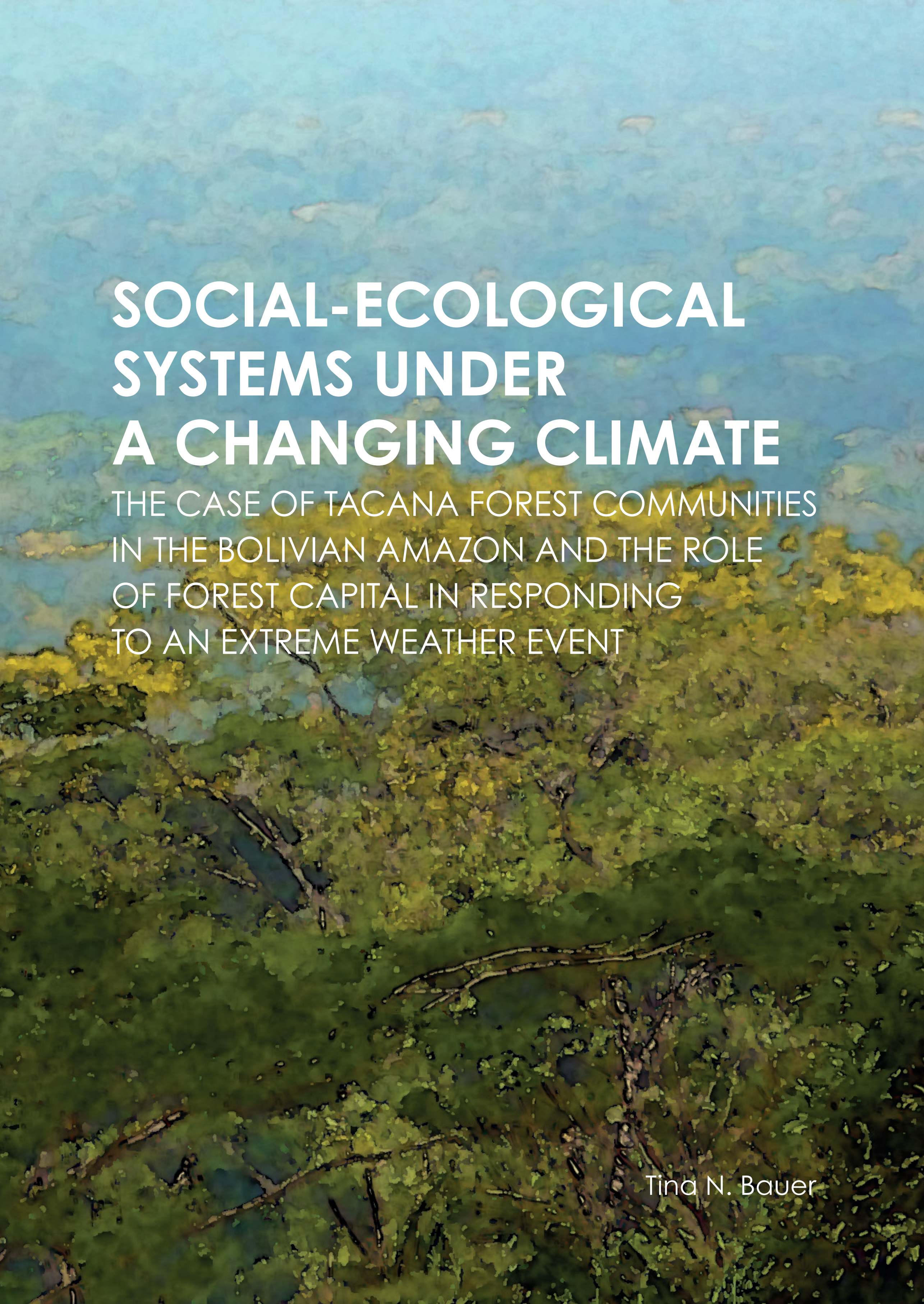

SOCIAL-ECOLOGICAL SYSTEMS UNDER A CHANGING CLIMATE

THE CASE OF TACANA FOREST COMMUNITIES IN THE BOLIVIAN AMAZON AND THE ROLE OF FOREST CAPITAL IN RESPONDING TO AN EXTREME WEATHER EVENT

Tina N. Bauer

Propositions

1. Climate risk management strategies can only be successful when considering differences in livelihood strategies.
   (this thesis)

2. Understanding forest-dependence is fundamental to increasing the livelihood resilience of Amazonian communities.
   (this thesis)

3. The current sustainability certification schemes for natural tropical forest management are not sufficient to secure sustainable timber production.

4. In a world full of big data, case studies are more useful than ever.

5. Scientists would benefit from being a research subject.

6. Only by analysing the past can we develop sustainable solutions for the future.

Propositions belonging to the thesis, entitled

Social-ecological systems under a changing climate:
the case of Tacana forest communities in the Bolivian Amazon and the role of forest capital in responding to an extreme weather event

Tina Nannette Bauer
Wageningen, 21 September 2022

Social-ecological systems under a changing climate:

the case of Tacana forest communities in the Bolivian Amazon and the role of forest capital in responding to an extreme weather event

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This research was conducted under the auspices of the Graduate School Wageningen School of Social Sciences.

Social-ecological systems under a changing climate:

the case of Tacana forest communities in the Bolivian Amazon and the role of forest capital in responding to an extreme weather event

Tina N. Bauer

Thesis

submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University,
by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Wednesday 21 September 2022
at 11 a.m. in the Omnia Auditorium.

Tina N. Bauer
Social-ecological systems under a changing climate: the case of Tacana forest communities in the Bolivian Amazon and the role of forest capital in responding to an extreme weather event

PhD thesis, Wageningen University, Wageningen, the Netherlands (2022)
With references, with summary in English and Spanish

ISBN: 978-94-6447-291-2
DOI: https://doi.org/10.18174/572483

Dedicated to two twinkling stars that crossed my life for far too short but gave me the lasting inspiration and motivation to go ahead and finish what I had to finish.

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List of abbreviations

AEU	Adult equivalent unit
BV	Buena Vista
CF	Contributing factor
CIPTA	*Consejo Indígena del Pueblo Tacana*
DFID	Department for International Development
GDP	Gross domestic product
INRA	*Instituto Nacional de Reforma Agraria*, Bolivia
IPCC	Intergovernmental Panel on Climate Change
IP	Indigenous peoples
LRI	Livelihood resilience index
LVI	Livelihood vulnerability index
MAS	*Movimiento al Socialismo*
N	Napashi (or San Silvestre)
NAP	National adaptation plan
NDC	Nationally determined contributions
NTFPs	Non-timber forest products
REDD+	Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SES	Social-ecological system
SLA	Sustainable Livelihood Approach
SLR	Systematic literature review
SRM	Santa Rosa de Maravilla
TCO	*Tierra Comunitaria de Orígen*
TEK	Traditional ecological knowledge
UN	United Nations
WCS	Wildlife Conservation Society

I

Chapter 1

General introduction

1.1 Problem statement

Over the past century, the influence of social systems on ecological systems has increased, resulting in side effects that are perceived as stress factors (Anderies, Janssen and Ostrom 2004)). In turn, stress factors like climate change influence the social systems, such as people's well-being, security, and survival (Folke et al. 2016). Climatic and weather anomalies directly influence the variability of temperature, rainfall, wind, and the frequency and time of extreme weather events. Human responses to the latter may include using elements of the ecological system and can influence livelihood vulnerability, resilience, and the sustainability of social-ecological systems (SES). Examining how climate change affects particular social groups, especially in regions with high climate sensitivity, is essential for both climate change adaptation and mitigation efforts (Davidson, Williamson and Parkins 2003).

Natural hazards amplified by climate change (IPCC 2012) are of growing concern in Bolivia, where climate-related disasters are expected to be more frequent and affect large parts of the population, economy, and ecosystems (Seiler, Hutjes and Kabat 2013a). The South American country is situated in a region where adverse impacts of climatic change on ecosystems have already been observed, such as rainfall decline in the Altiplano and severe droughts and forest fires in the Chiquitania dry forest in the lowlands (Killeen et al. 2008, Andersen and Mamani 2009; Brando et al. 2020; IPCC 2014). Climate models suggest further temperature increases of 2.58° to 5.98°C. Climate variability might intensify extreme weather events, increasing the frequency of floods, droughts and bushfires (Cai et al. 2014; Marengo and Espinoza 2015; Seiler, Hutjes and Kabat 2013a). The Northern Bolivian Amazon ecosystem has frequently been hit by heavy floods over the last years (Brakenridge 2016). Since the 1990s, extreme weather events have resulted in floods in 2007, 2008, 2014 (Gloor et al. 2013; Ovando et al. 2016). In 2014, the severest flood in Bolivia's history hit the northern lowland part of the country, affecting 340,000 people (Ovando et al. 2016).

As a significant component of the ecological system, forests play a crucial role in climate change adaptation and mitigation (Locatelli et al. 2011). The impact of climate change on forest goods and services can have socio-economic consequences for forest-dependent people. In turn, the impact of climate change on the livelihoods of poor people (Seppälä, Buck and Katila 2009), particularly on smallholders with primarily subsistence livelihoods (Harvey et al. 2014), may lead to adverse effects on the forest and the ecosystem services it provides. During crises and shocks, rural households may turn to forests and other environmental resources as safety nets to collect forest products or convert forests to cropland (Angelsen and Wunder 2003; Takasaki, Barham and Coomes 2004; Sunderlin et al. 2005; Delacote 2007). However, the use of forest products may be only one of many or part of a set of responses to economic shock (Wunder et al. 2014). Climate change response strategies by forest-dependent people may be influenced by traditional methods and traditional knowledge (Pyhäla et al. 2016; Petzold et al. 2020), as well as their perception of changing weather conditions (Mc Daniels, Axelrod and Slovic 1996; Adger et al. 2009; Djoudi, Brockhaus and Locatelli 2011; Harvey et al. 2014).

Until the start of this Ph.D., no scientific research had been conducted on the impact of extreme precipitation events on rural households in forested lowland Bolivia. While there is abundant literature on the potential impact of climate change on local communities in the Bolivian highlands (amongst others Valdivia et al. 2010; McDowell and Hess 2012; Boillat and Berkes 2013; Vidaurre de la Riva, Lindner and Pretzsch 2013; Montaña, Diaz and Hurlbert 2015; Chelleri, Minucci and Skrimizea 2016), the effects of extreme weather events on forest-based lowland livelihoods had yet to be analysed. Since 2015 research on the effects of climate change on the Tsimane Indigenous society has been published (for instance, Fernández-Llamazares et al. 2015a; Fernández-Llamazares et al. 2015b).

Scholars have analysed the impact of climate change on the vulnerability of forest-dependent people (Eriksen, Brown and Kelly 2005; Nkem et al. 2013; Walton et al. 2016; FAO and CIFOR 2019; Smith and Dressler 2019; Choden, Keenan and Nitschke 2020; Thakur et al. 2020). However, the role of forest products for Indigenous forest-dependent peoples in the context of climate change remains an under-researched subject, particularly in Bolivia. Few studies have looked at Indigenous communities with livelihood strategies other than agriculture (Ruiz-Mallén, Fernández-Llamazares and Reyes-García 2016). Also, many climate-related events with adverse effects on the poor in developing countries remain unrecognized (IPCC 2014). Earlier climate change studies have primarily focused on entire communities (Pyhäla et al. 2016), but disaggregated evidence at the household level is scarce.

As extreme weather events are hardly predictable, quantitative scientific ex-ante and ex-post studies on the impacts of extreme weather events are rare, resulting globally in insufficient empirical evidence of the socio-economic impacts of climate change on local realities and complexities of Indigenous groups in vulnerable regions. In methodological terms, no widely accepted or commonly used quantitative approach for assessing livelihood vulnerability and resilience exists (Chuang et al. 2018). No detailed analysis on the livelihood resilience and vulnerability to extreme weather events of households in lowland Bolivia has been performed yet. Furthermore, there is no synthesized overview providing global evidence of Indigenous responses to climate change and the possible prevalence of coping, adaptation, and mitigation strategies.

This Ph.D. thesis explores the potential impacts of climate change on Indigenous forest-dependent livelihoods and forest products use from a local to global perspective. It contributes to the understanding of the impact of the 2014 extreme precipitation weather event in Northern

Bolivia by analysing its socio-economic effects on and coping strategies of rural households of the TCO Tacana I (*Tierra Comunitaria de Origen*, Communal Land of Origin) in the country's Amazon region, and the perception held by these households on these effects. The thesis also includes a systematic literature review of Indigenous responses to the effects of climate change that examines and quantifies the prevalence of various adaptation and mitigation strategies, their drivers, and the role of perception and traditional knowledge in forest use and management on a global scale.

The scientific insights derived from this thesis demonstrate how case study research can inform local, national and global climate change academic inquiry and policy debates and decisions. The research, for instance, is relevant for Bolivian policy makers to strengthen the voice of lowland forest-dependent Indigenous peoples and supports Bolivia's sustainable development objectives and Nationally Determined Contribution. Internationally, the insights can inform policy decisions to create a more favourable framework for climate change adaptation of forest-dependent Indigenous peoples and related risk mitigation. The findings also offer opportunities for other countries to learn, especially those with high forest cover and forest-dependent people.

1.2 Objective and research questions

The overall objective of this thesis is to understand better the effects of climate change on and response strategies of forest-dependent people. To achieve this objective, it explores the effects of an actual extreme weather event on forest livelihoods of three Indigenous communities of the TCO Tacana I in Northern Amazonian Bolivia. The thesis furthermore examines the forest-related climate response strategies of Indigenous forest-dependent people by undertaking a systematic literature review. Understanding response strategies to the effects of extreme weather events is relevant as it contributes to the wider understanding of the socio-economic impact of climate change on Indigenous communities, possible ecological consequences, and the strategies and policies that may support more resilient forest-dependent livelihoods and ecosystems.

The following research questions are addressed in four chapters, followed by a synthesis:

(1) How did the 2014 extreme precipitation event affect households of three Indigenous communities of the TCO Tacana I in the short- and medium-term? (**Chapter 2**)

(2) What defined livelihood resilience and vulnerability of Indigenous communities in the context of an extreme weather event, and what are the implications of policies in shaping current conditions of resilience and vulnerability at the local level? (**Chapter 3)**

(3) How are changing weather patterns and traditional weather indicators perceived locally? How are livelihood capitals affected by and utilised to overcome the extreme precipitation event? (**Chapter 4**)
(4) What was the role of forest products in coping with the extreme precipitation event in the case of the three Tacana communities? (**Chapters 2,3,4**)
(5) How do Indigenous peoples across the globe adjust the use or the management of forest and forest products as a response to extreme events and climate change? (**Chapter 5**)

1.3 Theories and analytic framework

1.3.1 Sustainable Livelihood Approach

The Sustainable Livelihood Approach (SLA) provides an analytical framework for understanding local-level dynamics within a defined social-ecological system (Brocklesby and Fisher 2003). The SLA was guided by trends and ideas such as the Farming System Research, Amartya Sen's book Commodities and Capabilities (Sen 1985), Brundtland Commission report (World Commission on Environment and Development 1987), Human Development Index (UNDP 1990) (Morse and McNamara 2013) and developed in the 1990s. In 1991, Chambers and Conway published 'Sustainable Rural Livelihoods: Practical concepts for the 21st century' and the Earth Summit in Rio and Agenda 21 acknowledged the notion of 'sustainable livelihood'. Chamber and Conway (1991, 1) define a livelihood as "people, their capabilities and their means of living, including food, income, and assets." They distinguish between an environmentally sustainable livelihood, which maintains or enhances the capitals on which it depends, and a socially sustainable livelihood to cope with and recover from stresses and shocks and provide for future generations.

Various development organisations, like Oxfam and Care started using the SLA concept, but The Department for International Development (DFID) initiated the first research program on sustainable livelihoods (1996). In 1998, both Carney (DFID) and Scoones (IDS) published their own framework on sustainable livelihoods (Carney 1998, Scoones 1998). One can find both sustainable livelihoods frameworks being used in peer-reviewed publications since that time (see Knutsson 2006; Scoones 2009; Chen et al. 2013; Morse and McNamara 2013; Reed et al. 2013; Ifejika Speranza, Wiesmann and Rist 2014). Following the definition of Chamber and Conway (1992), DFID defined a livelihood as "sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base." (DFID 1999, 23).

A key concept in the SLA is that contextual factors determine household livelihood strategies expressed as a portfolio of capitals (Figure 1). Present capital portfolios and the livelihood that households adopt influence future capitals. The SLA recognizes five core capital categories, namely natural, physical, human, financial, and social capitals (Table 1). Livelihood strategies are dynamic, and in circumstances of vulnerability to seasonality, trends or shocks, households try to rearrange their livelihood capitals. These rearrangements are mediated by policies, institutions and processes, like social relations, institutions such as land tenure arrangements, and markets (DFID 2001, Figure 1). The vulnerability of the studied social-ecological system was to an extreme precipitation event in 2014. An increase in extreme weather events in Bolivia is likely due to global climate change (Seiler, Hutjes and Kabat 2013). The results of the present SLA analysis of the vulnerability to the extreme weather event can be helpful for future risk mitigation measures. Throughout chapters 2-4 of this thesis, the SLA framework proposed by Carney (DFID 1998), and the sustainable livelihood guidance sheets (DFID 1999) are employed as an analytical framework for the analysis of the vulnerability of household livelihood dynamics.

Table 1. Main indicators for livelihood capitals according to DFID (1999)

Natural capital	Human capital	Social capital	Financial capital	Physical capital
• Natural resource stocks • Services deriving from natural resources	• Skills • Knowledge • Ability to labour • Health staturs • Household size	• Networks and connectedness • Membership of more formalised groups • Relationships of trust, reciprocity and exchanges	• Available stocks • Regular inflows of money	• Basic infrastructure • Producer goods to support livelihoods

1.3.2 The concepts of livelihood resilience and vulnerability

The concept of resilience derives from ecology and is defined as the capacity of an ecological system to experience disturbance and absorb changes and persist (Holling 1973). The definition of the **livelihood resilience** framework (Chapter 3) is guided by Ifejika Speranza, Wiesmann and Rist (2014), defining three factors that contribute to resilience: buffer capacity, self-organization and the capacity for learning. Only a resilient livelihood can sustain its vital functions while absorbing negative impacts that cause production to decline and well-being to decrease (Ifejika Speranza, Wiesmann and Rist 2014). Livelihood choices, such as accumulating financial capitals, diversifying livelihood activities, or investing in physical capitals, but also external changes like improved access to resources, means of transportation or support facilities, can increase livelihood resilience. External and internal conditions can influence livelihood options and access to resources; shocks, such as the loss of livestock, can decrease livelihood resilience (Sallu, Twyman and Stringer 2010).

Vulnerability is a function of exposure, sensitivity, and adaptive capacity and is composed of both external and internal factors (IPCC 2001). Within the climate change debate, exposure is defined as "the nature and degree to which a system is exposed to significant climate variations" (IPCC 2001, 995). Sensitivity is "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (IPCC 2001, 993), and adaptive capacity refers to the potential or capability to adjust to or cope with change and stresses. There is no universally agreed definition of **livelihood vulnerability.** Most assessments of livelihood vulnerability, however, emphasize the exposure to particular risks, shocks or seasonality, the susceptibility to the latter (sensitivity), and the ability to recover (adaptive capacity) (Cutter 2003; Eakin and Luers 2006, Panthi et al. 2016). In this context, the SLA offers a guiding set of tools to analyse the contextual situation, livelihood capitals, and what measures contribute to building resilience.

There is scientific debate on whether vulnerability is the antonym of resilience (Folke et al. 2002; Gallopín 2006; Miller et al. 2010; Nkem et al. 2013). Both resilience and vulnerability emphasize ecological-biophysical, and/or social-political dimensions oriented towards responses to stress and perturbations and offer opportunities for integration (Miller et al. 2010). Miller et al. 2010 suggest incorporating vulnerability and resilience as more hybrid and pluralistic approaches into research methodology. This is taken up in chapter 3 of this thesis, which focuses on the household as part of a social-ecological system and the analysis of livelihood capitals to influence livelihood resilience and vulnerability.

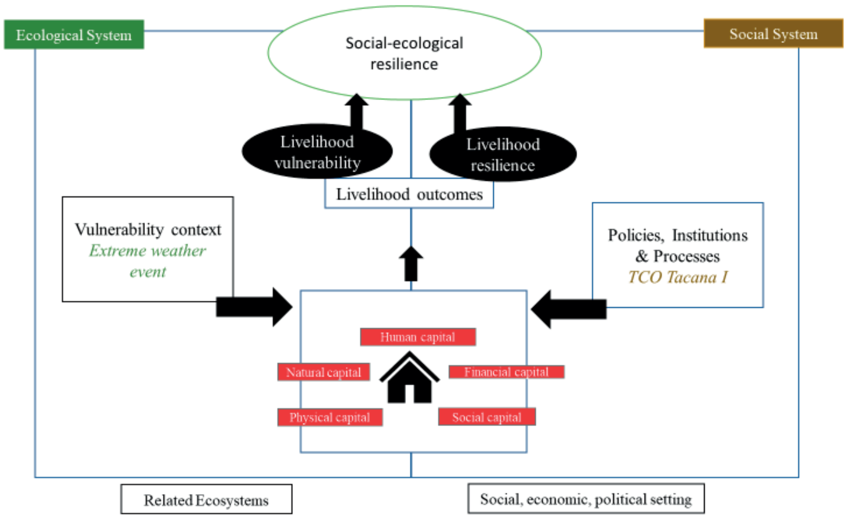


Figure 1. Simplified analytical framework, based on DFID (1999) and Ostrom (2009). Arrows indicate possible implications for respective aspects. This research combines social-ecological system theory and the sustainable livelihood approach (SLA) for analysis. While SLA seeks to analyse the social system, particularly the micro-level, from a unilateral and anthropocentric perspective, the SES includes the interactions and feedback loops between the social and ecological system in its conceptualization (Binder et al. 2013). The combination provides a holistic approach to achieve the research objective. The synergy between the two systems allows to better understand the linkages between the social and ecological systems on a household level.

1.4 Research methodology

1.4.1 Methodological design

Case study

For the studies of chapters two to four, a case study design was chosen to empirically analyse the socio-economic effects of the 2014 extreme precipitation event on households. Using a case study, it is possible to investigate a real-life phenomenon within its environmental context to understand its complexity (Ridder 2017). Contrary to experiments, the contextual conditions are not delineated or controlled but are part of the investigation. Contrary to quantitative logic, which often includes randomization, the case is strategically chosen because it is of scientific interest for in-depth instead of generalized knowledge (Stake 2005; Ridder 2017). Considering the local perspective and perceptions, a case study on the local level can corroborate and calibrate large-scale models (Teodoro et al. 2019). The initial intention was to analyse the role of forest capital and climate change in two regions in lowland Bolivia. The focus was reoriented towards examining the effects of an actual extreme weather event that incidentally occurred soon after the fieldwork had started in northern Bolivia. Around the end of 2013, an extraordinary heavy and long-lasting rainfall occurred immediately after the baseline study had been completed. The rains caused regionwide flooding in early 2014. The repeat of the baseline survey in 2015 allowed the study to become a socio-economic impact assessment of the extreme precipitation event (before-after measurement).

Systematic Literature Review

For chapter 5, scientific and non-scientific publications were analysed to produce a set of data that characterize responses among Indigenous peoples to climate change and the adjustments in forest use and management under climate change. The review analysed reported drivers, the role of perceptions, and traditional ecological knowledge in climate change mitigation and adaptation strategies. A qualitative stepwise approach following the methodology proposed by Koutsos, Menexes and Dordas (2019) for systematic literature reviews was applied, i.e. (1) scoping, (2) planning, (3) searching, and (4) screening. The review also included studying countries' national climate adaptation (National adaptation plans, NAPs) and mitigation policies (Nationally determined contributions, NDCs) regarding pre-defined indicators to complement the outcomes.

1.4.2 The Bolivian case – description of the study site

Political, economic and environmental setting

The Plurinational State of Bolivia is a sovereign state and a presidential representative democratic republic. The current president, Luis Arce, is head of state and the government (Ministerio de la Presidencia 2021). After the forced resignation of president Evo Morales at the end of 2019, which incited racist attacks, humiliations, and killings against Indigenous peoples (OAS 2019), the position of the head of state was vacant, and an interim presidency was provided by Jeanine Áñez until Luis Arce was elected on 23 October 2020. Bolivia is divided into nine departments and has a decentralized administration system. Law No. 31 (*Ley N°031* 2010) on autonomy and decentralization transfers rights and responsibilities for public infrastructure and services to administrative structures of departmental and municipal governments (Espada 2011). The currently governing left-wing and socialist political party Movimiento al Socialismo (MAS) was founded in 1997 and has governed the country since 2006. Bolivia's current constitution came into effect in 2009 and changed the name of the country to "Plurinational State of Bolivia", recognizing the multi-ethnicity and providing a more prominent position to the Indigenous peoples of Bolivia. The constitution acknowledges the right of Indigenous peoples to obligatory free, informed consent before the exploitation of non-renewable natural resources in a particular territory. However, the application of the consent procedure is limited to gas and oil, and the consultation processes are prescribed as ad hoc, with so far limited participation and benefits for local communities (Schilling-Vacaflor 2011; Flemmer and Schilling-Vacaflor 2016; Bohoslavsky 2020; Schilling et al. 2021).

From 2006 to 2019, Bolivia significantly improved its economy while reducing poverty and inequality. With the fourth highest economic growth in Latin America and the Caribbean, Bolivia is now a middle-income country, as its GDP grew almost fourfold between 2005-2017 (ECLAC 2018a, The World Bank 2022). According to the National Institute of Statistics (INE 2021), the poverty rate fell from 59.6 % (2005) to 34.6 % (2018), and the Gini coefficient decreased from 0.61 in 2002 to 0.45 in 2017 (ECLAC 2018b). Evo Morales increased state revenues by direct taxes on hydrocarbons, joined with public investment, and intensified domestic consumption (Bohoslavsky 2020). As the export of raw materials, such as minerals and hydrocarbons, remains an important source of state revenue, its current economic model is associated with 'neo-extractivism' (Svampa 2019). In recent years, the government promoted industrialization and economic diversification, including agriculture, hydroelectric power, renewable energy, and lithium production (Bohoslavsky 2020). Economic growth provided many benefits and social welfare to the population. But there has been sharp criticism of the contrast between the concept of *Living Well*, land properties and collective rights on the one hand, and mass consumption and extractivism and its burden on the environment (Botero and Galeano 2017; Bohoslavsky 2020).

Bolivia has an estimated forest cover of 50 834 000 ha and -0.43 % (225,000 ha) annual net loss of forest cover between 2010 – 2020 (FAO 2020). Natural forests are categorized in closed and open forests (FAO 2010). The closed forest includes lowland tropical rainforest, the semi-deciduous and deciduous Chiquitania dry forest, and Sub-Andean and Andean forest.

The study site of this research is situated in the lowland rainforest of Bolivia, which consists of three forest types: humid foothill forest, seasonal humid Amazonian rainforest, and riverside forest (Ribera 1992).

Decentralized forest management in Bolivia

Bolivia implemented a process of decentralising forest administration since the mid-1990s (Pacheco 2002), which included new land, forest and environmental laws aimed at reducing state expenditure and promoting private investments, and related social reforms (Pacheco 1998, Pacheco and Pacheco 2004). The starting point for the far-reaching reforms was the 'March for Territory and Dignity' of Indigenous lowland communities, which ended at the seat of the Bolivian government in La Paz on September 17, 1990. The main goals behind the march were to claim access to natural resources and traditional territories and raise awareness of and respect for lowland Indigenous communities in the Bolivian society at large. As a result of the march, the Bolivian state incorporated Indigenous concepts into national policies, including using a definition of territory to mean socio-economic space, biodiversity contained therein, and habitat. In 1994 and 1995, it reformed its constitution (of the year 1967) to Bolivia being a 'multi-ethnic and pluricultural' nation. The change of the constitution led to another important revolution: the creation of *Tierras Comunitarias de Orígen* (TCOs) (Dockry and Langston 2019). In 1996, the Agrarian Reform Law (*Ley N°1715* 1996) was ratified, and the INRA (Institute for National Agrarian Reform) was created, aiming to make land tenure more equitable, secure, and sustainable, as well as fulfil a social-economic function (INRA 2008). Several size classifications of private property were defined, the collective community lands recognized, and most importantly, a typology of communal land for Indigenous peoples was adopted, referred to as TCOs. A TCO is defined as a geographical area that Indigenous people and communities traditionally relied upon to maintain and develop their own economic, social, and cultural arrangements and structures for survival and development. A TCO is an inalienable, indivisible, irreversible, collective title held by communities or an association of TCO residents. Three laws of the reform can be considered most influential for forest users: the Popular Participation Law (*Ley N°1551* 1994), the Land Reform Law (*Ley N°1715* 1996), and the Forest Law (*Ley N°1700* 1996) (Benneker 2008).

Two other reforms accompanied the decentralization process in the forest sector: the institutionalization of social participation of municipalities and the forest regulations reform, both promoting the involvement of municipal governments in forest administration (Pacheco 2002). Compared to other Latin-American governments, such as Honduras, Brazil, or Costa Rica, Bolivia transferred more power over forest resources to municipalities (Larson et al. 2007). The Forest Law also aimed at integrating the formerly neglected forest-dependent Indigenous communities from the tropical lowland (Pacheco 2006). It also defined how TCOs can be used and transferred exclusive rights to Indigenous communities to make decisions over timber harvesting in TCOs (*Ley N°1700* 1996). The law was progressive in that it assumed forest management only to be sustainable through scientific and regulated forest management. This included long-term planning, sustainable harvesting, regeneration measures, timber processing, transportation, monitoring, and evaluation. TCOs were allowed to harvest timber for traditional or domestic purposes without permits; commercial timber harvest (done by TCO members or a contracted timber operator) required the abiding by sustainable harvest regulations and applications of forest management plans.

TCO Tacana

The Tacana language family covers the bordering territories of Bolivia, Peru, and Brazil. The ethnohistory of the Tacana has been described by Wentzel (1989) based on her own research and prior reports by Schuller (1922), Hissink (1955 – 1961), and Ottaviano and Ottaviano (1979, 1980). Tacana history can be traced back to prehistoric times, as archaeological findings show pre-Columbian settlements in the region. Colonial sources reveal several Inca expeditions into the lowlands (Wentzel 1989), which disrupted the social organization of Tacana and other Amazonian groups (Diaz Astete 2011). Some argue that the interactions between highland and lowland Indigenous groups date back to around 1200 AD, the period of the Mollo culture (Bustos 1978; Renard-Casevitz, Saignes and Taylor 1986).

In search of El Dorado, or Paititi, the Spanish conquistadores started their first military expedition, accompanied by missionaries, into the lowland territory just after the conquest of the Inca empire. Around 1680 Franciscan monks entered the northern part of the Catama River, the region later known as Apolobamba, describing the peaceful and hospitable character of the Tacana people. Permanent Franciscan missions were established when Tumupasa was founded in 1713. This resulted in the fusion of various Tacana dialects into the one Tacana lingua franca spoken today (Wentzel 1989).

The situation of the Indigenous people worsened with the independence of the Bolivian Republic in 1825. The Franciscans no longer maintained the power to prevent outsiders from settling in the former missions of Tumupasa, Ixiamas, and San José. First, the booms of quinine (1850-70) and later rubber (1880-1900) extraction attracted all kinds of immigrants. The demand for labour in the *barracas* (rubber camps) led to the persecution of Indigenous people, many of whom perished due to forced relocation, breaking up of families, slave labour, and brutal treatment. The Tacana suffered similar relocation and dispersion of their communities.

During and after the Chaco War between Bolivia and Paraguay (1932-35), the government presence in the Tacana historical territories grew. Iturralde province was founded in 1938, schools opened, and military service became obligatory also for the Indigenous people of Bolivia. The Tacana who remained in the former missions or lived in new communities continued to combine subsistence agriculture with occasional wage work (Wentzel 1989; Diez Astete 2011).

The Tacana have recovered from their demographic collapse caused by the conquest and resources booms. Wentzel (1989) recognises a Tacana cultural continuity expressed, for instance, by the persistence of shamanism and its rituals, which she attributes to Catholic rituals that Tacana people could use to maintain traditional political and religious authorities, but also because the Tacana maintained control over their territory, despite the successive invasions they suffered.

Today, the Bolivian Tacana population is around 11,000 people (INE 2012), located in the regions from the Madre de Dios River to Riberalta; the Beni River to San Buenaventura; and the area of Apollo. Most of the Tacana live in the southwest zone of the Iturralde province in the department of La Paz in the TCO Tacana I (Diez Astete 2011). The TCO Tacana I is situated in the buffer zone of the Biosphere Reserve and TCO Pilón Lajas, on the South-East flank, while it borders with the Madidi National Park in the East. The Madidi National Park has recently been confirmed as the world's most biodiverse park (NYT 2018, WCS 2018) with 265 mammals, 1028 bird species, 105 reptiles, 109 amphibians, at least 314 fish species, 5,515 plants, and 1,544 butterfly species.

The three study communities, Santa Rosa de Maravilla, San Silvestre (also named Napashi) and Buena Vista, are situated in very humid foothill forests and Amazonian seasonal humid forests. Santa Rosa de Maravilla borders the Madidi National Park (Figure 2). Ribera (1992) describes the very humid foothill forest as a forested area with soft hills (altitude 250-400m). The canopy height of the forest can reach 30 meters on average and is highly diversified. Most common tree species are Cedro (*Cedrela odorata* L.), Mara (*Swietenia macrophylla* King.); Bibosi (*Ficus pallida* Vahl.), Mapajo (*Ceiba pentandra* (L.) Gaertn.), Ochoo (*Hura creptans* L.), Verdolago (*Terminalia amazónica* (Gmel.) Exell), Palo Maria (*Calophyllum brasiliense* Camb.). Common palm species are Motacu (*Attalea phalerata* Mart. ex Spreng.), Chonta (*Astrocaryum* spp.), Pachiuva (*Socratea exorrhiza* (Mart.) H.Wendl.), Asai (*Euterpe precatoria* Mart.) and Cup (*Iriartea deltoidei* Ruiz & Pav.). The Amazonian seasonal humid forest has a canopy height of up to 35 meters, according to Ribera (1992). Representative tree species are of the genus *Pouteria, Chrysophyllum, Eschweilera,* and *Calophyllum brasiliense* Cambess, *Terminalia amazónica* and *Jacaranda copaia* (Aubl.) D.Don. Palm tree species in the area are *Attalea phalerata*, *Astrocaryum* spp., Majo (*Oenocarpus bataua* Mart.), and *Iriartea deltoidei*.

As for their representation before the State, in 1993, the Tacana of the Iturralde province created the Indigenous Council of the Tacana People (CIPTA), which comprised 20 communities (CIPTA and CIMTA 2014) by the time this research was conducted. It is affiliated with the

Central de Pueblos Indigenas de la Paz (CPILAP), which in turn is incorporated into the CIDOB (*Confederación de Pueblos Indígenas del Oriente Boliviano*) as a second-level regional organisation. Through the CIPTA, the Tacana people claimed the lands covering the TCO Tacana I in 1997. They received a land title for their land by 2003 after jointly submitting a claim to the Bolivian Land Reform Institute (INRA) (Quenevo Cartagena and Delgado 2007). Within the TCO, the inhabitants are free to redistribute the land according to their customs and traditions on the condition that the distribution adheres to national legislation (Hernaíz and Pacheco 2000). Tacana communities are organised with a community head (*Corregidor*), president of the OTB (*Organizaciones Territoriales de Base*), responsible for local administration, and a president of the School Board. Since 2001, the TCO Tacana has followed a strategic development plan for sustainable resource use, jointly prepared with the support of the Wildlife Conservation Society (WCS) (CIPTA 2002).

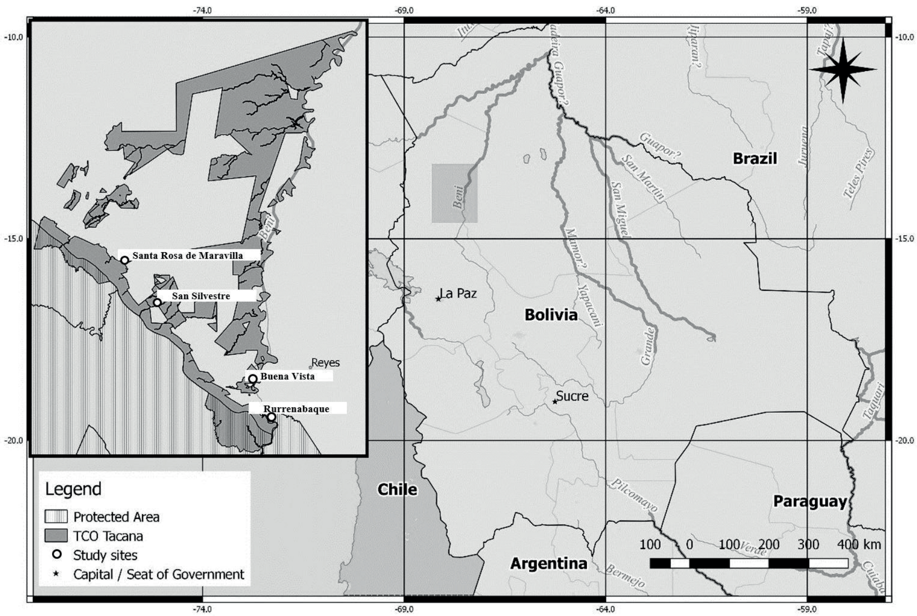


Figure 2. Left side: Location of study communities Santa Rosa de Maravilla, San Silvestre (or Tacana name Napashi), Buena Vista as part of the TCO Tacana I (department La Paz); and location of the closest weather station with comprehensive data sets in Rurrenabaque (department Beni); right side: location within Bolivia, source: own elaboration

1.4.3 Data collection and analysis

The three Tacana communities, Santa Rosa de Maravilla, San Silvestre and Buena Vista, situated in the municipality of San Buenaventura and Ixiamas in the Abel Iturralde Province, were selected jointly with a member of CIPTA based on 1) the diversity of incomes activities and micro-ecosystems, (2) proximity to forests and (3) accessibility. Consent was obtained from community heads and research participants. Fieldwork was conducted by a team of 2-4 persons (researcher, 1-2 research assistants and where possible, a Tacana assistant from the community where the data collection took place) between October 2012 and July 2015. Information was gathered by applying quantitative and qualitative techniques. Following a reconnaissance survey in 2012, socio-economic data of 50 households across the three communities were collected during September and November 2013 (ex-ante). The baseline study covers between 46 and 100 % of all households in the sample communities and represents 8 % of the total number of households of the TCO Tacana. In June-July 2015, one year after the extreme precipitation event, 45 households could be revisited to be interviewed a second time (ex-post). An adjusted version of the prototype questionnaire, developed by the Poverty Environmental Network by CIFOR (2007a)[1] was used to collect and code[2] data, including general household information and data on the cash and subsistence productive activities for September/November 2012 to September/November 2013 and June/July 2014 to June/July 2015. Furthermore, the research team recorded income losses from 2014 and qualitative context information, such as on past activities (10–15 years ago), weather indicators, perception and photo-voioce data. This allowed obtaining insights into the socio-economic impact, livelihood strategy changes, perceptions and role of forest products in the direct aftermath of the extreme weather event. In chapter 2, hierarchical cluster analysis was used to divide the households into livelihood strategies and investigate the impact of the extreme weather event on different activities and strategies. Strategy shifts could then be detected comparing data from 2013 and 2015. In chapter 3, a novel approach was introduced to compare households quantitatively regarding their livelihood resilience and vulnerability. The assessment was based on a combination of theoretical resilience and vulnerability frameworks and a practical indexing method to calculate the factors contributing to livelihood resilience and vulnerability (IPCC 2001; Hahn, Riederer and Foster 2009; Alinovi, Mane and Romano 2010; Ifejika Speranza, Wiesmann and Rist 2014; Panthi et al. 2016). A household-level index was obtained by defining and normalising contributing factors, components, and indicators. Subsequently, differences between livelihood activities and vulnerability and resilience of livelihood strategies and the contributing factors, components, and indicators were tested. Chapter 4 documents how historical climate data, semi-structured interviews, and a participatory visual data collection method called photo-voice were used to capture households' insights regarding the influence of extreme weather events on their livelihoods and to understand local perceptions of climate change, traditional knowledge, and the coping strategies households adopted when faced with climate change impacts. In Chapter 5, underlying linkages between data deriving from the systematic literature review (see 1.4.1) were analysed with multiple correspondence analysis.

1 The Spanish version of the questionnaire can be found under https://www2.cifor.org/pen/wp-content/uploads/sites/33/2017/05/Cuestionario_Prototipo_PEN_Espanol-version4.pdf

2 The PEN Code list can be found under https://www2.cifor.org/pen/wp-content/uploads/sites/33/2017/05/PEN_Codes_Version_7.7_February_2014.pdf

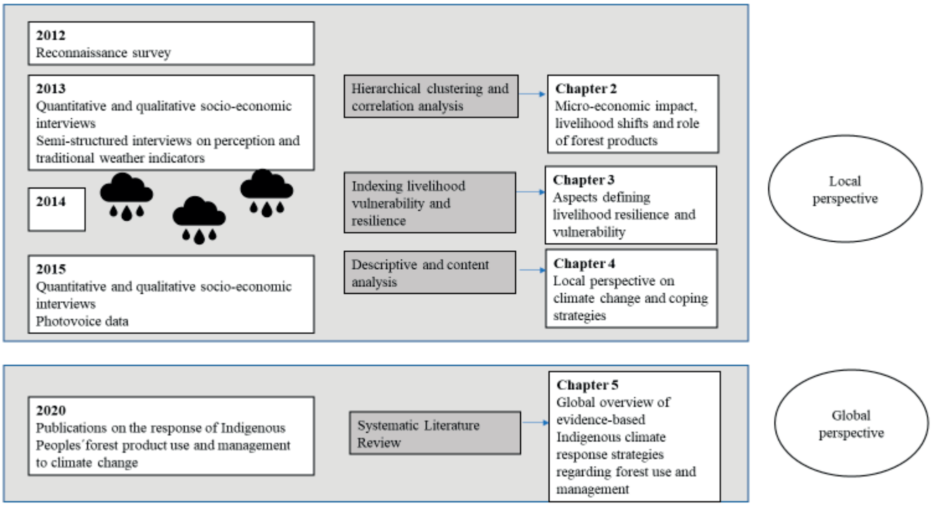


Figure 3. Overview of overall timeframe, data collected, methods used and research focus of main Chapters 2 - 5

1.4.4 Unit of analysis and income definitions

In this thesis, the central unit of analysis is the household, representing a group of people (blood-related or not) who live together under one roof and pool resources such as labour and income (see PEN guidelines, CIFOR 2007b). In order to account for variation in household composition and varying individual income, an adult equivalent unit (AEU) was calculated to compare household revenues objectively. The PEN prototypes for researching forest dependence (CIFOR 2007a) were used to guide the interviews. Forest income was defined as products harvested or collected from a forest, including timber, non-timber forest products (NTFPs), and game if its supply depends on the existence of forest resources and wages derived from logging activities. Fish was also classified as a forest product, as the Amazon rivers and lakes are in a tight relationship with the forest. Environmental income was defined as income from the harvesting of resources derived from natural processes which do not require intense management, such as grass serving as fodder. Farm income is defined as cash and subsistence income from farm activities such as livestock, agriculture, and wage income. Non-farm income is derived from non-forest, non-agricultural sources, including business revenues and earnings from other income sources such as pensions or remittances.

