial) and intangible (social, human), and both the dependence on and the availability of the latter defines survival and well-being needs. Natural capital comprises the natural resource stocks; cash, savings, economic assets are defined as financial capital; human capital encompasses the skills, knowledge, leadership potential, health status, and ability to labor; physical capital includes the producer goods, infrastructure; and social capital comprises the networks, social claims, social relations, affiliations and associations of communities (Scoones 1998). SLA will be used to illustrate forest households' experiences, in particular adverse impacts on livelihood capitals, and how the latter were mobilized to cope with an extreme event.

METHODS

Study area

The study was conducted in the Indigenous Communal Territory, TCO (Tierras Comunitarias de Origen) Tacana, situated in the northern Amazonian lowland part of the Department La Paz, Bolivia. The TCO Tacana I (Fig. 1) comprises 621 families who live in 20 communities, which hold a formal title over 389,303 ha of primarily forested lands. TCO Tacana I is located adjacent to the Madidi National Park (CIPTA and CIMTA 2014, WCS 2017). We studied 49 households in the communities of Santa Rosa de Maravilla (n = 12, 100% of the community), San Silvestre (n = 8, 89%), and Buena Vista (n = 29, 46%). All three communities are Indigenous and have self-declared Tacana members. In-migrants are accepted after a community's consent, but they must follow community rules. All community members of the Indigenous communities are hereafter referred to as "the Tacana." The communities were selected in close collaboration with the CIPTA steering committee based on the following criteria: (1) representability of diversity in terms of income activities and micro-ecosystems, (2) close proximity to forests (accessible by motorbike). Free, prior, and informed consent was obtained from community heads and research participants.

TCO Tacana I is dominated by humid foothill forests, seasonal humid Amazonian rainforest, and riverine forests (Ribera 1992). The prevalent land uses are small-scale agriculture with annual crops, agriculture with perennial crops (cacao), pasture and silvi-pasture for livestock production, and forestry (CIPTA and CIMTA 2014). The climate is classified as tropical Af, according to Köppen-Geiger, with an average annual precipitation of 1800–2500 mm, an average annual temperature of 26 °C, and a dry season from May to August (CIPTA 2002, Beck et al. 2018). In the last three decades, extreme weather events, such as flooding, became more frequent (Gloor et al. 2015, Ovando et al. 2016). The TCO was profoundly affected by the extreme precipitation

Table 1. Summary of the datasets 1, 2, 3, and 4, including year of collection, number of households, and methods used to obtain and analyze information on the local perceptions of changing weather patterns, weather indicators, and coping strategies used by the Tacana. SENAHMI = National Meteorological and Hydrological Service.

Dataset	Year of collection	N Households	Data source & analysis	Questions
Dataset 1	2013	49	Semi-structured interviews & qualitative content analysis	Q1: Have you ever heard of climate change?
				Q2: Have you noticed any changes in weather patterns in recent years? If yes, what changed? Q3: Do these changes have consequences for your household?
Dataset 2	2018		SENAHMI & descriptive analysis	- Annual average temperature - Annual min/max temperature - Number of annual rainy days - Annual cummulative precipitation
Dataset 3	2013	45	Semi-structured interviews & qualitative content analysis	Q1: Do you know any traditional indicators to predict the weather? If so, which ones?[†] Q2: Did they change in recent years?
Dataset 4	2015	44	Photovoice method, oral explanatory information, & qualitative content analysis	Q1: Which important aspects of the livelihood of your household were affected by the extreme weather event? Q2: What has helped your household to cope with the impact of the extreme weather event?

[†]In Spanish, we used the word "creencia."

in 2014, when the most severe flood in Bolivia's history hit the northern lowland part of the country, affecting 340,000 people (Ovando et al. 2016, Bauer et al. 2018). At the closest weather station, in Rurrenabaque, a 380% higher than the normal discharge of the Beni River was observed (Espinoza et al. 2014).
Data collection and analysis

Mixed methods were used to generate four datasets (Table 1): Semi-structured household interviews (dataset 1 and 3), meteorological data (dataset 2), and the photovoice method (dataset 4; Wang and Burris 1997). During an initial presentation round in each community, we explained the study background and interview time planning, obtained community leaders' and households' consent, and provided a short description of the photovoice method to be used. The information gathered to produce three of the four sets of data (1, 3, and 4) comes from the same pool of informants, although the sample size of households varied between datasets. Some households did not mention traditional weather indicators (dataset 3) or were not comfortable participating in the photovoice study (dataset 4) and were thus not interviewed. Interviews were held in Spanish with assistance from a Tacana language speaker if needed and generally undertaken with the household head or a person designated by him or her (40 male, 9 female). In most cases, the entire family was also present. The age of the respondents ranged between 30 and 86 years, with an average of 52.3 years. The four datasets and how data was produced and analyzed are briefly explained below.

Dataset 1 (Research question 1): Data set 1 comprises qualitative data collected in 2013 through semi-structured interviews using three open questions on previous knowledge on climate change, changing weather patterns, and consequences of the perceived changes. If changes were perceived, we asked the respondent to define those further. The time frame of changes was not specified, but a 10–20 year period was proposed if asked. Qualitative content analysis (Mayring 2000) was used to inductively determine the categories temperature, seasonality, rainfall, and wind for changing weather patterns, and human diseases, farming, plant damage, transportation, access, and destruction as categories for consequences. The data were subjected to descriptive analysis to establish frequency distribution. Responses were not controlled by the factor age (average of 51.9 years for respondents familiar with the term climate change versus 52.9 years of respondents who were not familiar with it).

Dataset 2 (Research question 1): Meteorological data were obtained from the National Meteorological and Hydrological Service (Servicio Nacional de Meteorología e Hidrología, SENAMHI, http://senamhi.gob.bo/index.php/sismet) for the closest meteorological station at Rurrenabaque (at 11–70 km distance to the communities) providing yearly precipitation data since 1946 and temperature data since 1958. The data included average annual temperature, monthly minimum and maximum temperatures, the number of annual and monthly rainy days, and total annual precipitation. Meteorological data time series were plotted, and linear regression and Mann-Kendall trend tests for changes in annual average, monthly minimum, and maximum temperature (Appendix 1), as well as total annual, monthly precipitation rate, and monthly precipitation days (Appendix 2) were used to estimate possible trends (Mudelsee 2019). Additionally, we applied the standard precipitation index (SPI) to reveal long-term precipitation patterns. Related supplementary information can be found in the Appendix 3. The Rurrenabaque weather station does not record wind data, and no analysis of wind patterns was possible. Where meteorological data were available, local perceptions (results of dataset 1) were compared with meteorological trends to answer research question one.