1.5 Thesis outline

This thesis is structured in six chapters, including the introduction and conclusion. Four journal articles were elaborated in the frame of this thesis and submitted to scientific journals. The articles presented in chapters two, three and four were published in 2018 (doi:

10.1505/146554818824063050) and 2022 (doi:10.5751/ES-12837-270117; doi:10.1016/j.landusepol.2022.106146), respectively. The manuscript for Chapter 5 has been accepted for publication. Following the four research objectives, all chapters contribute to increasing the understanding of the effects of extreme weather events and climate change on forest-dependent Indigenous communities in the Bolivian Amazon and globally. The problem statement, objectives and research questions, theories and analytical framework, and the overall research methodology are presented in **Chapter 1**. **Chapter 2** provides ex-ante and ex-post socio-economic household data from Indigenous forest communities living in the TCO Tacana I, collected to obtain insights into the economic performance, livelihood strategy changes, and role of forest products in the direct aftermath of the extreme weather event. **Chapter 3** introduces a novel indexing method to quantify livelihood vulnerability and resilience and estimate the contributing factors. This chapter presents in-depth insights into how different livelihood activities, levels of forest resource dependence and livelihood capitals are used by households and the implications of policies shaping current conditions of livelihood vulnerability and resilience to climate change. **Chapter 4** looks at the synergies between traditional ecological and scientific knowledge and how households of forest-dependent Indigenous communities in the Amazon cope with the impact of climate change. This chapter analyses the significance of local perceptions, immediate coping mechanisms, and traditional ecological knowledge among forest-dependent households in the context of climate change. In **Chapter 5**, the response of Indigenous peoples to climate-induced changes or extreme weather events in the form of coping, adaptation, and mitigation strategies in forest use and management is analysed through a systematic literature review. The research questions are answered, and the main findings are concluded in a broader context in **Chapter 6**.


2

Chapter II

THE SOCIO-ECONOMIC IMPACT OF EXTREME PRECIPITATION AND FLOODING ON FOREST LIVELIHOODS: EVIDENCE FROM THE BOLIVIAN AMAZON

2 THE SOCIO-ECONOMIC IMPACT OF EXTREME PRECIPITATION AND FLOODING ON FOREST LIVELIHOODS: EVIDENCE FROM THE BOLIVIAN AMAZON[3]

T. Bauer, V. Ingram, W. de Jong, B. Arts

Abstract

In early 2014, unprecedentedly heavy rainfall led to a flood in northern lowland Bolivia affecting the livelihoods of thousands of people relying on ecosystem services and climate sensitive sectors for their daily livelihood. Based on a case study of 50 households from Indigenous forest communities living in the TCO Tacana I, ex-ante and ex-post household data were collected to obtain insights into the economic performance, livelihood strategy changes and role of forest products in the direct aftermath of the extreme weather event. A negative impact on natural resource-dependent livelihood strategies was found as an immediate consequence. However, most households had recovered just one year later. There was no increase in the use of forest products to mitigate immediate income shortages. A typical high contribution of forest products to household income from before the flood continued afterwards. This article contributes to the understanding of livelihood-based efforts of people living in tropical lowland forests to adapt to weather extremes.

Keywords:
Forest livelihoods, forest dependence, extreme weather events, climate change, social-ecological systems

3 This chapter is based on the paper published as Bauer, T., V. Ingram, W. De Jong, and B. Arts. 2018. "The Socio-Economic Impact Of Extreme Precipitation And Flooding On Forest Livelihoods: Evidence From The Bolivian Amazon". *International Forestry Review* 20 (3): 314-331. doi:10.1505/146554818824063050.

2.1 Introduction

Climate change represents one of the most challenging threats of our times. It demonstrates itself in extreme weather events such as an intensification of minimum and maximum daily temperatures, unseasonal dry spells and excessive precipitation (Marengo et al. 2009, IPPC 2014). Extreme weather events are defined as the exceedance of a weather parameter above a high threshold (Stephenson 2008). In particular, wet tropical regions are likely to experience severe rainfall events more frequently. These regions mostly occur in developing countries or emerging economies. Increased vulnerability, as well as intensified severity and frequency of climate events, increases the risk of disaster among low-income communities (Mirza 2003; IPCC 2012).

Human society and nature are interwoven and interact with each other in many ways. The integrated study of these two sub-systems is often called the social-ecological system (SES) approach. An SES consists of multiple relations, internal variables and external drivers (Janssen and Ostrom 2006, Ostrom 2009). Shocks, such as extreme weather events, can serve as catalysts for change in an SES (DiGiano and Racelis 2012) and can stimulate it to change its stability (Renaud et al. 2010).

Extreme weather events, such as heavy precipitation, can threaten the social system of an SES due to potential negative impacts on economic sectors and the destruction of property, infrastructure and agriculture (Campbell and Luckert 2002; Piguet and Laczko 2014). In general, rural income-poor people are more likely to engage in climate-sensitive sectors such as farming and thus are more vulnerable to being affected, while they have few alternative economic opportunities to compensate for such events (Silva, Matyas and Cunguara 2015).

Rural low-income livelihoods are often dynamic and include a variety of natural resource-dependent and nondependent income activities (Carney 2003). Farmers may partially or completely change their livelihood portfolio under the influence of shocks that result in a decline in agricultural productivity and cause food insecurity (Antoci, Russu and Ticci 2009). Some of those livelihood strategy shifts can lead to the overexploitation of forest resources or even to accelerated forest conversion and may in return, negatively affect or threaten the provision of ecosystem services of forests (Nkem et al. 2007). Forest ecosystems form a complex interwoven SES with adjacent users who depend on forests to meet livelihood needs. Rural households may turn to forests and other environmental resources as safety nets during crises and economic shocks, to collect forest products or convert forests to cropland (Angelsen and Wunder 2003; Takasaki, Barham and Coomes 2004; Sunderlin et al. 2005; Delacote 2007). The use of forest products, however, is maybe only one of many responses to an economic shock, reducing their importance as safety nets or coping strategies (Wunder et al. 2014). Turning to forest product extraction to cope with emergencies also depends on the type of shock (Völker and Waibel 2010). Poor households are more likely to opt for forest products after a covariate (a household-external shock e.g. weather, food prices) than after an idiosyncratic shock (a household-internal shock, such as health problems of a household member). This study provides evidence of the direct impact of the 2014 extreme weather event in Northern Bolivia by analysing its socio-economic impact on rural households of the Communal Land of Origin (*Tierra Comunitaria de Origen* in Spanish, or TCO) with the name Tacana I in the Amazon region. Unprecedented rainfall and consequent flooding resulted from an anticyclonic anomaly: exceptional warm conditions in the western Pacific-Indian Ocean and the South Atlantic Ocean, favouring humidity transport. At the hydrological station at Rurrenabaque, at the upper Beni River, precipitation 108 % above normal was measured in January and February. River discharge was higher than normal since December 2013 and lasted until March 2014, with a peak of 25 000 m^3 s–1 (Figure 4) on February 12, 2014. This was the highest observed value since 1967 until present and 380% above normal (Espinoza et al. 2014). The extraordinary levels of rainfall caused floods, which affected an area of 71,305 km2 (+93 % above the mean), 340,000 people and damaged 49,000 km^2 of crops (Ovando et al. 2016) in the Bolivian lowland departments of Beni, La Paz, Pando, Northern Santa Cruz and Cochabamba. The country declared a state of emergency. The flood caused the highest discharge ever reported in the Madeira River (Espinoza et al. 2014). Literature on the impact of weather extremes and climate change on local communities in Bolivia is abundant for the country's highlands (amongst others Valdivia et al. 2010; McDowell and Hess 2012; Boillat and Berkes 2013; Vidaurre de la Riva, Lindner and Pretzsch 2013; Montaña, Diaz and Hurlbert 2015; Chelleri, Minucci and Skrimizea 2016), but is largely absent for the lowlands. Furthermore, an often-underestimated aspect in the assessment of the impact of disasters in developing countries on GDP is the size of the shadow economy, including activities such as subsistence farming (Loayza 1997; Klomp 2016). Particularly subsistence farmers are rendered vulnerable to floods and droughts (Sivakumar, Das and Motha 2005). At the micro-level, this study explores the impact of the heavy rainfall and flood in 2014 on rural forest livelihoods to obtain insights into the socio-economic effects of extreme weather events in the Amazon, which might be amplified in frequency and severity by climate change in the future. Household surveys were conducted before and after the flood[4] to investigate its impact. During the surveys, economic performance was measured, subsistence and cash incomes quantified, and shifts in livelihood activities and strategies were observed.

4 Initially, this study was not intended to study shocks, but planned as a livelihood research, analysing the role of forest (products) and climate change in lowland Bolivia. The flood shock happened right after the baseline study, and was repeated post flood to allow a socio-economic impact assessment.

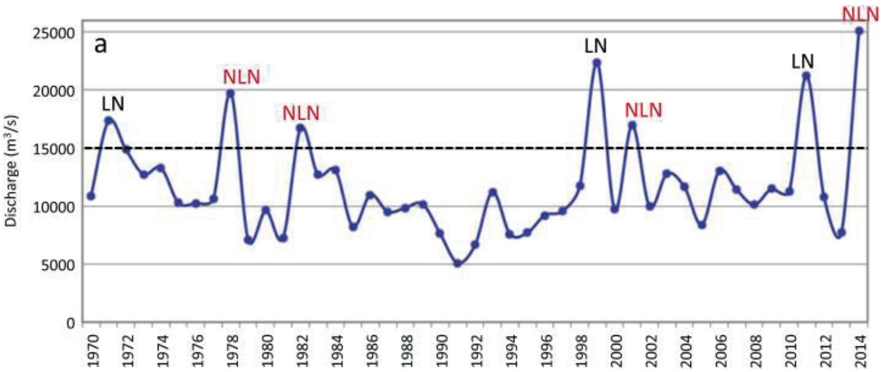


Figure 4. Time series of annual maximum river discharge measurements of flood area in Bolivia (upper Madeira Basin drainage area, Rurrenabaque station), LN = La Nina, NLN = no La Nina extreme floods, source: Espinoza et al. 2014)

2.2 Methods

2.2.1 Study region

The fieldwork for this study was carried out in the TCO Tacana I, which covers 325 327 ha of Indigenous territory and is located in the lowland part of the department of La Paz in Bolivia (Figure 2). The climate is tropical, with an average annual precipitation of 1800–2500 mm (CIPTA 2002; CIPTA and WCS n.d.), average annual temperature of 26 °C and a distinct dry season from May to August. Three dominant natural vegetation types characterize the area: humid foothill forest, seasonal humid Amazonian rainforest, and riverside forest (Ribera 1992). The TCO is situated in the proximity to the river Beni and it's over 100 small tributaries, which impact local communities with yearly minor pluvial floods (Townsend 2017).

A TCO is defined as a geographical area that constitutes the land of Indigenous people and communities which they traditionally relied upon to maintain and develop their own forms of economic, social and cultural structures for their survival and development. A TCO is an inalienable, indivisible, irreversible, collective title held by communities or an association of TCO residents (Gobierno de Bolivia 1996). The Indigenous Tacana people, through the Tacana Indigenous People Council (CIPTA), claimed the lands covering the TCO Tacana I in 1997. The CIPTA was formed in 1993 and comprises 20 communities (CIPTA and UMSS 2010). They received a land title over their land by 2003 after they had jointly submitted a claim to the Bolivian Land Reform Institute (INRA) (Quenevo Cartagena and Delgado 2007). During pre-colonial times, the Tacana people were highly mobile and built only small settlements next to rivers or creeks. From the 17th century onward, Franciscan missionaries arrived, settled the Tacana and other populations into missions and incorporated them into a colonial economy by paying them to collect wild cacao, vanilla and other natural resources

(Wentzel 1989; Chiovoloni 1996; CIPTA 2010). Today, the Tacana are completely sedentary and live from agriculture, fishing, hunting and the use of forest products such as timber and non-timber forest products (NTFPs). Villages may focus more on fishing or hunting, depending on whether they are located next to a river or in the foothills. A major part of the produce is for subsistence purposes, while surplus production is commercialised (Townsend 2017). Cattle ranching is found in the natural savannahs close to Ixiamas within the TCO Tacana I, but it is often done by immigrants who came from the Bolivian highlands (personal observation). The Bolivian population is generally poor with 39.2% of the total population and 57.5% of the population in rural areas living below the national poverty line of 550.6 Bolivian Bolivianos (Bs) per capita per month in 2015 (INE 2015), equivalent to 800.91 USD for a whole year (1.7.2015). In 2013, the poverty line for rural areas was 542.3Bs /month (INE 2014) or 784.84 USD for a year (1.12.2013).

Table 2. Research questions and expected relationships

	Research question	**Literature**
Micro-economic impact		
RQ1	What was the short-term (2014) and medium-term (2015) economic impact of the 2014 flood on households and livelihood strategies?	Poverty and the impacts of climate change are connected; Climate variability worsens existing poverty (Reed 2013, IPCC 2014)
RQ2	How did the flood affect poverty?	
Livelihood shifts		
RQ3	To what extent did the flood encourage farm households to shift their livelihood activities?	Climate-related hazards decrease crop yields; Due to high crop losses, farm-based strategies are likely the most affected; Climate hazards can erode farming livelihoods (IPCC 2014) Declining agricultural yields may contribute to forest conversion (Nkem et al. 2007)
RQ4	To what extent was there an increase in the number of timber-based households in 2015?	
The role of forest products		
RQ5	How did forest products fulfil a role as a backstop resource and safety net?	Forest products are gap filler, safety nets and backstop resources in response to unpredictable shocks and predictable food shortages (Kaimowitz 2002; Cavendish 2003; 2014) Coping capacity increases "forest insurance" (Cavendish 2003) of forest-based strategies

2.2.2 Data collection

The TCO Tacana I comprises a population of 3500 persons (Díez Astete 2011) and has been titled in favour of 20 Indigenous communities (CIPTA 2002). Three communities (Santa Rosa de Maravilla (SRM), Napashi (N), Buena Vista (BV)) were selected for research based on the following criteria (1) representability of a diversity in terms of incomes activities and micro-ecosystems, (2) proximity to forests and (3) accessibility. In addition to secondary forest and agricultural fields, SRM is surrounded by humid foothill forest and seasonal humid Amazonian rainforest; N by seasonal humid Amazonian rainforest and BV by seasonal humid Amazonian

rainforest and riverside forest. All households in the three communities rely in part on forests to meet subsistence needs or to sell forest products. SRM was actively operating a forest management plan at the time of the study and households in the other two communities also exploited timber. Table 3 provides more details on the main community characteristics. After a reconnaissance survey in 2012, community meetings were held in each of the three communities in 2013, the research was explained, and appointments with the participants were arranged on a voluntary basis. A member of the CIPTA steering committee and the respective head of the community aided in contacting households who were interviewed. In order to reach households that were not present at the meeting, the community head and already interviewed households were asked for contact information. In total, 50 households were selected and interviewed between September and November 2013. In June-July 2015, a year after the heavy rainfall and flood had occurred, the communities were revisited, and 45 households were interviewed a second time. Two households had migrated out of the TCO, and three were absent. To gather and code the data, an adapted version of the prototype questionnaires developed by CIFOR's Poverty Environmental Network (PEN, CIFOR 2007a) and technical guidelines (CIFOR 2007b) were used. To provide objectivity and comparability (Kusters et al. 2005), general household information and data on cash and subsistence productive activities was collected for the period September/November 2012 to September/November 2013 and June/July 2014 to June/July 2015. In addition, income losses in 2014 caused by the intense rainy season were recorded. Furthermore, qualitative context information was gathered during the interviews, such as for example on past activities (10–15 years ago). In order to provide a comfortable atmosphere, interviews were held at families' homes or at peoples' working places with household heads or husband and wife, if possible. During the survey, the research team of Bauer and up to three national assistants stayed in the communities for periods varying between 4 and 12 weeks. Direct observations of daily life activities and assets, as well as informal talks during the field stay allowed to triangulate the data and provided further insights. The interviews were conducted in Spanish. A translation into Tacana language was not necessary since older Tacana largely speak both languages, and among younger people, Tacana is hardly spoken anymore.

Table 3. Characteristics of the sample

	SRM	N	BV
Year of establishment	1982	1962	1953
No. of households (interviewed in 2013/2015/total community 2015)	12/11/11[5]	9/7/9	29/27/63
Distance closest market (km)	25 km (Tumupasa)	7km (Tumupasa)	16km (San Buenaventura)
Main livelihood activities	Individual + collective timber production, NTFPs, Agriculture	Agriculture, hunting, NTFPs	Agriculture, hunting, fishing, off-farm
Accessibility	Next to unpaved main road (N16)	5 km to unpaved main road (N16), isolated	6 km to unpaved main road (N16), river access

2.2.3 Definitions

In line with the PEN method, a household was defined as a group of people gathered under one roof ("eating from the same pot") and pooling resources, such as labour and income. Income was defined as the added value of labour and capital as gross value minus the total costs of purchased inputs (CIFOR 2007b). Family labour was not included into calculations. Subsistence income was calculated by asking about the total harvest or catch and how much of the specific type of income is usually not sold but consumed directly by the household. Total household income comprises subsistence and cash income for the time span of 12 months prior the interview. To adjust total household income and to take into account inter-household variations in household size and demographic compositions, adult equivalent units based on Cavendish (2002) were used. Total income consisted of the following components: forest income (fish, game, timber, firewood, processed forest products, seeds, fruits and wages), environmental income, farm income (crops, livestock and wages) and non-farm income (business, remittances, nonfarm and non-forest wages). Environmental income in our study comprises non-forest environmental income derived "from the harvesting of resources provided through natural processes not requiring intensive management" (CIFOR 2007b, 19), such as pasture or environmental products outside forests. Income data from 2015 was used to analyse the medium-term economic impact. Data on losses of 2014 (reported in 2015) are defined as short-term impact. If not differentiated explicitly in the following, the term 'flood' is used as a synonym for the extreme weather event of heavy rainfall and consequent flooding. Figure 5 summarises the impact of the extreme weather event on economic activities.

5 One household migrated to Brazil end 2013

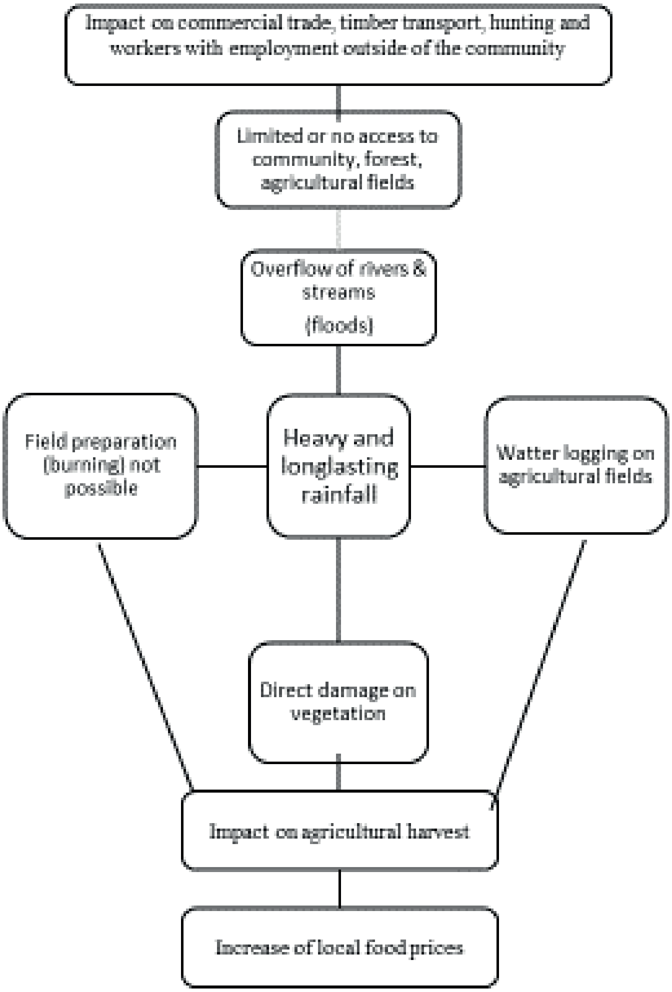


Figure 5. Illustration of impact of the extreme weather event on economic activities, own elaboration

2.2.4 Data analysis

Data from three communities was pooled as a single data set to obtain statistical viability, thus resulting in a data set for 2013 and 2015. Recall data of 2014 are based on a simplified calculation: income of 2013 taken as baseline minus income losses during the rainy season 2014. 2014 data is only available for total agriculture output and timber. 2013, 2014 and 2015 data sets were compared using a non-parametric Wilcoxon signed rank test to verify the economic impact of the flood (Dytham 2011). The hierarchical clustering with Wards's linking method and Squared Euclidian Distance were used to cluster the sampled households into four livelihood strategies based on 24 income types of 2013 (Sharma 1996). To assess differences between the strategies, Kruskal-Wallis with Dunn-Bonferroni post-hoc tests were used (Brienen and Zuidema 2006). The impact of the extreme weather events on the livelihood strategies was determined by comparing the average income outcomes per activity in each strategy of 2013, 2014 and 2015, using the Wilcoxon signed-rank test. Post-flood changes in livelihoods were identified by performing a second cluster analysis with income data from 2015. A comparison of the number of households who pursued the different livelihood strategies in 2013 and 2015 provided information on shifts and trends. Using correlation analysis (Spearman's rank), possible relationships between forest dependence and total income for 2013 and 2015 (Dytham 2011) were tested. Furthermore, each community's change in forest use was examined.

2.2.5 Limitations

There are limitations of the methods used. The small sample size allows limited generalisation of the findings to the wider TCO area or Northern Bolivia in general. Also, the time series provides a spatially and timely limited sample of two years of recall data but no intra-annual recall periods. A long-term study would certainly reveal more accurate trends and long-term impacts. And finally, it might be possible that interviewees did not reveal all the details on their past timber harvesting and selling, in case this was done without following legal administrative procedures.

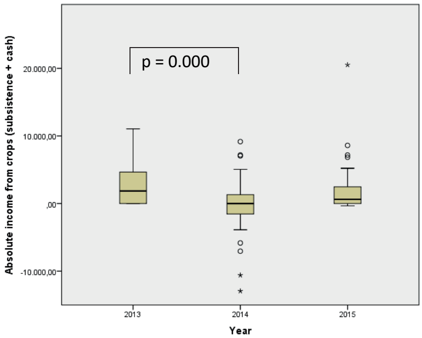
2.3 Results

2.3.1 Micro-economic impact of the flood disaster 2014 on rural households in the TCO Tacana I

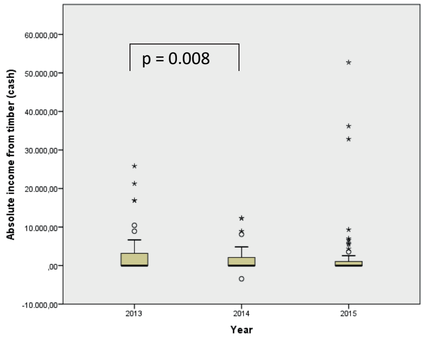
Overall household economic impact

Key result: Compared to the baseline 2013, recall data suggest a short-term drop in income in 2014, but this drop is corrected in 2015.

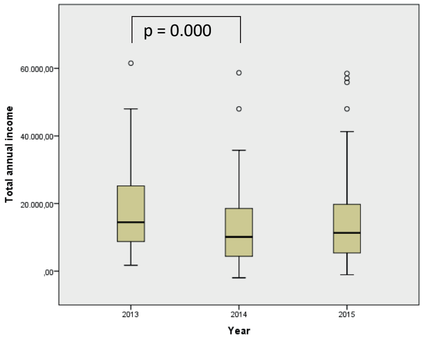
Figure 6 presents an overview of differences in average annual absolute and relative income from all sources in 2013 and 2015, as well as reported short-term losses in 2014. The complete table can be found in Appendix.Table 19. The principal sources of income remained the same after the flood; a combination of fish (subsistence), crops (subsistence) and the sale of timber. Food commodity prices increased during and after the flood (table 4), influencing the income gained from agriculture. The average size of agricultural fields decreased from 2.02 ha in 2013 among 36 households who had cultivated farmland, or an average of 1.46 ha for all 50 households to 1.19 ha among 27 households with cultivated farmland, or an average of 0.71 ha for 45 households in 2015.



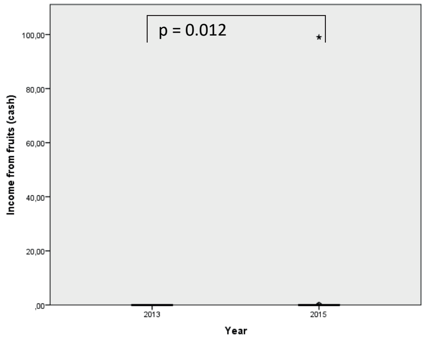
a) Absolute income from crops, subsistence and cash income combined



b) Absolute income from timber production, cash only



c) Total annual income, subsistence and cash income combined



d) Relative income from the sale of fruits, cash only; no data available for 2014

Figure 6. a)-d) Significant differences in mean absolute (Bs) and relative annual household income for 2013, 2014 and 2015; significance at $p < 0.05$ (Wilcoxon test), complete and detailed table of all income activities can be found in the Appendix.Table 19

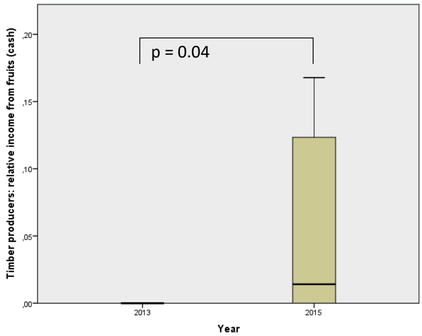
Table 4. Change in food prices before and after the flood, @ = 1 arroba, 11.5 kg

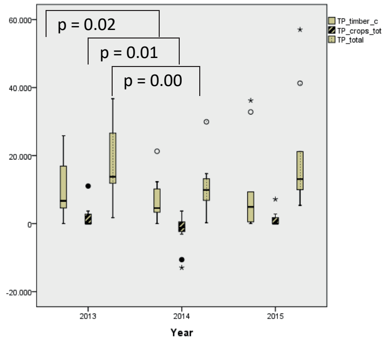
Staple crop	Rice	Corn (Fodder)	Plantain	Cassava
Price in Bs (2013-2015)	30-43Bs/@ - 50-80Bs/@	30-40Bs/@ - 30-40Bs/@	15-22/bundle – 20-40	15-20/@ - 25/@

Impact on livelihood strategies

Key result: Compared to the baseline 2013, recall data suggest a short-term drop in 2014 in timber sales, subsistence production, and overall farm and local business strategies.

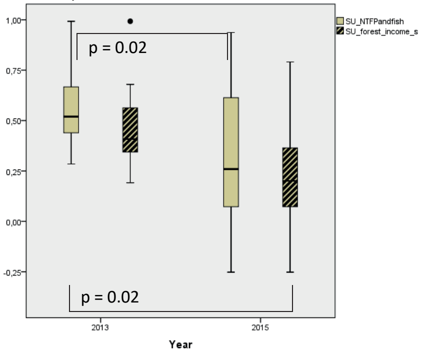
A hierarchical cluster analysis of income activities in 2013 revealed four different livelihood strategies: (1) timber, (2) subsistence, (3) farm and local business, and (4) wages (Table 5). Timber strategy households are highly forest-dependent, with an average income from the forest in 2013 above 80% of the total household income. The main income source is the production of timber or forest work, combined with income from fishing. The subsistence strategy is the largest group and oriented towards products deriving from subsistence agriculture, hunting and fishing. The farm and local business strategy relies on crop production and small-scale

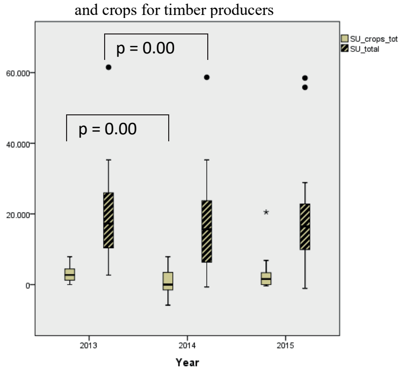




a) Relative annual income share from fruits (cash) for timber producers

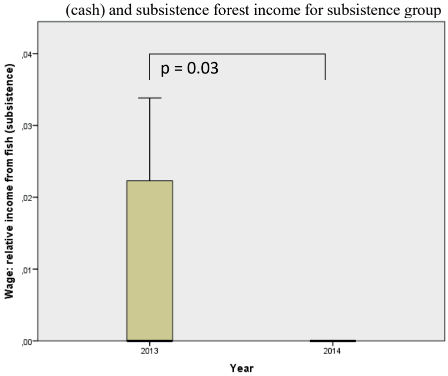
b) Total annual income and income from timber (cash) and crops for timber producers

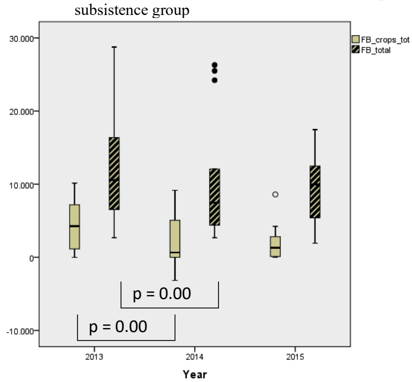




c) Relative annual income share from NTFPs, including fish (cash) and subsistence forest income for subsistence group

d) Total annual income and income from crops for subsistence group





e) Relative annual income share from fish (subsistence) for wage group

f) Total annual income and income from crops for farm and local business group

Figure 7. a)-f) Significant differences in mean absolute (Bs) and relative annual household per income strategy group for 2013, 2014 and 2015; significance at $p < 0.05$ (Wilcoxon test)

business activities such as local bakeries, shops or taxi drivers. Wage strategy households generate close to 90 % of their income as a salary from employment, such as teacher or worker in a sugar cane company. Figure 7 shows how the four livelihood strategies changed relatively and absolutely after the flood. There is some variation in the effect of the flood on the four strategies in 2014. As of 2015, none of the four strategies showed a persisting negative impact on total income of the 2014 flood.

Table 5. Livelihood strategy characteristics in communities SRM, N, BV of the TCO Tacana 2013

Characteristics	Timber (n = 11)	Subsistence (n = 20)	Farm & local business (n = 14)	Wage (n = 5)
Fraction of households	22 %	40 %	28 %	10 %
Field size (ha)	0.36	1.4	2.2	0.35
Household size	3.7	4.4	4.4	3.4
Education (years)	8.2	7.7	7	11.5

Poverty

Key result: The ratio of better-off to income-poor households in 2013 (43:7), dropped to 31:14 in 2014 and adjusted to 37:8 in 2015.

In 2015, 37 of the interviewed households were found to have a gross income above the poverty line, while eight remained poor. Households with an income above the poverty line before and after the flood are defined as better-off. Households with an income below the poverty line in 2014 are described as previously poor. Households below the poverty line in 2015 but which were previously better-off are transient poor, and households that did not have a gross income before are after the flood exceeding the poverty line are chronic poor (Figure 8).

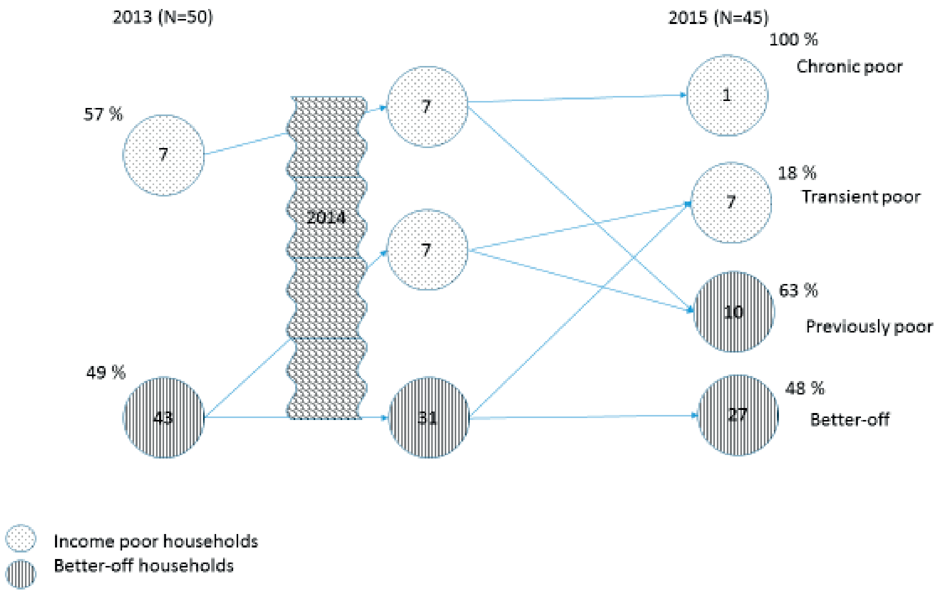


Figure 8. Changes in household poverty from 2013 to 2014, figures in the circles represent the number of households, figures next to the circles define the average share of forest income per income group

2.3.2 Livelihood changes after the flood

Key result: Households in the communities had adopted two new livelihood strategies in 2015: diversified and off-farm. The diversified strategy was the most common in 2015, and included households who previously had had a farming strategy, i.e. either a subsistence strategy or a farming and business strategy.

Households following a farming strategy changed their strategies most and included a switch to a timber strategy. The number of households who followed a farm and local business and wage livelihood strategies decreased. A new diverse strategy was the most common in 2015 and was mainly adopted by households who had had subsistence households and farmer and local business strategy. The income of members of the diverse strategy includes a mix of farming (subsistence), remittances and livestock (subsistence), but also fishing and hunting in some cases. Households following a timber strategy changed fewest as seven households persisted in this strategy. Five other households shifted livelihood strategies between 2013 and 2015.

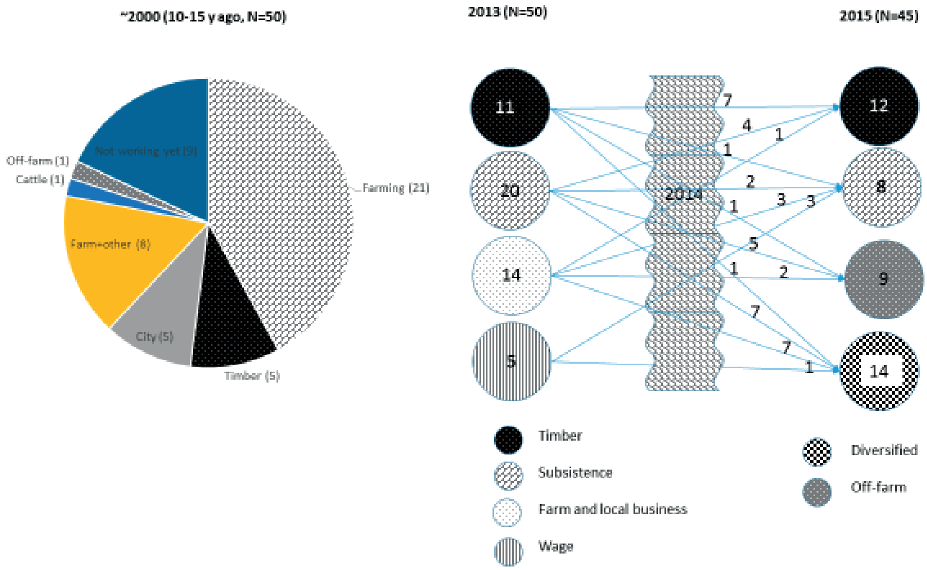


Figure 9. Livelihood strategies over time; oldest series (10-15 years ago, n=50), 2013 (n=50) and 2015 (n=45) show distribution of income activities in number of households livelihood strategies of 2013 (n=50) and amount of households in brackets are shown below; bars and figures illustrate their evolution in 2015 (n=45)

2.3.3 The role of forest products

Key result: In comparison to 2013, no statistically significant increase in forest product harvesting was observed in 2015.

In order to analyse whether forest products would contribute to overcoming poverty or income decline in the aftermath of the flood the difference in the contribution of forest products to income between 2013 and 2015 was analysed. The absolute income from the sales of forest fruits increased in 2015, compared to 2013. A test to correlate forest products and total income in 2013 and 2015 (Table 6) shows that fish used for household consumption was found to correlate positively with total household income. In contrast to 2013, the commercialisation of timber, fish and game did not correlate significantly with total household income in 2015. Households with a timber strategy originated mainly from the SRM community, and pre and post-flood data suggest a slight but not statistically significant increase in timber extraction in SRM.

Table 6. Spearman rank correlation coefficients of forest product contribution to total income 2013 and 2015, significance at p < 0.05 (numbers in bold)

Income activity (share)	2013		2015	
	Correlation coefficient	p value	Correlation coefficient	p value
firewood_s	**-,391****	**0.004987**		
game_c	**,367****	**0.008751**		
fish_s			**,336***	**0.024133**
fish_c	**,315***	**0.025961**		
timber_c	**,332***	**0.018468**		
fruits_s			**-,308***	**0.039411**

2.4 Discussion

2.4.1 Micro-economic impact of the flood disaster 2014 on the performance of rural households in the TCO Tacana I

A negative short-term impact of the flood in 2013 was observed in 2014 on the economic performance of households that had a timber, subsistence and farm and local business livelihood strategy. No significant difference was observed for 2015. Our analysis showed a slight increase of households falling below the national Bolivian poverty line in the aftermath of the floods. Of the four livelihood strategies prior to the flood, the immediate economic consequences in absolute terms were the severest for households dependent on timber revenues.

This may be explained by the fact that timber production relies heavily on access to forests where timber can be harvested, as well as the ability to transport timber to the market. Both require roads along which heavy machinery can be transported and lorries can drive. Severe precipitation caused damage to roads and bridges, making areas inaccessible or leading to significantly higher costs. According to the representative of the local forest management group in SRM, production costs increased by approximately 50% after the flood, mainly to maintain skid roads. Occasionally, timber already logged had to be abandoned in the forest because it could not be taken out. Furthermore, the timber livelihood strategy is highly specialised, which also reduces the ability to adapt to changing conditions (Marshall et al. 2007). A decline in the principal source of income is likely to have a more severe impact on households with a specialised livelihood strategy than on households with a diversified strategy. Severe floods or other weather calamities pose risks for forest conditions, but it also may have serious impacts on forest product supply. Impacts of weather calamities can result in large regional fluctuations in production, prices and market demand of forest products (Kirilenko and Sedjo 2007). The adverse short-term effects after climate-related hazards on smallholder farmers through yield losses, crop destruction and subsequent food insecurity are consistent with predictions on the impact of extreme weather events on livelihoods (IPCC 2012). These effects are in line with results obtained from South Africa (Khandlhela and May 2006), the Carribeans (Smith and Rhiney 2016), South-East Asia (Haque and Jahan 2015) and Southern Europe (Radovic, Pejanovic and Marincic 2015). In the TCO Tacana I, the harvesting season of the two annual staple crops corn and rice takes usually place between February and April. The heavy rainfall and consequent flooding 2013/2014 lasted from December until May and thus flooded fields and destroyed fields and crops, resulting in an average loss of crop income of 93 % (Appendix. Table 19). Because of the scarcity of agricultural produce, the agricultural value chain changed dramatically, which favoured those with an excess of agricultural produce, but disfavoured those who needed to buy food. Not only did income decrease during and after the flood, also people's purchasing power decreased as a result of increasing commodity prices. For instance, in 2014 the price of rice in a local shop was 7–8 Bs/kg, while its production cost, when grown in the villages, was 2.5–4 Bs/kg. Producers and consumers are constantly responding to the dynamic agricultural systems (Adams et al. 1998), so during and shortly after the flooding food production became scarce. Once the reserves were used up the dependence on and demand for external food supplies increased, raising food prices (Table 4). Under such conditions, the resources and reserves of those dependent on market purchases for basic provisions diminish rapidly. Inflated crop prices will reduce poor households buying food, which implies that they are more vulnerable to negative impacts of more frequent and extreme weather events. On the contrary, those households holding significant reserves were able to sell their products for higher prices following a period of flooding. Table 4 shows the higher prices of staple crops in 2014/2015 than in 2013, which created windfall profits for households that had had excess production previous the flood and had kept reserves. Because of food scarcity during and after the flood NGOs and government agencies distributed food and seeds in communities (Nicolas Cartagena, CIPTA, pers. com 2015). Global impacts of extreme weather events and climate change on agricultural commodity prices have been analysed in a global study by Zhao et al. (2005), confirming the price fluctuations related to climate change. It is often stressed that climate variability and shocks worsen existing poverty (Reed et al. 2013; IPCC 2014). Our results confirm this to be the case in the short term. The majority of households in the research communities, however, recovered their pre-flood income levels by 2015. Chhibber and Laajaj (2007) suggest that after a disaster several possible GDP/capita recovery scenario are possible (Figure 10).

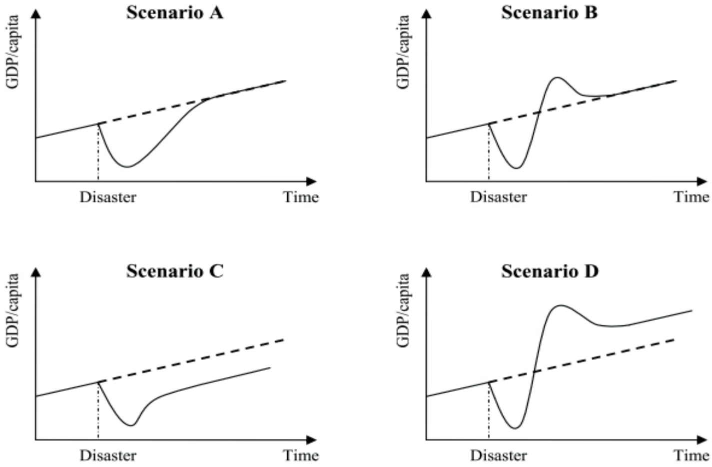


Figure 10. Scenario development after the occurrence of a disaster, source: Chhibber and Laajaj (2008)

The situation in the TCO Tacana I seems to correspond to scenario A: A shock interrupts the initial economic development pathway, but its temporary character leads to a return to the original pathway (Klomp 2016). A number of reasons explain the recovery to the initial path in the study area. First, increased prices of crops just after the shock event positively influenced household incomes, whether or not they sold products. Without the elevated profit margins due to higher crop prices, the impact on farm households would have been worse. Second, successful coping mechanisms, like diversification and external initiatives coordinated by NGOs and government distributing cows, seeds and material to re-establish agricultural fields in 2014/2015 supported households to return to their initial economic status. Third, the geographical location, in particular not being situated in the floodplain area in the Northeast part of the TCO, has influenced the severance of and thus the recovery from the impact. According to an out-migrated family, originally from an interior (hard-to-access) floodplain community, communities and their fields were entirely flooded and households lost up to all their belongings. Yet, a full explanation of the resulting scenario would require additional analysis and a more in-depth study on vulnerability, recovery and resilience of the respective households and communities is in preparation by the first author. Relative similar poverty ratios were observed in 2013 and 2015. Households falling below the poverty line in 2014 all engaged in one of the three natural resource livelihood strategies, i.e. subsistence, farming and business or timber, which confirms the link between natural resource dependence and vulnerability to climate extremes. In contrast, the fact that in 2015 the number of transient poor households dropped approximately to the initial ratio suggests that mitigation of income losses has been largely successful. However, an important factor contributing to this turn around was the higher prices of staple crops and how that influenced the household income picture in 2015, and not the recovery of agricultural yields. Generally, these findings stress the high exposure and thus

vulnerability of natural resource dependent households of the TCO Tacana I to weather-related calamities. The surprisingly fast recovery to initial economic status might not lead to a major flood-induced collapse in the micro-economy in the long run. Further in-depth research is required to analyse factors that contributed to sensitivity, exposure and resilience of households.

2.4.2 Livelihood strategy shifts

Adverse effects on farm income in response to the flood disaster were observed. This raises the question of whether households with farm-based livelihood strategies would shift their livelihood activities, including a shift to a timber strategy. It was expected that the perception of the 2014 flood would encourage shifts in livelihood activities, possibly even leading to increased forest conversion, as suggested by Nkem et al. (2007). While farm income seems stable due to the elevated crop prices, approximately 41.1 % of the total cultivated area of 2013 was abandoned in 2015, after the flood. The drop decline in farming activities evidenced by the decline in cultivated farmland per household does suggest a shift in livelihood activities. People reported having no trust in the weather anymore. "Ya no es como antes" (it is not like before) was one of the most repeated sentences during the interviews. It would rain at any moment even in the dry season and consequently, burning and preparing agricultural fields, which is normally done between June-August (CIPTA 2002) became a challenge due the limited amount of sunny days. Consequently, many families suffered yield losses, reduced the size of their agricultural field or ceased to farm. Although Figure 9 shows a general slight trend away from farming, in particular as the only income activity, the flood might have accelerated this shift. Our results demonstrate that especially the two farm-based strategies subsistence and farm and local business diversified income activities in the aftermath of the flood. Income spreading to manage risk, cope with cropping shortfall and alleviate poverty is a common strategy of rural (poor) households in developing countries (Reardon and Vosti 1995; Ellis 2000; Adger et al. 2004). Income smoothing (reducing the share of commercial crops) was observed by cash farmers, livestock liquidation by subsistence farmers and the dependence on remittances among households that shifted to a diversified strategy. Diversification, whether or not by necessity, appears to have played a vital role in coping with the extreme weather event and thus contributing to fast recovery. Despite the abandonment of agricultural fields, no considerable shift towards timber extraction was found, contrary to expectations (Cavendish 2003; Kaimowitz 2003). While the majority of households changed their livelihood strategies, the composition of the 2013 timber strategy remained fairly stable in 2015. The timber strategy includes largely members of the SRM community. SRM held a communal forest management plan which continued during and after the flood, but also households held individual land clearing plans (*plan de desmonte*), which allows clearing of five ha of forests annually and selling the timber. After the flood, three additional households applied for such land clearing plans and a new forest management group was established. In the three villages, the amount of households involved in timber extraction did not change much, but a progressive specialisation in timber economic strategy took place in SRM. Generally, our results underline the dynamic character of livelihood strategies described by Carney (2003) in response to a shock. Mainly the two farming strategies (subsistence and farming and businesses) diversified their livelihood strategies. No significant shift from farming to timber production became evident. More favourable conditions in one of the study communities led to an increase in households pursuing a timber strategy, which is linked to forest conversion. Whether this was a response to the extreme weather event remains unclear. Forest clearing for pasture due to expanding cattle ranching seemed to emerge and land clearing plans, which is a cover strategy to obtain timber incomes, deserve further attention regarding their adverse effects on the sustainability of the social-ecological system of forest communities.

2.4.3 The role of forest products

Forest products are widely perceived to serve as safety nets for rural households in developing countries and to contribute to coping with economic shocks (Angelsen and Wunder 2003; Shackleton and Shackleton 2004; Takasaki, Barham and Coomes 2004; Paumgarten 2005; Sunderlin et al. 2005; Delacote 2007). However, Wunder et al. (2014) challenged this perception by arguing that forest products as gap filler could be less important than thought before. Analysing the impact of a shock on natural resource-dependent households and potential negative feedback loops on the ecological system as a response contributes to a more holistic understanding and can facilitate climate change adaptation. The outcomes of this study suggest that timber and non-timber forest products were not found to act as a gap filler in response to the shock. Even when testing households of the timber community SRM separately, an increasing trend of timber extraction but no significant increase in relying on other forest products was revealed. However, forest products do play a crucial role for Tacana livelihoods (Townsend 2017). The high contribution of forest products to households' incomes before and after the disaster confirms Angelsen et al. (2014), stressing the overall significance of environmental products, especially for subsistence purposes. To use timber as a formal backstop resource would imply short-term accessibility, whether in terms of infrastructure or harvesting rights and related procedures. Due to the infrastructural constraints caused by the heavy and long-lasting rainfall, immediate access to timber was blocked. Nevertheless, timber-households managed to produce timber later in the year 2014 and compensated for the earlier losses. In this way, mitigation of the economic short-fall and fast recovery was possible. The rather specialised timber strategy can thus be described as profitable but risky and yet successful in overcoming the economic impacts of the 2014 flood. Expanding the use of land clearing plans to facilitate timber extraction should, however, be considered carefully for their possible negative impacts. With regard to non-timber forest products the only significant difference and increase in a contribution after the flood was forest fruit collection, linked to the introduction of a project to commercialise majo (*Oenocarpus bataua* Mart.) and acai (*Euterpe precatoria* Mart.) in SRM. Hence, the elevated share of fruits in people's income portfolio also cannot be attributed to the flood. While fish for subsistence purposes was a strong contributor to total income, in absolute terms, it did not increase after the flood. In contrast to 2013 when various commercialised forest products contributed strongly to total income, in harsh times, people appear to reduce their sales. The substitution of the sale of fish by its consumption shows the importance of fish for food security even though general production did not increase. A study by Townsend (2017) on wildlife changes after the 2014 flood suggests that (riverine) Tacana communities had suffered among others under decreasing wildlife, which confirms our results of a not statistically significant decrease in hunting. The game as a daily and safety resource is thus not a question of opportunity but availability. Comparing the overall contribution of forest products to the four income groups, i.e. better-off, previously poor, transient poor and chronic poor, it seems that all groups have a high dependence on forests, except the transient poor. Transient poor households were part of the subsistence, farming and business, and wage strategies in 2013. It requires more than just income shares alone to provide an explanation for their low performance and possible links to forest dependence after the flood. A strong positive relationship between total income and forest product contribution was found before and after 2014. However, relative dependence varied and there is no clear trend whether forest share is higher with better-off or with poorer households. According to these findings, the importance of forest products for the livelihoods of rural households can be confirmed, as can their recovery after shocks. However, there is no indication of forest products as gap filler during or after a shortage of food. Instead, forests are a constant food supplier and echo as such 'the function of substantial contribution', as suggested by Cavendish (2000).

2.4.4 Social-ecological system

A resilient socio-ecological system has the capacity to recover to the initial state after a shock (Holling 1973). Economically, the social system had largely recovered after one year, however, the ecological recovery system remains questionable up to date. Townsend (2017) shows that wildlife, as one of the most important contributors to Tacana livelihoods, had still not recovered. Negative socio-ecological responses, possibly caused by a decrease in key resources, can cause livelihood strategy and consequently land-use shifts (Lambin 2010). Short-term coping strategies, which might lead to long-term adaptation strategies such as the observed cattle ranching or the commercial exploitation of NTFPs, would require the introduction of a sustainable management system to avoid negative long-term consequences on the ecological system. This again can contribute to avoiding the depletion of forest resources and biodiversity and consequent adverse effects for forest-dependent households and ecological services, such as buffer functions, provided by the forest. The impact of diversification of income activities on the socio-ecological system can be both negative or positive, depending on whether or not diversification leads to non-farm activities, which would reduce natural resource dependency (Reardon and Vosti 1995).

2.5 Conclusion

The outcomes of this study provide empirical evidence of the socio-economic impact and forest product use in three communities of the TCO Tacana I before and after an extreme weather event in 2014. This study documents the high significance of natural resources for the livelihoods of native Tacana people, creating an integrated social-ecological system. Households' strong reliance on natural resources, such as farm and forest products, led to increased economic losses shortly after the flood in 2014, but no significant impact was found for 2015. In the short term, a slight increase in poverty was observed after the flood. By 2015, however, the majority of households had returned to their 2013 income level. In response to the flood, livelihood activity shifts were documented indicating that a prevalent risk response strategy was livelihood diversification. Forest products played a minor role as gap filler, but were more important as a constant contribution to rural households' livelihoods. Given the findings of this paper, efforts to reduce or prevent weather-related impact on rural households should be household income-generating strategy-specific. A one size-fits-all solution will not be sufficiently effective. Local processing of timber and thus value-adding could improve livelihoods of timber-strategy focused households and provide jobs and income during the time when the forest is impassable. The commercialisation of NTFPs, in particular forest fruits, such as promoted already in one community with success in raising incomes, would be another option if sustainably managed. In any case, it is crucial to avoid forest depletion, which would destabilize the ecological system and could have adverse effects on social systems' adaptive capacity and even increase flooding and landslides. Climate change is expected to intensify future severe weather events and seasonal shifts, thus potentially becoming a more frequent threat to forest farmers. Adapting to weather extremes, whether or not linked to climate change, helps forest farmers to prepare for the latter (Travis 2014). National policies should raise awareness, prevent risks and explore impact mitigation options in lowland Bolivia. After the flood disaster of November 2014, the Bolivian government promulgated a new law (*Ley N°602* 2014) on disaster risk management. It defines the institutional frame and prescribes the obligatory incorporation of risk planning as a transversal element into development plans and territorial planning. The empirical evidence provided in this article contributes to developing a more precise disaster risk management at the local level.


3

Chapter III

THRIVING IN TURBULENT TIMES: LIVELIHOOD RESILIENCE AND VULNERABILITY ASSESSMENT OF BOLIVIAN INDIGENOUS FOREST HOUSEHOLDS

3 THRIVING IN TURBULENT TIMES: LIVELIHOOD RESILIENCE AND VULNERABILITY ASSESSMENT OF BOLIVIAN INDIGENOUS FOREST HOUSEHOLDS [6]

T.N. Bauer, W. de Jong, V. Ingram, B. Arts, P. Pacheco

Abstract

Climate change affects ecosystems and the well-being of rural households relying on ecosystem services for their livelihoods. The ability to withstand the adverse effects of climate change depends on their livelihood resilience. The relationship between natural resource dependence and livelihood resilience of Indigenous forest households in the Amazon region is still poorly understood. We used a case study approach to identify factors contributing to the livelihood resilience and vulnerability of 45 households in the Communal Land of Origin Tacana I area in the Bolivian Amazon. Household income data were collected before (2013) and after (2015) an extreme weather event. We combined a theoretical resilience framework with a practical indexing method to calculate the factors contributing to livelihood resilience and vulnerability. Additionally, conditions, regulatory and policy frameworks shaping vulnerability and resilience at the local level were reviewed. Our results show that income activity choice influences households' livelihood resilience and vulnerability. Regarding natural resources, a low vulnerability was linked to selling game and fish or pursuing a wage livelihood strategy, while high resilience was related to hunting and cattle. Our results underline the importance of social networks and capital for low cash-income households to provide support. National development policies prioritize economic growth based on strengthening the energy, agro-livestock sector and boosting oil and mining sectors with industrialization. Some of these priorities may threaten the resilience and increase the vulnerability of Indigenous forest-dependent peoples and their subsistence livelihoods. External pressure on forest resources, including fish, requires a holistic focus on livelihood resilience in national adaptation strategies. Anchoring sustainable natural resources management and monitoring strategies at all policy and operative levels is crucial to the livelihood resilience of forest-dependent (Tacana) households and forest ecosystem health. Risk management approaches need to be developed inclusively and have an integrated socio-ecological focus to avoid adverse spill-over effects.

Keywords:
Forest-dependence; coping; indexing method; risk management; flooding; climate policies; extreme weather event

6 This chapter is based on the paper published as Bauer, T., W. De Jong, V. Ingram, B. Arts and P. Pacheco. 2022. "Thriving in turbulent times: Livelihood resilience and vulnerability assessment of Bolivian Indigenous forest households". *Land Use Policy* 119: 106146. doi:10.1016/j.landusepol.2022.106146.

3.1 Introduction

Climate change affects ecosystems and the well-being of poor rural households, relying on ecosystem services for their livelihoods (IPCC 2014). The impacts of global warming of 1.5 °C above pre-industrial levels are disproportionately higher for vulnerable populations such as some Indigenous people and local communities with agricultural livelihoods (Carter et al. 2017, IPCC 2018). Vulnerability is defined as the function of exposure, sensitivity, and adaptive capacity (IPCC 2001), while the ability of households to withstand negative effects depends on their livelihood resilience, referred to as the capacity to sustain and improve livelihood opportunities notwithstanding environmental disturbances (Tanner et al. 2014).

Livelihood characteristics, such as productive activities and capitals, are important factors determining how vulnerable or resilient livelihoods are to extreme weather events (IPCC 2014). For example, rain-fed subsistence farming (Gentle and Maraseni 2012), agro-livestock smallholding (Panthi et al. 2016), and pastoralism (Sallu, Twyman and Stringer 2010) have been considered sensitive to climate change. Adger (2000) established a link between natural resource-dependent societies and resilience, specifically within social systems that are dependent on a single ecosystem or natural resource. Yet, opinions differ on whether dependence on forest products is associated with increased vulnerability (Pavageau et al. 2018). The use and sale of non-timber forest products (NTFPs) can function as an important safety net for rural households, under the condition that access is not restricted, as case studies from Central and South Africa show (Paumgarten 2005, Ingram, Abdon and Schure 2016). However, in the Congo Basin, dependence on forest products has been recognized as a potential poverty trap, given the pressure on forest resources (Pavageau et al. 2016), suggesting compromised resilience. Furthermore, there is insufficient evidence on the functioning of NTFPs as a safety net in the context of shocks (Paumgarten 2005), such as the shocks predicted to occur under climate change scenarios.

Robust evidence indicates that climate variability worsens poverty and inequalities and triggers new vulnerabilities (IPCC 2018). Climate variability is also expected to slow economic growth and create or extend poverty traps. Adverse livelihood outcomes can accelerate food and livelihood insecurity due to the inability to rebuild affected assets (IPCC 2014). In contrast, financial capital provides a buffer capacity for households (Ifejika Speranza, Wiesmann and Rist 2014), allowing daily expenditures and responses to a disaster (SEI, IUCN and IISD 2003). Sufficient buffer capacity can help mitigate and meet the costs of adapting to climate change (Ifejika Speranza 2013; Ifejika Speranza, Wiesmann and Rist 2014). There is, however, little empirical evidence about the contribution of subsistence income to resilience or vulnerability, despite the growing literature on the relationship between the impact of climate change on poverty and poverty reduction (Adger 1999; Barbier 2015; Zhou et al. 2017; Olayide and

Alabi 2018; Hansen et al. 2019). Subsistence income is the value of products produced or collected for household consumption or given to family or friends (CIFOR 2007).

Globally, Indigenous peoples in vulnerable regions may be severely affected by climate change (Bose 2017). Still, few studies have looked at Indigenous communities with livelihood strategies other than agriculture (Ruiz-Mallén, Fernández-Llamazares and Reyes-García 2016). Also, many climate-related events with adverse effects on the poor in developing countries remain unrecognized (IPCC 2014), and quantitative case studies on the actual response of livelihoods to extreme weather events are rare. Further research is required to understand better climate change impacts on local realities and marginal groups' livelihood strategies (Bose 2017). So far, no widely accepted or commonly used quantitative approach for assessing resilience exists (Chuang et al. 2018). To the best of our knowledge, no detailed analysis on the livelihood resilience and vulnerability to extreme weather events of households in lowland Bolivia has been published yet. The livelihood perspective provides a holistic picture and considers the inter-household heterogeneity and livelihood diversity, common within many rural communities and among households of the TCO Tacana I (Bauer et al. 2018).

This paper is the first attempt to use and test a novel combination of a theoretical resilience approach (Ifejika Speranza, Wiesmann and Rist 2014) and vulnerability assessment indices (Panthi et al. 2016). It is based on empirical evidence from Bolivian forest-dependent households of the *Tierra Comunitaria de Origen Tacana I (*Communal Land of Origin, abbreviated to TCO Tacana I) in the Bolivian Amazon who experienced an extreme weather event. The extreme weather event referred to consisted of heavy precipitation and consequent flooding in 2014, which affected mainly rural populations in the sub-basins of the rivers Beni, Madre de Dios, and the Mamoré in the Northern Bolivian departments Beni, the lowland part of La Paz, and Pando (Espinoza et al. 2014), also affecting the TCO Tacana I. Based on an analysis of responses to changes experienced at the household level, a disaggregated understanding is developed that enriches our knowledge of livelihood dynamics linked to households' responses to extreme weather events, specifically how people's livelihoods relate to vulnerability and resilience. An additional issue is how conditions shaping vulnerability and resilience at the local level are affected by wider regulatory and policy frameworks and whether they affect household livelihoods dynamics on the ground. Complementary analysis like this can contribute to informing policy frameworks

The following four key research questions are addressed. First, what is the relationship between pre-flood household income activities and livelihood strategies of Indigenous households in the TCO Tacana I and their livelihood resilience and vulnerability? Second, how did different levels of pre-flood forest income contribute to livelihood resilience and vulnerability? Third, how did different levels of pre-flood income (comprised of cash and subsistence income) influence livelihood resilience and vulnerability? Fourth, what are the implications of policies in shaping current conditions of resilience and vulnerability at the local level, and what is this case contribution to informing current existing gaps for those policies to be more responsive to local realities?

3.2 Conceptual framework

3.2.1 The concept of livelihood resilience and vulnerability

Two concepts are used to express the magnitude of the ability to withstand perturbations: vulnerability and resilience. Vulnerability as the function of exposure, sensitivity, and adaptive capacity integrates both external and internal factors (IPCC 2001), with exposure being: "the nature and degree to which a system is exposed to significant climate variations" (IPCC 2001, 995). Sensitivity is "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (IPCC 2001, 993), while adaptive capacity refers to the potential or capability to adjust to or cope with change and stresses. The concept of resilience derives from ecology and is defined as the capacity of a system to undergo disturbance and to absorb changes and persist (Holling 1973). This paper focuses on the household as part of a social-ecological system and household members' livelihoods.

Simply put, livelihood is a means of gaining a living. It is seen as the capabilities, capitals, and activities or stocks and flows of food and cash to meet basic needs (Chambers and Conway 1991). A resilient livelihood, therefore, can sustain its vital functions and absorb negative impacts that cause declines in production and well-being (Ifejika Speranza, Wiesmann and Rist 2014).

A resilient system is less vulnerable than a non-resilient system, and the concepts of resilience and vulnerability are intertwined (Gallopín 2006). However, they have often been used separately to analyse livelihood responses to perturbations (Hahn, Riederer and Foster 2009; Alinovi, Mane and Romano 2010; Reed 2013; Antwi et al. 2015; Panthi et al. 2016; Platt, Brown and Hughes 2016; Rahman, Nurhasanah and Nugroho 2016). Few studies integrate both concepts in a single analysis. Maru et al. (2014) suggest using the two concepts to analyse adaptation in remote, disadvantaged communities. This study attempts to combine both concepts to provide a more comprehensive picture of the intra-community complexities of climate change vulnerability and resilience. The integrated assessment allows diverse perspectives on system dynamics to be captured and builds upon the strength of each (Miller et al. 2010). Livelihood vulnerability and resilience comprise various livelihood aspects, including those affected during that shock and those that contributed to coping. In this study, livelihood resilience and vulnerability indexes are compared relatively between households, reflecting a state at a moment of time and comprising the stage during and the outcome of an extreme weather event.

Livelihood Resilience Index (LRI)

The analysis of livelihood resilience was guided by the framework developed by Ifejika Speranza, Wiesmann and Rist (2014), recognizing three contributing factors (CF), namely buffer capacity (BC), self-organization (SO), and the capacity for learning (CL). The combination of those three factors led to the following livelihood resilience index (LRI, from here on resiliency and LRI are used interchangeably):

$$\text{LRI} = \text{Buffer Capacity} + \text{Self-organization} + \text{Capacity for Learning} \qquad \text{Eq. (1)}$$

Each contributing factor consists of several components. Buffer capacity is formed by the components of financial, natural, human, social, and physical capital and access to basic services and its respective indicators. Social safety net, professional cooperation, and reliance on their own resources and their indicators comprise the components of self-organization. Skills, knowledge, awareness, and coping strategies and their indicators shape the capacity for learning.

Each contributing factor, or the sum of its components, can range between 0 and 1, resulting in an LRI (all contributing factors summed up) scaled from 0 (least resilient) to 3 (most resilient).

Household-level indicators of the components buffer capacity and self-organization are inspired by indicators developed by Ifejika Speranza, Wiesmann and Rist (2014). Capacity for learning indicators are based on knowledge of threats and knowledge identification capability, and we integrated the components “coping strategies” and “skills”. Coping strategies were considered necessary, as they are integral to adaptive management. Instead of a cross-cutting dimension, as proposed by Ifejika Speranza, Wiesmann and Rist (2014), we included diversity under skills as a contributing factor for capacity for learning. The modification is justified as we refer specifically to income diversification, which can reduce seasonal income variability (Ellis 2008).

Livelihood Vulnerability Index (LVI)

The IPCC (2001) proposes that climate change vulnerability is a function of the contributing factors sensitivity (SE), exposure (EX), and adaptive capacity (AC). Using this functional relationship. Hahn, Riederer and Foster (2009) propose a livelihood vulnerability index (LVI, from here on vulnerability and LVI are used interchangeably) as:

$$\text{LVI} = (\text{Exposure} - \text{Adaptive Capacity}) \times \text{Sensitivity} \qquad \text{Eq. (2)}$$

The LVI is scaled from -1 (least vulnerable) to 1 (most vulnerable), given that each contributing factor can range between 0 and 1. In contrast to the LRI, contributing factors to LVI are only represented by indicators, no components, and are listed in Table 7. Exposure indicators reflect exposure to shocks such as crop shocks, losses in timber production, and or water outages. Sensitivity indicators heighten or lower the impact of exposure and refer to qualities like health status, age, and dependence on weather-related income activities. And lastly, determinants of adaptive capacity include economic resources, available technology, information and skills, infrastructure, institutions, and social equality (IPCC 2001).

Table 7. The Livelihood Resilience Index and Livelihood Vulnerability Index and their contributing factors and components

Contributing factor (CF) and component (C)	Explanation and sources (Indicators in Annex 1)
LIVELIHOOD RESILIENCE INDEX	
Buffer capacity (CF)	Livelihood capitals and their dynamics: the capacity to mitigate change while using emerging opportunities to achieve better livelihood outcomes (Ifejika Speranza 2013; Ifejika Speranza, Wiesmann and Rist 2014)
Financial capital (C)	Financial capital provides different livelihood options and means for daily expenses, investments in productive assets and to respond to the effects of a disaster (recovery, reconstruction, etc.) (SEI, IUCN and IISD 2003)
Human capital (C)	Defined as the quantity and quality of household labour available contributes directly to resilience, as it contributes to decision-making power over resources (Ifejika Speranza 2010) Illiteracy as one determinant factor of low adaptive capacity (Magalhāes 1996)
Natural capital (C)	Natural resources that contribute to rural household livelihoods (e.g. food, or conversion into financial capital) (Lee et al. 2008) Natural capital as provisioning ecosystem service and buffer of livelihood base (e.g. food. construction material, conversion into financial capital) (Reed et al. 2017) Crucial aspect of resilience, as it cannot be substituted (Hassler and Kohler 2016)
Social capital (C)	Resilience and adaptive capacity are determined and facilitated by the ability to act collectively (Adger 2003)
Physical capital (C)	Lack of physical capital can reflect higher susceptibility and lower resilience (Karfakis, Lipper and Smulders 2012)
Access to basic services (C)	Influences resilience by improving the effectiveness of access to assets and thus enhancing the household's capacity to manage risks and the response to a disaster (Alinovi, Mane and Romano 2010)
Self-organization (CF)	Level of which a social network can steer its actions and outcomes; it indicates the degree of autonomy, freedom to act, collective action, self-help, self-reliance, independence, power, and control of own actions; contributes to empowerment by promoting identity, trust and confidence (Ifejika Speranza, Wiesmann and Rist 2014)
Social safety net (Private network) (C)	Trust, reputation and reciprocal action between different actors can enhance resilience (Adger 2003)
Professional cooperation (work-related network) (C)	Trust, reputation and reciprocal action between different actors can enhance resilience (Adger 2003)
Reliance on own resources (C)	Reduces the dependency on external income and food resources and saves time to act quickly (Ifejika Speranza, Wiesmann and Rist 2014)

Table 7. The Livelihood Resilience Index and Livelihood Vulnerability Index and their contributing factors and components (*continued*)

Contributing factor (CF) and component (C)	Explanation and sources (Indicators in Annex 1)
Capacity for learning (CF)	Adaptive management; acquired knowledge and skills and the translation into action (Ifejika Speranza, Wiesmann and Rist 2014)
Skills (C)	Part of the human capital dimension; the ability to learn at the individual and household levels, contributes to building resilience (Barnett 2001) diversified skills within one household provide more flexibility to respond to a disaster (Ellis 2008, Ifejika Speranza, Wiesmann and Rist 2014)
Knowledge (C)	Familiarity with climate change and traditional knowledge; adaptation to environmental change is determined by the in-depth knowledge of the land and environment (Nakashima et al. 2012)
Awareness (C)	Lack of climate awareness can hinder coordination for effective response (Archer and Dodman 2015)
Coping strategies (C)	Knowledge and application of coping strategies contribute to resilience (Mavhura et al. 2013)
LIVELIHOOD VULNERABILITY INDEX	
Exposure (CF)	The degree to which a system is exposed to significant climate variations shocks caused by the disaster (IPCC 2001)
Sensitivity (CF)	Livelihood characteristics that are heightened or lowered by exposure to a shock, such as human capital, dependency on weather-sensitive activities and perception of happiness and self-sufficiency (IPCC 2001)
Adaptive capacity (CF)	Capacities that facilitate or constrain the development and deployment of adaptive measures, Cross-cutting dimension of capacity (IPCC 2001)

The Livelihood Resilience Index and Livelihood Vulnerability Index and their contributing factors and components.

All contributing factors (LVI) and components (LRI) contain multiple indicators, reflecting the empirical complexity found in studies of resilience and vulnerability. Many indicators are drawn from the literature (IPCC 2001; Hahn, Riederer and Foster 2009; Alinovi, Mane and Romano 2010; Ifejika Speranza, Wiesmann and Rist 2014; Panthi et al. 2016), and some (size of farmland, individual timber harvest, origin, Tacana identity, position in the community) were added to adapt to the context of this study. This suite of multiple indicators — shown in Appendix.Table 20 — were used to provide rounded measures reflecting the Bolivian context and enable triangulation between indicators.

3.2.2 Assessment of LRI and LVI

To obtain a household-level index of the contributing factors, we used the formula of Hahn, Riederer and Foster (2009) to normalize components (LRI) or indicators (LVI), respectively:

$$CF_h = \frac{\sum_{i=1}^{n} Wmi\, Mhi}{\sum_{i=1}^{n} Wmi} \qquad \text{Eq. (3)}$$

For LRI calculations: CF_h indicates the contributing factor, n is the number of components for that factor, W_{mi} is the weight of each component $m_{i,}$ determined by the number of components forming one CF, and M specifies the components for household h, indexed by i.

For LVI calculations: CF_h indicates the contributing factor, and n is the number of indicators for that factor. W_{mi} is the weight of each indicator $m_{i,}$ determined by the number of indicators forming one CF, and M specifies the standardized indicator for household h, indexed by i.

Due to the different nature of the two formulas, we apply a composite index for LRI to integrate the components into the contributing factors; and based on the IPCC framework, we calculate LVI only through contributing factors.

$$LRI_h = BC\left(\frac{\sum_{i=1}^{6} Wmi\, Mhi}{\sum_{i=1}^{6} Wmi}\right) + CL\left(\frac{\sum_{i=1}^{4} Wmi\, Mhi}{\sum_{i=1}^{4} Wmi}\right) + SO\left(\frac{\sum_{i=1}^{3} Wmi\, Mhi}{\sum_{i=1}^{3} Wmi}\right) \quad \text{Eq. (4)}$$

$$LVI_h = \left(EX\left(\frac{\sum_{i=1}^{8} Wmi\, Mhi}{\sum_{i=1}^{8} Wmi}\right) - AC\left(\frac{\sum_{i=1}^{12} Wmi\, Mhi}{\sum_{i=1}^{12} Wmi}\right)\right) \times SE\left(\frac{\sum_{i=1}^{11} Wmi\, Mhi}{\sum_{i=1}^{11} Wmi}\right) \quad \text{Eq. (5)}$$

The term m_i can be either a component (LRI) or an indicator (LVI). The sum of the weight of all components composing one contributing factor is 1. Likewise, all indicators composing one component are equal and sum up to the weight of their respective superior component. The result is that components (LRI) or indicators (LVI) within a contributing factor have the same weight, but not necessarily in the comparison between different components or contributing factors. This top-down weighting is justified based on the conceptual model of resilience (Ifejika Speranza, Wiesmann and Rist 2014), which assumes equal weighting of buffer capacity, self-organization, and capacity for learning. If all indicators across the components had the same weight, it would make an implicit and incorrect judgement of the degree of influence of the indicators (Eakin and Bojórquez-Tapia 2008) (Figure 11).

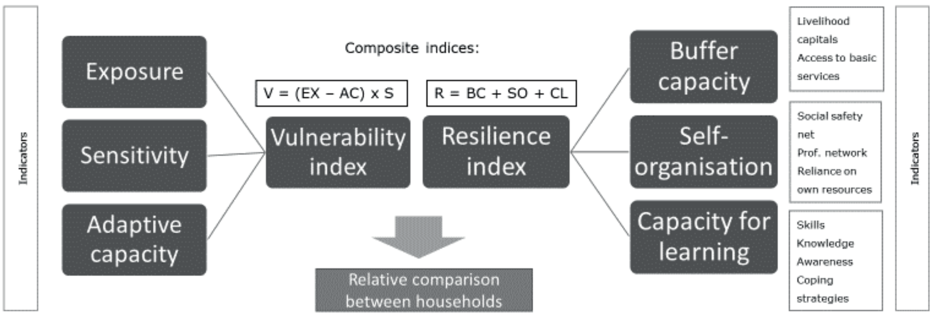


Figure 11. Computation of indices as a combination of an adapted theoretical resilience framework and an indexing method, based on Hahn, Riederer and Foster 2009, Ifejika Speranza, Wiesmann and Rist 2014

To calculate the components for the contributing factors of the LRI (Hahn, Riederer and Foster 2009), equation (6) is used, in which M_h represents the component and index S is the standardized indicator. Standardization is necessary because indicators are measured using different scales.

$$M_h = \frac{\sum_{i=1}^{n} indexShi}{n} \qquad \text{Eq. (6)}$$

The above formula concerns only the calculation of the LRI since the LVI has no components.

The standardization of the numerical values of all indicators of LVI and LRI follows the Human Development Index (UNDP 2019), which is applied as follows:

$$\text{Index } S_h = \frac{Sh - Smin}{Smax - Smin} \qquad \text{Eq. (7)}$$

Here, S_h is the indicator for household h, and S_{min} and S_{max} are the minima and maximum values. The standardized value ranges between 0 and 1, reflecting low or high vulnerability and resilience.

Based on Bauer et al. (2018), households were grouped in four activity groups reflecting their dominant livelihood activities in terms of income sources: 1) timber strategy (logging and selling timber); 2) subsistence strategy (households who consume most of what they produce by agriculture or foraging); 3) farm and local business strategy (agricultural production combined with small-scale business activities such as community shops, taxi, etc.), and 4) wage income strategy (includes households with paid jobs, such as teacher, medical assistant). The grouping allowed a comparison between livelihood strategies in terms of LRI or LVI.

3.3 Background information and methods

3.3.1 Study area

Bolivia is one of the poorest countries in Latin America and is situated in a region where adverse impacts of climatic change on ecosystems have been observed (IPCC 2014). Climate models suggest further temperature increases, and climate variability might intensify extreme weather events, such as droughts and floods (Seiler, Hutjes and Kabat 2013a). Since the 1990s, extreme weather events have become more frequent, resulting in floods in 2007, 2008, and 2014 (Gloor et al. 2013; Ovando et al. 2016). In 2014, the severest flood in Bolivia's history hit the northern lowland part of the country, affecting 340,000 people (Ovando et al. 2016). The high precipitation events in 1998, 1999, 2009, 2011, 2012 have been linked to La Niña, a weather pattern counterpart to El Niño due to its unusually cold ocean surface water along the tropical west coast of South America. The 2014 flood is associated with an anticyclonic anomaly, i.e., warm conditions in the western Pacific-Indian Ocean, which led to unprecedented above-average rainfall (Espinoza et al. 2014), provoking the highest recorded discharge of the Beni-Madre de Dios and Mamoré-Guaporé river system (Ovando et al. 2016). It resulted in 380% higher than normal discharge in the city of Rurrenabaque (Espinoza et al. 2014). This region is home to livestock farmers and over half of the 36 recognized Indigenous groups in Bolivia, who mainly live off small-scale subsistence agriculture and harvesting forest products.

The study was carried out in three communities of TCO Tacana I (Figure 2), which covers 20 communities, 486 households, and 389,303.9 ha of the Northern part of the department of La Paz in Bolivia (CIPTA and CIMTA 2014). A TCO defines a geographical area where Bolivian Indigenous people and communities have traditionally resided, and the ownership is given to communities to maintain and develop their traditional lifestyles (Gobierno de Bolivia, 1996).

The communities Buena Vista (BV), Santa Rosa de Maravilla (SRM) and Napashi (N) are in areas between 210 m and 275 m above sea level, at the foothills of the Cordillera Oriental of the Andes, surrounded by the Madidi National Park on the Western flank and the river Beni to the East (Gobierno Municipal de San Buenaventura). Three natural vegetation types dominate the area: humid foothill forest, seasonal humid Amazonian rainforest, and riparian forest (Ribera 1992). The climate is tropical, with an average annual precipitation of 1800–2500 mm, an average annual temperature of 26°C, and a distinct dry season from May to August (CIPTA 2002).

In the 17th century, Franciscan missionaries described the Tacana people as a typical "tropical forest tribe" (Wentzel 1989). These days, they are sedentary and live from agriculture, timber, and non-timber forest products. On average more than 40% of their activities derive from subsistence activities, such as fishing, hunting, and farming (Bauer et al. 2018).

3.3.2 Policy framework shaping climate change response in Bolivia

Relevant policies related to climate change on international, national, departmental, municipal and TCO-level can be found in Appendix.Table 21, all laws and degrees under http://www.gacetaoficialdebolivia.gob.bo/. On the international level, Bolivia has ratified the United Nations Framework Convention on Climate Change (Law N° 1576, Gobierno de Bolivia 1994) and the Paris Agreement (Law N° 835, Gobierno de Bolivia 2016a). The Bolivian Intended Nationally Determined Contribution (iNDC) was submitted in 2016. A revised version for the period 2021-2030 is in preparation. The national legal framework is guided by the Mother Earth Law (N°300, Gobierno de Bolivia 2012) and the Patriotic Agenda 2025 as a strategic framework (Law N° 650, Gobierno de Bolivia 2015), which defines priorities for action and budget lines. Law N° 777 (Gobierno de Bolivia 2016), the National Integral Planning System (SPIE), provides the planning framework at the different levels of government in the framework of Vivir Bien (Living Well). Law N° 786 (Gobierno de Bolivia 2016b), the National Economic and Social Development Plan 2016-2020, establishes the basis of the development plan and defines the mechanisms for coordination and evaluation. Law N°602 (Gobierno de Bolivia 2014) assigns risk management under the mandate of autonomous territorial entities (Law N°031 on decentralisation, Gobierno de Bolivia 2010) in coordination with central state, coordinated by COEN (National Operational Emergency Committee), organized in Technical Round Tables. In an emergency, COEN also defines the severity of sectoral damage and losses and the necessities needed per region, sector, and affected population.

Approved sectoral plans (Planes Sectoriales de Desarrollo lntegral para Vivir Bien, PSDI) are available for the period of 2016-2020, including environment and water, and agriculture and approved territorial plans at the departmental and municipal level (Planes Territoriales de Desarrollo lntegral para Vivir Bien, PTDI) for the period 2016-2020. The La Paz Departmental Law N° 159 (Gobierno Autónomo Departamental de La Paz 2018b) establishes the Municipal Committees for Risk Prevention and Management. Law N° 195 (Gobierno Autónomo Departamental de La Paz 2020) establishes the framework for prevention, protection, and strengthening of native Indigenous nations and peoples in situations of vulnerability in the department of La Paz.

To answer research question four, relevant policies affecting vulnerability and resilience outcomes of this analysis were reviewed concerning the integration of adapted management strategies.

3.3.3 Data collection

Before the field data collection, three communities of the TCO Tacana I were selected jointly with a member of the steering committee of the Indigenous Council of the Tacana People (Consejo Indigena del Pueblo Tacana, CIPTA). Its steering committee recommended three communities of the TCO Tacana I to (1) ensure the representability of diverse income activities and micro-ecosystems (2) proximity to forests used to extract resources, and (3) accessibility. Consent was obtained from community heads and research participants. Following a reconnaissance survey in 2012, 50 households were identified on a voluntary basis during initial community meetings and interviewed between September and November 2013. The baseline study covers between 46 % and 100 % of all households in the sample communities and represents 8 % of the total number of households of the TCO Tacana (Table 8). Initially, the study was intended as livelihood research, analysing the role of forest products and climate change in lowland Bolivia. The flood shock happened in 2014, right after the baseline study in 2013.

The research focus was adapted, and repeated data collection in June and July 2015 allowed a comparative analysis. The second interview round was conducted with 45 of the households, two had moved, and three were absent. An adapted version of the prototype questionnaires developed by CIFOR's Poverty Environmental Network (PEN, CIFOR 2007a) and technical guidelines (CIFOR 2007b) were used to gather data on general household characteristics, cash and subsistence productive activities for the period September/November 2012 to September/November 2013 and June/July 2014 to June/July 2015. In addition, income losses in 2014 caused by the extreme weather event were recorded. More detailed information can be found in Bauer et al. (2018).

The income data collected in 2015 established the factors contributing to LVI and LRI (Annex 1). Income data and the main livelihood strategies identified as timber strategy (11 households), subsistence strategy (20 households), farm and local business strategy (13 households), and wage labour strategy (4 households) are based on the pre-flood income of 2013, which are presented in detail in Bauer et al. (2018). Subsistence and cash income were classified into the forest, farm, environmental, and non-farm income. Forest income comprises income from fish, game, timber, firewood, processed forest products, seeds, fruits, and wages. Farm income consists of crops, livestock, and farm wages. Environmental income includes products derived "from the harvesting of resources provided through natural processes not requiring intensive management" (CIFOR 2007b, 19), such as pasture or environmental products outside forests. Non-farm income covers business, remittances, non-farm, and non-forest wages.