Dataset 3 (Research question 2): The semi-structured interviews conducted in 2013 on traditional indicators comprised two open questions (Table 1). No predefined answers were provided, but if the response was not detailed enough, we asked further about changes in atmospheric indicators, such as clouds, animal presence, and behavior, or plants. We used the Spanish word *creencias* to inquire about indicators. We then used qualitative content analysis (Mayring 2000) to determine local weather indicators. We categorized those as atmospheric, astronomic, zoo-, phyto- and human indicators. The data for dataset 3 was again subjected to descriptive analysis to establish frequency distribution.

Dataset 4 (Research question 3 and 4): Photovoice data was gathered from 44 households in 2015. Households were given cameras to record and use visual images as evidence to answer the questions: (1) Which important livelihood aspects were affected during the extreme precipitation and flooding in 2014? (2) Which livelihood aspects have helped to cope with the event in 2014? The method recognizes that by using a camera, people will record visual evidence that reflects relevant processes, trends, or changes according to their understanding and knowledge. It makes the views of the persons doing the photo-voicing the driving force of knowledge creation, rather than the interests and needs of the researcher (Wang and Burris 1997). The process of taking photographs gives time to reflect, can include issues and voices that are sometimes excluded from debates, and enables co-production of knowledge (Masterson et al. 2018). When cameras were retrieved (usually after 1–3 days), households that had agreed to provide more information were asked to explain each photograph.

To explore how participants responded to the research questions, we categorized all information into (1) oral explanatory information with photographs (data type 1), (2) oral explanatory information without photographs (data type 2), and (3) photographs without oral explanatory information (data type 3). While being open to interviews, some Indigenous families were shy, felt uncomfortable using a camera, or were afraid. Many of the households had never used a camera before, and approximately 25% of families preferred only to be interviewed, resulting in data type 3. The sample size of households who contributed to the different data types in dataset 4 varied (Question 1: data type 1: n = 19; data type 2: n = 11; data type 3: n = 14 and Question 2: data type 1: n = 18; data type 2: n = 15; data type 3: n = 11). Multiple answers were possible, and six households responded with two aspects per question as per the above categories, resulting in 50 answers.

The data analysis followed a two-step approach to answer research questions three and four: (1) Photovoice data was analyzed using qualitative content analysis and coded applying deductive categorization (Mayring 2000). Thereby the images were categorized, and results quantified based on counting "the frequency of certain visual elements in a clearly defined sample of images and then analyzing those frequencies" (Rose 2001:56). We started the analysis with data type 1, photos, and accompanying information and coded the information into categories, portraying similar objects (e.g., produce, cacao fruit for research question 1, e.g., food support, tools for research question 2). Similarly, data type 2 oral responses were coded, and new categories such as "no effect" were added, where earlier categories did not apply. Data type 3 information was coded accordingly into the earlier defined categories based on Rose (2001). (2) In a second step, the SLA was applied to cluster data types 1–3 into employed livelihood capitals. Thereby, all coded information was subsequently grouped into the corresponding livelihood capitals or, if not applicable, defined as "others."

The researcher later grouped all responses according to the time frame, stimulation, and the scope. Coping strategies can be "individual," meaning that the strategy was based alone on the household's initiative or "group," when it involved other community members (Armah et al. 2010). The time frame was classified as immediate, and short term (as soon as possible in the same year, for example, as soon as access to the communities was possible).

RESULTS

Perceptions of changing weather patterns

Table 2 summarizes household perceptions on weather anomalies. Twenty-nine of the respondents in the household survey reported having heard the term climate change; among them, six had heard the term but could not make sense of it. Forty-eight households (98%) perceived changes in the weather phenomena over the last 10–20 years. The most frequently cited changes referred to changes in temperature, mentioned by 38 (77.5%) of the respondents, followed by changes in seasonality (26 households, 53%), rainfall (26, 53%), and wind (8, 16%). Within changes in temperature, the most often cited were warming temperatures (30, 61%) and sunburns (14, 29%), while for seasonality, it was shifting seasons (26, 53%). Within changes in rainfall, most respondents perceived an increased number of rainy days (17, 35%), and wind changes of the *sur* were indicated. *Sur* or *friajes* are expressions used to describe the incursion of masses of cold air or cold spells coming from Antarctica that generate drastic temperature drops in their passage through Bolivia, sometimes below 15 °C in tropical regions. Usually, this phenomenon occurs during May, June, and July and causes decreased temperatures, increases in rainfall, and thunderstorms. Forty-four (90%) households reported the consequences of the changing weather patterns. Livelihood consequences of the changing weather conditions were mentioned by 44 (90%) out of 49 households. The most frequently cited consequence mentioned by 30 (61%) respondents was an increase in human diseases, followed by 17 (55%) citing increased challenges to farming, and 17 (35%) flooding, 9 (18%) mentioned that heavy rain damages the crops, 4 (8%) said bad roads impede transportation, and 1 (2%) respondent mentioned restricted access and destruction because of the heavy thunderstorm.

Of all changes reported, only temperature and rainfall could be analyzed against meteorological data because of a lack of data at the Rurrenabaque weather station on seasonality and *sur*-periods. The perception of warmer temperatures (61%) was in agreement with a significant trend in meteorological data, showing an increase in annual average temperatures (Fig. 2), while the perception of colder temperatures (4%) was not confirmed, neither for average nor for extremes. The monthly extreme temperature data analysis showed generally increased temperatures both for monthly maximum and minimum temperature, with a strongly significant increase in minimum temperatures for the months of March and June. The perception of increased rainfall days (35%) was consistent with a trend in meteorological data suggesting a significant increase in the average amount of yearly rainy days (Fig. 3). The perception of

Table 2. Summary of perceived weather-related changes, including the total number of households providing information on the awareness, temperature, seasonality, rainfall, and *sur* (the local word for the incursion of masses of cold air or cold spells coming from Antarctica), the number of households stating a specific change and perceived consequences; multiple answers were possible.

Perception	N of households	N of households responding specifically	Responses	% of N responding households
Familiarity with the term "climate change."	49	29 (59.18%)	Have heard the term (among 6 households have heard the term but cannot make sense of it)	
		20 (40.82%)	Have never heard about it	
Awareness of weather anomalies	49	48 (97.96%)	Have noticed changes in either seasonality, temperature, rainfall, or wind and have felt consequences	
		1 (2.04%)	Has not noticed any changes in weather patterns	
Temperature	38	30 (61.22%)	Warmer (consistent with meteorological data)	
		14 (28.57%)	Sunburns (lack of meteorological data)	
		2 (4.08%)	Colder (not consistent with meteorological data)	
		2 (4.08%)	Temperatures are more extreme (partly consistent with meteorological data)	
Consequences				
	36	19	Increase in human diseases	50.00
		16	Impeded farming	42.11
		9	Flooding	23.68
		7	Heavy rain affects crops	18.42
		2	Bad roads hinder transportation	5.26
		2	Droughts	5.26
		1	Destruction from strong thunderstorms	2.63
Seasonality	26	26 (53.06%)	Shift in seasons (lack of meteorological data)	
Consequences				
	24	18	Increase in human diseases	69.23
		15	Impeded farming	57.69
		12	Flooding	46.15
		5	Droughts	19.23
		4	Bad roads hinder transportation	15.38
		3	Heavy rain affects crops	11.54
		1	Destruction from strong thunderstorms	3.85
Rainfall	26	17 (34.69%)	Rainfall has increased (days; consistent with meteorological data)	
		6 (12.24%)	Rainfall intensity has increased (partly consistent with meteorological data)	
		3 (6.12%)	Rainfall pattern is different now (lack of meteorological data)	
Consequences				
	24	14	Impeded farming	53.85
		13	Increase in human diseases	50.00
		8	Flooding	30.77
		7	Heavy rain affects crops	26.92
		3	Droughts	11.54
		3	Bad roads hinder transportation	11.54
		1	Destruction from strong thunderstorms	3.85
Sur	8	6 (12.24%)	*Sur* is out of season (lack of meteorological data)	
		2 (4.08%)	*Sur* stronger and storm (lack of meteorological data)	
Consequences				
	7	6	Impeded farming	75.00
		3	Increase in human diseases	37.50
		2	Flooding	25.00

increased rainfall intensity (12%) is largely in agreement with meteorological data; however, annual average precipitation shows a weak, non-significant trend of increase and seems to remain relatively stable in the last 75 years (Fig. 4). For December to May (rainy season), the number of rainy days has significantly increased, and for January and April, also the precipitation. Details of the statistical results can be found for both temperature and precipitation in the Appendix 1 and Appendix 2.

Traditional weather indicators

Table 3 presents traditional indicators derived from dataset 2. Tacana households employ 43 (38 unique) atmospheric, astronomic, zoo-, phyto-, and human indicators to predict weather phenomena. Most of the flora, fauna, or astronomic indicators refer to observations in the environment. Two indicators (placing a machete in the yard and hitting tree roots) are said to help in preventing damage from thunderstorms. All indicators are short term, with a maximum forecast of a few days. Some 42% of the interviewees questioned the current applicability of climatic indicators and reported changes in zoo-indicators and unpredictability of the weather. Most changes perceived were related to animal migration and an increase in insects and mosquitos. According to interviewees, animals had moved farther away from villages, and fewer birds sing these days. Especially a decrease in macaws was mentioned. A general decline in the diversity and population of wild fauna and flora was observed, which participants explained as being caused by environmental pressures, such as deforestation, hunting, and monoculture farming, for example, sugarcane. The complete list of perceived changes can be found in Appendix 4. Table 3 takes into account

Table 3. Summary of 43 (38 unique) phyto-, zoo-, atmospheric (atmo), astronomic (astro), and human (hum) weather-related indicators stated by Tacana households.

Type	Weather indicator	N
Rain predictors		
Phyto	Leaves of the Ambaibo tree (*Cecropia* spec.) turn upside down	16
Phyto	Leaves of the Ambaibo tree do not move but flip	1
Zoo	The appearance of lots of insects (mosquitos, small stingless bees, small black moths (*jelen*), and wasps)	10
Zoo	*Guaracachi* (local bird name, *Ortalis* spp.) sings at night	7
Zoo	Frogs sing in the wetland	3
Zoo	Big hunting ants that bite hard and walk in a group	2
Zoo	Appearance of tarantulas to hunt	2
Zoo	Ducks wallow in dirt, flap their wings, or run	2
Zoo	Partridge (*Perdiz*, local name for various bird species) used to forecast	1
Zoo	*Chubi* (local name of a bird, species not identified) sings in the morning	1
Zoo	*Paitechi* (local name of a bird, species not identified) sing	1
Zoo	*Racua* lizard (the one who eats cockroaches) sings	1
Zoo	Appearance of snakes	1
Zoo	Horses run	1
Zoo	Monkeys sing	1
Zoo	Toucans sing	1
Atmo	Dark clouds	7
Atmo	Clouds hang low	1
Astro	Sun has a ring	3
Astro	Sun seems low	1
Astro	Sun in combination with strong wind	1
Astro	Sun becomes yellow	1
(Thunder)Storm predictors		
Zoo	Toucans sing	1
Atmo	White clouds	1
Astro	Sun has a tricolored ring	1
Hum	House will not be hit too hard if a machete is put in the yard	1
Hum	Some tree roots are hit by stones to prevent thunderstorms from being too heavy	1
Sur predictors		
Zoo	Monkeys start singing	1
Zoo	*Guaracachi* (local bird name, *Ortalis* spp.) sings at night	1
Atmo	Clouds coming from North	1
Bad weather predictors		
Phyto	Big trees fall (“out of nothing”) in forest	3
Phyto	When it starts to vent, and the plants move, the fourth day the rain will fall	1
Phyto	There is a particular leaf in the forest that moves	1
Zoo	Borochi (wolf, *Chrysocyon brachyurus*) whinnies loudly	1
Zoo	In the mountains, there is the Jucumari (bear, *Tremarctos ornatus*) which screams	1
Atmo	Three days of wind either from north or south, never east or west	6
Atmo	Wind from north indicates rain	1
Astro	Moon is surrounded by “water“	2
Astro	Moon has an outer borderline	2
Hum	Body hurts	1
Good weather predictors		
Zoo	Cicadas (*Cicadidae* spp.) in the forest announce sun	2
Zoo	Eagle flies high	1
Drought predictor		
Phyto	Forest is dry	1

overlaps between general bad weather predictors and the individual predictors of rain, wind, *sur*, and thunderstorms.