Table 8. Sample size and representativeness

Community (Year of foundation)	**Santa Rosa de Maravilla (1982)**	**Napashi (1962)**	**Buena Vista (1953)**	**Total**
Households interviewed in 2013/2015	12/11	9/7	29/27	50/45
Total households per community 2013/2015	12/11	9	63	83
Representativeness of sample	100 % (2013) 100 % (2015)	100 % (2013) 78 % (2015)	46 % (2013) 43 % (2015)	82% average 73% average

3.3.4 Data analysis

All indicators were normalized to calculate components and contributing factors of LVI and LRI – see section 2.1. As the sample size is small and not all livelihood groups were normally distributed, non-parametric tests such as the Spearman Rho and Mann-Whitney U tests were found appropriate to test for correlations and differences between livelihood groups. The non-parametric Spearman-Rho correlation analysis was conducted to detect monotonic trends between pre-flood livelihood activities and income groups, respectively, and LVI and LRI. To test for differences between the livelihoods group's vulnerability, resilience, and the contributing factors, components, and indicators, a pairwise Mann-Whitney U test between all groups was employed (IBM SPSS 21). Before the Mann-Whitney U test, Levene´s test for heteroscedasticity showed homogeneity of variances, which is one of the assumptions of the Mann-Whitney U tests. For binary data, we employed Fisher´s exact test for comparison.

3.4 Results

3.4.1 Pre-flood household income activities and livelihood strategies of selected households associated with vulnerability or resilience

Table 9 shows all activities contributing to differences in either LRI or LVI. Our findings revealed a strong correlation between cash income from hunting and livelihood resilience. In contrast, the relation between subsistence hunting or cash income from cattle (cash income from environmental produce) was significant but less strong. Activities correlating strongly with buffer capacity were the sale of wild game, seeds and cattle and business activities. At the same time, however, business activities reduced self-organization. The collection of NTFPs, specifically game for subsistence use and environmental income, controlled the contributing factor capacity for learning.

Our analysis indicates that three livelihood activities have a negative correlation with vulnerability: commercial hunting, fishing, and monthly wages. Households with higher income shares of those activities have a lowered LVI. The collection of wild fruits for subsistence and subsistence farming is strongly correlated with sensitivity, contributing to LRI.

We also found significant differences in LVI, exposure, and factors contributing to LRI between the four livelihood strategies; Figure 12 provides a detailed overview. We did not see a significant difference in LRI among the four household strategies. We found differentiation in two factors that increased LRI: reliance on a household's own resources (share of productive output destined for household consumption) and knowledge (a combination of traditional knowledge, traditional weather indicators, and familiarity with climate change).

Comparing the four livelihood strategies, we found that the timber strategy has a comparably high vulnerability and exposure, medium subsistence share, and knowledge on climate-related aspects. The subsistence strategy has a comparably low vulnerability and exposure and knowledge on climate aspects. The percentage of subsistence income is high. Households with a farm and local business strategy had a high vulnerability, exposure, and share of subsistence income, but the knowledge was low. The wage livelihood strategy had a low vulnerability, exposure, and subsistence income, while knowledge was high.

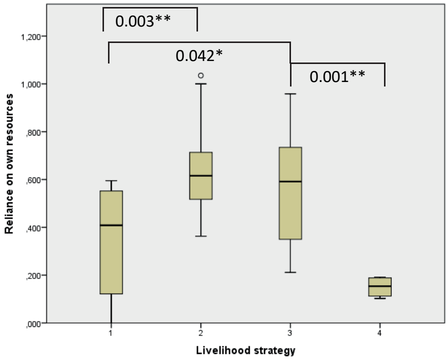
Table 9. Correlations between relative income share of livelihood activities and contributing factors to vulnerability and resilience, only significative results shown

Livelihood activity & income type	**Vulnerability (V)**			**Resilience (R)**				
S= subsistence C=cash Tot=total	V	Sensitivity	Exposure	Adaptive Capacity	R	Buffer Capacity	Self-Organization	Capacity for learning
Forest income								
game_s					ρ = 0.341 p = 0.022*			ρ =0.463 p = 0.001**
game_c	**ρ = -0.332 P = 0.026***			ρ = 0.43 p = 0.003**	ρ =0.545 p = 0.000**	ρ = 0.414 p = 0.005**		ρ = 0.376 p = 0.011*
seeds_c				ρ = 0.323 p = 0.030*		ρ = 0.375 p = 0.011*		;
fish_c	**ρ = -0.336 P = 0.024***		**ρ = -0.335 P = 0.024***					
fruits_s		ρ = 0.435 P =0.003**						
forestder_s			**ρ = -0.318 p = 0.033***					
forestwages			ρ = 0.315 p = 0.035*					
NTFP								ρ = 0.417 p = 0.004**
Environmental income								
env_s		ρ = 0.3 P = 0.045*						
env_c				ρ = 0.316 p = 0.034*	ρ =0.335 p = 0.024*	ρ =0.488 p = 0.001**		ρ = 0.301 p = 0.045*
env_tot				ρ = 0.312 p = 0.037*				ρ = 0.345 p = 0.02*

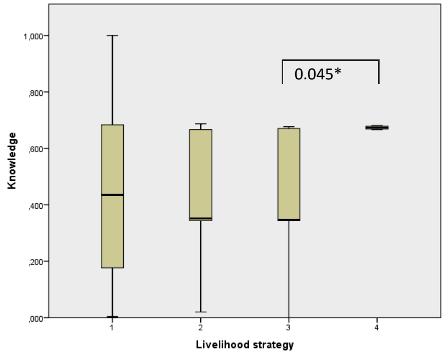
Table 9. Correlations between relative income share of livelihood activities and contributing factors to vulnerability and resilience, only significative results shown (*continued*)

Livelihood activity & income type	Vulnerability (V)		Resilience (R)		
Farm income					
crops_s		ρ = 0.376 P = 0.011*			
crops_c			ρ = 0.312 p = 0.037*		
livestock_s			ρ = 0.312 p = 0.037*		
Non-farm income					
wage	**ρ = -0.36** **P = 0.015***				
business				ρ = 0.39 p = 0.008**	**ρ =-0.408** **p = 0.003***

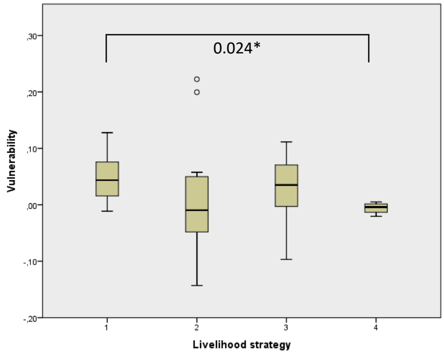
Key: n = 45, income data collected in 2013; vulnerability and resilience data in 2013/2015, statistical significance: **p < 0.05; **p < 0.01* (Spearman-Rho test), negative correlations are given in **bold**



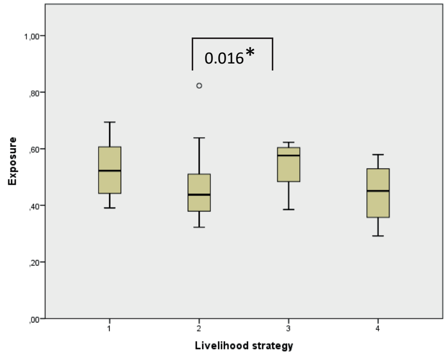
a) Significant differences in the self-organisation-component reliance on own resources: share of subsistence income differs between three livelihood strategies.



b) Significant differences in the capacity for learning-component knowledge between the farm-and-local business and wage livelihood strategy



c) Significant differences in vulnerability between the timber and wage livelihood strategies



d) Significant differences in the exposure between subsistence and farm-and-local business livelihood strategies

Figure 12. Significant differences in contributing factors and components of vulnerability and resilience between livelihood strategies (Mann-Whitney-U test). Livelihood strategy 1 = timber (n = 11); 2 = Subsistence (n = 20); 3 = Farm and local business (n = 13); 4 = Wage (n = 4), only significant results shown

3.4.2 Pre-flood forest-dependent activities and strategies of selected households associated with vulnerability and resilience

We looked at forest dependence from two angles: analysing forest income activities and forest-dependent livelihood strategies based on Bauer et al. (2018).

Besides results shown in table 9, we also analysed the correlation between components of LRI and cash income from timber and subsistence income from forest products (consisting of firewood, game, fish, timber, seeds, fruits, and forest-derived products), shown in table 10. The results indicate a correlation between cash income from timber and collaboration for the studied households. Furthermore, there was a positive correlation between subsistence forest income and human capital and reliance on own resources, and a negative correlation with physical capital.

Table 10. Correlations between relative income share of forest activities and resilience components, only significative results shown

Livelihood activity & income type	Buffer Capacity		Self-Organization	
S= subsistence C=cash	Human capital	Physical capital	Cooperation	Reliance on own resources
timber_c			ρ = 0.303* p = 0.043	
forest_s	**ρ = 0.303* P = 0.043**	**ρ = 0.376* P = 0.043**		ρ =0.361* p = 0.015

Key: n = 45, income data collected in 2013; vulnerability and resilience data in 2013/2015, statistical significance: *$^*p < 0.05$;* (Spearman-Rho test), negative correlations are given in **bold**

Comparing forest-depending strategies against the non-forest strategies, we found that timber strategy households were significantly more vulnerable than wage labour strategy households. Subsistence strategy households had the lowest median of all four strategies, but there was no significant difference to other strategies (Figure 12c).

The analysis of contributing factors and indicators of LVI (Table 11) of the timber strategy households revealed a strong economic shock on the timber revenues. Likewise, the indicators show that household features like the not-owning an agricultural parcel, no livestock to sell in cases of emergency and low subsistence income, and high weather sensitivity, contributed to decreasing LRI and raising LVI.

Subsistence strategy households had lower exposure to the extreme event than farm and local business strategy households. One indicator was the damage to houses, which seemed less affected by the flood among subsistence strategy households than households pursuing other strategies. In comparison to farm and local business strategy households, subsistence strategy households also had broader traditional knowledge, such as the use of various NTFPs such as medicine and food, which allowed them to bridge times of food shortage. Compared to wage strategy households, subsistence strategy households were less literate, less familiar with climate change, relied more on weather-sensitive activities for their production to meet daily needs than any other household strategy.

Table 11. Comparison of resilience and vulnerability indicators of the timber and subsistence strategies with farm and wage strategies (only significant indicators listed), "-" indicates a significantly lower, "+" a significantly higher indicator of either timber or subsistence strategy

Forest-strategy		Indicator	*Farm*	Sig.	*Wage*	Sig.
Timber	**Resilience**					
	Buffer capacity	Ownership parcel	-	0.003**		
	Capacity for learning	Traditional knowledge	+	0.049*		
	Capacity for learning	Sale of livestock	-	0.04		
	Vulnerability				+	0.024*
	Sensitivity	Distance to road	-	0.003**	-	0.024*
	Exposure	Timber shock	+	0.003**		
		Weather sensitivity			+	0.004**
Subsistence	**Resilience**					
	Buffer Capacity	Literacy level Financial capital *Total income 2015*	 - -	 0.020* *0.014**	- 	0.033*
	Capacity for learning	*Traditional knowledge*	+	0.012*		
	Capacity for learning	*Familiarity climate change*			-	0.042*
	Vulnerability					
	Sensitivity	*Weather sensitivity*			+	0.019*
	Exposure		-	0.016*		
	Exposure	*House shock*	-	0.048*		

Key: n (timber) = 10, n (subsistence) = 18, n (farm) = 13, n (wage) = 4; , income data collected in 2013; vulnerability and resilience data in 2015; Statistical significance: *p < 0.05; **p < 0.01 (Mann Whitney U for continuous, Fisher´s exact test for categorial data)

3.4.3 The role of pre-flood income in coping with the extreme precipitation and flood event

Differences between total, cash, and subsistence income influenced LRI and LVI (table 12). A higher proportion of cash income in total household income was associated with individual households harvesting timber or being a member of a forest user group, possessing higher financial and physical capital, receiving monetary transfers from family members and having experienced more with different crop options. Households with a higher proportion of their products used for household consumption were associated with higher levels of social capital, more labour-power, more farmland, lower physical capital, and high self-organization and learning capacity. Relatively seen, vulnerability decreased with increasing total or cash income. A higher total income was also associated with a higher adaptive capacity and reduced exposure than households with lower total income. Cash income was negatively related to an increase in production costs (defined as cash expenses required for agricultural or timber production) caused by the need to re-establish crop fields after the flood. Increasing subsistence income was positively related to happiness and modesty.

Table 12. Correlation analysis of income and indicators of resilience and vulnerability, only significant results shown in the table

	Subsistence income		**Cash income**		**Total income**	
	Correlation coefficient	**p**	Correlation coefficient	**p**	Correlation coefficient	**P**
Vulnerability			**0.349**	**0.019***	**0.450**	**0.002****
Adaptive Capacity					0.332	0.26*
Exposure					**0.340**	**0.022***
Crop shock					**0.325**	**0.030***
House shock					**0.356**	**0.016***
Increase in production costs			**0.324**	**0.030***	**0.307**	**0.040***
Sensitivity						
Happiness factor	0.462	0.001**				
Sufficiency factor	0.301	0.044*				
Resilience	0.356	0.017*	0.337	0.024*	0.386	0.009**
Buffer capacity						
Social capital	0.309	0.039*				
Human capital						
Labour power	0.364	0.014*				
Natural capital						
Farmland	0.352	0.029*				
Individual timber harvest			0.345	0.020*		
Financial capital	0.363	0.014*	0.668	0.000**	0.369	0.013*
Total income 2015					0.391	0.008**
Non-agricultural assets			0.294	0.050*		
Livestock			**0.307**	**0.040***		
Physical capital	**0.417**	**0.004****	0.400	0.007**		
Roof			0.420	0.004*	0.385	0.009**
Gas	**0.51**	**0.000****	0.321	0.031*		
Access to basic services						
Distance to water			**0.323**	**0.031***	**0.403**	**0.006****
Radio					**0.318**	**0.033***
Self-organization					0.322	0.023*
Social Safety Net					0.320	0.032*
Transfer government	0.297	0.048*				
Family transfer	0.346	0.020*	0.526	0.000**	0.580	0.000**
Sum of options	0.335	0.032*			0.398	0.010*
Cooperation and networks						
Memberships	0.371	0.012*				
Member of a Forest User Group			0.356	0.016*		
Reliance on own resources	0.581	0.000**	**0.377**	**0.011***		

Table 12. Correlation analysis of income and indicators of resilience and vulnerability, only significant results shown in the table (*continued*)

	Subsistence income		**Cash income**		**Total income**	
	Correlation coefficient	**p**	Correlation coefficient	**p**	Correlation coefficient	**P**
Capacity for learning						
Skills	0.341	0.022*				
Diversification	0.341	0.022*				
Coping strategies						
Crop Experimentation	0.295	0.049*	0.336	0.024*	0.331	0.26*
Fertilizer	0.363	0.014*			0.354	0.17*

Key: n = 45, income data collected in 2013; vulnerability and resilience data in 2013/2015, statistical significance: $*p < 0.05$; $**p < 0.01$ (Spearman-Rho test), negative correlations are given in **bold**

3.4.4 Policies shaping current conditions of resilience and vulnerability

A detailed overview of the policy review can be found in Appendix.Table 21. Bolivia has adopted a comprehensive regulatory framework for regulating the use of natural resources condensed in the Mother Earth Law 300 (Gobierno de Bolivia 2012), and development planning, which includes all major sectors. Most of these plans were completed for the period 2016-2020. The main focus of the regulatory and policy framework is to develop those activities with the potential to generate economic growth (such as energy mining) and generate income and employment (such as agro-livestock sector) and the technologies and incentives for supporting these activities, as well as strategies to mitigate likely impacts from climate change, e.g., risk prevention and insurance systems.

The departmental and municipal plans tend to replicate the emphasis on supporting agro-livestock development, focusing on those activities that have the largest potential for development in the north of La Paz (e.g., sugarcane, cacao). While there is a recognition of the importance of fishing on local economies and local diets, the emphasis is on the support of fish farming due to their potential to complement income streams.

There is legislation to support wildlife management and the protection of fauna and flora threatened species, but with a lack of guidance on supporting sustainable management. The prevention of risks associated with climate change, particularly risk management and response actions associated with natural events disasters, is regulated. Different institutional mechanisms have been devised at different levels to organize responses. Most of the risk management strategies focus on reducing vulnerability. There is an evident lack of mechanisms to support and enhance the adaptive capacity and resilience of forest-dependent local people and economies to climate change. Bolivia has not yet prepared a National Plan of Adaptation to Climate Change.

3.5 Discussion

3.5.1 Activity choice and implications for vulnerability and resilience

Among the selected TCO Tacana I households, we analysed livelihood activities and strategies that played significant roles in defining LVI or LRI in the context of the flood that affected the region in 2014. Vulnerability decreased among households with a higher share of commercialized game or fish; resilience increased among households whose livelihoods included a higher share of game and commercialized cattle (environmental income). Our results indicate that livestock, hunting, and fishing activities and incomes were less affected by the flood than other livelihood activities. Hunting game is one of the essential activities pursued by Tacana people (Townsend 2017), but its contribution to household income depends on the availability of the game in the forest. According to some hunters, animals concentrated around dry spots in the forest during the flood, which facilitated hunting. However, this short-term bounty combined with land-use change led to a long-term decline in wildlife in the region (Townsend 2017). The high availability and traditional importance of fish for Tacana households to overcome the flood and its aftermath was confirmed by Townsend (2017). Increased fish population after flooding has been observed in slower-moving rivers, as flooding typically increases the amount of plankton and the size of spawning areas (Hickey and Salas 1995). Cattle ranching contributed to resilience by providing buffer capacity, such as either meat or milk products, or cash if cows are sold. Generally, both wild and domestic animals played a crucial role in reducing vulnerability and exposure and as a result, increased LRI. Generally, the higher the dependence on natural resource-related activities, such as hunting or fishing, the lower the household´s vulnerability.

Commercial business activities enhanced buffer capacity but correlated negatively with self-organization. Households with a business, such as a sawmill or a shop, were more likely to have a more significant number of consumer items, such as a refrigerator, a TV, or a motorbike, but less likely to have a well-established social safety net or intra-communal network. A possible explanation might be that such households were often in-migrants or non-Tacanas and therefore had less chance to build up social networks and social safety nets.

Subsistence activities, such as collecting NTFPs or other environmental products, and the production of crops, appeared more sensitive to extreme weather events than other commercial activities. In contrast, commercial crop production seemed less affected by the extreme weather event because the decrease in harvest volumes was partly compensated by increased prices (see Bauer et al. 2018); physical losses, however, were the same.

The vulnerability of households with farm and local business strategy was linked to their exposure to the extreme weather event, reflected in financial losses due to physically affected crops, destruction of houses, and various simultaneous shocks (loss of work, family members, livestock, etc.). The vulnerability of farm and local businesses strategy households is similar to the vulnerability of subsistence farming strategy households elsewhere in Bolivia (McDowell and Hess 2012) and globally (see Armah et al. 2010; Gornall et al. 2010; Krishnamurthy 2012; Shiferaw et al. 2014; Panthi et al. 2016; Kangalawe et al. 2017).

3.5.2 Forest income and implications for vulnerability and resilience

Regarding livelihood strategies, the findings suggest that no generalization can be made whether forest dependence is positively associated with resilience or vulnerability. However, analysing the activities independently from the livelihood strategies, forest-based activities that increase the contributing factors of LRI, or decrease LVI, are hunting and commercial fishing.

When we compared strategies individually, the timber livelihood strategy showed a non-significant trend to be the most vulnerable group. The largest number of such timber strategy households are residents of the community Santa Rosa de Maravilla, the only community with an approved forest management plan in 2013. Some households in the community also joined a development project by the Japanese International Cooperation Agency, JICA, to promote paddy rice production. According to community members, some rice production was destroyed by the flood. However, internal conflicts between the households who joined the project and project coordinators resulted in their ending the project in 2015, followed by many households abandoning agriculture and focusing solely on timber to generate cash. Increased maintenance costs due to damaged skid roads and already felled timber left in the forest in 2014 caused significant income losses due to low timber revenues. Even though affected households suffered considerable income losses, their cooperation skills, as a component of self-organization, illustrate how participation in community forestry in Santa Rosa de Maravilla consolidated the horizontal connectivity among households. The high amount of social capital that was formed seemed a result of the inter-household cooperation necessary for community forestry activities related to timber extraction; something also confirmed in other studies on social capital among small-scale forestry groups (Guillén, Wallin and Brukas 2015) .

The latter finding mirrors the literature on the role of social capital as a prerequisite for (Pretty and Ward 2001) and a product of collaborative natural resource management (Fernandez-Gimenez, Ballard and Sturtevant 2008).It can be perceived as a risk management strategy and adaptation to climatic hazards (Adger 2003). There is broad agreement on the positive contribution of social capital to mitigate the impact of climatic hazards and contribute to disaster resilience (e.g., Burton and Kates 1963; Adger 2003; Aldrich 2011; 2012; Usamah et al. 2014;

Lo et al. 2015). MacGillivray (2018), however, suggests the need to be cautious and critical and not to focus only on the density of network ties but also on their content. MacGillivray (2018) divides the concept of social capital into bonding, linking, and bridging capital. In the case of the three Tacana communities, bonding capital, defined as interactions between family, friends, and neighbours, played an important support function. However, despite the linked cooperation capacity, timber dependence made households less resilient because of increased production costs and the lack of alternative sources of income for timber strategy households. Thus, to improve the resilience of families specialized in timber extraction, only promoting alternative sources of income for times when the forest is inaccessible can increase resilience. Local primary and secondary processing of timber could help to bridge times of limited access and, at the same time, promote local value creation. Currently, mainly unprocessed logs are sold from the communities.

A possible explanation for the correlation between subsistence income from the forest and human capital might be the larger household size in terms of members and, thus, the related labour-power. Physical capital is usually the result of a financial investment such as in a gas stove, a vehicle, or a tin roof. The latter investments might be harder to undertake; the higher the ratio subsistence to cash income. Commercialised NTFP like wild game and fish contributed prominently to reducing vulnerability, and the consumption and sale of the game also positively influenced resilience. This underlines the importance of wildlife for the Tacanas in general, especially during harsh times. Indigenous communities in the Amazon have a long hunting tradition, and hunting for subsistence purposes is not generally seen as unsustainable (Alvard et al. 1997). The traditional ecological knowledge held by Tacana communities helps to regulate and manage their territory as they have an intrinsic interest in the health of their forests and their wildlife population. However, the commercialisation of game, also within the community, and the possible intensification of hunting after a shock, such as an extreme weather event, can seriously threaten healthy wildlife populations, cause defaunation (Krause and Nielsen 2019), and affect forest regeneration and integrity (Ghazoul and Sheil, 2010; Coad et al. 2013).

3.5.3 Cash and subsistence income and implications for vulnerability and resilience

Total and cash income contributed positively to increasing LRI and decreasing LVI. Separating between the share of cash and subsistence income shows vulnerability increases with a decreasing share of cash income. Generally, poor households were significantly more vulnerable to the flood than better off, confirming the expected link between vulnerability and poverty (IPCC 2014). Our results demonstrated the strong exposure to weather influences: many income-poor households are farm households and experienced high crop production losses. Also, houses of low-income families often had a thatch roof, which significantly more often appeared affected than houses of wealthier households, often covered with a tin roof. The lack of financial capital (cash) increased the household's vulnerability and can risk the creation of an irreversible poverty trap (Holling 2001). Poor initial livelihood conditions with an economic shock, such as the flood, can hinder households from crossing the threshold to overcome a low-level state and exit the poverty trap (Berhanu and Fayissa 2009).

On the other hand, households with higher shares of subsistence income sustained closer sharing networks and social relationships, including self-coordination of activities. This shows the vital role social capital plays in contributing to resilience. Our results demonstrate the link between low income and vulnerability of the selected households in the TCO, results that align with experiences from other regions worldwide (IPCC 2014).

3.5.4 Critical reflections on the novel methodological approach to resilience and vulnerability estimation

For the first time, a theoretical resilience framework (Ifejika Speranza, Wiesmann and Rist 2014) was combined with a pragmatic indexing method (Hahn, Riederer and Foster 2009; Panthi et al. 2016) to calculate LRI and LVI. The selected indicators are based on site-specific considerations, allowing for empirical realities, and on indicators shown as relevant in studies, implying a subjective bias may be possible in the outcomes of the analysis. Similar vulnerability and resilience index studies (Hahn, Riederer and Foster 2009; Panthi et al. 2016) have different indicators, meaning that comparisons between studies can only cautiously be made. However, if the same indicators are used, this method allows an analysis of variances in LVI or LRI within one region. Hahn, Riederer and Foster (2009) and Panthi et al. (2016) used analogous methods to compare vulnerability between communities, summarizing the vulnerability of different households as a community-level outcome.

In contrast, this study recognizes the heterogeneity of households and, for the first time, compares and considers variations within a community. A critical point of discussion is the contribution of each indicator to the LRI or LVI; as we decided to keep equal weighing between all components and between all contributing factors, some indicators have a higher impact than others. However, equalizing indicators would implicitly judge the degree of influence of the indicator, component, and contributing factor (Eakin and Bojórquez-Tapia 2008), which was to prevent. A possible strategy to bypass this dilemma could be reducing indicators to one per component or contributing factor, which would need to be evaluated case by case whether it is feasible for the respective study. Our results also suggest that the livelihood vulnerability index (Hahn, Riederer and Foster 2009) should be used with caution. Generally, increased sensitivity would reduce vulnerability when the adaptive capacity factor is numerically higher than the exposure (Panthi et al. 2016). Therefore, it is recommended to additionally analyse and compare all contributing factors (EX, SE, AC) separately, as we did. All standardized indicators and calculations are relative, thus providing a comparative picture of vulnerability and resilience within the community studied over a specific period. Last but not least – LRI and LVI are livelihood strategies and extreme weather event-specific (here heavy precipitation and consequent flooding). They cannot be generalized as resilience or vulnerability to the impact of climate change as such.

While acknowledging the methodological limitations of this study, composite indexing of each component and contributing factor provides a simple and pragmatic method to enable a relative comparison of vulnerability and resilience between households in a specific social-ecological landscape.

3.5.5 Implications of the policy framework for current conditions of resilience and vulnerability in the TCO Tacana

The implications of the current policy framework for the three main natural resources-related livelihood activities enhancing resilience (hunting, cattle ranching) and lowering vulnerability (hunting, fishing) of Tacana households are discussed.

Hunting

The present analysis results showed that hunting is an important livelihood contribution and safety net in case of emergency. Ecological sustainability of small-scale and subsistence hunting in the Amazon has been the subject of comprehensive discussions (Robinson and Redford 1991; Alvard et al. 1997; Peres 2000; Krause and Nielsen 2019). Aspects, such as permanent wildlife monitoring to inform local land-use plans, decisions, and management are critical first, to avoid adverse long-term impacts of hunting on the ecosystem, and second, to contribute that hunting remains a stable fall-back option in case of a (climatic) emergency (Noss, Cuéllar and Cuéllar 2004).

National policies (i.e., Law °1333 Gobierno de Bolivia 1992; Law °3048 Gobierno de Bolivia 2017a; the Biodiversity Strategy and Action Plan, Ministerio de Medio Ambiente y Agua and Estado Plurinacional de Bolivia 2018 and Decree °4489 Gobierno de Bolivia 2021) emphasize the importance of conservation and sustainable management of wildlife and prevent trade in threatened species. However, the reviewed operative territorial plans (departmental and municipal), if at all, only consider the sustainable management of Caiman (*Caiman yacare*).

Participatory wildlife monitoring in the TCO Tacana with the support of the Wildlife Conservation Society is practised since 2001, and the TCO disposes of a Wildlife Management Plan. However, these regulations are only TCO-internally on the local level and external, threats, such as forest clearing and illegal hunting by extractive outside colonist settlements (Painter, Duran and Miro 2011; Müller, Pacheco and Montero 2014), contribute to habitat fragmentation, loss, and wildlife population decline and thus threatens ecological sustainability livelihood and resilience of the Tacana that goes beyond the local level. Hence, sustainable and integrative wildlife management and monitoring need to be acknowledged in higher-level strategies and operative plans such as in the PTDI (municipal and departmental), contingency and recovery plans, and forest management plans. This is particularly important as the TCO Tacana I is situated in the buffer zone of the Madidi National Park, the most biodiverse natural area in the world (WCS 2018).

Fishing

For some river-side communities in the TCO Tacana, such as Buena Vista, the dependence on fish is high (Tschirhart 2011; Bauer et al. 2018). Fishing also served as a fall-back option during the extreme weather event.

Fish monitoring is an integrative part of the participatory wildlife monitoring and management plan in the TCO Tacana. The national development plans, the sectoral plans of agriculture, and the La Paz department's development plans include considerations for fisheries management and commercial fish production. The two integrated territorial development plans elaborated at the municipal level—for Ixiamas and Rurrenabaque—highlight the importance of fishing for the local livelihoods yet fail to devise specific strategies for monitoring and regulation besides suggesting action lines to develop some fish farming for complementing local incomes.

Related to the national focus on economic growth, two external threats to the main livelihood of fish-dependent communities around the Beni river further underline the need for integrative management and environmental safeguards:

First, gold mining in the upper Beni river basin and consequent mercury contamination has taken place since the 1970 s (Maurice-Bourgoin et al. 1999). Recent governmental initiatives approve the extension of gold mining permits in the Tuichi river (CEDIB 2021) running through the Madidi National Park and the Protected Area Pilon Las Lajas and discharging into the Beni river. Bolivia has the largest mercury import worldwide (WITS 2019) and increasingly expands its gold exploitation, also related to Covid-19 recovery (CEDLA 2021). Despite ratification of the Minamata Convention on Mercury in 2013 (Ley N° 759, Gobierno de Bolivia 2013), uncontrolled mercury use is causing contaminations to the environment and harming human health and livelihoods (Maurice-Bourgoin et al. 1999)[7]. Gold mining in the

7 Mercury is a persistent, bioaccumulative, toxic pollutant. When released into the environment, it accumulates in water-laid sediments, where it converts into toxic methylmercury and enters the food chain. Various earlier studies have shown the presence of mercury contamination along the Beni river, including the community of Buena Vista (Tschirhart et al. 2012, Maurice-Bourgoin et al. 2001). A recent study of the exposure of women in various Latin-American countries to mercury (Bell and Evers 2021) revealed an exposure of Indigenous Esse Ejje higher than 7-times of the threshold level of 1ppm of Mercury concentration. The study site was a community

Tuichi river is expected to worsen contamination in the Beni river and deliberately undermine the rights of residential Indigenous forest-dependent communities. In this way, Indigenous territories and national protected areas are weakened in favour of extractivism.

Due to the high risk of mercury poisoning, fishing as a livelihood and resilience strategy is not recommended for communities in contaminated areas (such as Buena Vista). Alternative livelihood strategies, also regarding climate change, require further investigation. Furthermore, permanent mercury monitoring systems need to put in place and safeguard measures for resident population and biodiversity integrated into the Tacana territorial management plan, municipal and departmental PTDIs while ultimately a governmental commitment to sustainable mining and respect of national Indigenous and protected areas is a prerequisite.

Second the potential construction of a hydroelectric dam. *El Bala* is a project of national interest and priority (Ley Nº628, Gobierno de Bolivia 1984; Ley N°1887, Gobierno de Bolivia 1998) to gain energy sovereignty. The dam project will potentially have significant effects on the water and ecological dynamics of several large rivers, including Beni. Radical changes in fish population are predicted, as 85 % of the fish consumed by Tacana people are migratory and would be adversely affected in their annual upstream cycles. Even a transfer system for migratory species would not exclude severe changes, as the construction period of dams alone will alter the natural behaviour of these species and will force them to seek alternative routes (Miranda-Chumacero et al. 2020), threatening fish supply for local livelihoods.

Cattle ranching

We revealed that small-scale commercial cattle ranching contributes to increasing household resilience. Cattle ranching is promoted as one of the main economic strategies in the Patriotic Agenda 2025, the National Development Plan 2016-2020, and the agricultural sector development plan. At the municipal level, plans also stress cattle ranching and commercial crops such as sugar cane, cocoa, and rice for income generation and rural development, whilst not considering potential conflicts with existing livelihood strategies given that ranching constitutes one of the major drivers of deforestation (Müller, Pacheco and Montero 2014). Despite being a strategy contributing to household climate resilience, the adverse environmental side-effects need to be considered holistically in cross-sectoral management strategies.

close to Rurrenabaque living of fish from the Beni river. The contamination was considered very high, and immediate action is required to stop further environmental contamination, causing a severe impact on the entire socio-ecological system Madidi Nationalpark and Indigenous communities (Bell and Evers 2021).

3.6 Conclusion

Increasing concern has been expressed about the vulnerability of natural resource-dependent and Indigenous communities to global climate change and its consequences. Understanding how livelihoods at a household level respond to extreme weather events and what makes them vulnerable and resilient will facilitate policymakers to develop strategies that enhance the livelihood resilience of forest-dependent Indigenous households and reduce their vulnerability. This article has provided in-depth insights into how different livelihood activities, levels of forest resource dependence, and sustainable livelihood capitals used by Indigenous households shaped their livelihood vulnerability and resilience to an extreme precipitation event. Our results show that income activity choices influence households' livelihood resilience and vulnerability indexes. High resilience was related to hunting and cattle. A low vulnerability correlated with the sale of game and fish and receiving a wage. The results also underline the critical role social networks play for low cash income and collaboration for timber households, mutual support and thus enhanced resilience. For example, participation in community forestry activities consolidated horizontal connectivity among households and created social capital in the community.

This paper reviewed key policies and aspects potentially affecting livelihood resilience and vulnerability from a local perspective. The regulatory frameworks and policies for addressing climate change have stressed risks prevention but are associated with responses to natural disasters and severe climate events. Mechanisms to improve the resilience and adaptative capacities of forest-dependent local populations whose livelihoods are affected by climate change are not in place. National development policies indicated prioritization of economic growth based on strengthening the energy, agro-livestock, and tourism sector, and boosting oil and mining sectors with industrialization (Gobierno de Bolivia 2015, Gobierno de Bolivia 2016) and tend to consider non-commercial support economies as a lower priority. Some of these priorities (mining, energy, ranching) may threaten livelihood resilience and increase the vulnerability of forest-dependent Indigenous peoples and their local economies in lowland La Paz.

We revealed the significance of anchoring sustainable natural resources management strategies at all policy levels as a prerequisite to forest health and livelihood resilience of forest-dependent Tacana households. Strengthening intra-and inter-communal bonding as a local adaptation strategy can increase short-term resilience. However, the external pressure on forest resources, including fish, requires a holistic and cross-sectoral focus on livelihood resilience in national adaptation strategies. Inclusive risk management approaches need to be developed in a participatory manner and should have an integrated social-ecological focus to ensure adaptive resource management and avoid adverse spill-over effects.


4

Chapter IV

PERCEPTION MATTERS: AN INDIGENOUS PERSPECTIVE ON CLIMATE CHANGE AND ITS EFFECTS ON FOREST-BASED LIVELIHOODS IN THE AMAZON

4 PERCEPTION MATTERS: AN INDIGENOUS PERSPECTIVE ON CLIMATE CHANGE AND ITS EFFECTS ON FOREST-BASED LIVELIHOODS IN THE AMAZON[8]

T. N. Bauer , W. de Jong, V. Ingram

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.

Keywords:

Forest communities; coping; methodology; social-ecological system; traditional ecological knowledge

8 This chapter is based on the paper published as Bauer, Tina N., Wil de Jong, and Verina Ingram. 2022. "Perception Matters: An Indigenous Perspective On Climate Change And Its Effects On Forest-Based Livelihoods In The Amazon". *Ecology And Society* 27 (1). doi:10.5751/es-12837-270117.

4.1 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 unfavourable economic, social, and political conditions (Ford 2012; Wildcat 2013; Savo et al. 2016; Belfer, Ford and Maillet 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, Hutjes and Kabat 2013a; 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, Buck and Katila 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?

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; Ruiz-Mallén, Fernández-Llamazares and Reyes-García 2016). 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, McKey and Aumeeruddy-Thomas 2004). Our study acknowledges explicitly intra-communal heterogeneity of livelihood strategies and its relevance in climate change coping by focusing on responses of households.

4.2 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, Alam and Mushtaq 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, Brockhaus and Locatelli 2011; 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, Subramanian and Hiemstra 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, Hesseln and Johnston (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, Nordi and Alves 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, Chiang and Cane 2004; Alves and Barboza 2018). The observation of animals, their behaviour, 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. 2015a). At the same time, however, evidence shows that TEK related to agricultural practices, calendars, and bioindicators is eroding (Kronik and Verner 2010; Garteizgogeascoa, García-del-Amo and Reyes-García 2020), and biocultural diversity is declining (Loh and Harmon 2014). The adaptive capacity of TEK may be challenged by the decreased intergenerational sharing (Aswani, Lemahieu and Sauer 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. 2015a). 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, Hesseln and Johnston (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 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.

4.3 Methods

4.3.1 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 (Figure 2) 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 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).

4.3.2 Data collection and analysis

Mixed methods were used to generate four datasets (Table 13): 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.

Table 13. 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?

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

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.Table 22), as well as total annual, monthly precipitation rate, and monthly precipitation days (Appendix.Table 23) 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.Figure 40. 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 13). 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 behaviour, 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, Mahajan and Tengö 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).

4.4 Results

4.4.1 Perceptions of changing weather patterns

Table 14 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 (Figure 13), while the perception of colder temperatures (4%) was not confirmed, neither for average nor for extremes.

Table 14. 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)	

Table 14. 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. (*continued*)

Perception	N of households	N of households responding specifically	Responses	% of N responding households
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

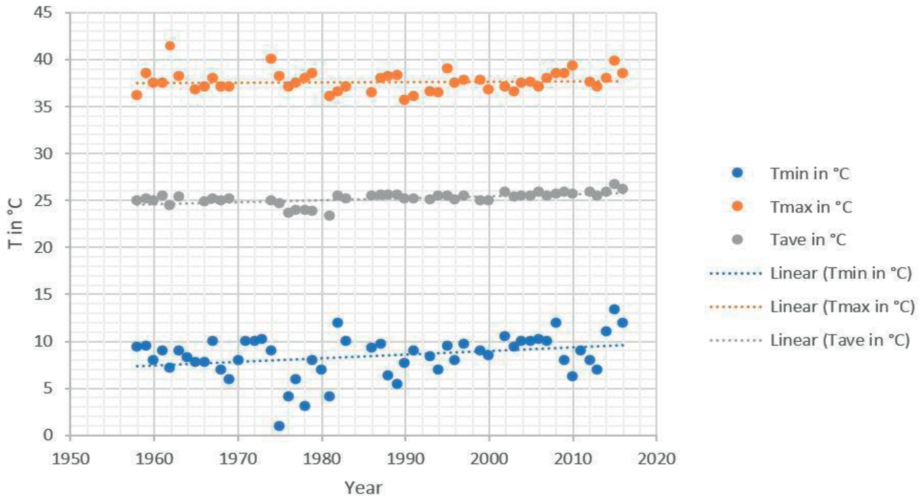


Figure 13. Climatic trends (annual average temperature, yearly maximum temperature, yearly minimum temperature) in °C for the years 1958–2016 for the closest meteorological station, Rurrenabaque. Data source: SENHAMI (National Meteorological and Hydrological Service)

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 (Figure 14).

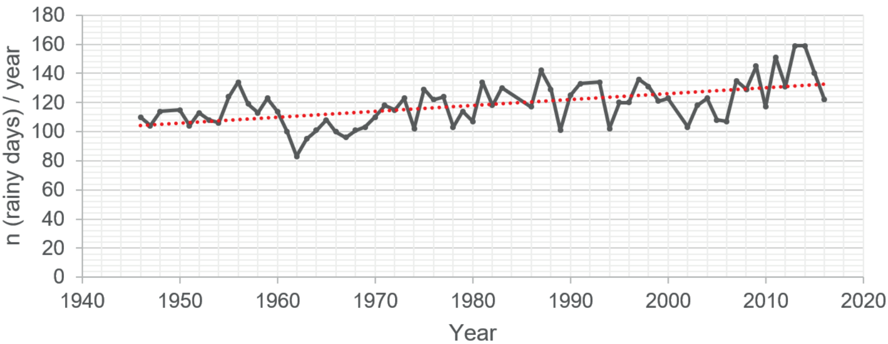


Figure 14. Climatic trends (number of rainy days/year) for the years 1946–2016 for the closest meteorological station, Rurrenabaque. The dotted line shows the line of best fit. Data source: SENAMHI (National Meteorological and Hydrological Service)

The perception of 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 (Figure 15). 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.Table 22 and Appendix.Table 23.

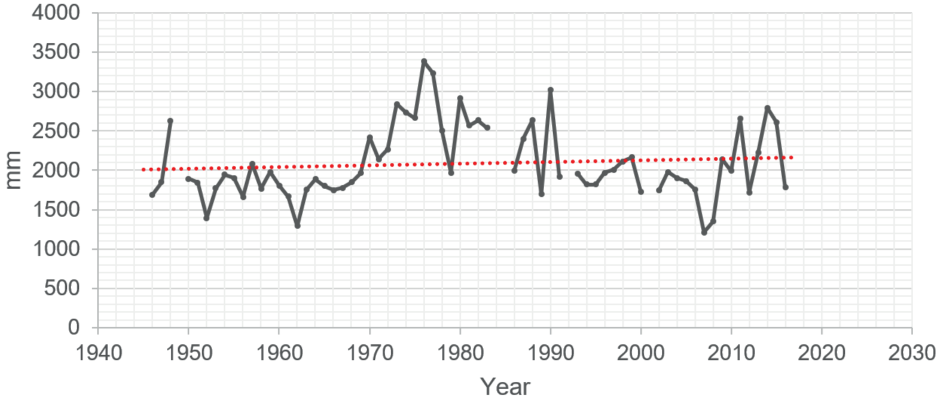


Figure 15. Climatic trends (annual cumulative precipitation) in mm for the years 1946–2016 for the closest meteorological station, Rurrenabaque. The dotted line shows the line of best fit. Data source: SENAMHI (National Meteorological and hydrological Service)

4.4.2 Traditional weather indicators

Table 15 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.Table 24. Table 15 takes into account overlaps between general bad weather predictors and the individual predictors of rain, wind, *sur*, and thunderstorms.