Affected livelihood capitals

All households’ responses (dataset 4) relate to livelihood aspects affected during a specific extreme weather event in 2014. Figure 5 shows the results grouped according to livelihood capitals. Of all 50 responses, 58% included negative impacts on the natural capital, such as crop fields, cacao trees (Fig. 6), firewood, and forest and fruit tree plantations; 28% presented damage to their physical capital, e.g., houses, road, produce (Fig. 7), livestock, and a sawmill; 8% of the responses comprised negative effects on human capital, such as on health, work, and education of children as schools were not accessible and therefore closed (a picture of

Fig. 2. Climatic trends (annual average temperature, yearly maximum temperature, yearly minimum temperature) in °C for the years 1958–2016 for the closest meteorological station, Rurrenabaque. Data source: SENHAMI (National Meteorological and Hydrological Service).

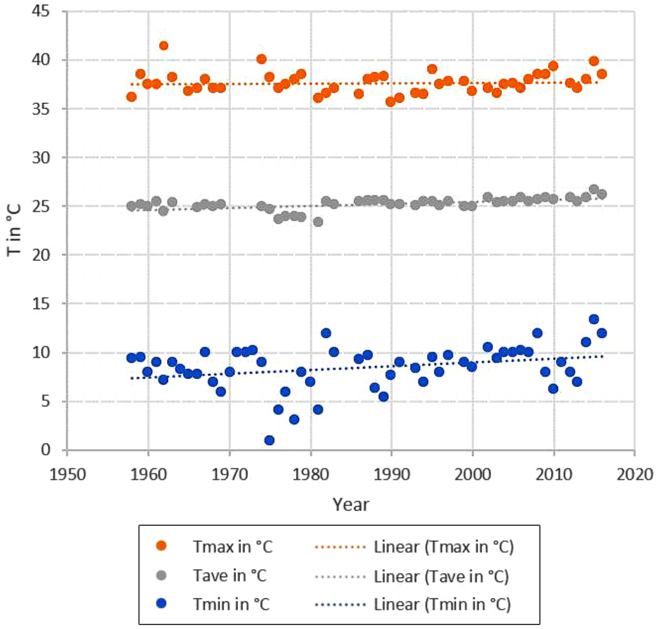
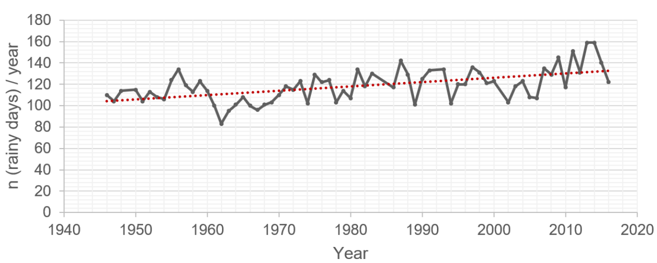


Fig. 3. Climatic trends (number of rainy days/year) for the years 1946–2016 for the closest meteorological station, Rurrenabaque. The dotted line shows the line of best fit. Data source: SENAMHI (National Meteorological and Hydrological Service).

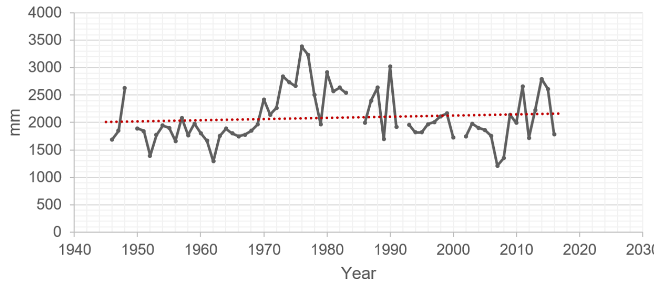


the school was taken, see Fig. 8). One household reported negative effects on the family (social capital), one indicated no effects, and another reported everything was affected. Livelihood aspects most mentioned or shown in the photos as being negatively affected were crop fields (reported by 48% of all 44 households), produce (11%), forest (9 %), and dirt roads (9%).

Coping strategies

Household responses regarding coping strategies (dataset 4) showed the use of 16 different strategies to cope with the extreme precipitation and flooding in 2014 (Table 4). Of the 44 households, 29 (65%) reported social capital related strategies, mainly external emergency support of food, tools (Fig. 9), livestock, and seedlings

Fig. 4. Climatic trends (annual cumulative precipitation) in mm for the years 1946–2016 for the closest meteorological station, Rurrenabaque. The dotted line shows the line of best fit. Data source: SENAMHI (National Meteorological and Hydrological Service).



(17 households, 39%), and family support (8 households, 18%; Fig. 10) and community support (4 households, 9%). The Bolivian state and NGOs provided external support in the form of non-perishable food such as rice, oil, and canned food, as well as seeds, seedlings, livestock, and kitchen and farming equipment. Natural capital coping strategies (reported by 9 households, 20%) were diverse. They included consuming palm fruits and palm hearts, the inner edible part of the *Euterpe edulis* palm tree (Fig. 11), reseeding (Fig. 12), and selling timber, cacao (Fig. 13), surplus crops, and the naturally higher situated fields and houses. Human capital strategies (4 households, 9%) included self-organization (3 households, 7%; Fig. 14), as Tacana leaders organized themselves to repair broken bridges and asked for governmental help resulting in helicopters bringing food. Financial capital was mentioned the least (2 households, 5%). Other strategies comprised "doing nothing" (4 households, 9%) and "praying to God" (1 household, 2%). Tacana household responses to overcome the impacts of floods can be categorized into three group and thirteen individual strategies, eleven immediate and five short-term.

DISCUSSION

Local weather perceptions and meteorological data

Some 40% of studied households were unaware of the meaning of "climate change," but nearly all households observed changes in weather patterns. Using methods to capture local perceptions on climate change shows that meteorological observations like the increase in temperature and annual rainy days corresponded with observations of local households. Observations by Tacana residents offered more detailed information, such as a shift in seasons, rainfall patterns, and *sur* patterns, which could not be observed from meteorological data. The latter information is relevant because it is linked to the timing and practice of livelihood activities like farming, hunting, and timber production.

An often-mentioned concern was the instability and unpredictability of the wet and dry season, which has been reported in other studies about Bolivia (Boillat and Berkes 2013, Fernández-Llamazares et al. 2017, Meldrum et al. 2018) and the Amazon (Gloor et al. 2015), and which has a direct impact on farming activities. A similar study presenting Tsimane's

Fig. 5. Forty-four household responses (interviews and photographs) on aspects that were negatively affected by the extreme weather event of 2014, summarized in livelihood capitals.

observations, a neighboring Indigenous group in lowland Bolivia, also found robust associations between their perception of climate change and local weather station data (Fernández-Llamazares et al. 2017). When access to phone or internet coverage or long-term weather records from a nearby weather station is limited, remote communities may rely only on their perceptions, observations, and related traditional knowledge to make critical livelihood decisions involving natural resources. Also, in regions with a low density of weather stations, it can be useful to complement meteorological data with weather-related perceptions when developing risk management strategies. This could help to give general climate data a specific local reference and improve the information for regions of interest (Fernández-Llamazares et al. 2017).

Table 4. Summary of applied coping strategies by Tacana people classified into livelihood capitals, including number of households (N) and share of people pursuing the strategy across all participating 44 households, the scope of the action, and the time frame; six households provided two responses.

Livelihood capital	N (share)	Coping strategy	Scope	Time frame
Social (n = 29)	17 (38.6%)	External support (food, tools, livestock, seedlings)	Group	Short term
65.9%	8 (18.2%)	Family support	Group	Immediate
	4 (9.1%)	Community support	Group	Immediate
Natural (n = 9)	3 (6.8%)	The placement of house and fields (altitude)	Individual	Immediate
20.5%	2 (4.5%)	Reseeding	Individual	Short term
	1 (2.3%)	Eating palm fruits and hearts	Individual	Immediate
	1 (2.3%)	Selling timber	Individual	Short term
	1 (2.3%)	Selling surplus crops	Individual	Short term
	1 (2.3%)	Selling cacao seeds	Individual	Short term
Others (n = 5)	4 (9.1%)	Doing nothing	Individual	Immediate
11.4%	1 (2.3%)	Praying to God	Individual	Immediate
Human (n = 4)	3 (6.8%)	Self-organization	Individual	Immediate
9.1%	1 (2.3%)	Being patient	Individual	Immediate
Financial (n = 2)	1 (2.3%)	Financial reserves	Individual	Immediate
4.5%	1 (2.3%)	Living from pension	Individual	Immediate
Physical (n = 1)	1 (2.3%)	Food reserves	Individual	Immediate
2.3%				

Fig. 6. Cacao fruit (taken by a household in San Silvestre).

Fig. 7. Produce, prepared for food (taken by a household in San Silvestre).

Fig. 8. School, as a symbol for education (taken and explanation given by a household in Buena Vista).

Fig. 9. Tool donations (social capital).

Fig. 10. Family support (social capital), persons intentionally blurred.

Fig. 11. Palm tree used for palm hearts (natural capital).

Fig. 12. Corn seeds, a symbol for repeated farming after crop damage due to the extreme weather event (natural capital).

Fig. 13. Selling cacao beans (natural capital).

Fig. 14. Photograph portraying the household head as self-organization (human capital); person intentionally blurred.

In our study, the information deriving from local perceptions and the meteorological dataset largely coincided, suggesting a complementarity. Variability in outcomes between the two sources of knowledge should not devalue any one of the two. Instead, recognizing and respecting both can contribute to debate (Klein et al. 2014) and help to improve knowledge innovation (Tengö et al. 2014) and synthesis (Sterling et al. 2017). Integrating Tacana perceptions of changing weather phenomena may improve engagement and participation in developing local climate change adaptation strategies, which can be more robust, specific, and effective (Makondo and Thomas 2018).

The urge of such inclusive strategies is underlined by the reported adverse effects of climate variability on Tacana livelihoods, perceived by 90% of the households. The increase in vector-borne diseases, such as Dengue or Chikungunya, in Bolivia and elsewhere due to climate and environmental change has been documented (Githeko et al. 2000, Moya Quiroga Gomez et al. 2018). The resulting vulnerability of residents is exacerbated by poor health care coverage in the communities, particularly because of limited accessibility during the rainy season. Previous research from other regions in Bolivia (Vidaurre de la Riva et al.

2013, Meldrum et al. 2018), documenting the challenges that climate variability and extreme weather events pose on subsistence farmers is also confirmed by the perception of Tacanas. Extreme weather events can trigger coping measures related to resource degradation (IPCC 2012). To avoid adverse long-term consequences for livelihoods and the Amazon ecosystem, increasing awareness of all actors is a necessary first step to enhance adaptive capacity of forest livelihoods.

Traditional weather indicators and environmental change

Wentzel (1989:143, 145) described in 1989 the Tacana world view as "profoundly animistic with a large pantheon of mountain, forest, water and animal and plant spirits" and with in-depth "knowledge about environmental phenomena," which are an integral part of Tacana livelihoods (CIPTA and UMSS 2010). A non-exhaustive list of 38 traditional weather indicators from three Tacana communities confirms this still active knowledge and detailed interaction with the natural environment. Comparative TEK studies from lowland Bolivia, or Tacana people, are rare. However, there are some similarities to bioindicators used for weather forecasting by the lowland Bolivian Tsimane (Fernández-Llamazares et al. 2015), such as the galactic halo, the singing of the Bolivian red howler monkey (*Alouatta sara*) and Toco Toucan (*Ramphastos toco*), the leaves of the Ambaibo tree (*Cecropia menbranacea*) turning over as rainfall predictors, the singing of cicadas (*Cicadidae* spp.) to predict good weather, and the singing of *Ortalis motmot* to indicate the arrival of a *sur*. The parallels in the use of ecological indicators for weather forecasting with the Tsimane study demonstrate both long-time observations of the local environment and the relevance of TEK indicators.

The variety of indicators used to forecast different weather scenarios reflect years of observations and comprise knowledge, practice, and belief, which has been gained and transmitted through the experience of generations (Huntington et al. 2005). Their largely short-term scope is likely linked to its application for agriculture and hunting purposes. Their reliability, however, was questioned by interviewed persons. Although astronomic weather indicators are still widely used by the Tacana, the current applicability of zoo-indicators was questioned by many households. Notably, bird diversity is said to have decreased, which are the animals most commonly observed for weather forecasting. Directly and indirectly, the behavior of flora and fauna is stressed by climatic, environmental, and anthropogenic changes, such as land-use change and hunting. Consequently, weather indicators may no longer work as effectively or may seem obsolete (Melka et al. 2013), explaining why their applicability was questioned.