Table 15. 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

Table 15. Summary of 43 (38 unique) phyto-, zoo-, atmospheric (atmo), astronomic (astro), and human (hum) weather-related indicators stated by Tacana households (*continued*)

Type	Weather indicator	N
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

4.4.3 Affected livelihood capitals

All households' responses (dataset 4) relate to livelihood aspects affected during a specific extreme weather event in 2014. Figure 16 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 (Figure 17), firewood, and forest and fruit tree plantations; 28% presented damage to their physical capital, e.g., houses, road, produce (Figure 18), 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 the school was taken, see Figure 19). 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%).

Figure 16. Forty-four household responses (interviews and photographs) on aspects that were negatively affected by the extreme weather event of 2014, summarized in livelihood capitals

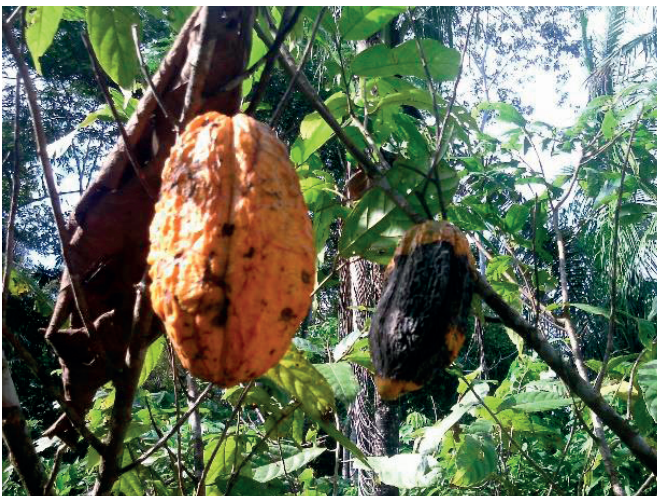


Figure 17. Cacao fruit (taken by a household in San Silvestre)

Figure 18. Produce, prepared for food (taken by a household in San Silvestre)

Figure 19. School, as a symbol for education (taken and explanation given by a household in Buena Vista)

4.4.4 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 16). Of the 44 households, 29 (65%) reported social capital related strategies, mainly external emergency support of food, tools (Figure 20), livestock, and seedlings (17 households, 39%), and family support (8 households, 18%; Figure 21) and community support (4 households, 9%).

Figure 20. Tool donations (social capital)

Figure 21. Family support (social capital), persons intentionally blurred

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 (Figure 22), reseeding (Figure 23), and selling timber, cacao (Figure 24), surplus crops, and the naturally higher situated fields and houses. Human capital strategies (4 households, 9%) included self-organization (3 households, 7%; Figure 25), 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.

Figure 22. Palm tree used for palm hearts (natural capital)

Figure 23. Corn seeds, a symbol for repeated farming after crop damage due to the extreme weather event (natural capital)

Figure 24. Selling cacao beans (natural capital)

Figure 25. Photograph portraying the household head as self-organization (human capital); person intentionally blurred

Table 16. 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%				

4.5 Discussion

4.5.1 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 observations, a neighbouring 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).

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, Lindner and Pretzsch 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.

4.5.2 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. 2015a), 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, Kassa and Schmiedel 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. 2015a). If environmental changes are now progressing faster than TEK can adapt, the adaptive capacity of Tacanas' SES might be compromised, as described for neighbouring Tsimanes in Fernández-Llamazares et al. (2015a). 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, Gearheard and Barry (2010), and Tanzania (Chang'a, Yanda and Ngana 2010).

Literature shows that TEK can provide key insights for the adaptability and resilience of natural-resources-dependent communities (Fernández-Llamazares et al. 2015a; 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.

4.5.3 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 labour 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, Corbera and Reyes-García 2013) .

4.5.4 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 neighbours 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).

4.5.5 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.

4.6 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, Sherren and Thornton 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 behaviour 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, Sherren and Thornton 2020). Such synthesized and integrated knowledge can foster social and ecological resilience (Eriksen, Brown and Kelly 2005; Chia et al. 2015; Sterling et al. 2017).

5

Chapter V

ADJUSTMENTS IN INDIGENOUS PEOPLES´FOREST USE AND MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE – A GLOBAL SYSTEMATIC LITERATURE REVIEW

5 ADJUSTMENTS IN INDIGENOUS PEOPLES´ FOREST USE AND MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE – A GLOBAL SYSTEMATIC LITERATURE REVIEW[9]

T. N. Bauer

ABSTRACT

The global diversity and variation of forest use and management responses of forest-dependent Indigenous peoples to climate change remain poorly understood and lacks synthesis. Yet, such scientific insights are essential for informed policy decisions and inclusive mitigation strategies. An evidence-based framework can ensure that policy questions are sustained by science to better inform resulting policies. Through a systematic literature review, forest-dependent Indigenous peoples´ responses to climate change and extreme weather events were analysed and the prevalence of the strategies, their drivers, and the role of sensitivity to climate change and traditional ecological knowledge (TEK) in forest use and management examined and quantified. Also, it was assessed how forest dependence and traditional knowledge are acknowledged in Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs). The results show knowledge clusters around coping and adaptation, mitigation, and joint strategies in North and South America and Asia. Reported Indigenous-driven coping and adaptation actions, all ex-post, were largely linked to their sensitivity to a changing climate and involved TEK. The diversity of applied strategies found, mostly related to non-timber forest products (NTFPs), comprised ecologically sustainable and unsustainable practices. Reported mitigation strategies, mostly Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) projects, were found to be ex-ante and driven mainly by external initiatives, largely omitting information on the sensitivity of the studied Indigenous group and involvement of traditional knowledge. Joint strategies seem to be a good compromise of participatory efforts linked to the integration of sensitivity of Indigenous peoples and TEK. Knowledge gaps include documented experiences from the African continent and forest-related resilient livelihood strategies. Future research should focus on participatory and sustainable climate measures, the role of TEK and the driver for the success of forest-related climate responses, and the potential effectiveness of joint adaptation-mitigation measures for forest-dependent Indigenous peoples on a global scale.

Keywords:
Indigenous forest management; climate policies; traditional ecological knowledge; adaptation; mitigation; SLR

9 An adjusted version of this chapter is accepted for inclusion in a Special Issue of the International Forestry Review on *Indigenous people and forests* and currently being copy-edited.

5.1 Introduction

Globally, 2.4 billion people depend on forests and forest products for their livelihood (FAO 2014), of which approximately 200 million people are of Indigenous origin (Chao 2012). Climate change and extreme weather events affect forest systems and their productive capacity (FAO 2013, Tian et al. 2016) and how forest-dependent people respond (Locatelli et al. 2010). Responses can be multi-faceted and vary in time scope, drivers, prior experience, and knowledge. For the time scope, coping strategies seek to overcome adverse conditions to return to basic functioning with a short-term vision (for example, one season). Coping strategies mainly refer to (unplanned) ex-post actions related to survival and can be linked to resource degradation and, in this way, undermine opportunities for adaptation in the future (Touza et al. 2021). Adaptation strategies aim to adjust to actual or expected climate changes and their long-term effects. Mitigation strategies aim to reduce climate change by managing its causal factors (IPCC 2012). Responses by forest-dependent peoples can differ in their driving forces; measures can be initiated and supported by external bodies such as NGOs, governmental institutions, and development cooperation or can originate intrinsically from a household or community initiative. Also, the extent to which different knowledge systems are used may define strategies. Petzold et al. (2020) show that Indigenous or traditional knowledge in adaptation strategies can play an important role in climate change adaptation by Indigenous peoples. Furthermore, the sensitivity to or perception of climate change is likely to impact the response towards it (McDaniels et al. 1996, Adger et al. 2009, Djoudi et al. 2013, Harvey et al. 2014). These and other factors may influence responses to climate change and extreme weather events and possibly the success of these strategies in the long run.

Scholars have analysed the impact of climate change on rural livelihoods (Agrawal and Perrin 2001; Krishnamurthy 2012; Alam, Alam and Mushtaq 2017; Bose 2017), the vulnerability of forest-dependent people (Eriksen, Brown and Kelly 2005; Nkem et al. 2013; Walton et al. 2016; FAO and CIFOR 2019; Smith and Dressler 2019; Choden, Keenan and Nitschke 2020; Thakur et al. 2020) and Indigenous peoples to climate change (Kronik and Verner 2010; Vidaurre de la Riva, Lindner and Pretzsch 2013; Loaiza, Nehren and Gerold 2015; Ahmed and Atiqul Haq 2017; Meldrum et al. 2018), as well as the evidence of the role of Indigenous knowledge in climate change adaptation (Petzold et al. 2020). There was a strong tendency to view Indigenous peoples more as passive objects and victims of climate impacts (Belfer, Ford and Maillet 2017), and only recently, the focus seems to turn to their active role in fighting climate change. For example, only in 2019, at the COP25, was the role in and contribution to climate change adaptation and mitigation of Indigenous peoples and local communities formally acknowledged in the adopted workplan. However, the Local Communities and Indigenous Peoples' Platform (LCIPP) had already been adopted at the COP21 Paris Agreement in 2015 (Figure 26). The COP25 was the first formal meeting in the history of climate change negotiations where Indigenous people's representatives had equal representation and authority with state parties for negotiation. After decades of struggles to be heard by states and politicians, this workplan recognizes the values and roles of Indigenous traditional knowledge and cultural practices to contribute to climate change resilience (IUCN 2019). Yet, published data on forest-dependent Indigenous people's active role in forest use and management in the context of climate change is limited, which challenges the design of interventions and policies, and might be a reason that this societal group risks being left behind in the context of the SDGs (FAO and UNEP 2020).

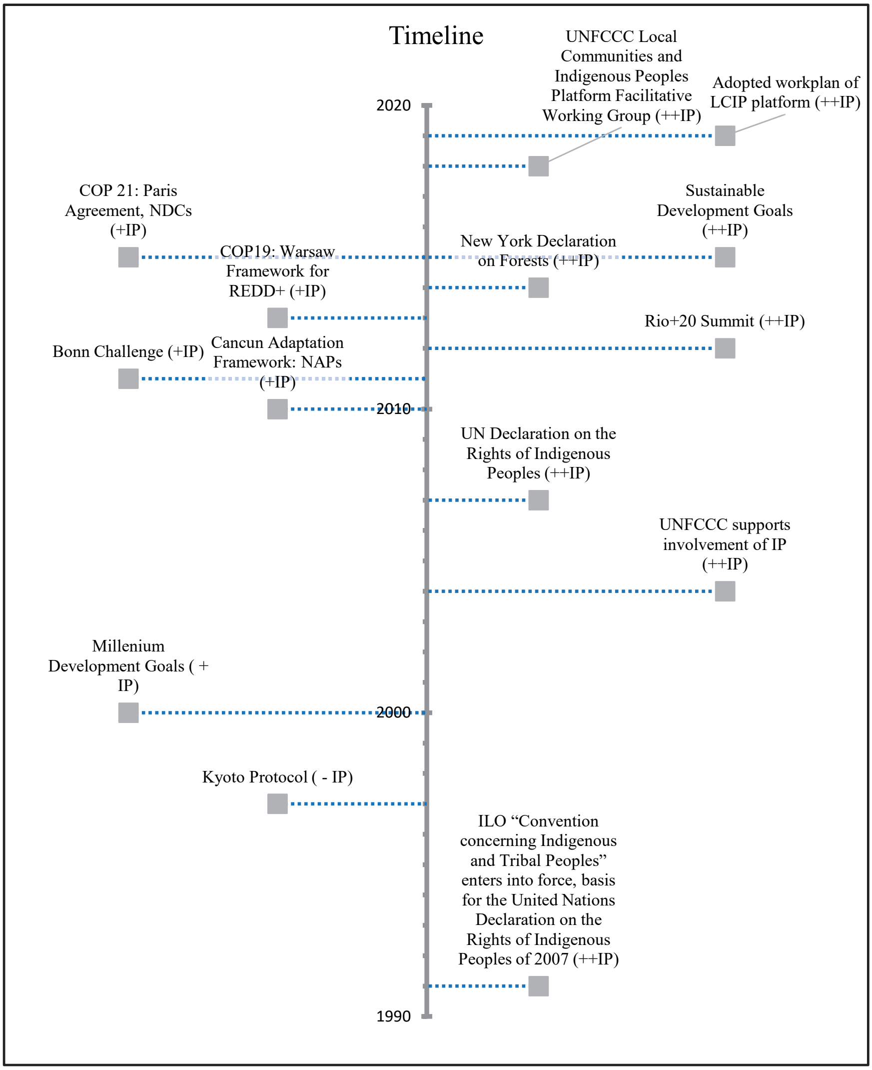


Figure 26. Timeline of Indigenous peoples´ involvement (++) and acknowledgement (+) into climate change-related policies

The global diversity and variation of forest use and management responses of forest-dependent Indigenous peoples to climate change remain poorly understood and lack synthetisis. Yet, such knowledge is essential for informed global policy decisions, as it can contribute to a framework for climate change adaptation favourable to forest-dependent people and inclusive mitigation strategies. However, climate policy questions are often holistic on general societal issues and thus rarely answered through individual research projects. Narrow scientific papers might lack relevance to the generic question, and possible inaccessibility might challenge policymakers and provoke mismatches between specific questions addressed by science and generic issues addressed by policy. An evidence-based framework, such as proposed by Pullin, Knight and Watkinson 2009 can ensure that policy questions are sustained by science and better inform resulting policies. In evidence-based frameworks, the key methodology consists of a systematic literature review of primary research publications (Pullin and Knight 2001; Pullin and Stewart 2006), providing the evidence on key policy issues which can guide decision-making and future research ((Pullin, Knight and Watkinson 2009).

The present systematic literature review addresses the gap mentioned above by providing a global overview of Indigenous peoples´ response strategies to a changing climate in forest use and management, the initiating drivers of these responses, the role of traditional knowledge and the acknowledgement of sensitivity therein. Such a review should evaluate the linkages between the drivers, the scope, and the integration of traditional knowledge in climate practices to assess if the generic type of responses can be recognized. If the analysis is then put into a policy context, it can be assessed how Indigenous and forest-dependent peoples and traditional knowledge are acknowledged in national climate policies, such as National Determined Contributions (NDCs) and National Adaptation Plans (NAPs). A synthesis can highlight existing evidence and research gaps, draw conclusions supporting Indigenous representation in global policy, and inform the development of policy frameworks and practices concerning Indigenous forest-dependent peoples.

5.2 Methods

5.2.1 Framing

An evidence-based approach for environmental management proposed by (Pullin, Knight and Watkinson 2009 was used to answer the research question and guide future research. In this way, potential strategies provided generic answers to the research question. The generic strategies consist of individual interventions identified through a systematic literature review. In a second step, those could be evaluated in terms of their effectiveness (not part of this paper).

A systematic literature review was conducted (see chapter 5.2.2.) to identify the existing body of research on Indigenous peoples´ forest use and management in the context of climate change and extreme weather events. The PIC_O (population, interest, context) tool for qualitative reviews was used (Munn et al. 2018) to frame the review questions. The population was defined as Indigenous people. The interest is the documented temporary or permanent adjustments in forest and forest product use and management, and the context is the effects of climate change and extreme weather events (CCEWE). In a second step, national climate strategies were analysed of the countries where the studies resulting from the systematic literature review were undertaken (see chapter 2.4.).

No official definition of *Indigenous peoples* has been adopted by any United Nations system body. Rather than defining Indigenous peoples, the UN (UNHCR 2013) proposes self-identification at an individual level and acceptance by the respective community. The term *Indigenous* is generic, and depending on the geographical, political, and scholarly context, terms such as *Native*, *Autochthonous*, *Aboriginal*, *First Nations* are used (Peters and Mika 2017). Besides self-definition, Indigenous peoples "…form at present non-dominant sectors of society and are determined to preserve, develop and transmit to future generations their ancestral territories, and their ethnic identity, as the basis of their continued existence as peoples, in

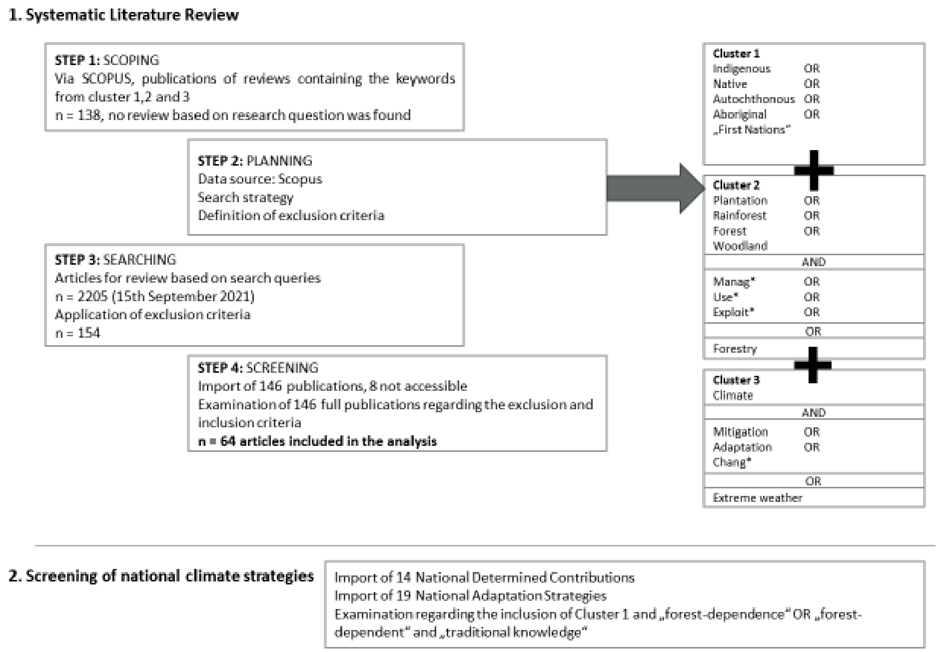


Figure 27. Study design: a systematic literature review (SLR) and consecutive screening of national climate strategies of the countries covered by the articles included in the SLR

accordance with their own cultural patterns, social institutions and legal system." (Martinez Cobo in UNHCR 2013, 6). The term Indigenous peoples was used throughout the article representing its synonyms.

5.2.2 Systematic literature review

Following the methodology proposed by Koutsos, Menexes and Dordas (2019), a qualitative four-step approach was applied (Figure 27). The individual steps are described below. No previous systematic reviews were found in Scopus based on the focused questions and applied terms.

Scoping

The scoping of this review is based on the overall objective to analyse the documented evidence of Indigenous peoples´ responses in forest and forest product use and management in the context of climate change and extreme weather events. Selective contextual factors, such as response time, driver, climate sensitivity and the involvement of traditional ecological knowledge (TEK) were considered. The following research questions (RQ) 1-7 seek to provide an overview of documented responses.

(1) What is the documented evidence for Indigenous peoples changing the use or the management of forest and forest products to climate change and extreme events?
(2) If adjusting, how (coping, adaptation, mitigation, or joint strategies) did the use or management of forest and forest products change?
(3) If adjusting, was it an ex-ante or ex-post response?
(4) If adjusting, was the adjustment self-driven (internally) or externally driven?
(5) Was the sensitivity of Indigenous peoples to climate change addressed?
(6) What was the reported role of TEK?
(7) Are there any underlying linkages between outcomes of the foregoing questions?

The verb a*djust* is used to comprise all types of activity changes, temporary adjustments or permanent changes, carried out or planned to adapt to or mitigate climate change or extreme weather events. Those activities should be linked either to forest resource use or forest management (FUFM). The definition of *forest* is adopted as given in the literature found. Forest use can comprise unsustainable ad-hoc exploitation of resources, while management usually follows a rather long-term strategy or plan. I will not further differentiate the adjustments found in this SLR into forest use or forest management as a clear distinction is not always possible for the provided level of detail in the reviewed literature. The changes can include coping (usually short-term), adaptation (long-term), mitigation, and joint strategies. The latter combines coping, adaptation, and mitigation measures with the linked objective. Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2007), while mitigations comprise actions that reduce greenhouse gas emissions. So can mitigation projects facilitate the adaptation of Indigenous peoples to climate change, while adaptation can increase the sustainability of mitigation projects (Locatelli et al. 2011). Strategies can be ex-post, in response to a specific climatic event, or ex-ante, in anticipation of an adjustment or a combination of both when strategies are based on past experiences but are continuously considered to adapt to the future. Concerning the driver, I differentiated between externally driven strategies (initiated by a body (governmental, civil society, research, cooperation) external to the Indigenous peoples; self-driven or internal strategies, and jointly driven (f. ex, as a combination of traditional and scientific knowledge).

The study combined the often interchangeably used terms Indigenous knowledge (IK), local knowledge (LK), and traditional (ecological) knowledge 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". As in this systematic literature review, original knowledge holders cannot be traced back; TEK is used as a collective term for local, Indigenous and traditional (ecological) knowledge.

Planning

After comparing suitable digital databases, the database chosen as the main source of the eligible studies was SCOPUS online. Queries were developed – shown in the clusters in Figure 27 - using Boolean operators in the advanced search tool of Scopus to identify articles related to Indigenous forest use and management and climate change.

TITLE-ABS-KEY ((indigenous OR native OR autochthonous OR aboriginal OR "first nations") AND (((plantation OR rainforest OR forest OR woodland) AND (manag* OR us* OR exploit*)) OR forestry) AND ((climate AND (mitigation OR adaptation OR chang*)) OR (extreme weather)))

For the selection of articles, the following exclusion criteria were set for reviewing the titles and abstracts:
(1) The abstract is not written in English
(2) The abstract does not concern forest management or use
(3) The abstract does not mention Indigenous peoples (or synonyms thereof)
(4) The abstract does not relate to climate change or an extreme weather event(s)

Searching

The queries developed in the search strategy (Figure 27) were executed, and the search history was saved in SCOPUS. This resulted in 2205 documents found (on September 15, 2020), for which the title and abstract were then reviewed to confirm that the search results concerned

Indigenous forest and forest products use and management in the context of climate change and extreme weather events. No additional searches were performed, or additional sources for identifying articles or articles were added manually. After the abstract review, 154 documents were retained for a full review.

Screening

Of the 154 pre-selected articles, 146 could be imported as full-text to Mendeley library, eight publications were not accessible to the author, and no duplicates were found. The full text of 146 selected articles was reviewed against the following criteria:

(1) The paper describes forest and forest product use and management by Indigenous peoples or synonyms
(2) The paper relates to climate change or an extreme weather event
(3) The paper describes either an existing strategy, an adopted measure, or anticipated adjustments in forest and forest product use and management

The full-text screening excluded 82 articles due to non-fulfilment of at least one of the abovementioned criteria; the final selection consisted of 64 articles. The criteria were established on the generic questions (who, what, when, where, why, how) for information gathering. Applying qualitative content analysis (Mayring 2000), all included articles were further examined regarding the documented study groups´ sensitivity to climate change, the driver of the adjustment, applied TEK, and the response time, type, and strategy used (Table 17). The different response types (coping, adaptation, mitigation) are stated as reported in the reviewed literature. Joint strategies were, if not stated directly, taken from the context of the article.

Table 17. Criteria and corresponding coding classification were used for the content analysis of the 64 publications

	Criteria	Coding Classification
1	Document type (RQ 1)	
2	Year (RQ 1)	
3	Country or region (RQ 1)	
4	Study group (Appendix.Table 25)	
5	Adjustment (RQ1)	Yes, no adjustment change anticipated
6	Generic response type (RQ 2)	Coping, adaptation, mitigation, joint strategy
7	Response strategy (RQ 2)	Specific measure
8	Response time (RQ 3)	Ex-ante (pro-active), ex-post (reactive)
9	Driver (RQ 4)	External, internal, no information
10	Climate change sensitivity of study group (RQ 5)	Yes, no, no information
11	Integration of TEK (RQ 6)	Yes, no, no information

Analysis

The data were extracted by coding the individual publications according to the criteria defined under *d)*. Multiple correspondence analysis (MCA) in XLSTAT was applied to the coded data to analyse potential underlying linkages in the data set (RQ7). MCA is a method that is commonly used to illustrate and analyse categorical data in social and environmental sciences (Greenacre 2009). MCA is employed for more than two (categorical) variables. The following variables were included: Generic response type, sensitivity, driver, TEK, and response time. The analysis was conducted along with groupings of variables of the different response types. The distance among dots refers to the degree of similarity (the closer the similar).

5.2.3 Screening of national climate policies

To complement and frame the applied climate practices, in a second step, the corresponding national climate policies of the countries that were covered by the systematic literature review were analysed regarding research question 8:

(8) What role do Indigenous peoples, forest dependence, and traditional ecological knowledge play in the domestic climate policies of the study countries?

National climate policies represent the country's commitments either in adaptation (National Adaptation Plans, NAPs) or mitigation (Nationally Determined Contributions, NDCs). The NAP is a country-driven process initiated under the Cancun Adaptation Framework in 2010. Countries elaborate and implement NAPs by identifying medium- and long-term adaptation needs and developing and implementing strategies to address those needs (UNFCCC 2021a). Submitted NAPs can be found here https://www4.unfccc.int/sites/NAPC/Pages/national-adaptation-plans.aspx.

Along with the Paris Agreement in 2015, countries are required to prepare, communicate and maintain nationally determined contributions (NDCs) that are intended to reduce national emissions and adapt to the impacts of climate change. Participating parties shall pursue national mitigation measures to achieve long-term goals (UNFCCC 2021b).

Submitted NDCs can be found here:

https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx

The screening of NDC and NAPs consisted of a thorough analysis regarding the inclusion of Indigenous peoples (Figure 27, cluster 1), forest-dependence (and related terms: forest-dependent, forest-dwelling, community forest), and TEK (and related terms: traditional, indigenous, ancestral knowledge) to examine their acknowledgement in national climate policies.

5.3 Results

5.3.1 General evidence

A total of 58 scientific journal articles, three book chapters, one commentary, one conference proceeding, and one review article were reviewed. The earliest study was published in 2006, analysing environmental changes in Boreal forests in Russia. The number of studies relating to the topic of FUFM and climate change has increased since 2016, not counting 2020 as a full year as the analysis took place in September (Figure 28).

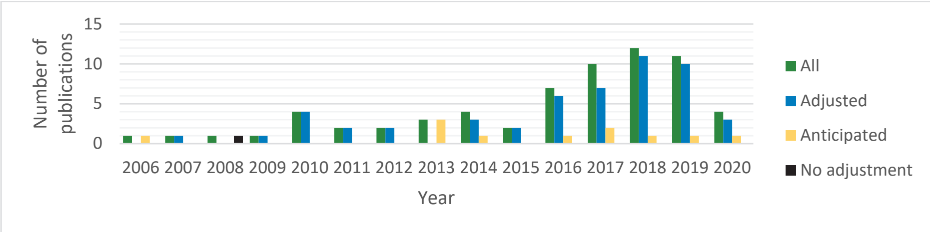


Figure 28. The number of publications on Indigenous peoples´ forest use and management in the context of CCEWE. The green bars represent the number of all publications per year; the blue bars represent publications with evidence on adjusted measures, the yellow bars show the number of publications with anticipated measures. A black bar indicates publication of the topic, but no adjustments were reported

Analysis of the publications' geographical range revealed two studies on Europe, four on Australia, four on Africa, 17 on Asia, 18 on North America, and 20 on South America. The review covered 24 countries and five regions. The country most researched was India, with five studies. 50 (78 %) articles documented adjustments in the use or management of forest and forest products in the context of climate change, 11 (17 %) articles included anticipated adjustments, two (3%) evidenced part of the study group adapting, some others not; and one publication (1,5 %) stated no adjustment in forest management, despite awareness of climate change effects. A complete list of included literature and details can be found in APPENDIX. Table 25.

Chapter 5

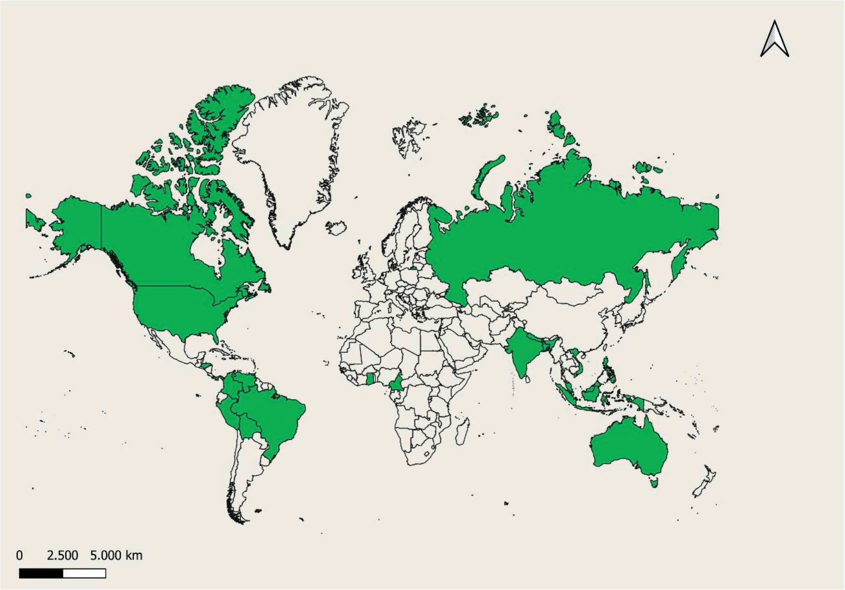


Figure 29. World map showing all countries included in the SLR with reported evidence of adaptation measures (including joint measures) in green. Details of all included studies can be found in Appendix.Table 25

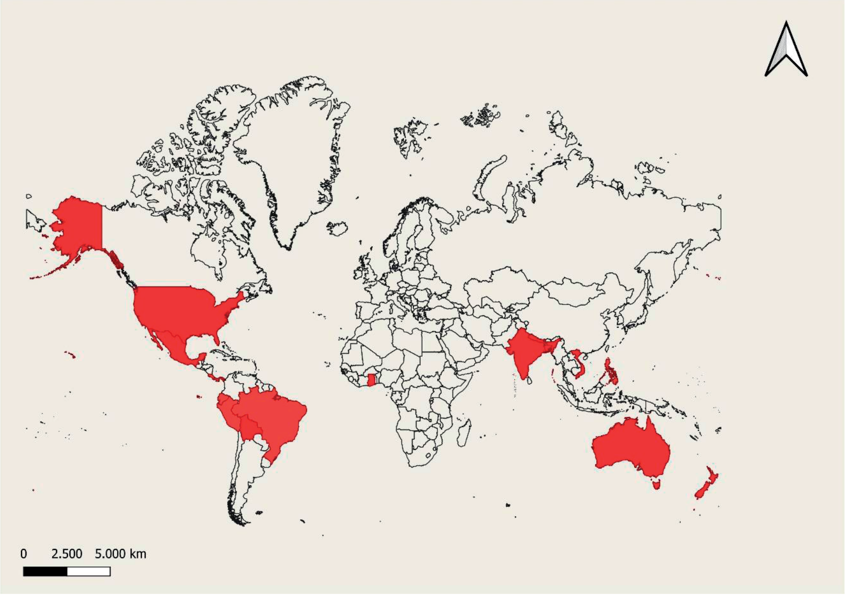


Figure 30. World map showing all countries included in the SLR with reported evidence of mitigation measures (including joint measures) in red. Details of all included studies can be found in Appendix.Table 25

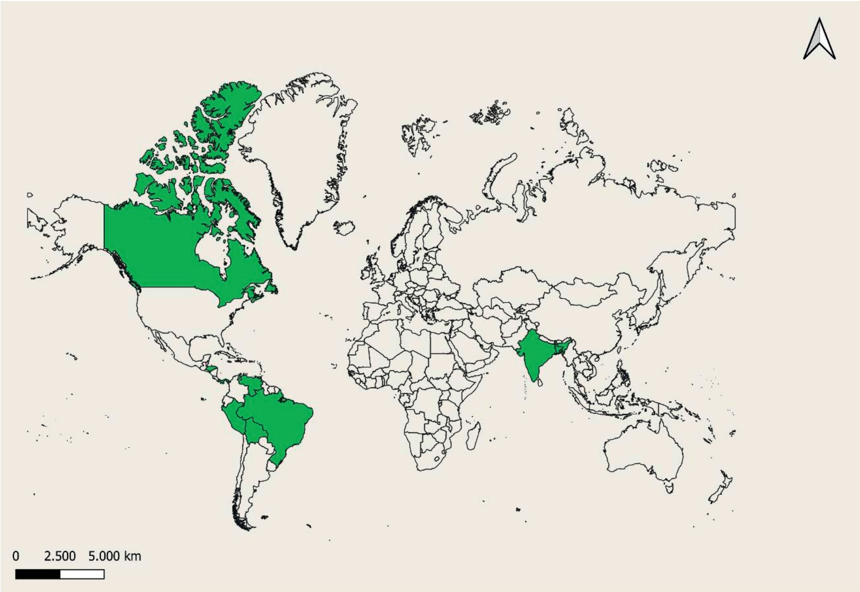


Figure 31. World map showing all countries included in the SLR with reported evidence of coping measures (including joint measures) in green. Details of all included studies can be found in Appendix.Table 25

5.3.2 Generic response type and strategy

Of the publications providing evidence of adjustments, including the two publications with mixed results (in total 52), 20 (38 %) presented pure mitigation, 13 (25 %) pure adaptation, and four (8 %) pure coping strategies. Eight publications (15 %) reported joint adaptation-mitigation, five (10 %) joint coping-adaptation and two (4 %) a coping-adaptation-mitigation strategy. A listing of all strategies per response type can be found in table 18.

The most popular coping strategy was crop diversification, the most applied adaptation strategy was to adapt hunting areas and species, the most common mitigation strategy was forest conservation and agroforestry, while 12 (60%) of all mitigation strategies were embedded into *Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries* (REDD+) projects. The most popular joint measure was agroforestry.

Table 18. Aggregated strategies of adjustments per response type. Only publications reporting adjusted strategies are shown; anticipated strategies are not included. Publication numbers are in brackets; details can be found in Appendix.Table 25

Generic response type	Strategy
Coping strategies	- Crop diversification (1; 34) - Increased Non-Timber Forest Product (NTFP) use (3) - Intensified forest clearing (28) - Agroforestry (34)
Adaptation strategies	- Adapted hunting areas and species (7; 26; 39; 61) - Agroforestry (10; 29) - Increasing forest cover (10) - Integration of TEK into fire management (12) - Adapted reindeer grazing (22; 26) - Application of non-Indigenous species and sites for livelihood and ethnopharmacopoeias (27) - Forest conservation (29) - Livelihood changes (49) - Unsustainable land use and overharvesting (46) - Relocation (52) - Reforestation of mangroves (60) - Adapted NTFP collection (61; 63)
Mitigation strategies	- Land titling (6) - Forest conservation (9; 13; 11; 21; 25; 58) - Reforestation (11; 20; 21; 59) - Community-based forest management (43) - Unspecified REDD+ measures (45; 47) - Monitoring: MRV (51) - Forest patrolling (19) - Anti-logging policy (31) - Controlled burning (35) - Agroforestry (41; 59; 53; 8; 16)
Joint coping-adaptation	- Local Institutional Innovation in Land Tenure (33) - Adapted reindeer grazing (57) - Adapted hunting species (64) - Reducing forest food (64) - Traditional fire management (5) - Education (17)
Joint adaptation-mitigation	- Traditional fire management (2; 54) - Forest monitoring (4) - Reforestation (4) - Agroforestry (23; 37; 48) - Diversification (23) - Organic Certification (23) - Increased timber extraction (23) - Migration (23; 24) - Plant protection (37) - Enrichment planting (42)
Joint coping-adaptation-mitigation strategies	- Agroforestry (38; 44) - Adapted Land-Use planning (38) - Shelterbelts (44)

5.3.3 Response time, driver, sensitivity, and integration of TEK

Among the 52 publications providing evidence of an adjustment in FUFM in response to climate change or extreme weather events, I found 41 publications (79 %) presented an ex-ante adaptation or mitigation strategy of the study group(s), eight studies (15 %) showed ex-post responses, three studies (6%) were both, reactive and proactive.

28 (54 %) of the 52 studies reported internally driven (initiated by the study group) response strategies, of which three were related to (but not driven by) a national or international project, such as REDD+ or development projects. 14 (27 %) studies were initiated by external drivers, of which 13 were part of projects, and one study comprised anticipated measures, without a project, related to Douglas fir management for teepee pole production affected by climate change in the USA (study number 36). Nine (17%) articles reported a mix of internally-externally driven responses, and one (2 %) publication did not provide any information related to the impulse of the strategy.

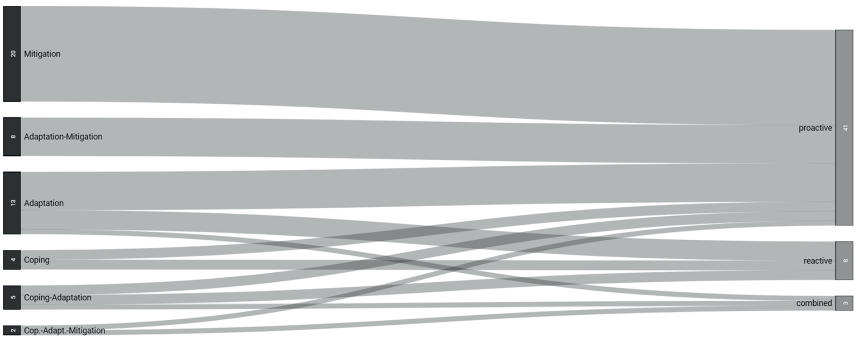


Figure 32. Sankey diagram of 52 publications of reported adjusted measures showing the link between the response type (mitigation, adaptation-mitigation, adaptation, coping, coping-adaptation, and coping-adaptation-mitigation) and response time (pro-active, reactive, combined)

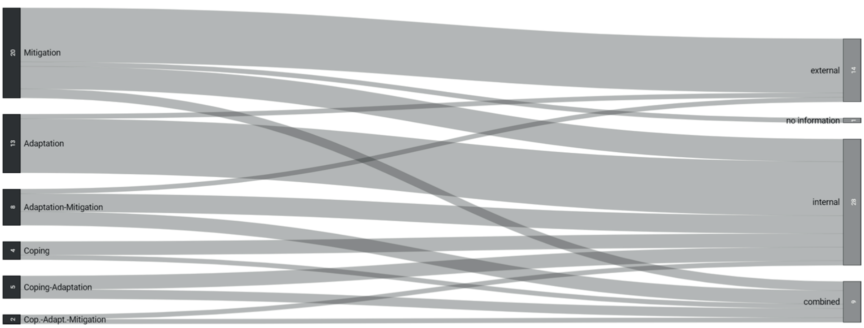


Figure 33. Sankey diagram of 52 publications of reported adjusted measures showing the link between the response type (mitigation, adaptation-mitigation, adaptation, coping, coping-adaptation, and coping-adaptation-mitigation) and the driver (external, internal, combined, no information)

29 publications (56 %) stated that the study group was sensitive to changing climate, earliest publication dates of 2010. One journal article documented climatic changes sensed by the study group, which did not coincide with weather records. 23 (44 %) publications did not provide any related information.

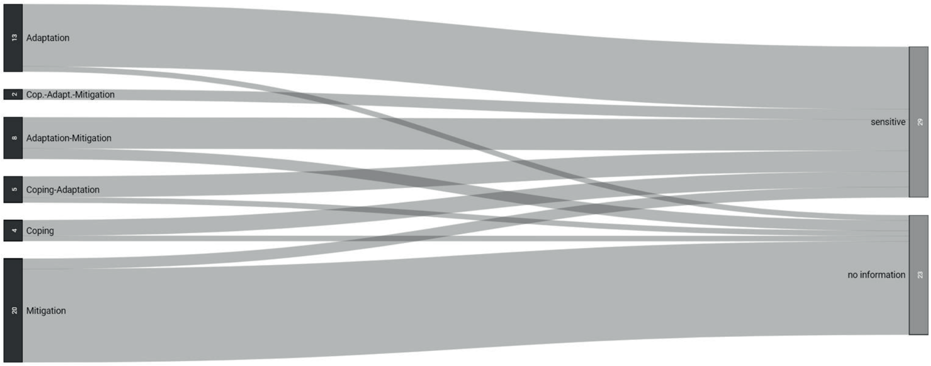


Figure 34. Sankey diagram of 52 publications of reported adjusted measures showing the link between the response type (mitigation, adaptation-mitigation, adaptation, coping, coping-adaptation, and coping-adaptation-mitigation) and the sensitivity of the study group to climate change (sensitive, no information)

In 25 (48 %) of the publications, the use of traditional ecological knowledge (TEK, in a broader sense as defined under 2.2.) in the context of the climate change adaptation or mitigation efforts was mentioned, of which in two (4 %) it only partly contributed. In two (4 %) of the documents, the authors stated that TEK was decreasing. In 23 (44 %), TEK did not play a role, or the papers did not provide any information.