In regions with limited access to meteorological forecast methods (at the time of the research, none of the communities had a phone network and radio broadcasting was only partly available because of a lack of electricity), traditional forecasting remains important for local livelihood decisions and activities. However, traditional knowledge evolves and adapts through experiences and observations at a certain pace (Fernández-Llamazares et al. 2015). If environmental changes are now progressing faster than TEK can adapt, the adaptive capacity of Tacanas' SES might be compromised, as described for neighboring Tsimanes in Fernández-Llamazares et al. (2015). Reduced reliability of and erosion of knowledge on weather indicators has not only been reported from Indigenous communities in lowland Bolivia but also Andean communities (Kronik and Verner 2010, Valdivia et al. 2010), the Artic (Weatherhead et al. 2010), and Tanzania (Chang'a et al. 2010).

Literature shows that TEK can provide key insights for the adaptability and resilience of natural-resources-dependent communities (Fernández-Llamazares et al. 2015, McNamara and Buggy 2017). Tacana are well-known for being ambitious to preserve their Indigenous knowledge, traditions, and language, which is also an integral part of the Tacana Peoples' Sustainable Development Strategy and Territorial Management Plan 2015–2025, supported by Wildlife Conservation Society. In combination, however, changing weather patterns eroding knowledge, and reliability of environmental indicators can adversely affect Tacanas' livelihoods and ability to cope and adapt. Thus, on the one hand, preserving TEK, which is already strongly promoted in the TCO Tacana, is one crucial aspect; on the other hand, a more in-depth analysis of local indicators and how they have changed is needed. Only a deeper understanding of environmental change on a local scale may enable Tacana to pursue longer term, sustainable, and inclusive adaptation and mitigation strategies. Bringing local perception of changing indicators and scientific studies on climate and environmental change may facilitate participatory climate change communication to Tacana families and support the development of inclusive, effective, and site-specific conservation efforts for key species and coping and adaptation strategies.

Household experiences of the impact of an extreme precipitation event

The outcomes of the photo-elicitation study reflect households' views on the most severe impacts of the rainfall and flood event for their livelihoods. The question asked to the participants invited them to freely interpret the meaning of being affected without further specifying the scope. This was intentionally done to avoid a purely economic or ex-situ driven perspective and to understand more thoroughly the perspective of local people themselves of affected livelihood dimensions. Tacana households identified natural capital, followed by physical capital, as the most critical resources negatively affected by the extreme weather event. The finding of natural capital being affected is consistent with the results of an earlier quantitative study (Bauer et al. 2018), where we compared pre-flood income with losses and post-flood income and found economically significant losses in crops, forest fruits, and timber. This also concurs with the experiences of forest-dependent people in Africa (Somorin 2010, Onyekuru and Marchant 2014) and Bangladesh (Rahman and Alam 2016).

Tacana households live in a close interlinked SES (Lehm 2010) based on hunting, fishing, farming, forest product foraging, and small-scale livestock breeding and adverse effects on natural resources affect their livelihoods. Although in quantitative terms income from crops and the sale of timber decreased significantly during the extreme weather event year of 2014, from a Tacana perspective, the most often stated impact was a decline in crop yields. The forest being used for timber and non-timber forest products was less represented in the pictures or oral responses. A possible explanation is that in 2013, only 11 of the households derived their primary income from timber, and most of the losses were mitigated by boosting timber production after the flood

(Bauer et al. 2018). Traditionally, a large percentage of Tacana livelihoods are based on the consumption of self-produced natural products (Wentzel 1989, Bauer et al. 2018). Before the extreme precipitation event, 34 households out of 50, or 68%, pursued a pure subsistence or farming combined with a small local business (e.g., selling some consumer goods or offering motor taxi rides) livelihood strategy. This reveals the importance of and dependence on self-produced crops for many households, the dependence on the opportunities to sell those locally, but also the importance of opportunities for seasonal labor on others' agricultural fields (Bauer et al. 2018).

Thus, the study's findings support and complement the socioeconomic evidence from these earlier studies and enhance our understanding of how extreme events affect local livelihoods. By analyzing both the socioeconomic consequences and the perceptions of households, a so-called perception gap is avoided. Considering perception gaps between research studies or development strategies and Indigenous people is important to avoid externally proposed climate change adaptation strategies resulting in poor adoption. An enhanced understanding by considering both in situ and ex situ perspectives can support the development of more effective adaptation and mitigation strategies and potentially strengthen the entire SES's resilience (Gómez-Baggethun et al. 2013).

Livelihood dimensions and coping strategies

In the context of the 2014 flood, the most important livelihood capital to cope with the extreme weather event was social capital. Both forms of social capital, bonding capital, and networking capital, were vital to the Tacana people. Networking social capital reaches outside the defined socioeconomic group and consists of economic or other ties of interest (Adger 2009). Tacana people's networking capital was underlined by collective action. Interviewees mentioned that calls for and the organization of support and emergency relief from state and non-state actors were pro-actively initiated by Tacana authorities. Although the organization of support testifies a strong pro-active spirit, in the short term Tacana livelihoods were characterized by a high reliance on external support for emergency relief. The most prominent immediate coping strategy used was support by the intra-communal social network, describing a well-established bonding capital. Bonding social capital comprises the social ties in a defined socioeconomic group and can be based on family, friendship, and locality, in our case, family and community as the first point of contact. The generation and maintenance of well-established social safety nets relate to trust, reciprocity, and exchange for non-economic reasons (Adger 2009). Those social nets are often indispensable in coping with extreme weather events and their impacts, and the ties of everyday social interaction may be a community's best immediate resource in maintaining the capacity to cope with climate change (Pelling and High 2005). Social ties are particularly strong between Indigenous Tacana households in the communities. Migrant colonists from the Andes, however, often follow a more economically oriented livelihood strategy (Wentzel 1989) and as a result occupy different roles in Tacana communities (Bauer, personal observation). When aiming on strengthening social bonding and networking capital to increase adaptive capacity, strategies should be inclusive and respectful to households that might not fall under the social community umbrella to benefit from traditional reciprocity.

Tacana people maintain a close relationship with the natural environment to sustain their livelihoods (CIPTA and UMSS 2010). The photovoice method and oral interviews demonstrated, that, for example, palm hearts were used to bridge food shortages, cacao beans were sold, and the natural geographical setting (houses or crop fields at higher altitude levels) supported coping. Nevertheless, the use of forest products to overcome the weather shock was less prominent than expected. This result reflects findings by Wunder et al. (2014) in a global analysis of forest use suggesting forest products to be less of a buffer for agricultural harvest loss than previously assumed. Contrary to the suggestion that community safety strategies might become less viable during a covariate shock, as all family, friends, and neighbors are affected simultaneously (Wunder et al. 2014), we found that social safety-net mechanisms were still stronger than the natural safety-net mechanisms. One reason was that during the flooding, the forest was largely inaccessible for timber extraction and agricultural products were heavily affected. Surprisingly, hunting and fishing, which in 2013 and 2015 contributed a considerable average share of income to Tacana livelihood (Bauer et al. 2018), and have been analyzed to contribute to Tacana overcoming the extreme flood (Townsend 2017) were neither mentioned by participants nor were pictures taken of these activities. Methodological limitations due to difficulties taking pictures of those activities could be one reason.

Tacana people's perceptions show that financial reserves contributed little to cope with the extreme weather event. It seemed that Tacana people rely more on cooperation and reciprocity than on financial reserves to overcome shocks. It also underlines the importance of a holistic perspective of Indigenous well-being beyond economic welfare and recognizes the links between ecosystems, people's values, and capabilities, and well-being (Sangha et al. 2015, Sterling et al. 2017).

Methodological challenges

We faced some methodological limitations when using the photovoice method, which relates to those described in Masterson et al. (2018). Some activities like, for example "self-organization," cannot be portrayed in pictures, other activities were easier to photograph (farming vs. hunting). For this reason, they suggested embedding photographs into interviews so as not to miss out on contextual information. Also, applying the typical five SLA capitals made us sensitive that a sixth "culture" capital, as proposed by (Daskon and McGregor 2012), might improve the understanding of livelihood vulnerability and risk. We encountered several obstacles during the photovoice empirical data collection. First, while being open to interviews, some Indigenous families were uncomfortable using a camera and preferred only to be interviewed. Second, during the initial fieldwork, one of the cameras was destroyed in a fire. This event influenced the entire community's mood and focus and led us to adjust our planning with less time and fewer cameras. This resulted in a delay in data collection and led to datatype 3: photographs without additional interviews. By applying content analysis of the results of datatypes 1 and 2, we could triangulate photograph interpretations objectively and to the best of our knowledge. Despite the challenges, the majority of the participants were fascinated by the method, and we felt that it led to higher local ownership of the research.

CONCLUSION

Indigenous people in regions susceptible to climate change are expected to be among the most affected by adverse climate change effects (Bose 2017). However, their local narratives are often neglected in scientific discourses on climate change adaptation (Soubry et al. 2020). This study aimed to contribute new insights from the Bolivian Amazon by presenting the perspective of forest households of Indigenous Tacana communities on climate change in general and the experiences made during an extreme precipitation event. The findings of this study also create a baseline for further multidisciplinary studies on forest-dependent communities and the effects of environmental and climate change on Indigenous well-being in the Amazon.

Our study led to four major insights: (1) It showed that observations and interpretations of weather trends and livelihood impacts of Indigenous knowledge holders and western science researchers complement each other because they provide different sets of details. (2) The study revealed 38 unique traditional weather-related indicators exemplifying the close interaction of Tacana with their environment. However, changing weather patterns in combination with reported declining reliability of TEK, such as the weather indicators, can adversely influence Tacana people's ability to detect weather changes and thus affect livelihood activities. (3) Photovoice outcomes suggested that natural capital, particularly their crop field, was perceived by most households as the most important livelihood aspect affected during the extreme weather event. And (4) Tacana households mainly relied on networking and bonding social capital to facilitate external and intracommunal relief to cope with an extreme weather event.

The adaptive capacity of the Tacana SES can potentially increase when jointly developing site-specific monitoring and conservation efforts for affected key indicator species. Coping and adaptation strategies, which are jointly and inclusively designed, consider the importance of natural and social capital for Tacana people to contribute to sustainable livelihoods. Moreover, considering the underlying perceptions and experiences that drive behavior and livelihood strategies can also assist natural resources management and inform decision making on various scales.

By factoring multiple evidence, our findings demonstrate the added value of mixed, and particularly participatory, data collection methods in mutually complementing local perception, traditional ecological, and scientific knowledge. Such co-production of knowledge can facilitate follow-up science-based communication to local or Indigenous people. In return, local knowledge can support the understanding of climate and environmental change and inform local and regional risk management planning, interventions, and policy recommendations. This can considerably enhance the effectiveness and robustness of such strategies while counteracting the loss of traditional ecological knowledge. Ex-situ policies and management, which recognize and respect local views and values, can lead to more effective syntheses and long-term on-the-ground impacts (Daniel et al. 2012, Sterling et al. 2017, Soubry et al. 2020). Such synthesized and integrated knowledge can foster social and ecological resilience (Erikson et al. 2011, Chia et al. 2015, Sterling et al. 2017).

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12837

Author Contributions:

Tina Bauer conceived the idea and designed the study; Wil de Jong and Verina Ingram contributed to the discussion of the results and the writing of the final manuscript.

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Data Availability:

The data used in the manuscript is not publicly available because of ethical restrictions. The containing information could compromise the privacy of research participants. This research study was designed and implemented following the code of ethics of Dresden University and Wageningen University, where institutional approval was granted.

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Appendix 1.

Table A1.1 Results of Mann Kendall Trend test demonstrating significant changes in annual average temperature, maximum and minimum monthly temperatures for the years 1958 - 2016 weather station at Rurrenabaque, Bolivia. Significance levels are defined as: 0.1(+), 0.05(*), 0.01(**), 0.001(***).

Time series	First year	Last Year	n	Test Z	Significance
Tave in C°	1958	2016	46	4,72	***
Tmax JAN	1958	2016	58	0,69	
Tmax FEB	1958	2016	57	0,27	
Tmax MAR	1958	2016	55	-0,33	
Tmax APR	1958	2016	57	1,55	
Tmax MAY	1958	2016	58	0,78	
Tmax JUN	1958	2016	58	-0,13	
Tmax JUL	1958	2016	57	1,71	+
Tmax AUG	1958	2016	58	2,33	*
Tmax SEP	1958	2016	57	0,03	
Tmax OCT	1958	2016	58	2,30	*
Tmax NOV	1958	2016	54	2,31	*
Tmax DEC	1958	2016	56	0,75	
Tmin JAN	1958	2016	58	2,39	*
Tmin FEB	1958	2016	59	1,62	
Tmin MAR	1958	2016	58	4,20	***
Tmin APR	1958	2016	58	1,39	
Tmin MAY	1958	2016	59	1,93	+
Tmin JUN	1958	2016	59	3,65	***
Tmin JUL	1958	2016	59	0,37	
Tmin AUG	1958	2016	59	2,22	*
Tmin SEP	1958	2016	58	0,81	
Tmin OCT	1958	2016	58	2,35	*
Tmin NOV	1958	2016	58	1,63	
Tmin DEC	1958	2016	57	2,68	**

Appendix 2.