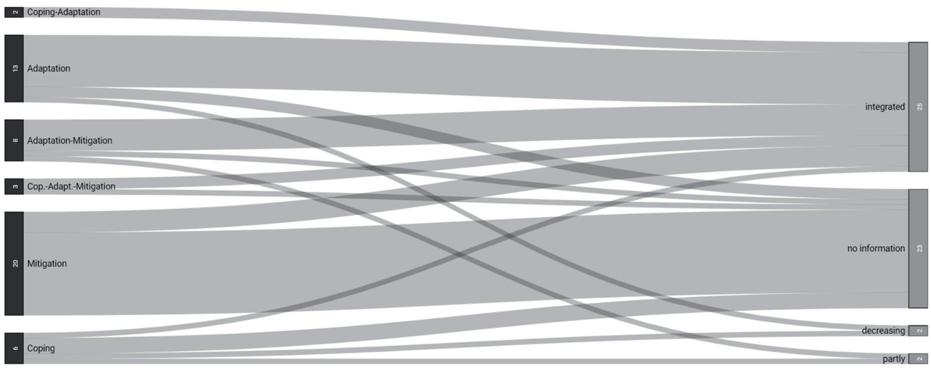


Figure 35. Sankey diagram of 52 publications of reported adjusted measures showing the link between the response type (mitigation, adaptation-mitigation, adaptation, coping, coping-adaptation, and coping-adaptation-mitigation) and the involvement of TEK (integrated, partly integrated, no information, TEK decreasing)

5.3.4 Underlying patterns of variables

By using correspondence analysis, linkages between the variables were analysed, such as example between the generic response type, mitigation, and its driver. Multiple correspondence analysis (MCA) was used to reveal patterns or associations between several variables. Detailed results of the correspondence analysis can be found in Appendix.Figure 41; a summary of all variables (MCA) can be found in Figure 36. Visual analysis of Figure 36 shows three patterns of groupings of closely related variables. Individual observations (articles) are represented by blue points, variable by red points. The distance between red and blue points estimates their similarity; articles with similar profiles are grouped, and so are their variables. The two dimensions are sufficient to retain 30,9 % of the data. Pattern 1 (quadrant 2, group on the left side): Articles documenting mitigation strategies are most correlated with an ex-ante approach, external drivers, or no information on the driver and related to no information in the article on climate sensitivity on the integration of TEK. Pattern 2 (quadrant 1, upper group right side): Adaptation strategies were reactive to an experience made like drought or flooding and grouped with internal drivers and integration of TEK. Pattern 3 (quadrant 4, lower group right side): Coping and Joint strategies were found close together. Coping strategies were found to be rather ex-post, jointly driven, with a slightly decreasing role or partly involvement of TEK and a climate-change sensitive study group. Mixed strategies were found to be combined or

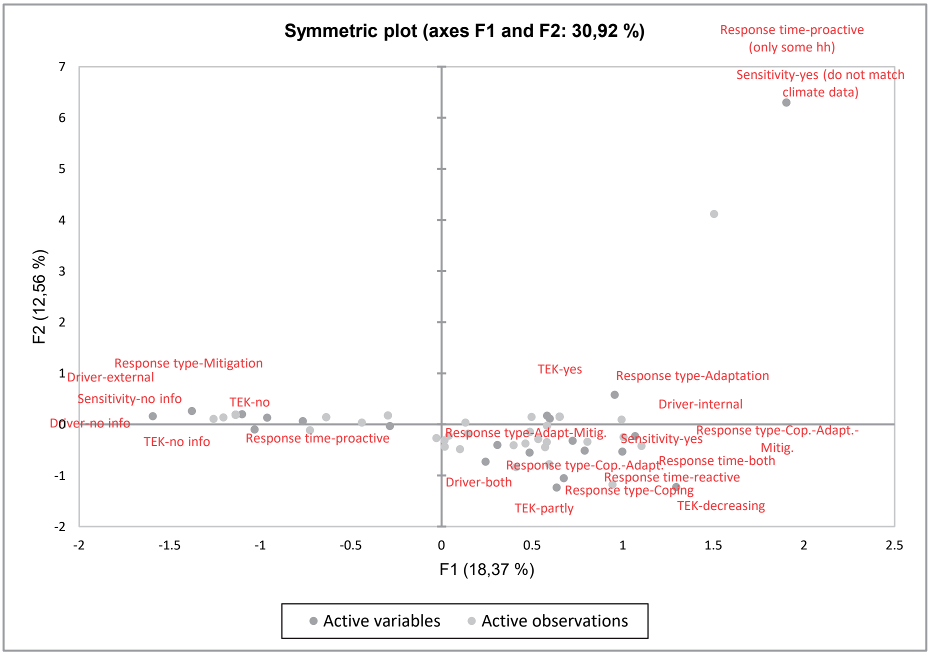


Figure 36. Multiple Correspondence Analysis of the variables response type, driver, integration of TEK, response time, and related articles (active observations). The dimensions represent the different variable categories

ex-ante, likely driven by collaborative initiatives, study groups were sensitive to climate change, and TEK was integrated mainly.

5.3.5 Domestic climate policies of the study countries

Corresponding to the 24 countries that were covered by the present systematic literature review, the National Adaptation Plans and strategies (NAPs) of 19 countries were reviewed, covering those countries where studies on adaptation measures were found (Figure 37, a detailed list can be found in Appendix.Table 26). The NAP of Vietnam was not published yet at the time of the review. The publication date of the NAPs ranged from 2011 (The Philippines) to 2020 (Russia). Forest-dependent people as a stake were mentioned in 12 (50 %) of the adaptation policies, of which in three NAPs it was stated only indirectly. This refers to Brazil's NAP mentioning "natural-resources dependent" (without explicitly stating forest) and Honduras´ and India's NAPs integrating community forestry. While the role of Indigenous peoples for climate change adaptation was defined in 17 (89%) of the NAPs, in the NAPs of India and Indonesia, the role of IP was omitted. 15 (79 %) of the NAPs included TEK to contribute to climate change adaptation. Panama, Indonesia, and Malaysia did not refer specifically to TEK.

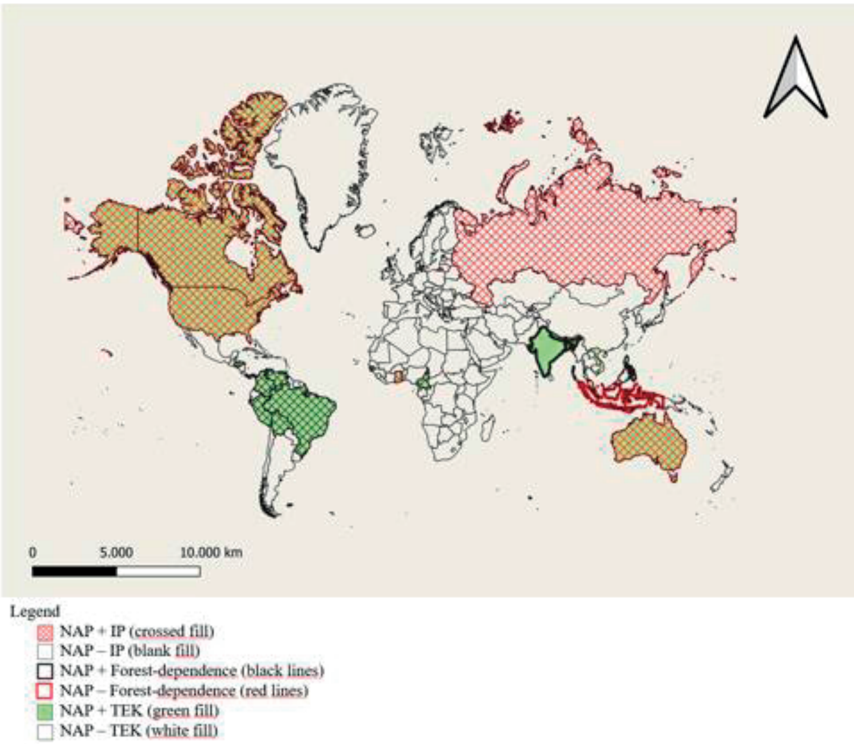


Figure 37. World map showing the countries and characteristics of respective NAPs: acknowledgement of Indigenous peoples (crossed); filled green (TEK), filled white (no TEK); black lines (forest-dependence), red lines (no forest-dependence)

Likewise, Nationally Determined Contributions (NDCs) of 14 countries were analysed, of which evidence of mitigation responses were found in the reviewed articles (Figure 38). NDCs covered the period 2016 to 2021. In six (43 %) of the 14 mitigation policies, forest-dependent people were considered, namely Bangladesh, Bolivia, Mexico, Nepal, Panama, and Vietnam. Evidence concerning the acknowledgement of Indigenous peoples was found in 11 (79%) out of 14 countries, not in Australia, Bangladesh, and India. The contribution of TEK was considered in nine (64 %) of the NDCs, not in Australia, Bangladesh, Brazil, Nepal, and Peru.

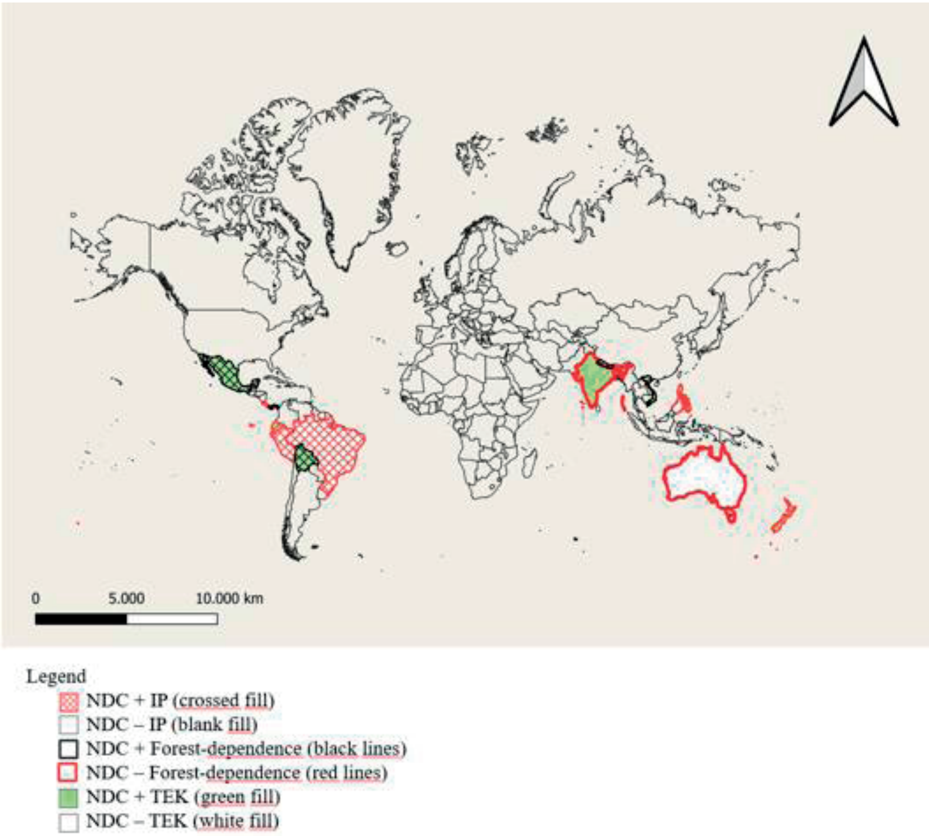


Figure 38. World map showing the countries and characteristics of respective NDCs: acknowledgement of Indigenous peoples (crossed); filled green (TEK), filled white (no TEK); black lines (forest-dependence), red lines (no forest-dependence)

5.4. Discussion

This paper provides the first systematic global evidence of forest use and management adjustments to respond to climate change by forest-dependent Indigenous peoples. The discussion will address the guiding questions 1-8 from section 2.2 based on the generic response types: coping, adaptation, mitigation, and joint strategies. The results indicate that it is a relatively recently analyzed topic. The number of published articles has only been growing since 2015, which might also be a reaction to international discussions on the involvement of Indigenous peoples in forest restoration and climate change-related frameworks like the Bonn Challenge and REDD+. The active role as a stakeholder increased with the Rio +20 Summit (2012) and in the New York Declaration on Forests in 2014. Yet, their active participation in the United Nations Framework Convention on Climate Change was only recognized in 2018 in the form of a Local Communities and Indigenous peoples Platform Facilitative Working with an adopted workplan in 2019 (Figure 26). The increasing interest in the involvement of Indigenous peoples on the international climate change agenda, events, and policies is well-reflected in the number of research papers studying Indigenous adaptation and mitigation measures. Geographically, Africa was found under-researched regarding forest adaptation and mitigation strategies by Indigenous peoples, which is most likely linked to the search term itself. According to the AFDB (2016), an objection has been raised among African countries to using the term Indigenous peoples. Most of the African societies existed before colonisation and are ´indigenous´ to Africa; according to Sena (2010, 2), the concept of self-determination proposed by the UN is viewed with opposition by most African states and seen "… as a vehicle aimed at dividing countries and to challenge government authority". The term is often associated with discrimination and marginalisation from governance but also with being holders of unique knowledge. Thus, climate change-related forest strategies practised by specific groups are likely to exist beyond this rather generic SLR.

5.4.1 Coping and adaptation

During the systematic literature review, it became evident that self-reported coping (short-term strategies) and adaptation (long-term strategies) were not always based on a common understanding and, on some occasions, used interchangeably. This is the reason for combining the discussion of coping and adaptation measures here.

The results of the SLR revealed a wide range of reported strategies; from forest destructive (28, numbers referenced in Appendix.Table 25 1) to protective (29), from livelihood changes (49) to adjustments in hunting behaviour (7, 26, 61) and NTFP use (3, 61, 63); from sustainable to unsustainable, from temporary to permanent. The present results also confirm the resource degradative character of some strategies, which can undermine sustainable opportunities for future adaptation (Touza et al. 2021). In particular, NTFPs, like game and ecological indicator species, were prominent for both coping and adaptation strategies. In years of crop failure resulting from droughts and floods, NTFPs can act as an "effective autonomous coping mechanism" (Shackleton 2014, 697) and safety net (Paumgarten 2005) by providing a source of food and income and thus contributing indirectly to food security. The wide range of coping and adaptation actions documented globally also demonstrates the wide range of positive or adverse socio-economic and ecological impacts that might be triggered by those responses to climate change and extreme weather events.

Both ex-ante and ex-post coping and adaptation measures were found: However, a large part of adopted adaptation strategies was proactive. This might indicate the adaptive capacity of forest-dependent Indigenous peoples and relate to the reported sensitivity of Indigenous peoples regarding changing weather patterns. All of the reported coping strategies, such as increased NTFP use and adaptation strategies, like agroforestry, were mainly driven by Indigenous peoples. Or, as in one case of Li and Ford (2019), forest clearing was intensified as a response to climate change and was reportedly driven by both internal (land scarcity and population growth) and as a result of external factors (governmental policies). The publications show that Indigenous-driven coping or adaptation actions reflect Indigenous peoples' sensitivity to a changing climate. On the other side, they also exemplify the ownership of the measures being taken.

The integration of TEK is found reflected in 79 % of the reviewed adaptation publications and in 79 % of the national adaptation policies (except those of Indonesia, Malaysia, Panama, and Russia). This confirms that Indigenous and local people´s traditional knowledge and cultural approaches are increasingly relevant for climate change coping and adaptation (Petzold et al. 2020). TEK was, however, thematised in related publications for Malaysia and Russia (Ahmad Wani and Ariana 2018; van Gevelt et al. 2019). In Malaysia, TEK has been recognized as a tool that promotes socio-ecological resilience (Hosen, Nakamura and Hamzah 2020), and scholars claim that TEK should be integrated into national climate adaptation policies ((Ariando 2018; Hosen, Nakamura and Hamzah 2020).

Indigenous and forest-dependent peoples were largely found integrated into NAPs, except for Indonesia, yet the SLR showed that the Bajo peoples play an important role in planting and preserving mangrove forests for climate change adaptation (60). Generally, the results of the SLR show that on a global scale, forest-dependent IPs actively cope and adapt to the effects of climate change, while there is still potential for countries, such as Indonesia, to acknowledge IPs stake in their NAPs. Omitting Ips' interest or local peoples´ dependence on natural resources could on one side, lead to hidden unsustainable adaptation strategies with adverse ecological and social consequences or, on the other side, the hidden potential for sustainable and culturally adapted strategies. Furthermore, aligning climate change and forestry policies with research to understand and conserve the conditions under which forests remain their function as safety nets seems crucial (Sills et al. 2011).

While TEK, with 79%, was rather prominently found in NAPs, the topic of forest dependence was present in 63 % of the NAPs. Interestingly, countries such as Canada, Ghana, and Indonesia did not emphasize forest-dependent people, yet participatory forest management and community forestry are often argued to be the most successful approach for climate change adaptation (Furness and Nelson 2012; Ayers and Forsyth 2009; Reid 2016). In other countries, such as Australia, Russia, and the USA, lower forest cover, numbers of forest-dependent peoples, land use, and other factors might define adaptation priorities in NAPs differently.

5.4.2 Mitigation strategies

In contrary to the ex-post coping and adaptation measures as a response to experienced hardship caused by climate change or an extreme weather event, all mitigation strategies were stated to be implemented ex-ante. External drivers (national and internal projects, governmental programmes) initiated the majority of mitigation strategies implemented by Indigenous peoples. This review shows that purely externally driven mitigation strategies comprised 92 % REDD+ related projects. Scholars have criticized the rather top-down government-led institutional measures of many REDD+ projects and the limited integration of local Indigenous narratives (Evans, Murphy and de Jong 2014; Bayrak and Marafa 2020). Furthermore, this is reinforced by the fact that all mitigation articles on REDD+ omitted information on the climate change sensitivity of the people implementing the measure. Integrating sensitivity surveys of (Indigenous) peoples involved into externally proposed mitigation measures can assist both the effectiveness and inclusiveness of interventions (Freitas, de, Bastos and Dias 2018; Wyllie de Echeverria and Thornton 2018).

According to Ramos-Castillo, Castellanos and Galloway McLean (2017), Indigenous peoples and local communities and their traditional knowledge have a pivotal role in successful mitigation efforts. It is further claimed that despite being vulnerable, Indigenous peoples are not simply victims of climate change but have an essential contribution to make due to their close relationship with their environment and role in the conservation of biodiversity. However, this role of Indigenous peoples was found less pronounced in mitigation policies. In particular, Poudyal et al. (2020) found in a case study of Nepal that achieving REDD+ objectives will remain an ambition unless and until the historical contributions of Indigenous peoples and local communities to the state and management of forests are recognised and respected. Underlying reasons and potential measures to recognize Indigenous peoples and local communities in national mitigation policies should be further investigated regarding counteracting potentially adverse consequences on Indigenous groups at an early stage and striving for inclusive policies.

While many internationally acknowledged climate change mitigation strategies are forest-related, such as REDD+, forest landscape restoration, or measures under the Global Climate Fund, only less than half of the NDCs considered in some degree forest-dependence (independent of being Indigenous or not). Reasons might be related to the chosen national mitigation strategies and general political recognition of forest-dependent and Indigenous peoples in the particular country.

TEK has been recognized to potentially strengthen climate mitigation efforts and contribute to achieving sustainable development goals (ILO 2016). The international recognition of the contribution of TEK was also visible on the one hand in the SLR, as all of the reported Indigenous-driven mitigation measures were based on TEK. On the other side, in the review of NDCs, a prior review of intended NDCs in 2020 (most NDCs were submitted only at the end of December 2020) showed less than 50 % of the NDCs of the selected countries integrated traditional knowledge. In early 2021, the NDC review was repeated with the finalised NDCs, and the integration rose to 64 %. The acknowledgement of TEK into policies and strategies can be two-fold beneficial: first, TEK itself can be a valuable inspiration for effective mitigation measures, and second, Indigenous peoples might be less likely to oppose externally driven mitigation measures when they adequately represent local values (Brugnach, Craps and Dewulf 2014, Shawoo and Thornton 2019).

5.4.3 Joint strategies

The joint strategies are to contribute simultaneously to coping and/or adaption and mitigation. Examples of such joint measures are traditional fire management (2,54) and agroforestry strategies (23,37,48). Mitigation and adaptation strategies usually differ in spatial scale (global versus local), time scale (long-term versus short-term), and sector (f.ex. energy supply versus health) (Locatelli et al. 2011; Bakkegaard, Møller and Bakhtiari 2016), yet might create opportunities when pursued in a joint manner. In this systematic literature review, the most prevalent joint strategy was found to be agroforestry. Studies, such as from Bakkegaard, Møller and Bakhtiari 2016 have confirmed agroforestry as one of the key sectors with high potential for synergies and, in addition to that, possibly achieving adaptation and mitigation objectives at moderate cost with the awareness that lost short-term benefits of the first few years after tree planting can be offset by the services provided by agroforestry (Lasco, Delfino and Espaldon 2014). Agroforestry can have adaptive benefits with regards to protection against damaging wind or water and provide households with fuelwood, livestock feed or fruits, improved crop yields, and ecosystem services (Mercer, Frey and Cubbage 2017), while the system increases carbon storage and sequestration. However, a careful case-specific analysis of variables such as land, capital, labour, and time available can help determine whether agroforestry is an economically, socially, and environmentally feasible option (Mercer, Frey and Cubbage 2017). The fact that agroforestry was described in several articles implemented in a successful joint measure underlines its potentially participatory character. Nevertheless, contrary results were found in the Phillippines (49), where purely external programmes promoted agroforestry systems to reform swidden-based Indigenous livelihoods resulting in increased vulnerability to extreme weather events.

The drivers, like the strategies themselves, were found to be diverse in response time and driver. The correspondence analysis showed a link between joint strategies and joint efforts, the integration of sensitivity of Indigenous peoples, and the inclusion of TEK. Because of increasing financial resources and political interest, climate change mitigation currently controls policy and research agendas (Zhao et al. 2018). Additionally, adaptation strategies can be controversial due to the ambiguity of the magnitude of the impacts on forests and their dependent communities (Martens, McEvoy, and Chang 2009; Chia et al. 2015). Thus, synergetic concepts of joint adaptation-mitigation methods have the potential to mitigate climate change while producing adaptation outcomes, which, if inclusively and well planned, can avoid duplication of efforts and reduce financial and technical resources (Chia et al. 2015). So far, Bolivia is the only country in this study promoting a Joint Adaptation-Mitigation approach in its national climate policies. In-depth research on successful synergetic concepts could encourage and multiply global efforts when reflected and promoted in national climate policies.

5.4.4 Critical reflection and limitations

The results presented earlier have limitations concerning their scope. Contrary to other systematic literature reviews on Indigenous peoples and climate change (Petzold et al. 2020), I included SCOPUS-listed non-peer review publications, such as books and 'grey' literature. This, however, does not allow for performing a rigorous quality assessment of the reported practices. Only one report was left out from all excluded publications because of very poor quality. Furthermore, the assessment of the inclusion of the sensitivity and TEK cannot be claimed comprehensive as the present results fully rely on the arbitrariness to include this information in the publication. This SLR comprises all articles found on SCOPUS on the topic with English abstract. Limiting the search to an English abstract was necessary for defining the keywords, articles written in other languages than English were included. For publications on the topic from Africa and elsewhere, it can be assumed that more information is available on specific Indigenous groups and abstracts written in other languages but English. I choose to focus only on the national climate policies of the countries covered by the SLR as they seem representative of the specific forest focus. This, in return, limits the explanatory power to a fraction of all countries. Also, the recognition of Indigenous peoples may vary between countries and thus influence their acknowledgement in policies.

5.5 Conclusion

This systematic literature review provides an overview of the available evidence of Indigenous peoples´ responses to climate-induced adjustments or extreme weather events in the form of forest-related coping, adaptation, and mitigation strategies. Respective adjustments in forest use and management by Indigenous peoples have only started being documented in 2006 and are receiving increasing attention since 2015. This is not least because of the rising inclusivity of national and international climate policies that specifically address Indigenous peoples due to both the often exacerbated effects of climate change and extreme weather events on this societal group (Olsson et al. 2014) but also due to the increasing acknowledgement of their active role in forest preservation and fighting climate change (Fa et al. 2020, Walker et al. 2020).

The review demonstrated that the reported coping and adaptation strategies are mostly driven by Indigenous peoples themselves and were linked to their sensitivity to a changing climate and relying on traditional knowledge. The diversity of applied strategies, mostly related to NTFPs, comprised sustainable and unsustainable practices, such as intensified forest clearing, with adverse effects on forest resources. This implies and confirms that the generic claim for TEK integration into adaptation measures should be specific and contextualized to be effective and sustainable (Makondo and Thomas 2018). Reported mitigation strategies, mostly REDD+ projects, were found ex-post and driven mostly by external drivers, largely omitting information on the sensitivity of the studied Indigenous group and possible involvement of traditional knowledge. A more inclusive approach to mitigation strategies, such as integrating context-specific TEK, could enable participation, foster the Indigenous´ sense of ownership in forest management, and ensure transparency of environmental governance processes (Schroeder and Gonzales 2019, Zurba and Berkes, 2014). Synergetic adaptation-mitigation concepts, like agroforestry, can contribute to mitigating climate change while producing adaptation outcomes. If well planned, this could avoid duplication of efforts, reduce resources, enhance ownership, and emphasize the trade-offs that different adaptation and mitigation strategies inherently embody. The analysis of national climate change policies of the included countries showed that Indigenous peoples as a stakeholder group were largely acknowledged in NAPS and NDCs, while there is still potential to address forest-dependence, independent from the societal group, especially in countries where forests play a crucial role for climate adaptation and mitigation. Political agendas and financing of these agendas tend to emphasize mitigation measures, which are often linked to forest preservation, and less adaptation strategies (Chia et al. 2015), indicating the need to mainstream forest-dependence into mitigation agendas and practices. The strong connection Indigenous-driven climate change adaptation initiatives have to traditional land, and cultural values can be fostered by developing culturally responsive climate governance for and with Indigenous peoples (Nursey-Bray and Palmer 2018).

The systematic literature review and analysis of national climate policies identified the following research gaps

- Geographically, Africa was found under-represented with regards to forest adaptation and mitigation strategies by Indigenous peoples
- How to design external support measures to build upon inherent coping and adaptation strategies of Indigenous peoples which do not have an adverse long-term impact on the sustainability of forest resources
- Research remains to be done on whether the integration of TEK can influence the long-term success of climate change response strategies
- It is unclear whether there is a relation between the driver of a climate change response strategy and the success of the outcome
- There is need for studies of forest-related resilient livelihood strategies by Indigenous peoples on a global scale
- There is inadequate information on the potential effectiveness of joint adaptation-mitigation measures on a global scale

6

Chapter VI

SYNTHESIS

6.1 Introduction

A recent study that analysed the attribution of extreme weather to climate change indicates that 70 % of 405 extreme weather events and weather trends can be linked to climate change (Pidcock and McSweeney 2021). More frequent and intense precipitation events, droughts and shifting weather patterns may amplify the impacts of land use on natural resources, directly affecting livelihoods and the global economy (Valdivia et al., 2010; McDowell and Hess, 2012; Seneviratne et al. 2012; Smith and Rhiney 2016; Bouwer 2019). This has consequences for rural natural-resources dependent households in the tropics (Somorin 2010; FAO 2015; Wunder, Noack and Angelsen 2018), yet very few studies have focussed explicitly on Indigenous and forest-dependent peoples in the Amazon. This Ph.D. study has been inspired by the need to understand better the effects of extreme weather events on forest-dependent livelihoods and the role that forest products play in how people respond to those events. Knowledge of determinants of livelihood resilience and vulnerability and local people´s perspectives on climate change and its impacts may aid climate change risk management and adaptation strategies, as well as trade, development, land and forest policies.

6.2 Answers to the research questions

The overall objective of this research was to understand better the effects of climate change on and response strategies of forest-dependent people. This thesis explored the effects of an actual extreme weather event on forest livelihoods of three Indigenous communities of the TCO Tacana I in Northern Amazonian Bolivia and provided insights into the role of forest products in coping and adaptation strategies (Chapters 2 to 4). It further determined how forest-dependent Indigenous peoples elsewhere are adjusting forest use and forest management to the effects of climate change (Chapter 5). Understanding response strategies to the effects of extreme weather events not only sheds light on their socio-economic and possible ecological impacts but will also aid the formation of strategies and policies that support resilient forest-dependent livelihoods and ecosystems.

To achieve this objective, the following research questions were addressed:

(1) How did the 2014 extreme precipitation event affect households of three Indigenous communities of the TCO Tacana I in the short- and medium-term? (**Chapter 2**)

(2) What defined livelihood resilience and vulnerability of Indigenous communities in the context of an extreme weather event, and what are the implications of policies in shaping current conditions of resilience and vulnerability at the local level? (**Chapter 3)**

(3) How are changing weather patterns and traditional weather indicators perceived locally? How are livelihood capitals affected by and utilised to overcome an extreme precipitation event? (**Chapter 4**)
(4) What was the role of forest products in coping with the extreme precipitation event in the case of the three Tacana communities? (**Chapters 2,3,4**)
(5) How do Indigenous peoples across the globe adjust the use or the management of forest and forest products as a response to extreme events and climate change? (**Chapter 5**)

6.2.1 Short- and medium-term socio-economic impacts of the extreme precipitation event

Large aggregated socio-economic models on the impacts of climate change do not adequately embody heterogeneity within small social-ecological systems, such as variability in livelihood strategies in natural-resources dependent communities. Understanding this, however, is important for effective policies (Habtemariam, Abate Kassa and Gandorfer 2017). The TCO Tacana covers an area of 389,303 ha and comprises different social-ecological conditions. Natural resources and resources-based livelihood activities are diverse between communities and within communities. Household income includes income from forests (fish, game, timber, firewood, processed forest products, seeds, fruits and wages), other natural environments (e.g. pasture), and farm activities (crops, livestock and wages). Income from natural resources is complemented by other sources (e.g. business activities, remittances, non-farm and non-forest wages).

Even though high likeliness of intra-communal heterogeneity was suggested by earlier literature (Begossi, Hanazaki and Tamashiro 2002, Ghimire, McKey and Aumeeruddy-Thomas 2004), it has remained unacknowledged in the literature on global environmental change (Pyhäla et al. 2016). **Chapter 2** confirms that the socio-economic impact of the extreme precipitation event is heterogeneous for livelihood activities and strategies in the short-term (soon after the flood in 2014) and medium-term (in 2015) for the Tacana case:

1) Households with either timber, subsistence, or farm- and local business livelihood strategies experienced a significant negative economic impact in the short term. Households pursuing a wage livelihood strategy were less affected.
2) The percentage of households living under the national poverty line in 2013 (14%) increased during the flood year to 28%. These households engaged in one of the three above-mentioned natural resource-based livelihood strategies. This confirms the link between natural resources-dependence and vulnerability to climate extremes (IPCC 2007, IPCC 2012).
3) The three study communities underwent a rapid economic recovery in the medium term – 1.5 years following the extreme weather event. In this period, the overall situation improved significantly, the number of poor households dropped to approximately 17%, and some previously poor households increased their income to rise above the poverty line.

4) The post-flood analysis of 2015 showed that livelihood strategies had changed. Two new livelihood strategies could be distinguished that year: a diversified livelihood strategy (pursued by 31% of the households) and an off-farm livelihood strategy (pursued by 20%). The main sources of income, however, remained the same. The new, diversified livelihood strategy was most common and pursued by households that had previously followed a subsistence strategy or a farm- and local business strategy, i.e. both farming strategies. Portfolio diversification to reduce the overall risk is a common coping strategy observed in other regions (Delacote 2007; Ellis 2008; Boillat and Berkes 2013).
5) Fast economic recovery was due to household-internal aspects favouring livelihood resilience (also see **Chapter 6.2.3**.) but also factors external to the household, such as large fluctuations in production, prices and demand, as well as support from outside (see **Chapter 4**).

I do not claim to generalize the results over the entire TCO Tacana or the Northern Bolivian region, as there have been other less accessible, river-near communities also severely affected by the 2014 extreme weather event where inhabitants were injured, killed and entire communities were forced to migrate, such that a fast recovery in the short to medium term seems improbable. A key conclusion evidenced by the outcomes of this study is that the impacts of extreme events associated with climate change vary between livelihood strategies. Thus, if socio-economic risk adaptation and mitigation strategies are to be effective, they need to consider intra-communal heterogeneity at a household level.

6.2.2 Livelihood vulnerability and resilience

The concepts of livelihood resilience and vulnerability have recently gained momentum within international development and humanitarian research and organisations, yet methods for measuring and empirical testing are challenging and scarce (Carpenter et al. 2001; Walsch-Dilley et al. 2016; Quandt 2018). Quantitative household-level analyses can help to identify the most vulnerable and resilient groups in most settings and support dis-aggregated risk management approaches and policies.

The following components shaped both livelihood vulnerability and resilience during the time of the extreme precipitation event in the three Tacana communities: the share of cash income per household, the total household income, and the sales of hunted game. An analysis of the four identified household strategies suggests that the timber livelihood strategy has a comparably high vulnerability**,** as it is very much influenced by weather conditions **(Chapter 3)**. Furthermore, an increased vulnerability correlated with decreasing shares of cash income. Cash-poor households were significantly more vulnerable to the flood than better-off households, corroborating the outcomes of the socio-economic impact assessment (**Chapter 2**) and the link between poverty and climate vulnerability for lowland Amazon Bolivia (Kronik and Verner 2010) and other developing countries (Paumgarten 2006; Karfakis, Lipper and Smulders 2012; Olssen et al. 2014). Yet, it can also be confirmed that not all vulnerable households are poor (Moser 1998). The results indicated that three livelihood activities had a significant negative correlation with vulnerability: the sale of game or fish and monthly wages. Households with higher income shares of those activities had a lower vulnerability. Generally, the higher the dependence on hunting or fishing, the lower the household´s vulnerability was. The observation regarding fishing is similar to what was reported for riverine households in the Peruvian Amazon after crop flood losses (Takasaki, Barham and Coomes 2010); other NTFPs have also been reported to reduce vulnerability and ameliorate poverty (Shakleton et al. 2011). Yet, dependence on declining or shifting fish and game populations and changing ecosystems can adversely influence the climate vulnerability of Indigenous peoples (Ford and Goldhar 2012; Ojea, Lester and Salgueiro-Otero 2020; Lastra Landa and Bueno 2021).

Chapters 2 and 3 also showed that timber dependence made households less resilient to negative impacts from the flooding caused by the heavy rains, not only because of increased production costs but also because of the lack of alternative sources of income for households with a dominant timber strategy. Thus, to improve the resilience of households specialising in timber extraction, promoting alternative sources of income when the forest is inaccessible could significantly increase their resilience. Increased resilience was shown among households whose livelihoods included a higher income share of game (used for subsistence and sales), and commercialized cattle ranching (environmental income). Generally, both wild and domestic animals played a crucial role in increasing resilience: Hunting game is one of the essential activities pursued by the Tacana people, but its contribution to household income depends on the availability of the game in the forest. Cattle ranching contributed to resilience by providing a buffer capacity, such as meat or milk products, or cash when cattle is sold. The results also underlined the important role that social networks and collaboration played especially for households with high subsistence income share and for community forestry activities; demonstrating the vital role of social capital as a contributor to livelihood resilience **(Chapter 3 and 4**). Chapter 3 also showed that distinct livelihood activities could have distinct effects on both or either on resilience and/or vulnerability. This confirms Gallopín's suggestion that vulnerability is not just the flip side of resilience (Gallopín 2006) and demonstrates that vulnerability and resilience should be considered much more differentiated than the understanding of antonyms (Folke 2002).

A review of national and decentralized policy implications in shaping current conditions of resilience and vulnerability at the local level indicated prioritization of economic growth based on strengthening the energy sector and agro-livestock sector and boosting the oil and mining sectors with industrialization in Bolivia. Some of these priorities, such as the expanding mining activities linked to the usage of mercury, contaminate river streams, like the Beni river which is used for fishing. The high risk of mercury poisoning threatens fish-dependent livelihood resilience and increases the vulnerability of forest-dependent Indigenous peoples and their local economies in lowland La Paz. External pressure on natural resources, including fish, requires a holistic cross-sectoral focus on the implications for livelihood resilience in national adaptation strategies.

6.2.3 Local perspectives on climate change and the extreme precipitation event

Risk perceptions are subjective, culture and place-specific and influence individual and collective behaviour related to coping with extreme weather events and adapting to climate change (Weber and Hsee 1999; Sullivan and White 2019). Increasing the external understanding of how people in Indigenous Tacana communities perceive sudden and slow changes in weather patterns can facilitate future climate communication and adaptation strategies.

The pre-flood survey (2013) found that 98 % of the households perceived changes in weather phenomena over the last 10 to 20 years, with the most frequently cited changes referring to (warmer) temperature, changes in seasonality and (increased) rainfall. More than half of all households had never heard the term "climate change" or could not make sense of it. Meteorological observations like the increase in temperature and the number of annual rainy days corresponded with observations of local households. Furthermore, the study revealed 38 different atmospheric, astronomic, zoo-, phyto- and human indicators employed by Tacana households to predict weather phenomena. Most of the flora, fauna, or astronomic indicators refer to observations of their environment. Their largely short-term scope is likely linked to the application of indicators for agriculture and hunting purposes. Due to changes in zoo-indicators and the unpredictability of the weather, however, their reliability and present applicability was questioned by some 42% of the interviewees (**Chapter 4**). Changing weather patterns in combination with the reported declining reliability of traditional indicators can adversely influence Tacana people's farming, hunting and other livelihood decisions, which are usually based on traditional calendars and thus affect livelihood activities and outcomes. Policy-makers should evaluate dynamic and hybrid knowledge systems that acknowledge local experiences and knowledge while being adaptive to current environmental change and supporting Indigenous households' adaptive capacity and well-being (Gómez-Baggethun, Corbera and Reyes-García 2013; Reyes-García et al. 2015).

Tacana households identified natural capital, particularly crops, followed by physical capital, as the most critical resources negatively affected by the extreme weather event, which is consistent with the results of the socio-economic analysis (**Chapter 2**). The perceived most important livelihood capital to cope with the extreme precipitation event was social capital. Both forms of social capital, bonding capital and networking capital, were perceived as vital by the Tacana people. The strengthening of social dynamics in communities was also observed after a flood in Vietnam (Razafindrabe et al. 2014) and confirmed by a large body of scientific literature on community-based climate change adaptation, which recognises that adaptation is a social process (McNamara and Buggy 2017). Forest products, such as fruits, fish or game, were less present in the results of the photo-voice analysis (**Chapter 4**). This was a surprising finding, as hunting and fishing contributed a considerable share of income to Tacana livelihoods in 2013 and 2015 (**Chapter 2**) and were found to increase livelihood resilience and lower vulnerability in the context of the flood (**Chapter 3**). Methodological limitations due to difficulties taking pictures of those activities could be one reason, while another is that Tacana less recognized forest products as a gap filler in times of crisis, but more as a constant contribution to livelihoods.

A perception gap can be avoided by reflecting on and analysing both the in-situ (household´s perception) and ex-situ (socio-economic analysis) perspectives. This dissertation demonstrates that local perceptions might align (see changing weather patterns **Chapter 4**) or differ (coping strategies **Chapter 4**) with ex-situ analysis. Therefore, considering perception gaps between research studies or development strategies and hearing and understanding Indigenous people's perceptions are needed to avoid externally proposed climate change adaptation strategies, which are adopted poorly and do not foster resilient strategies nor resilience for the entire SES.

6.2.4 The role of forest products in the context of the 2014 extreme precipitation event

This dissertation contributes to the ongoing scientific discussions on whether or not forest products play a significant role as a safety net during and after climatic shocks. Case studies from South Africa (Paumgarten 2005), Zimbabwe (Woittiez et al. 2013) and Cameroon (Tieminie et al. 2021) suggest that NTFPs play a crucial role in assisting communities to cope with shocks, while the outcomes of a global study indicate the overall importance of forest products but provide less evidence that they are a gap filler (Wunder et al. 2014). An overview of the main findings is summarised in Figure 39 and discussed in detail below.

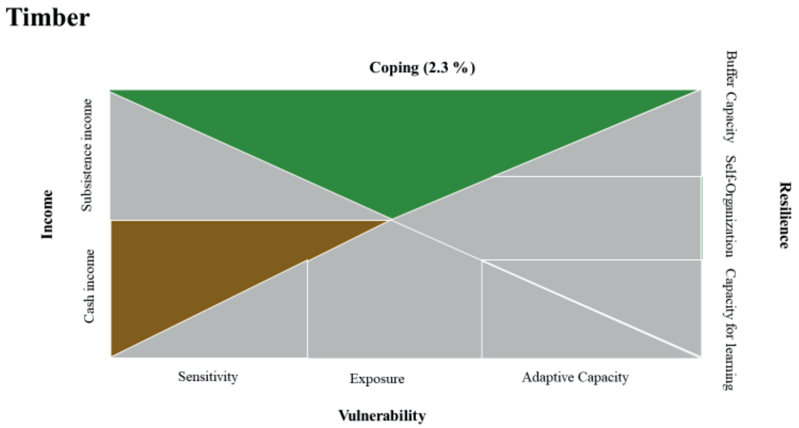
Some studies claimed that forest products would act as a gap filler, safety nets and backstop resources in response to unpredictable shocks and predictable food shortages (Kaimowitz 2002; Cavendish 2003; 2014). For the study region, the analysis between pre-and post-flood income showed a slight, but not significant, increase in timber harvest shortly after the flood in 2015 in one community **(Chapter 2)**. Using timber as a formal backstop resource would imply short-term accessibility, whether in terms of infrastructure or harvesting rights and related procedures. Due to the infrastructural constraints caused by the heavy and long-lasting rainfall, immediate access to timber was blocked. Nevertheless, timber-households managed to produce timber later in the year 2014 and compensated for the earlier losses. In this way, mitigation of the economic setback and fast recovery was possible. For NTFPs, a comparison of incomes in 2013 and 2015 showed no indication that forest products were used as gap fillers, as there was no significantly increased usage of NTFPs during or after the flood to compensate for economic losses of other livelihood activities. After the flood, the only significant difference and increase was the collection of forest fruits, linked to the introduction of a project to commercialise majo (*Oenocarpus bataua* Mart.) and açai (*Euterpe precatoria* Mart.). While fishing for subsistence purposes was a strong contributor to the total income, it did not increase in absolute terms after the flood. It was also found that the reliance on game depends on availability. From the perspective of a few Tacana households, the consumption of palm fruits and palm hearts and cacao sales helped them cope during the flood. In general, the use of forest products to overcome the weather shock was less prominent than expected, given other studies **(Chapter 4).** However, this study confirmed that forest products do play a crucial role in Tacana livelihoods. The high contribution of forest products to households' incomes before and after the disaster confirms Angelsen et al. (2014), stressing the overall significance of environmental products, especially for subsistence purposes. While there is no indication of forest products playing a significant gap filler role, instead, they provide a constant food supply and fulfil 'the function of substantial contribution' suggested by Cavendish (2000).

Tacana people maintain a close relationship with the natural environment to sustain their livelihoods, living by fishing, hunting, agriculture, timber and non-timber forest products. All studied households in the three communities relied to a varying degree (0% - 100%) on forest products to meet their subsistence needs or to sell **(Chapter 2)**. At the time of the fieldwork, timber exploitation took place through a forest management plan (Santa Rosa de Maravilla) or on an individual basis (Napashi and Buena Vista). In particular, timber strategy households were highly forest-dependent, with forest products contributing more than 80% (2013) to the total household income, followed by income from fishing. The subsistence strategy was found to be the strategy most used among all studied households and oriented towards subsistence agriculture, hunting and fishing. The complex interactions between Tacana people and the natural and forested environment manifest in in-depth knowledge about environmental phenomena, conveyed by a long list of traditional weather indicators (**Chapter 4**).