Table A2.1 Results of Mann Kendall Trend test demonstrating significant changes in total annual, monthly precipitation rate and rainy days for the years 1946 – 2016 weather station at Rurrenabaque, Bolivia. Significance levels are defined as: 0.1(+), 0.05(*), 0.01(**), 0.001(***).

Time series	First year	Last Year	n	Test Z	Signific.
P ANN	1946	2016	66	1,36	
P JAN	1946	2016	70	4,40	***
P FEB	1946	2016	71	0,47	
P MAR	1946	2016	70	0,70	
P APR	1946	2016	70	2,17	*
P MAY	1946	2016	71	1,21	
P JUN	1946	2016	71	0,03	
P JUL	1946	2016	71	-0,69	
P AUG	1946	2016	71	-0,66	
P SEP	1946	2016	69	-0,21	
P OCT	1946	2016	70	-0,69	
P NOV	1946	2016	70	-0,62	
P DEC	1946	2016	70	-0,57	
P ANN/d	1946	2016	66	4,40	***
P JAN/d	1946	2016	70	2,14	*
P FEB/d	1946	2016	71	3,33	***
P MAR/d	1946	2016	70	2,97	**
P APR/d	1946	2016	70	3,13	**
P MAY/d	1946	2016	71	2,77	**
P JUN/d	1946	2016	71	0,38	
P JUL/d	1946	2016	71	0,40	
P AUG/d	1946	2016	71	-0,45	
P SEP/d	1946	2016	69	0,27	
P OCT/d	1946	2016	70	0,81	
P NOV/d	1946	2016	70	0,80	
P DEC/d	1946	2016	70	2,55	*

Appendix 3.

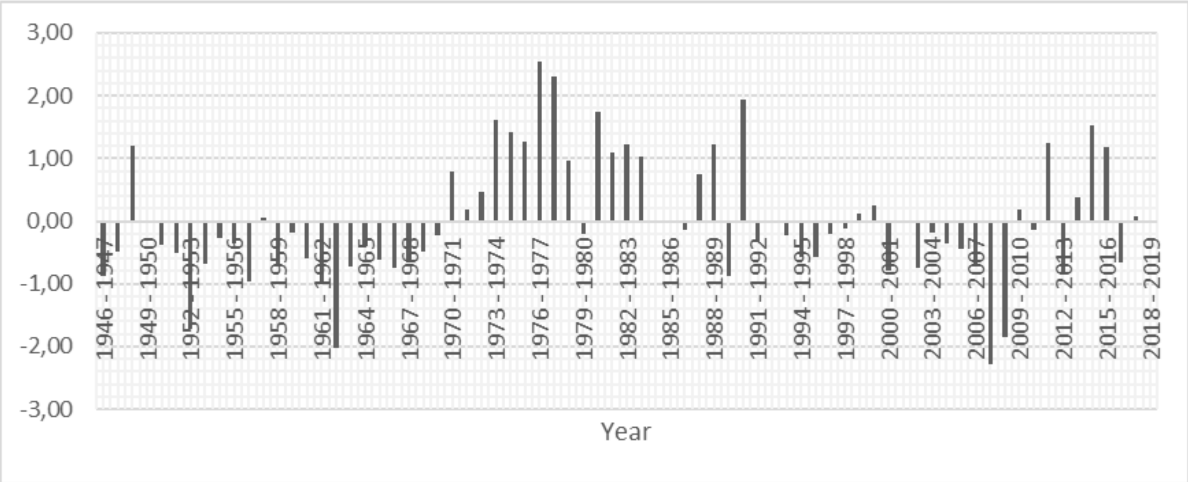

Fig. A3.1 Standard precipitation index (SPI) reflecting long-term precipitation patterns. The SPI is a probability index that can illustrate peak intensities of wet and dry periods and bring floods and droughts in perspective. It is based on "the difference of precipitation from the mean for a specified time period divided by the standard deviation where the past records determine the mean and standard deviation" (McKee et al. 1993: 1). SPI values were calculated for a period of 12 months and a period of 74 years (i.e. since the first recordings) for the weather station of Rurrenabaque using the drought indices calculator DrinC developed at the National Technical University of Athens (http://drought-software.com/). The 12-month SPI compares the precipitation for 12 consecutive months with the same 12 consecutive months during all the previous years.. Values between -1 or +1 represent an average year, -1 to -1.5 and +1 - + 1.5 show a moderately dry or wet year, while values above or below-1.5 or +1.5 mean a severely wet or dry year. Source: Data source: SENHAMI

Appendix 4.

Table 4.1 Summary of responses related to changes in atmospheric, astronomic, zoo-, phyto- and human indicators stated by number (N) of Tacana households.

Weather Indicator	N
Atmospheric indicators (clouds)	
In the past, there were big clouds, and we would know it would rain, but now we cannot predict it anymore.	2
Now, the sky is almost always cloudy.	3
Astronomic indicators (sun)	
In the past, when there was intense sun, and the wind was blowing hard, you knew it would rain — today you never know.	1
Zoo-indicators	
Animals seem to have gone far, replaced by more insects and mosquitos because of deforestation, machinery, and monocultures.	6
Fewer animals than in the past, need to walk far to hunt	5
Fewer birds sing these days (fewer parrots, macaws)	3
Today a lot more mosquitos	3
Rain predicting mosquitos and flies are more aggressive	1
No more butterflies	1
Cacao is infected with ants	1
Nowadays, the weather does not even respect the cicadas	1
Jaguar approaches the village	1
In the past, birds were sacred and respected; today they are hunt	1
In the past, animals killed people, today it is the opposite	1
Birds and insectivorous animals like the armadillo are disappearing, which are harmful to people's crops. Citrus fruits are becoming scarce, there are no longer any fruit trees, and if there are any, they are full of worms, and they conclude that there are no longer any consumers of insects like birds, and that is why they attack crops more than before.	1
Phyto-indicators	
Plants dry out more often	1
These days, platane leaves become yellow and white	1
Plants are yellow and have fungi	1
It feels warmer, and that changes the smell of the forest	1
The smell of some plants in the forest has gone	1
Plants flower earlier or later	1
Many colours in the forest have gone	1
Human indicators	
Weather is unpredictable	1
Traditional knowledge is lost	1