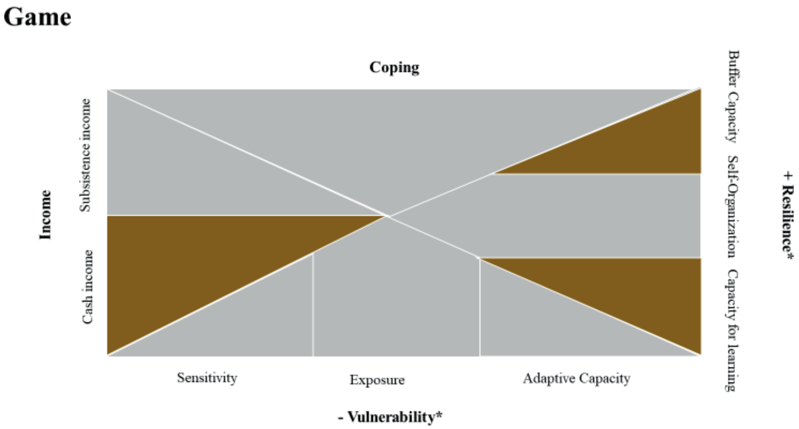
Livelihood strategy shifts or adaptations were found taking place among the households after the extreme weather event **(Chapter 2)**. Contrary to expectations, no considerable shift towards more timber extraction was found. While most households changed their livelihood strategies, households following the timber strategy in 2013 remained relatively similar in 2015. More favourable conditions in one of the study communities led to a slight increase in households pursuing a timber strategy linked to forest conversion. However, whether the increase can be attributed to the extreme weather event remains questionable. In response to the flood, livelihood activity shifts indicated livelihood diversification as a prevalent risk response strategy. Income diversification among forest-dependent lowland households in tropical Cochabamba, Bolivia, was found to be the norm (Uberhuaga, Smith-Hall and Helles 2011;

Nielsen et al. 2013). For the first time, the present study suggests portfolio diversification as a coping strategy (McSweeney 2004; Ellis 2008) for Bolivian lowland forest households and thus complements observations from Bolivian Andean communities (Vidaurre de Mulczyk 2016; Meldrum et al. 2017).

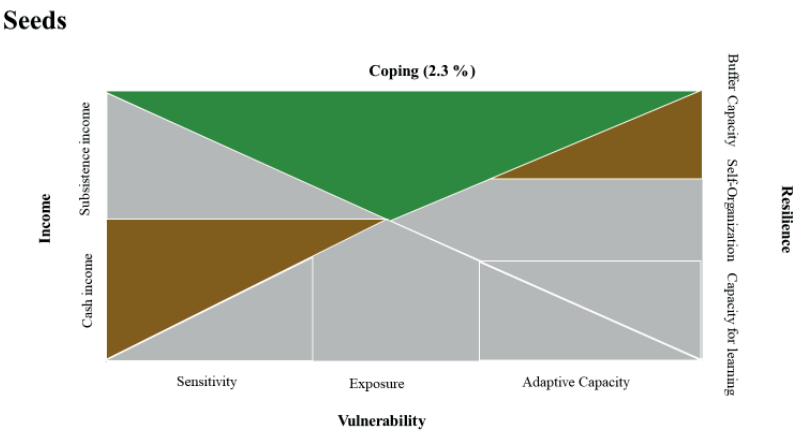
Furthermore, the link between the dependence on forest products and livelihood vulnerability and resilience among TCO Tacana households was analysed **(Chapter 3).** The findings suggest that no clear link between overall forest dependence and resilience or vulnerability exists, confirming evidence from the Congo Basin (Pavageau et al. 2018). Yet, it is suggested that an itemised consideration of forest-dependence components, such as timber, game, fish etc., can provide more insightful information. When comparing forest-dependent strategies against the non-forest strategies, timber strategy households were found significantly more vulnerable than wage labour strategy households. On the other hand, NTFPs, such as commercialised wild game and fish, prominently reduce vulnerability. This underlines once more the importance of wildlife for the Tacanas in general, but especially during harsh times. The high availability and importance of fish for Tacana households for income smoothing to overcome the flood and its aftermath was confirmed by Townsend (2017) and also observed in the Peruvian Amazon as a response to crop losses due to large flooding (Takasaki, Barham and Coomes 2010). As for the link between forest products and resilience, results demonstrated that the wildlife-dependent livelihood strategies positively influenced resilience, in particular for the households selling game. Sustainable and integrative wildlife management and monitoring need to be acknowledged in higher-level strategies and operative plans, contingency and recovery plans, and forest management plans to avoid exceeding critical socio-ecological thresholds and ensure long-term human and forest health. This is particularly important as the TCO Tacana is situated in the buffer zone of the Madidi National Park, the most biodiverse natural area in the world (WCS 2018).



a)



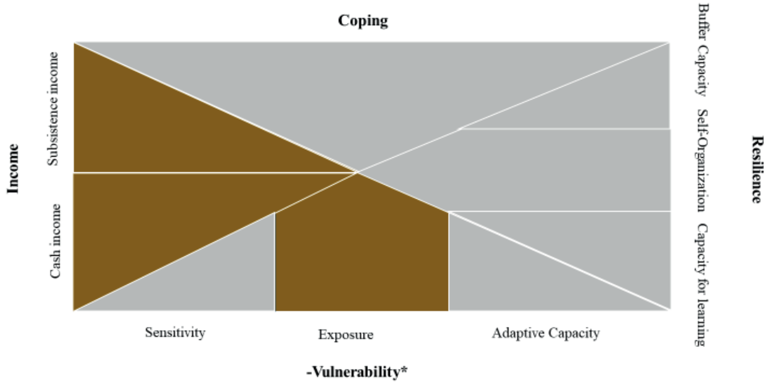
b)



c)

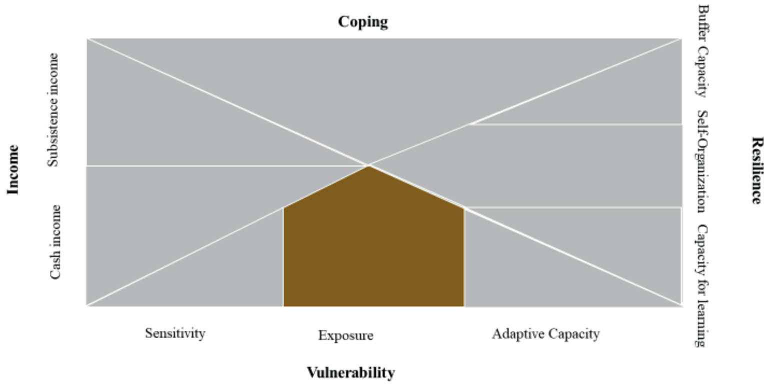
Chapter 6

Fish



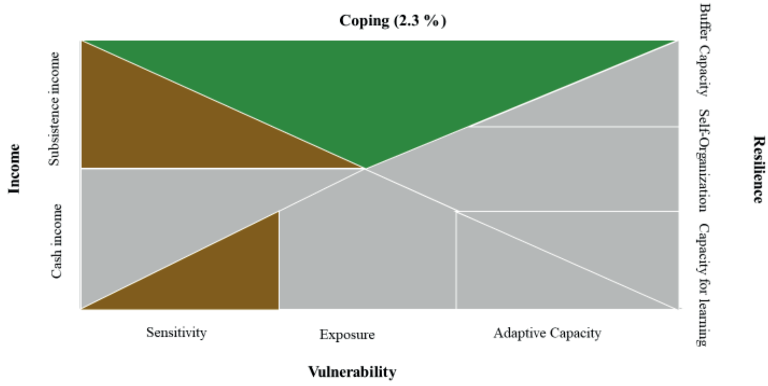
d)

Forest-derived products

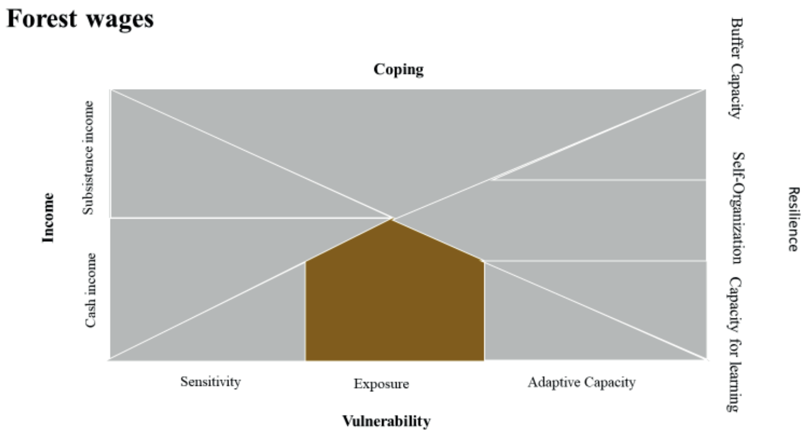


e)

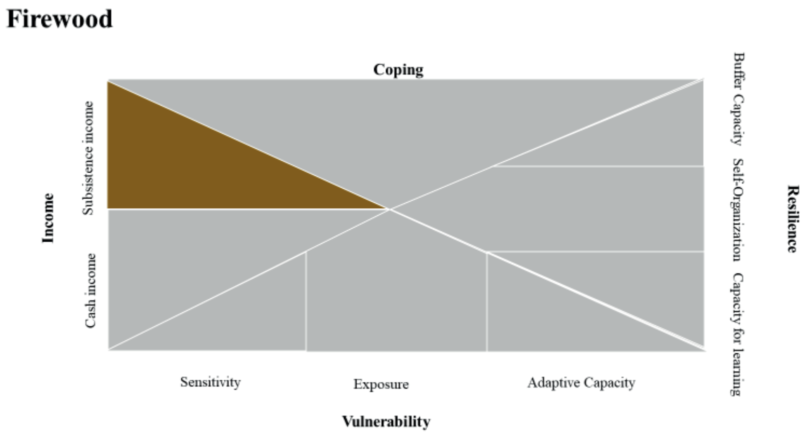
Fruits



f)



g)



h)

Figure 39. Contribution of forest products (a) timber, b) game, c) seeds, d) fish, e) forest-derived products, f) fruits, g) forest wages, and h) firewood to (cash and subsistence) household income, coping, livelihood resilience (and contributing factors) and livelihood vulnerability (and contributing factors). Brownish-marked parts and * indicate a statistical significance in the correlation of the particular forest product with either income, coping, livelihood resilience, or livelihood vulnerability; green-marked parts indicate the local perception (the percentage of households responding) of the contribution of the particular forest product to either income, coping, livelihood resilience, or livelihood vulnerability including; grey-marked parts indicate no contribution. – indicates a negative, + positive correlation

6.2.5 Global perspectives on local response strategies in forest use and management by Indigenous peoples in the context of climate change

Published evidence on forest-dependent Indigenous peoples´ adjustment of their forest use and management in the context of climate change is limited and challenges the design of effective interventions and policies. This is being addressed in **Chapter 5** as global analysis of published forest-dependent Indigenous peoples´ responses to climate change and extreme weather events. Respective adjustments in forest use and management by Indigenous peoples only started being documented in 2006 and have received increasing attention since 2015. This is most likely a reaction to international debates on the role of Indigenous peoples in forest conservation and restoration concerning climate change policy frameworks and is expected to continue at a faster pace.

The systematic literature review revealed that globally there are diverse strategies that Indigenous people use to change their forest use and management in response to changing weather and climate conditions, including both ecologically sustainable (e.g. forest conservation) and unsustainable practices (e.g. intensified forest clearing) with adverse effects on forest resources. Reported Indigenous-driven coping and adaptation actions were largely linked to people's sensitivity to changing weather conditions and involved TEK, confirming the Tacana communities' findings and observations (**Chapter 2-4**). Reported mitigation strategies, mostly REDD+ projects, were found to be ex-ante and driven mainly by external initiatives, largely omitting information on the sensitivity of the studied Indigenous group and possible involvement of traditional knowledge. External adaptation and mitigation strategies for Indigenous peoples to be effective should be designed with Indigenous peoples in a participatory manner, integrating the sensitivity and traditional knowledge where applicable. This will create a better understanding of local realities and more likely prevent perception gaps and possible adverse feedback loops in the social-ecological system.

There is evidence about how forest dependence can be addressed in national climate change policies. This is particularly important for countries where forests play a crucial role in climate adaptation and mitigation. As international political agendas and financing of these agendas tend to emphasize mitigation measures over adaptation strategies (Chia et al. 2015), better mainstreaming of matters related to forest-dependent (Indigenous) livelihood strategies into mitigation agendas and practices would likely contribute to more effective outcomes. Bolivia is one country that already pursues a Joint-Adaptation-Mitigation strategy and considers forest-dependent people in its national climate policy (Gobierno de Bolivia 2016).

6.3 Research contribution to science and society

By providing scientific insights from forested lowland Bolivia, this research contributes to increasing the theoretical and empirical evidence of coping strategies of forest-dependent households. The findings in Chapters 2 and 3 contribute to the academic debate on the forest dependence of rural households in the tropics and their livelihood resilience and vulnerability. The importance of forest products such as timber and NTFPs are considered central to the livelihoods of the poor and rural populations that live near forests (Ros-Tonen and Wiersum 2003; Wunder et al. 2014). This thesis confirms the critical importance of forest products for Bolivian lowland Indigenous communities, with forest products contributing to an average of 28% of subsistence income and 22% of cash income before the extreme weather event. This is higher in comparison to average forest income shares from natural forest (subsistence and cash combined) found for Asia (18.4%), Africa (20.5%) and Latin America (28.5%) (Angelsen et al. 2014). However, it aligns with results from research in Pando, Northern Bolivia, where the income from Brazil nut forests constitutes 42 - 64% of all sources of income (Zenteno et al. 2013, Duchelle et al. 2014). An increase in forest product harvest during the extreme weather shock was not confirmed, which contrasted with what was found by other researchers (Angelsen and Wunder 2003; Takasaki, Barham and Coomes 2004; Sunderlin et al. 2005; Delacote 2007). The Tacana case empirically confirms Wunder et al. (2014) that forest-based gap filling is a less common practice during natural disasters than had been expected. It also showed that forest dependence did not define total household income and thus challenges other studies from lowland Bolivia where a correlation between forest dependence and income was found, mainly defined by timber (Uberhuaga, Smith-Hall and Helles 2011) and studies demonstrating a link between forest dependence and poverty (Angelsen et al. 2011). Only by analysing the components of forest income separately, results demonstrate a strong correlation between cash deriving from the sales of timber, game and fish and total income (during pre-flood times), confirming observations by Angelson et al. (2014). After the flood, out of the forest products contribution, only fish for subsistence purposes correlated with total income. While the total forest income share did not influence livelihood resilience or vulnerability, considering forest income components separately, high importance of wildlife was observed as one determinant of livelihood resilience and vulnerability. **Chapter 3** provides disaggregated evidence to fill the research gap defined by Seppälä, Buck and Katila (2009) on the socio-economic effects of climate change on subsistence forest-dependent livelihoods and, in particular, possible links to resilience and vulnerability. The finding that cash-income poor households are more vulnerable to climate change events is in line with the literature (Smith and Petley 2009; Cardona et al. 2012). An important finding is that households with a high share of subsistence income demonstrated tighter sharing networks and social relationships, including self-coordination of activities, underlining the supportive role of social capital concerning the resilience of subsistence-reliant households.

Finding effective ways to increase the livelihood resilience of vulnerable societal groups while fostering sustainable use of natural resources will be key to meeting Bolivia´s national climate strategies and contributions to Sustainable Development Goals. Wild product harvesting by forest-dependent peoples, such as hunting, fishing, timber harvesting and NTFP collection, is believed to be a major threat to the biodiversity of tropical forests worldwide (Peres, Barlow and Laurance 2006). On the other hand, forests and forest products are a livelihood source for about 2.4 billion people globally (FAO 2014), and as shown above, hunting and fishing may also play a key role in increasing resilience and lowering vulnerability in the context of extreme weather events. This leads to two conclusions: Firstly, Integrated and adaptive wildlife management and targeted monitoring need not only be part of Tacana's local development plans (which is already the case) but should be promoted and supported through municipal and regional plans and risk management strategies. This study thus supports van Vliet, Fa and Nasi (2015) contention that wildlife management should go beyond a bushmeat hunting sustainability assessment and embrace more complexity and uncertainty in social-ecological systems, focusing on the resilience of the whole social-ecological system. The resilience focus in adaptive management acknowledges the opportunity for sustainable use and the benefits of hunting for local people depending on it but also permits to identify strategies to strengthen resilience and manage the capacity of the system to adapt to and shape change (Berkes, Colding and Folke 2003; Smit and Wandel 2006; van Vliet, Fa and Nasi 2015). Moreover, the regional authorities need to promote alternative fish or protein sources for the known mercury content in the Beni River, as continued consumption can cause serious health issues. The findings also show that future extreme weather events, climate change, and related intensified hunting and fishing activities may be a major challenge to maintaining wildlife biodiversity, intact forests, and the entire social-ecological system. Further research is recommended on effectively reducing the pressure on the ecosystem while maintaining sustainable livelihood activities.

6.4 Management and policy recommendations

At local and sub-national level

- Efforts to mitigate adverse weather-related impacts on rural households should consider heterogeneity in livelihood strategies (this implies understanding and engaging with vulnerable groups of the poor, farm, and timber-oriented households in the study communities).
- Opportunities for value creation of forest products (for instance, local processing of timber or fruits) should be promoted at community level. This could create income when roads are temporarily impassable and contribute to increasing the recovery and resilience of forest-dependent households during and after extreme weather events.
- Local adaptation strategies should build on the existing powerful traits of rural households, such as strengthening intra- and inter-communal bonding and increasing local knowledge sharing.
- Local perceptions of and experiences with changing weather phenomena should be considered to improve the robustness, specificity and effectiveness of climate change adaptation strategies.
- Risk management strategies that focus on promoting the livelihood resilience of forest households and communities in the TCO Tacana I should thus integrate adaptive forest

management that supports the renewal capacity of the forest ecosystem and the sustainable use and conservation of wildlife to avoid exceeding critical socio-ecological thresholds and ensure long-term forest health, forest governance strategies and management must include adaptive wildlife management based on sustainability principles.
- Risk management should be inclusive and participative and have a socio-ecological focus to ensure adaptive resource management and avoid adverse spillover effects.

At the national level
- Climate policies and strategies should increase the awareness of and the focus on the Bolivian lowlands. Forested regions in Bolivia's lowlands have long been off the radar of national climate change policies. This study shows the need to avoid negative effects of national policies on Bolivian lowland environments and livelihoods.
- Local knowledge is acknowledged in Bolivia´sintended nationally determined contribution. This should also be actively integrated into regional forest-related adaptation and mitigation strategies, as it can be a valuable inspiration for effective adaptation and mitigation measures while recognizing and respecting local values and experiences.

At a global level
- Particularly in countries with high forest cover, there is a need to mainstream forest dependence into mitigation and adaptation agendas and practices. Independent of the societal group, forest dependence should be acknowledged in national adaptation plans and nationally determined contributions.
- A more inclusive approach to mitigation strategies should be promoted to enable participation, foster the Indigenous' ownership in forest management, and ensure transparency of environmental governance processes.
- Synergetic adaptation-mitigation concepts can provide potential to mitigate climate change while producing adaptation outcomes. If well planned, this can avoid duplication of efforts, reduce resources, enhance ownership, and emphasize the trade-offs that different adaptation and mitigation strategies inherently embody.

6.5 Reflections on the methodology

6.5.1 Contributions

A large portion of the outcome of this Ph.D. study is based on a case study of a socio-economic pre-and post-assessment of 50 and 45 households from Indigenous forest communities. Ex-ante and ex-post household data allowed to obtain disaggregated insights into various relevant livelihood aspects, including the role of forest products in the direct aftermath of a flooding event. While the small sample indicates limited representativeness for Bolivian lowlands, it helps to formulate hypotheses and contributes to a global picture of the effects of climate change on forest-dependent communities, which can be useful to corroborate climate change coping modelling projections.

Chapter 3 introduced and tested a novel combination of a theoretical resilience approach (Ifejika Speranza, Wiesmann and Rist 2014) and vulnerability assessment indices (Panthi et al. 2016) for rural forest-dependent households. So far, no widely accepted or commonly used quantitative approach for assessing resilience exists (Chuang et al. 2018), and no detailed analysis of the livelihood resilience and vulnerability to extreme weather events of households in lowland Bolivia has yet been performed. The livelihood perspective provides a holistic picture and considers the inter-household heterogeneity and livelihood diversity, which are common within many rural communities, just as among households of the TCO Tacana I (**Chapter 2**). Therefore, responses to changes at the household level, as a disaggregated understanding of the poor (Hansen et al. 2019), enriches the understanding of livelihood responses to extreme weather events, specifically how livelihood aspects related to vulnerability and resilience. A critical analysis of this method can also be found in **Chapter 3**.

In **Chapter 4**, the perspectives of local households were analysed by applying a mixed-methods approach of semi-structured interviews, meteorological data and the photovoice method. By giving voice to and involving under-represented Indigenous households in the research process, the results allowed a more holistic view and facilitated the identification of key aspects that were important for Tacana households to withstand the extreme weather event. Overall, the photovoice method was well received as a participatory data collection method, albeit with limitations described below.

In **Chapter 5**, a combined systematic literature analysis and policy review were used to provide a global overview of the evidence on Indigenous responses in forest use and management to climate change and extreme weather events. It also explored the linkages between climate practices and the drivers, their time scope, the integration of traditional knowledge, and the type of response involved. The review assessed how Indigenous and forest-dependent people and traditional knowledge are acknowledged in national climate policies, such as NDCs and NAPs.

6.5.2 Limitations of the research design

This chapter reflects on different aspects and methodologies influencing and shaping this dissertation. In 2014, when the idea for the current research design was born, to the author's knowledge, this study was the first attempt to quantitatively and qualitatively analyse the effects of an extreme weather event with a focus on forest communities in lowland Bolivia. The study was originally part of a research programme (*International Network on Climate Change* (INCA), TU Dresden, Germany). Initially, this study intended to analyse the role of forest (products) for livelihoods and the likely effects of climate change on this role in different areas in lowland Bolivia. For this, research areas in two ecosystems were pre-selected – the Chiquitano dry forest and the Amazonian rainforest – and socio-economic data from 100 households were collected in 2013. In 2014, a cascade of external events adversely influenced the initial study idea and required a reorientation of the research design, which resulted in an exploratory study of an actual extreme weather event. The explorative research design allowed and required both flexibility and pragmatism in the way it progressed. However, the research circumstances were unique and made it a case that is difficult to repeat. Furthermore, the extreme precipitation event started in the rainy season, November 2013, during the baseline study of 50 households in the TCO Tacana and ended in spring 2014. In 2014, when the framework conditions of the research significantly changed, the author decided to focus only on the severely affected Northern Bolivian communities and repeated the socio-economic data collection in 2015. On the one hand, this decision meant to continue the study with a very small data set but allowed, on the other hand, to pursue a socio-economic impact assessment based on pre-and post-flood data. The small sample size does not allow general conclusions over the entire TCO Tacana I, the data is, however, representative for the three study communities. Additionally, the time series provides a spatially and temporally limited sample of two years of recall data but no intra-annual recall periods. A long-term study would undoubtedly reveal more accurate trends and long-term impacts. Thus, the generalisation of the findings to a broader context is limited.

By applying a cross-method approach and combining quantitative, qualitative (semi-) structured interviews with meteorological and photovoice data, the author tried to gain different perspectives on the socio-economic impact. Limitations of the photovoice method involved capturing non-tangible aspects, the unforeseen different data sets (see **Chapter 4**) and their analysis (similar challenges are described in Castleden, Garvin and First Nation 2008; Catalani and Minkler 2010; Masterson, Mahajan and Tengö 2018). Additionally, socio-economic household data can be susceptible to various challenges due to occasional language barriers[10] and cultural biases[11]. It might also be possible that interviewees did not reveal all the details on their overall income or past timber harvest and related sale if this was done without legal administrative procedures. The author tried to mitigate related risks by establishing a relationship of trust by staying with families in the communities and collaborating with Bolivian students and Tacana assistants to conduct the interviews. Preliminary results were already shared in a translated summary and provided to the communities, and a translation of recent results into

10 The author is not a Bolivian citizen, nor a native English, Spanish or Tacana speaker

11 The author may lack understanding of what it is like to identify as Tacana and how life is experienced, in particular during harsh times such as the extreme weather event. Different cultural backgrounds may have led to unconscious blind-spots during data interpretation. She seeked to mitigate described limitations by establishing relationships of trust with families and collaborating with Bolivian students and Tacana assistants to conduct the interviews.

popular scientific work is planned. In addition, it is essential to emphasise that the impact assessment mainly focuses on the social system of the SES; data on the direct ecological impact of the extreme precipitation, such as on ecosystem services beyond forest provisioning services, could not be estimated due to the lack of a baseline.

Finally, throughout the research project that lasted almost a decade, some personal challenges of the author defined decisions and the dissertation's duration. The decision to change the initial university in favour of the Forest and Nature Conservation Policy Group at Wageningen University as an external Ph.D. student allowed her to benefit from excellent but remote supervision while pursuing a parallel career in international development cooperation, which largely financed this research.

6.6. Further research recommendations

Some limitations of this study could be addressed in future research. Studies with larger coverage (households and environmental settings) and further time-series studies would contribute to a better understanding of people's responses to weather-related challenges, including long-term impacts, and whether livelihood activity shifts are temporary.

Future studies should further explore the social-ecological interrelation and interdependencies between forest households and the effects of climate change in Bolivia, the Amazon and globally. However, a holistic social-ecological system analysis requires an interdisciplinary research approach. By limiting this study to the socio-economic livelihood effects, the study did not explore the ecological system. This could be addressed in future research. Specifically, a more forest-ecological focus on how adaptive wildlife management can be realized to increase the resilience of a social-ecological system could be useful. From a social perspective, it would be interesting to study potential strategies to increase buffer and adaptive capacity and the overall livelihood resilience of forest households without lasting negative feedback loops on the ecological system.

Local and traditional (ecological) knowledge and local perceptions can influence people´s behaviour related to climate coping, adaptation and mitigation strategies. In this regard, future research should investigate how coping, adaptation and mitigation strategies can be more inclusive of forest-related traditional knowledge, local perceptions and how this knowledge might be affected by changing environmental conditions.

Finally, the application of participatory research methods to complement the study results should be encouraged, as they will allow scholars to see phenomena through different lenses and thus integrate different local perspectives into the research outcomes.

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Appendices

Appendix.Table 19. Significant differences in mean annual income (Bs) in 2013, 2014 and 2015 and standard error (SE) for subsistence (s) and cash (c) income; all values have been adult equivalent adjusted; significance at p < 0.05 (numbers in bold)

	Absolute income							**Relative income**				
	2013		**2014**			**2015**		**2013**		**2015**		
	n = 50	**SE**	**n = 45**	**SE**	**p**	**n=45**	**SE**	**n=50**	**SE**	**n=45**	**SE**	**P**
firewood_s	244.82	49.51				217.09	72.21	0.02	0.01	0.02	0.01	
firewood_c	0.00	0.00				31.49	31.49	0.00	0.00	0.00	0.00	
game_s	1325.15	298.60				893.60	235.80	0.09	0.02	0.05	0.01	
game_c	124.42	60.61				206.08	69.46	0.00	0.00	0.01	0.00	
fish_s	3090.67	765.07				3073.59	725.76	0.16	0.03	0.16	0.03	
fish_c	1100.23	467.00				466.34	245.54	0.04	0.02	0.03	0.02	
timber_s	89.43	49.22				21.95	11.41	0.01	0.00	0.00	0.00	
timber_c	**2752.36**	**827.78**	**1609.05**	**484.66**	**0.008**	3823.03	1556.95	0.13	0.03	0.14	0.04	
timber_tot	2841.78	828.39				3844.99	1555.80	0.13	0.03	0.15	0.04	
seeds_s	6.17	1.65				3.79	1.40	0.00	0.00	0.00	0.00	
seeds_c	32.98	27.93				2.34	1.63	0.00	0.00	0.00	0.00	
fruits_s	45.06	7.05				28.98	5.67	0.00	0.00	0.00	0.00	
fruits_c	0.00	0.00				334.35	132.22	**0.00**	**0.00**	**0.02**	**0.01**	**0.01**
forestder_s	15.81	7.62				0.00	0.00	0.00	0.00	0.00	0.00	
forestder_c	13.65	9.68				55.56	55.56	0.00	0.00	0.01	0.01	
forest_wages	262.59	121.42				334.75	216.48	0.04	0.02	0.03	0.01	
NTFPs	1778.59	332.11				1717.73	316.89	0.12	0.02	0.11	0.02	
NTFPandfish	5969.49	1048.7				5257.66	937.23	0.32	0.03	0.30	0.04	
for_inc_s	4817.11	806.39				4239.02	846.16	0.28	0.03	0.24	0.04	
for_inc_c	4286.22	987.92				5253.94	1629.58	0.22	0.04	0.24	0.05	
for_inc_tot	9103.33	1362.12				9492.96	1957.09	0.50	0.05	0.48	0.06	
env_sub	150.99	68.37				127.27	58.16	0.02	0.01	0.01	0.00	
env_cas	88.77	49.18				255.89	170.92	0.00	0.00	0.01	0.00	
env_tot	239.76	93.68				383.16	227.51	0.02	0.01	0.01	0.01	
crops_s	2177.81	338.88				1834.73	493.58	0.15	0.03	0.13	0.03	
crops_c	638.04	176.14				176.44	75.49	0.05	0.01	0.02	0.01	
crops_tot	**2816.59**	**411.92**	**-156.02**	**617.84**	**0.000**	2011.16	248.36	-0.01	0.01	0.06	0.04	
livestock_s	117.76	182.98				342.10	211.11	0.01	0.01	0.03	0.01	
livestock_c	474.34	254.50				437.52	142.59	0.01	0.00	0.03	0.02	
agr_wages	33.48	29.10				261.69	816.19	0.21	0.03	0.26	0.05	
farm_tot	3416.71	537.13				3052.48	1392.84	0.14	0.04	0.10	0.04	
salary	3820.79	1290.64				2924.06	272.99	0.07	0.03	0.06	0.03	
business	794.47	291.07				655.70	253.89	0.05	0.01	0.08	0.03	
remittances	714.81	155.19				846.45	2194.04	0.02	0.01	0.02	0.01	
total	**18115.32**	**1797.13**	**13099.88**	**1797.13**	**0.000**	17354.81	72.21					

Appendix.Table 20. Components, their contribution factors and indicators; the year the indicator data were collected and their weight

Components *Contributing factors*	Indicator	Explanation	Year	Weight
		RESILIENCE		
		Buffer Capacity, weight (w) = 1		
Financial capital w = 1/6	Total income (sum of cash and subsistence)	$ (2015) /Adult Equivalent Unit (AEU) *HB	2015	1/18
	Livestock	$ (2015) /AEU *HB	2015	1/18
	Non-agricultural assets	$ (2015) /AEU *HB	2015	1/18
Human capital Weight w = 1/6	Health	major health shocks or death of a household member during the past 12 months *LB	2015	1/18
	Labour power Adaptive Capacity (AC): Information & Skills	Household members working/ household size Children between 10–16 count as half *HB (2015)	2015	1/18
	Literacy level AC: Information & Skills	Years of school completed by household head *HB	2013	1/18
Natural capital w = 1/6	Farmland	Size of farmland (ha) used by the household *HB	2013	1/30
	Parcel	0/1 (yes/no) *HB	2013	1/30
	Individual timber harvest	Timber harvest (independently from any forest user group) *HB	2015	1/30
	Timber plantation	0/1 *HB	2015	1/30
	Fruit trees plantation	0/1 *HB	2015	1/30
Social capital w = 1/6	Origin	Household head born in the community 0/1 *HB	2013	1/18
	Tacana	Household considers itself as Tacana 0/1 *HB	2013	1/18
	Current group memberships	Group memberships (number) *HB	2015	1/18
Physical capital w = 1/6	Roof material	1 – Thatch 2 - Wooden 3 – Iron *HB	2015	1/24
	Vehicle	Quantity *HB	2015	1/24
	Type of house	1 – Fiber *HB 2 – Mud 3 – Wood	2015	1/24
	Gas	0/1 *HB	2015	1/24

Appendix.Table 20. Components, their contribution factors and indicators; the year the indicator data were collected and their weight (*continued*)

Components ***Contributing factors***	**Indicator**	**Explanation**	**Year**	**Weight**
Access to basic services ***w = 1/6***	Phone connection *AC: Infrastructure*	0/1 *HB	2015	1/36
	Electric power *AC: Infrastructure*	0/1 *HB	2015	1/36
	Distance to water	0–2 *LB 0 – at home 1 - <100m 2 - river	2013	1/36
	Distance to work	0–3 *LB 0 – Works at home 1 – community 2 - Field (+Distance) 3 – outside community	2015	1/36
	Radio *AC: Technology*	0/1 *HB	2015	1/36
	Village shop	0/1 *HB	2015	1/36
			Self-Organization, weight (w) = 1	
Social Safety net ***w = 1/3***	Remittances from family	0/1 *HB	2015	1/21
	NGO	0/1 *HB	2015	1/21
	Government	0/1 *HB	2015	1/21
	Different options	Sum *HB	2015	1/21
	Households with a good and helping relationship AC: Institutions	Number *HB	2015	1/21
	Trust in other community members AC: Institutions	1–3 *HB	2015	1/21
	Help from community members	1–3 *HB	2015	1/21
Cooperation and networks ***w = 1/3***	Income gained through membership in groups AC: Equity	$ *HB	2015	1/12
	Member of a Forest User Group	0/1 *HB	2015	1/12
	Community position	Sum of different positions *HB	2015	1/12
	Community position	0 – no position *HB 1 – administration 2 – power position (head of the community etc.)	2015	1/12
Reliance on own resources ***w = 1/3***	Subsistence share of total income	*HB	2015	1/3

Appendix.Table 20. Components, their contribution factors and indicators; the year the indicator data were collected and their weight (*continued*)

Components ***Contributing factors***	**Indicator**	**Explanation**	**Year**	**Weight**
		Capacity for learning, weight (w) = 1		
Skills ***w = 1/4***	Income diversification AC: Information&Skills	Sum of different sources of income *HB Simpson-Index 0–1	2013	¼
Knowledge ***w = 1/4***	Traditional knowledge	Number of medicinal plants used, not AEU modified *HB	2013	1/12
	Knowledge traditional weather indicators	0/1 *HB	2013	1/12
	Familiarity with Climate Change	0/1 *HB	2013	1/12
Awareness ***w = 1/4***	Awareness of threats	0 = no 1 = adapted cropping/harvesting to changes in seasonal calendar 2 = stopped farming *HB	2015	1/4
Coping strategies ***w = 1/4***	Use of forest products	0/1 *HB	2015	1/28
	Sale of assets during/after flood	0/1 *HB	2015	1/28
	Sale of animals (domesticated or hunted)	0/1 *HB	2015	1/28
	Migration	0/1 *HB	2015	1/28
	Experimentation - Crop adaptation AC: Technology	0/1 *HB	2015	1/28
	Fertilisers	0/1 (2015) *HB	2015	1/28
	Pesticides	0/1 (2015) *HB	2015	1/28

Appendix.Table 20. Components, their contribution factors and indicators; the year the indicator data were collected and their weight (*continued*)

Components *Contributing factors*	**Indicator**	**Explanation**	**Year**	**Weight**
		VULNERABILITY		
Sensitivity weight w = 1	Animal shock 2014	$ *LB	2015	1/11
	Health Shock	Health or death shock during the last 12 months *HB 2 = no 1 = yes 0 = severe (2013)	2015	1/11
	Other shocks 2014	Sum *LB	2015	1/11
	Well-being factor	(Rating of current life satisfaction (2015), compared to answer in 2013) 0–7 (2013–2015) *HB	2013/ 2015	1/11
	Sufficiency factor	(Rating of current income sufficiency (2015), compared to answer in 2013) 0–6 (2013–2015) *HB	2013/ 2015	1/11
	Past-present factor	(Rating of income sufficiency compared with the past, compared to answer in 2013) 0–4 (2013–2015) *HB	2013/ 2015	1/11
	Community is a good place to live	1–3 (2013) *HB 1 – no 2 – partly 3 – yes	2013	1/11
	Average age of households	Higher the more sensitive (2013) *LB	2013	1/11
	Dependence on weather-sensitive activities	Relative percentage, the higher, the more sensitive (2013) *LB	2013	1/11
	Use of credit	0/1 *LB	2015	1/11
	Distance to main road to market	Km *HB	2013	1/11
Exposure weight w = 1	Crop shock relative 2014	$ / income of 2013 *LB	2015	1/8
	Timber shock relative 2014	$ / income of 2013 *LB	2015	1/8
	Water outage	0/1 *LB	2015	1/8
	Household Food Insecurity Access Scale	0 - 4	2015	1/8
	House shock	0/1 *LB	2015	1/8
	Increase in production costs	0/1 *LB	2015	1/8
	School drop out	0/1 *LB	2015	1/8
	Shocks	Sum of the variables which indicate whether a household was hit or not by each shock typology during *LB	2015	1/8
Adaptive Capacity weight w = 1		**cross-cutting, highlighted in grey**		

HB: High is best
LB: Low is best

Appendix.Table 21. Revision of the integration of livelihood activities that contributed to resilience or decreasing vulnerability (hunting, ranching, fishing) into policy and regulatory framework related to climate change and natural resources management. YES indicates that the aspect was thematised in the policy, *indicates that sustainable management is promoted. Laws and degrees can be found under http://www.gacetaoficialdebolivia.gob.bo/.

Scope	Policy (Year)	Hunting (Wildlife Management)	Cattle ranching (Agro-Livestock)	Fishing	Resilience	Vulnerability
International						
UNFCCC	Law N°1576 (1994)	-	-	-	-	-
Paris Agreement	Law N°835 (2016)	-	-	-	-	-
Bolivian Intended Nationally Determined Contribution	INDC (2016)	Yes* (sustainable wildlife use)	Yes*	Yes* (sustainable wildlife use)	Yes	Yes
National						
Forestry	Law N°1700 (1996)	Yes* (sustainable wildlife use)	Yes	Yes* (sustainable wildlife use)	-	Yes (ecosystem)
Law of Autonomies and Decentralization	Law N°031 (2010)	Yes* (Art. 7.2.7)	Yes* (Art. 7.2.7)	Yes* (Art. 7.2.7)	-	Yes
Mother Earth	Law N°300 (2012)	(Yes)* (non-renewable components of Mother Earth)	Yes*(sustainable production systems)	Yes* (non-renewable components of Mother Earth)	Yes	Yes
Risk Management	Law N°602 (2014)	-	Yes	-	Yes	Yes
Patriotic Agenda 2025	Law N°650 (2015)	Yes (Sustaining the capacity of Mother Earth to regenerate)	Yes* (Sustaining the capacity of Mother Earth to regenerate)	Yes (Sustaining the capacity of Mother Earth to regenerate)	-	-
Integral State Planning System (SPIE)	Law N°777 (2016)	-	Yes (under sectoral plans)	Yes (under sectoral plans)	Yes	-
Economic and Social Development Plan 2016-2020 (PDES)	Law N°786 (2016)	Yes*	Yes*	Yes	Yes	Yes

Appendix.Table 21. Revision of the integration of livelihood activities that contributed to resilience or decreasing vulnerability (hunting, ranching, fishing) into policy and regulatory framework related to climate change and natural resources management. YES indicates that the aspect was thematised in the policy, *indicates that sustainable management is promoted. Laws and degrees can be found under http://www.gacetaoficialdebolivia.gob.bo/. (*continued*)

Scope	Policy (Year)	Hunting (Wildlife Management)	Cattle ranching (Agro-Livestock)	Fishing	Resilience	Vulnerability
Plan for the Agricultural and Rural Sector with Integrated Development for Living Well 2016-2020	Plan del Sector Agropecuario y Rural. con Desarrollo Integral para Vivir Bien, PSARDI (2017)	-	Yes*	Yes*	-	Yes
Sectoral Plan for the Integral Development of Environment and Water 2016-2020	Plan Sectorial de Desarollo Integral, PSDI (2017)	Yes* (sustainable wildlife management, focus solely on Camain and Vicuna)	Yes (more resilient and less vulnerable production systems)	-	Yes	Yes
International trade of flora and fauna threatened species	Decree N°3048 (2017)	Yes	-	-	-	-
Program to support resilience against climate change	Decree N°3419 (2017)	-	-	-	Yes	Yes
Biodiversity Strategy and Action Plan 2019-2030 (NBSAP)	Política y Estrategia Plurinacional para la Gestión Integral y Sustentable de la Biodiversidad Plan de Acción 2019 – 2030 (2018)	Yes*	Yes* (Sustaining the capacity of Mother Earth to regenerate)	Yes*	Yes	Yes
Wildlife Protection	Decree N°4489 (2021)	Yes*	-	Yes* (wildlife)	-	-

Appendix.Table 21. Revision of the integration of livelihood activities that contributed to resilience or decreasing vulnerability (hunting, ranching, fishing) into policy and regulatory framework related to climate change and natural resources management. YES indicates that the aspect was thematised in the policy, *indicates that sustainable management is promoted. Laws and degrees can be found under http://www.gacetaoficialdebolivia.gob.bo/. (*continued*)

Scope	Policy (Year)	Hunting (Wildlife Management)	Cattle ranching (Agro-Livestock)	Fishing	Resilience	Vulnerability
Departmental						
Integrated Territorial Development Plan for the Department of La Paz 2016-2020	PTDI (2016)	Yes* (sustainable biodiversity management)	Yes* (supporting sustainable production systems, enhancing their resilience to climate change)	Yes (sustainable biodiversity management)	Yes	Yes
Risk management and disasters prevention	Departmental Law N°159 (2018)	-	-	-	Yes	Yes
Prevent, protect, and strengthen Indigenous peoples in situation of vulnerability	Departmental Law N°195 (2020)	Yes (support to local economies)	Yes (support to local economies)	Yes (support to local economies)	Yes	Yes
Municipal						
Integrated Territorial Development Plan for the Municipality of Ixiamas, 2016-2020	Plan Territorial de Desarollo Integral, PTDI (2017)	Yes* (focus is solely on Caiman)	Yes (with emphasis on agroforestry and rice)	Yes (support to local initiatives)	-	Yes
Integrated Territorial Development Plan for the Municipality of San Buenaventrua, 2016-2020	Plan Territorial de Desarollo Integral, PTDI (2017)	-	Yes (with emphasis on cacao, sugarcane, rice)	Yes (support to fish farming)	-	Yes

Appendix. Table 21. Revision of the integration of livelihood activities that contributed to resilience or decreasing vulnerability (hunting, ranching, fishing) into policy and regulatory framework related to climate change and natural resources management. YES indicates that the aspect was thematised in the policy, *indicates that sustainable management is promoted. Laws and degrees can be found under http://www.gacetaoficialdebolivia.gob.bo/. (*continued*)

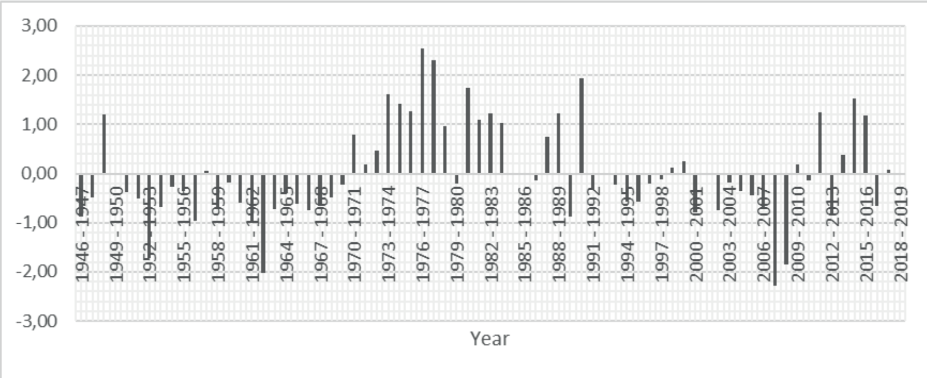
Scope	Policy (Year)	Hunting (Wildlife Management)	Cattle ranching (Agro-Livestock)	Fishing	Resilience	Vulnerability
TCO						
Territorial Management Plan, TCO Tacana 2015-2025	(2014)	Yes* (communities practice hunting following local devised sustainability criteria)	Yes (lack of zoning and planning, and weak regulations for accessing grazing areas and management of cattle herds for beef, milk or dual purpose)	Yes (as part of a plan of wildlife management)	Yes	Yes

Appendix.Table 22. 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.Table 23. 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.Figure 40. 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, Doesken and Kleist 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.Table 24. 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

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK

N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
1	Ahmed and Atiqul Haq (2019)	Bangladesh	Khasia, Tripura	yes	Diversification of crop production	Coping	yes	internal	ex-ante	yes
2	Appiah et al. (2010)	Ghana	no further specified	yes	Fire Management	Adapt-Mitig.	yes	internal	ex-ante	yes
3	Bauer et. al. (2018)	Bolivia	Tacana	yes	Intensified NTFP use	Coping	no info	internal	ex-post	no info
4	Bayrak and Marafa. (2019)	Vietnam	K'ho communities	yes	Forest monitoring and afforestation activities	Adapt-Mitig.	no info	external	ex-ante	yes
5	Bilbao, Leal and Méndez (2010)	Venezuela	Pemón people	yes	Traditional fire management	Cop.-Adapt.	no info	both	ex-ante	yes
6	Blackman and Veit (2018)	Amazon	various	yes	Land titling	Mitigation	no info	both	ex-ante	no
7	Chapin et al. (2010)	Usa	no further specified	yes	Changes in hunting areas and animals	Adaptation	yes	internal	proactive	yes
8	Cotta (2017)	Peru	Bora	yes	Fallow systems	Mitigation	no info	internal	proactive	yes
9	Cuenca et al. (2018)	Ecuador	various	yes	Conservation (REDD+)	Mitigation	no info	external	proactive	no
10	Dangi et al. (2018)	Nepal	various	yes	Agroforestry, forest cover growth	Adaptation	yes	internal	proactive	yes
11	Dressler et al. (2012)	Philipines	Tagbanua and Pala'wan farmers	yes	Livestock rearing, tree planting and direct financial incentives in the context of REDD+	Mitigation	no info	external	proactive	no
12	Eisenberg et al. (2019)	Canada	Kainai First Nation	yes	Incorporating TEK into wild fire management	Adaptation	no info	internal	ex-post	yes

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK (*continued*)

N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
13	Etchart (2017)	Ecuador	Huaorani, Sápara and Sarayaku Kichwa originar	yes	Forest conservation	Mitigation	no info	internal	proactive	no
14	Evans, Murphy and de Jong (2014)	Peru	Boras, Huitotos	anticipated	Potental conservation	Mitigation	no info	external	ex-ante	no
15	File and Derbile (2020)	Ghana	Sissala peopl	anticipated	Agroforestry	Adaptation	yes			
16	Funk and Kerr (2007)	New Zealand	Maori	yes	Carbon farming	Mitigation	no info	external	ex-ante	no
17	Furness and Nelson (2012)	Canada	First Nations	yes/no	Education	Cop.-Adapt.	yes	both	ex-ante	no
18	Gilani, Yoshida and Innes (2017)	Nepal	Dalit	anticipated	REDD+	Mitigation	yes	external	ex-ante	no
19	Hoang, Satyal and Corbera (2018)	Vietnam	K´ho, Ma	yes	Forest patrolling (REDD+)	Mitigation	no info	external	ex-ante	no
20	Holmes, Potvin and Coomes (2017)	Panama	Embera	yes	Carbon offset by reforestation (REDD+)	Mitigation	no info	external	ex-ante	no info
21	Holmes, Kirby and Potvin (2016)	Panama	Embera	yes	Conservation, restoration, afforestation,, reforestation (REDD+)	Mitigation	no info	external	ex-ante	no
22	Horstkotte et al. (2017)	Arctic	Sami	yes	Reindeer grazing	Adaptation	yes	internal	ex-ante	yes

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK (*continued*)

N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
23	Jacobi et al. (2017)	Bolivia	Moseten	yes	Increased timber harvest, agroforestry, diversification, certification organic	Adapt-Mitig.	yes	both	ex-ante	partly
24	Kala (2010)	India	no further specified	yes	Migration	Adapt-Mitig.	yes	internal	ex-ante	no
25	Krause and Nielsen (2014)	Ecuador	Kichwa	yes	Forest protection (REDD+)	Mitigation	no info	external	ex-ante	no
26	Ksenofontov, Backhaus and Schaepman-Strub (2018)	Russia		yes	New species and changes in abundance of original species in the forest tundra	Adaptation	yes	internal	ex-ante	yes
27	Kunwar et al. (2014)	Nepal	various	yes	Acceptance and application of nonindigenous species and sites for livelihood and ethnopharmacopoeias	Adaptation	yes	internal	ex-post	decreasing
28	Li and Ford (2019)	Panama	Ngöbe-Buglé	yes	Clear agricultural plots instead of semi-clearing, increased forest cover	Coping	yes	both	ex-post	decreasing
29	Makondo and Thomas (2018)	Africa	73 ethnic groups	yes	Various	Adaptation	yes	internal	ex-ante	yes
30	Mateo-Vega et al. (2017)	Panama	Embera and Wounaan	anticipated	Forest monitoring	Mitigation	no info	external	ex-ante	knowledge of their forest
31	Mathews (2009)	Mexico	Zapotec	yes	Anti-logging policy, desiccation theory	Mitigation	yes	both	ex-ante	yes

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK (*continued*)

N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
32	McIntyre-Tamwoy, Fuary and Buhrich (2013)	Australia	Aboriginal	anticipated		Adaptation	yes			
33	McSweeney and Coomes (2011)	Honduras	Tawahka	yes	Various, Local Institutional Innovation in Land Tenure	Cop.-Adapt.	yes	internal	ex-post	no
34	Meena et al. (2019)	India	Pangwals and Bhots	yes	Agroforestry, diversification	Coping	yes	internal	ex-ante	partly
35	Mistry, Bilbao and Berardi (2016)	South America	various	yes	Regular and sometimes opportunistic burning throughout the dry season	Mitigation	yes	internal	ex-ante	yes
36	Mockta et al. 2018.	USA	Mescalero Apache Tribe	anticipated	Exclusion from silv. Treatment, regeneration	Adaptation	no info	external	ex-ante	yes
37	Mukherjee et al. (2016)	India	various	yes	Agroforestry, plant protection	Adapt-Mitig.	yes	internal	ex-ante	yes
38	Vogt et al. (2016)	Brazil		yes	Agroforestry, adapted land-use-planning	Cop.-Adapt.-Mitig.	yes	internal	both	yes
39	Nkem et al. (2013)	Cameroon	Bantu, Pigmies	anticipated	Pygmies migrate to different hunting grounds or for NTFPs	Adaptation	no info	internal	not yes	no info
40	Ogden and Innes (2008)	Canada	Champagne and Aishihik First Nations	do not change		no change	yes	no	none	
41	Paladino (2011)	Mexico	Scolel Te'	yes	From coffee to agroforestry (REDD+)	Mitigation	no info	external	ex-ante	no

Appendices

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK (*continued*)

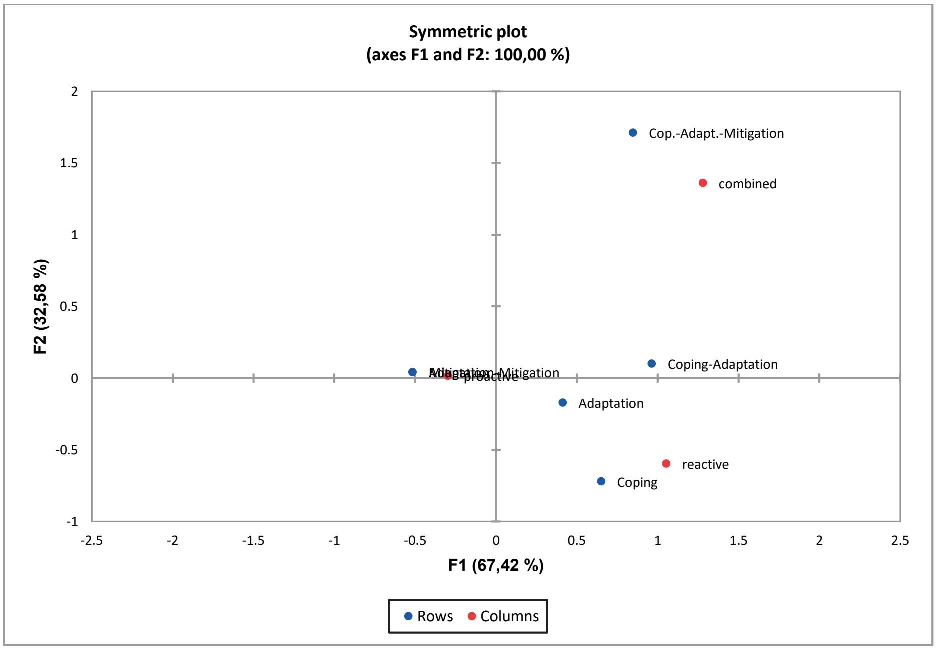
N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
42	Poffenberger (2015)	India	Khasi	yes	Degraded forests areas for restoration through closure and enrichment planting	Adapt-Mitig.	yes	both	ex-ante	yes
43	Poudyal et al. (2020)	Nepal	Tarai CF	yes	Exclusion due to REDD+	Mitigation	no info	external	ex-ante	no
44	Rahman and Alam (2016)	Bangladesh	various	yes	Shelterbelts, agroforestry	Cop.-Adapt.-Mitig.	yes	both	ex-ante	yes
45	Rajão and Marcolino (2016)	Brazil	Acapu	yes	ICT for redd carbon (REDD+)	Mitigation	no info	internal	ex-ante	no
46	Rodríguez et al. (2018)	Colombia	U'wa people,	yes	Unsustainable land use, including overharvesting practices	Adaptation	yes	internal	ex-post	no
47	Sauls (2019)	Mesoamerica	AMPB	yes	REDD+, several activities	Mitigation	no info	external	ex-ante	no
48	Sharma and Sharma (2017)	India	various	yes	Agroforestry	Adapt-Mitig.	yes	internal	ex-ante	yes
49	Smith and Dressler (2019)	Philipines	Pala'wan people	yes	Changing livelihoods	Adaptation	yes	internal	ex-post	no
50	Takakura (2016)	Russia	Sakha (Yakut)	anticipated	Pastoral adaptation	Adaptation	yes			
51	Torres, Acuña and Vergara (2014)	Mexico	various	yes	MRV, various (REDD+)	Mitigation	no info	external	ex-ante	no
52	van Gevelt et al. (2019	Malaysia	Penan	yes/no	Relocation of houses and crops	Adaptation	yes (do not match climate data)	internal	ex-ante (only some hh)	yes

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK (*continued*)

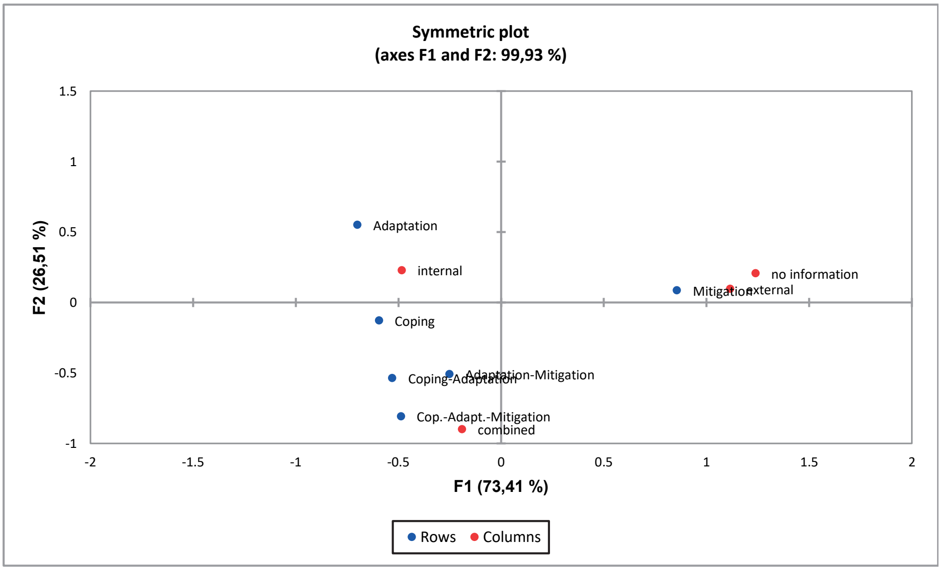
N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
53	Vera V, Cota-Sánchez and Grijalva Olmedo (2019)	Ecuador	Kichwa	yes	Chakra	Mitigation	no info	internal	ex-ante	yes
54	Vigilante et al (2017)	Australia	Aboriginal (Wunambal Gaambera)	yes	Traditional fire management	Adapt-Mitig.	no info	both	ex-ante	yes
55	Vitel et al. (2013)	Brazil	Suruí	anticipated	Conservation	Mitigation	no info	both	ex-ante	no
56	Vlassova, (2006)	Russia	Indigenous Peoples of the Russian North (IPRN)	anticipated	Establishment of a Boreal Residents Network for Socio-environment Assessments	Adaptation	yes			
57	Vuojala-Magga, and Turunen. (2015)	Scandinavia	Sami	yes	Raindeer feed on birch leaves now	Cop.-Adapt.	yes	internal	ex-post	yes
58	Walker et al. (2020)	Amazon	IPLC	yes	Carbon storage	Mitigation	no info	no info	ex-ante	no info
59	Wallbott and Florian-Rivero. (2018)	Costa Rica	various	yes	Reforestation, agroforestry, restoration (REDD+)	Mitigation	no info	external	ex-ante	no
60	Ahmad Wani and Ariana (2018)	Indonesia	Bajo tribe	yes	Planting mangrove	Adaptation	yes	internal	ex-ante	yes

Appendix.Table 25. Complete list of included literature, including author(s), country or region covered, indigenous group, adjustment, response strategy, response type, sensitivity of climate change, driver, response time and use of TEK (*continued*)

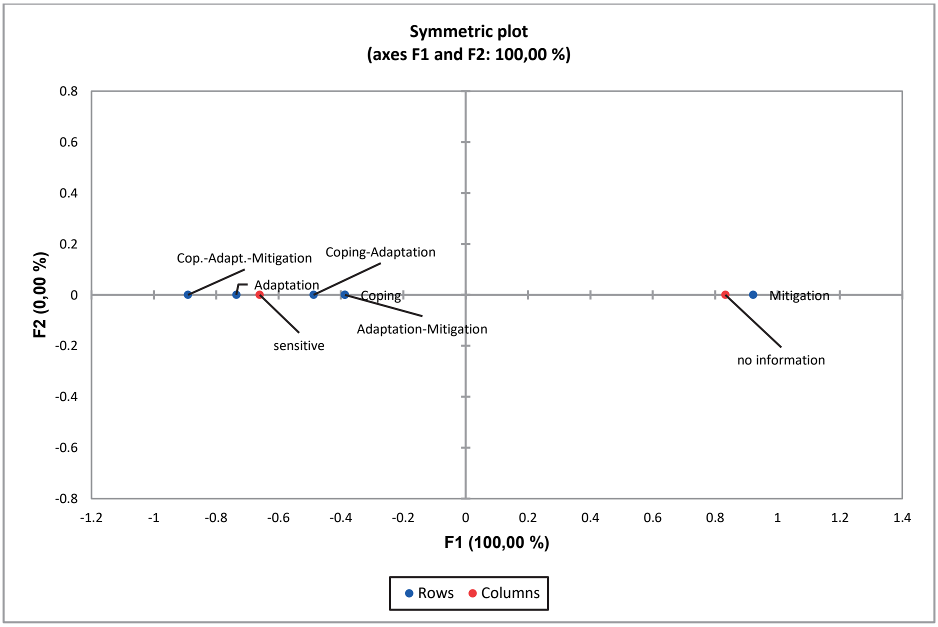
N°	*Authors*	*Country or Region*	*Indigenous group*	*Adjustment*	*Response strategy*	*Response type*	*Sensitivity*	*Driver*	*Response time*	*TEK*
61	Wyllie de Echeverria and Thornton (2019)	North America	Indigenous Nations, Tlingit, Haida, or Tsimshian	yes	Indicator species	Adaptation	yes	internal	both	yes
62	Yazzie et al. (2019)	USA	Navajo	anticipated	Adapting silviculture	Mitigation	yes	both	ex-ante	yes
63	Zahn, Palmer and Turner (2018)	Canada	8 First Nations	yes	NTFP collection different time	Adaptation	yes	internal	ex-ante	yes
64	Zavaleta et al. (2018)	Peru	Shawi	yes	Change in hunting species due to unavailability, less kids, eating forest food	Cop.-Adapt.	yes	internal	both	no



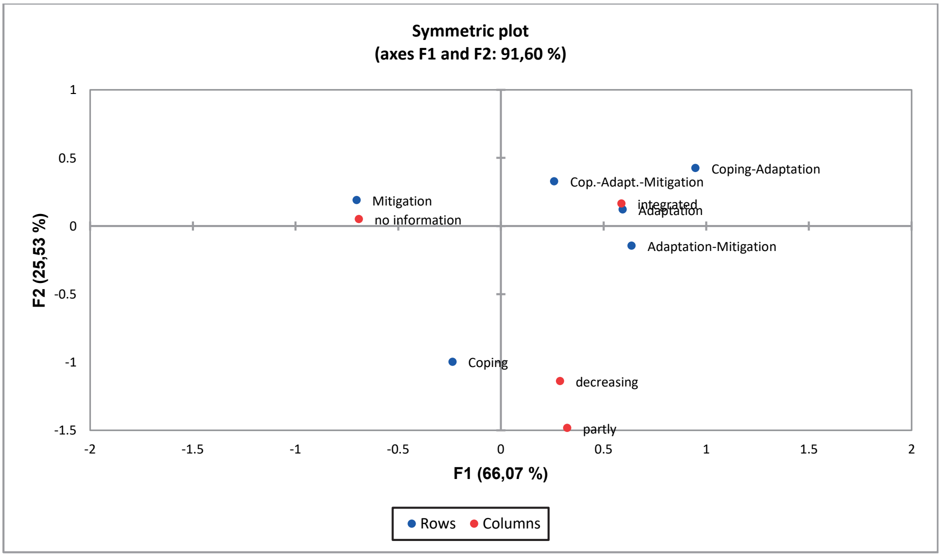
Appendix.Figure 41. Correspondence analyses of strategy and response time.



Appendix.Figure 42. Correspondence analyses of strategy and driver.



Appendix.Figure 43. Correspondence analyses of strategy and sensitivity of Indigenous peoples.



Appendix.Figure 44. Correspondence analyses of strategy and the application of TEK.

Appendix.Table 26. List of reviewed National Adaptation Plans and National Determined Contributions

Country	Strategy	Document	Year	Role of forest-dependence	Role of indigenous people	Role of TEK
Australia	Adaptation	National Climate Resilience and Adaptation Strategy	2015	no	(yes)	yes
Bangladesh	Adaptation	NAP in process 7. 5-year plan	2015	yes	yes	yes
Bolivia	Adaptation	Lineamientos y Acciones Estratégicas de la Política Plurinacional de Cambio Climático	2015	yes	yes	yes
Brazil	Adaptation	NAP	2016	yes	yes	yes
Cameroon	Adaptation	NAP	2015	yes	yes	yes
Canada	Adaptation	PAN-CANADIAN FRAMEWORK on Clean Growth and Climate Change	2016	no	yes	yes
Colombia	Adaptation	NAP	2018	yes	yes	yes
Ghana	Adaptation	Ghana´s National Adaptation Plan Framework	2018	no	yes	yes
Honduras	Adaptation	Plan Nacional de Adaptación al Cambio Climático 2018-2030	2018	community forestry	yes	yes
India	Adaptation	National Action Plan for Climate Change	2008	community forestry	no	yes
Indonesia	Adaptation	National Action Plan for Climate Change Adaptation (RAN-API)	2013	no	no	no
Malaysia	Adaptation	Malaysia-3rd-National-Communication-and-2nd-Biennial-Update-Report-to-UNFCCC-NC-3-BUR-21	2018	no	yes	no
Nepal	Adaptation	National Adaptation Plan Formulation Process May 2017	2017	yes	yes	yes
Panama	Adaptation	Plan Nacional de Adaptación al Cambio Climático	2015	yes	yes	no
Peru	Adaptation	Tercera Comunicación Nacional del Perú a la Convención Marco de las Naciones Unidas sobre el Cambio Climático	2016	yes	yes	yes

Appendices

Appendix.Table 26. List of reviewed National Adaptation Plans and National Determined Contributions (*continued*)

Country	Strategy	Document	Year	Role of forest-dependence	Role of indigenous people	Role of TEK
Philipines	Adaptation	National Climate Change Action Plan	2011	yes	yes	yes
Russia	Adaptation	National Climate Policy	2020	no	yes	no
USA	Adaptation	Climate Change Adaptation Plan	2014	no	yes	yes
Venezuela	Adaptation	2. National Communication	2017	yes	yes	yes
Vietnam	Adaptation	not yet developed				
Australia	Mitigation	updated NDC communication	2020	no	no	no
Bangladesh	Mitigation	updated NDCFi	2020	yes	no	no
Bolivia	Mitigation	NDC	2016	yes	yes	yes
Brazil	Mitigation	NDC	2020	no	yes	no
Costa Rica	Mitigation	NDC	2020	no	yes	yes
Ecuador	Mitigation	NDC	2019	no	yes	yes
India	Mitigation	NDC	2016	no	no	yes
Mexico	Mitigation	NDC	2020	yes	yes	yes
Nepal	Mitigation	NDC	2020	yes	yes	no
New Zealand	Mitigation	NDC+Climate Change Response (Zero Carbon) Amendment Act 2019	2020	no	yes	yes
Panama	Mitigation	updated NDC	2020	yes	yes	yes
Peru	Mitigation	updated NDC	2020	no	yes	no
Philipines	Mitigation	NDC	2021	no	yes	yes
Vietnam	Mitigation	NDC(combined)	2020	yes	yes	yes

Summary

Forest ecosystems form a complex interwoven social-ecological system with adjacent users who depend on them to meet daily livelihood needs. Climate change threatens local and Indigenous peoples in rural areas, whose reliance is based on natural resources to support food production systems and who have limited access to socio-economic resources. Their responses to changing weather conditions may include using elements of the ecological system and can influence livelihood vulnerability, livelihood resilience, and the sustainability of social-ecological systems (SES). The sensitivity of natural resources sectors to even minor changes in climate can increase the vulnerability of livelihoods relying on them. Examining how climate change affects particular social groups, especially in regions with high climate sensitivity, is essential for both climate change adaptation and mitigation efforts. Indigenous forest-dependent peoples´ responses to climate change are still poorly understood, particularly in Bolivia. Also, many climate-related events with adverse effects on the poor in developing countries remain unrecognized and earlier climate change studies have primarily focused on entire communities, while disaggregated evidence at the household level is scarce. This thesis explores the potential impacts of climate change on Indigenous forest-dependent livelihoods and forest products use from a local to global perspective. It contributes to the understanding of the impact of the 2014 extreme precipitation weather event in Northern Bolivia by 1) investigating its socio-economic effects on rural households of the TCO Tacana I (*Tierra Comunitaria de Origen*, Communal Land of Origin) in the country's Amazon region; 2) analysing the livelihood resilience and vulnerability, and implications of policies in shaping current conditions of resilience and vulnerability at the local level; 3) documenting the perception held by these households on the effects, traditional weather indicators, and affected and mobilized livelihood capitals to overcome the event; and 4) analysing the role of forest products in coping with the extreme precipitation event. The thesis also includes a systematic literature review of Indigenous responses to the effects of climate change that examines and quantifies the prevalence of various adaptation and mitigation strategies, their drivers, and the role of perception and traditional knowledge in forest use and management on a global scale. A case study approach was used in which 50 (45) households of three Indigenous communities of the TCO Tacana I in Bolivia formed the units of analysis. A mixture of quantitative and qualitative data collection methods was employed including socio-economic household interviews, participatory photo-voice and a systematic literature review.

The findings of this research show a negative economic impact on natural resources-dependent livelihood strategies as an immediate consequence of the 2014 extreme weather event. However, most households had economically recovered just one year later. Contrary to expectations, no considerable shift towards higher timber extraction was found. In response to the flood, livelihood activity shifts indicated livelihood diversification as an overall risk response strategy.

Livelihood resilience and vulnerability were influenced by income activities: the sale of game and fish correlated with a comparably low vulnerability, while the commercialization of game and cattle ranching related to higher resilience. Cash-poor households were significantly more vulnerable to the flood than better-off households. Currently, Bolivian development policies prioritize economic growth based on strengthening the energy, agro-livestock sector and boosting oil and mining sectors with industrialization. Some of these priorities threaten the resilience and increase the vulnerability of Indigenous forest-dependent people and their subsistence livelihoods. Tacana's perception of weather trends and those of western science-trained specialists were found to complement each other because they provide different sets of details. Thirty-eight traditional weather-related short-term indicators were documented, however, the current reliability of the indicators has been questioned, indicating a need for further observation and research for potential long-term environmental change. Natural capital, in particular crops, was perceived to be the most affected during the extreme weather event and the households' strong bonding and networking social capital (intracommunal and external) facilitated coping. The findings confirmed the important role forest products play as a constant income contribution and the minor role as gap filler. The results of the literature review revealed, that globally, knowledge clusters of forest-dependent Indigenous peoples´ coping and adaptation, mitigation, and joint strategies exist for North and South America and Asia. The Indigenous-driven coping and adaptation strategies reported, were all ex-post, and linked to people´s sensitivity to climate change and the involvement of Traditional Ecological Knowledge (TEK). Reported mitigation strategies, mostly REDD+ projects, were implemented ex-ante and driven mainly by external initiatives, largely omitting information on the sensitivity of the studied Indigenous group and TEK. Joint strategies seem to be a good compromise of participatory efforts linked to the integration of sensitivity of Indigenous peoples and TEK.

This research contributes to the understanding of how livelihoods of people living in tropical lowland forests cope with weather extremes. Chapter 2 concludes that the impacts of extreme events vary between livelihood strategies and thus if socio-economic risk adaptation and mitigation strategies are to be effective, they should consider intra-communal heterogeneity at a household level. Strengthened intra-and inter-communal bonding, hunting and fishing played a key role in increasing resilience and lowering vulnerability of Tacana livelihoods in the context of the extreme weather event. However, the external pressure on forest resources, including fish, requires a holistic and cross-sectoral focus on livelihood resilience. Sustainable and integrative wildlife management and monitoring should to be acknowledged in higher-level strategies and operative plans, contingency and recovery plans, and forest management plans. More importantly, measures need to be taken in place to avoid exceeding critical socio-ecological thresholds and ensure long-term human and ecosystem health (Chapter 3). Chapter 4 suggests that the acknowledgement of local knowledge and perceptions can avoid perception gaps and assist risk management strategies. Chapter 5 demonstrates that despite the increasing acknowledgement of Indigenous people´s active role in forest preservation and fighting climate change, there is a need for a more inclusive approach to mitigation strategies and a need to address forest-dependence, independent from the societal group, especially in countries where forests play a crucial role for climate adaptation and mitigation.

Resumen

Los ecosistemas forestales constituyen un complejo sistema socioecológico entrelazado con usuarios adyacentes que dependen de ellos para satisfacer sus necesidades diarias de subsistencia. El cambio climático amenaza a los pueblos locales e indígenas en las zonas rurales, cuya subsistencia se basa en los recursos naturales para apoyar sus sistemas de producción de alimentos y quienes tienen un acceso limitado a los recursos socioeconómicos. Sus respuestas a las condiciones climáticas cambiantes pueden incluir el uso de elementos del sistema ecológico y pueden influir en la vulnerabilidad de los medios de vida, la resiliencia de los medios de vida, y la sostenibilidad de los sistemas socioecológicos (SES). La sensibilidad de los sectores de recursos naturales incluso a cambios pequeños en el clima puede aumentar la vulnerabilidad de los medios de vida que dependen de ellos. Examinar cómo el cambio climático afecta a grupos sociales específicos, especialmente en regiones con alta sensibilidad al clima, es esencial para los esfuerzos de adaptación y mitigación del mismo. Las respuestas al cambio climático de los pueblos indígenas dependientes de los bosques aún son poco entendidas, particularmente en Bolivia. Además, muchos eventos relacionados al clima con efectos adversos en los pobres en los países en desarrollo siguen sin ser reconocidos, y estudios anteriores sobre el cambio climático se han enfocado principalmente en comunidades enteras, mientras que la evidencia desagregada a nivel de hogares es escasa. Esta tesis explora los impactos potenciales del cambio climático en los medios de vida indígenas que dependen del bosque y del uso de productos forestales desde una perspectiva local a una global. Contribuye a la comprensión del impacto del evento climático de precipitación extrema del año 2014 en el norte de Bolivia al 1) investigar sus efectos socioeconómicos en los hogares rurales de la TCO Tacana I (*Tierra Comunitaria de Origen*) en la región amazónica del país; 2) analizar la resiliencia y vulnerabilidad de los medios de vida, y las implicaciones de las políticas públicas en la determinación de las condiciones actuales de resiliencia y vulnerabilidad a nivel local; 3) documentar la percepción que tienen estos hogares sobre los efectos, los indicadores climáticos tradicionales, y los capitales de subsistencia afectados y movilizados para superar el evento; y 4) analizar el papel de los productos forestales para superar el evento de precipitación extrema. La tesis también incluye una revisión sistemática de la literatura de las respuestas indígenas a los efectos del cambio climático que examina y cuantifica la prevalencia de varias estrategias de adaptación y mitigación, sus impulsores y el papel de la percepción y el conocimiento tradicional en el uso y manejo de los bosques a escala global. Se utilizó un estudio de caso en el que 50 (45) hogares de tres comunidades indígenas de la TCO Tacana I en Bolivia formaron las unidades de análisis. Se empleó una combinación de métodos cuantitativos y cualitativos de recolección de datos que incluyeron entrevistas socioeconómicas a los hogares, foto-voz participativa y una revisión sistemática de la literatura.

Los hallazgos de esta investigación muestran un impacto económico negativo en las estrategias de subsistencia dependientes de los recursos naturales como consecuencia inmediata del evento climático extremo del 2014. Sin embargo, la mayoría de los hogares se habían recuperado económicamente después de solo un año. Contrariamente a lo esperado, no se encontró un cambio considerable hacia una mayor extracción de madera. En respuesta a la inundación, los cambios en la actividad de los medios de subsistencia indicaron la diversificación de los medios de vida como una estrategia general de respuesta al riesgo. La resiliencia y la vulnerabilidad de los medios de vida se vieron influenciadas por las actividades de ingresos: la venta de caza y pescado se correlacionó con una vulnerabilidad comparativamente baja, mientras que la comercialización de la caza y la ganadería se relacionó con una mayor resiliencia. Los hogares con bajos ingresos de efectivo eran significativamente más vulnerables a las inundaciones que los hogares más acomodados. Actualmente, las políticas de desarrollo bolivianas priorizan el crecimiento económico basado en el fortalecimiento del sector energético, agropecuario y el impulso a los sectores petrolero y minero con la industrialización. Algunas de estas prioridades amenazan la resiliencia y aumentan la vulnerabilidad de las comunidades indígenas que dependen de los bosques y sus medios de subsistencia. Se encontró que la percepción de los Tacana sobre las tendencias climáticas y la de los científicos occidentales se complementan entre sí porque proporcionan diferentes tipos de detalles. Se documentaron treinta y ocho indicadores tradicionales a corto plazo relacionados con el clima, sin embargo, la confiabilidad actual de los indicadores ha sido cuestionada, lo que indica la necesidad de una mayor observación e investigación para un potencial cambio ambiental a largo plazo. El capital natural, en particular los cultivos, se percibió como el más afectado durante el evento climático extremo y la fuerte vinculación entre los hogares y la creación de redes de capital social (intracomunal y externo) facilitaron la sobrevivencia. Los hallazgos confirmaron el importante rol que desempeñan los productos forestales como una contribución constante a los ingresos y el papel menor como ayuda para imprevistos. Los resultados de la revisión de la literatura revelaron que, a nivel mundial, existen grupos de conocimiento de los pueblos indígenas dependientes de los bosques con estrategias conjuntas en temas de sobrevivencia, adaptación, y mitigación en América del Norte, América del Sur y Asia. Las estrategias reportadas de sobrevivencia y adaptación impulsadas por los indígenas fueron todas ex-post y vinculadas a la sensibilidad de las personas hacia el cambio climático y su participación en los Conocimientos Ecológicos Tradicionales (CET). Las estrategias de mitigación reportadas, en su mayoría proyectos REDD+, se implementaron ex-ante y fueron impulsadas principalmente por iniciativas externas, omitiendo en gran medida información sobre la sensibilidad del grupo indígena estudiado y sus CET. Las estrategias conjuntas parecen ser un buen compromiso de los esfuerzos participativos vinculados a la integración de la sensibilidad de los pueblos indígenas y sus CET.

Esta investigación contribuye a entender como los medios de vida de las personas que viven en los bosques tropicales de tierras bajas afrontan los extremos climáticos. El capítulo 2 concluye que los impactos de los eventos extremos varían dependiendo de las estrategias de subsistencia y, por lo tanto, para que las estrategias de adaptación y mitigación de riesgos socioeconómicos sean efectivas, deben considerar la heterogeneidad intracomunitaria a nivel de los hogares. El fortalecimiento de los vínculos intra e intercomunitarios, la caza y la pesca desempeñaron un papel clave en el aumento de la resiliencia y la reducción de la vulnerabilidad de los medios de vida Tacana en el contexto del evento climático extremo. Sin embargo, la presión externa sobre los recursos forestales, incluidos los peces, requiere un enfoque holístico e intersectorial en la resiliencia de los medios de vida. Un manejo y monitoreo de la vida silvestre sostenible e integrador debe reconocerse en las estrategias y planes operativos a nivel superior, los planes de contingencia y recuperación, y en los planes de manejo forestal. Más importante aún, es necesario adoptar medidas para evitar superar los umbrales socioecológicos críticos y garantizar la salud humana y de los ecosistemas a largo plazo (capítulo 3). El capítulo 4 sugiere que el reconocimiento de los conocimientos y percepciones locales puede evitar vacíos de percepción y ayudar en las estrategias de gestión de riesgos. El capítulo 5 demuestra que, a pesar del creciente reconocimiento del rol activo de los pueblos indígenas en la preservación de los bosques y la lucha contra el cambio climático, existe la necesidad de un enfoque más inclusivo de las estrategias de mitigación y la necesidad de abordar la dependencia de los bosques, independientemente del grupo social, especialmente en los países donde los bosques desempeñan un papel crucial para la adaptación y mitigación del clima.

Acknowledgement

This thesis was only possible thanks to numerous people dear to me.

First and foremost, special thanks go to my supervision team **Wil, Verina** and **Bas**. Dear **Wil**, you have guided me through this journey from the start until the end. As my promotor, mentor and friend, we made this journey together and travelled the – not so seldom - roughest seas. You supported me in redirecting the sailboat, including bringing Bas and Verina on board. No matter how strong the wind blew from all directions, the three of you believed I could manage to travel this small canoe – so as it started – over the big ocean. You helped me transform the canoe into a proper sailboat which would withstand thunderstorms, hail and even attempts to let it sink. Your belief in me was the nails that held the ship together. I owe you a great debt of gratitude for your precious advice, revisions, knowledgeable and critical thoughts and patience, which concerns my rather busy circumstances. With every wave and storm overcome, the sailing of the boat improved. And while I initially "just" intended to sail across the ocean in a direct line, we eventually enjoyed a rather long world trip together. **Verina, Bas, and Wil**, thanks for the best supervision I could have ever imagined.

Individual thanks go to **Wil** for your guidance, open mind, pragmatism and humour. Although we regularly lived at least six time zones apart, I never felt any distance under your supervision. You were literally always there for me, and your encouragement and constructive feedback sharpened my ideas and eventually shaped this thesis. Also, thank you for inviting me to the incredibly wonderful and inspiring scientific workshops you organized in the Black Forest, Cusco and Huacho.

Verina, you are the perfect example of female power combining high-quality research, hard work, and dedication with the fun of remote fieldwork in the forest. Thank you for your trust in me and guidance from the first call we had, when I still lived in Kinshasa until now. You were the one who understood very well what it meant to combine a full-time job with PhD research for years.

Bas, I feel very honoured to have you as my first promotor. Your acceptance of me as a long-distance external PhD student at FNP and your constant interest in my work significantly boosted my motivation and inspiration. I highly appreciated your thorough feedback on all of my papers and thesis. Your encouraging supervision made my ship go far beyond what I had expected.

I would also like to thank the **Forest and Nature Conservation Policy (FNP)** Research Group, especially **Keen, Georg** and my **dear PhD companions**, for the scientific and social exchange. I wish I could have spent more time with you in Wageningen.

I would like to thank the PhD thesis committee **Prof. Dr. René Boot**, **Prof. Dr. Ingrid Visseren-Hamakers, Prof. Dr. Pieter Zuidema** and **Prof. Dr. Markku Kanninen,** for the effort and time to critically review this PhD thesis.

El tiempo que pasé en la TCO Tacana fue un privilegio y me gustaría expresar mi mayor gratitud a la organización de **CIPTA**, una organización dedicada a la preservación de la cultura e identidad Tacana y a la conservación de su medio ambiente. En particular, Don **Nicolas Cartagena** y Don **Hernán Chuqui**, gracias por su apoyo.

Me corresponde expresar la más profunda gratitud a mis **tres comunidades** de investigación con todas las familias que pertenecen a ellas. Muchas gracias por compartir sus vidas diarias, historias, tradiciones, sus preocupaciones, pero también su diversión, incluso a una u otra chicha. Aunque la investigación, los convenios y acuerdos internacionales y las estrategias de lucha contra el cambio climático suelen estar tan lejos de las personas que sienten los efectos tan cerca, con este trabajo me gustaría fortalecer su voz.

Santa Rosa de Maravilla - Gracias por acogernos en tus familias y por la profunda amistad que se ha desarrollado. En particular muchísimas gracias a la gran **familia Chuqui** por atendernos, llevarnos al campo y brindarnos apoyo en todo momento. **Don Rogelio**, ha sido un gran honor conocer y escuchar a usted.

Napashi o San Silvestre, gracias a todas familias por su hospitalidad. Un agradecimiento especial a la **familia de Don Feliciano**, que nos acogió muy cordialmente en su casa.

Buena Vista, bella gente – así sería el resumen corto de la comunidad. El recuerdo de este tiempo hermoso y lugar siempre permanecerá. Cuánto hemos aprendido, comido y reído juntos. **Doña Nancy** nos brindaste no solamente hasta tu propia cama – si no también tu apoyo en la recolección de datos. Y finalmente nos llevaste en tu moto en plena lluvia y rio creciendo de la comunidad hacia San Buenaventura para en último momento escapar de las inundaciones. Esto fue solo el principio de las inundaciones en 2013/2014.

Hay timbre. Funciona. **Bachi**, mi linda amiga. La recopilación de datos y, en última instancia, la finalización de esta tesis no hubiera sido posible sin tu apoyo, tu compromiso y amistad. Nuestra amistad va mucho más allá de esta disertación. Te agradezco de todo corazón por haberme introducido en la cultura boliviana. Me inspiraste siempre con tu cordialidad, tu franqueza, pero también tu sentido por la naturaleza, la familia y por la continuación de antiguas tradiciones y conocimientos. Juntos aprendimos sobre la vida de los Tacanas. Sobrevivimos el incendio en Maravilla, cruzamos juntos ríos caudalosos en la moto, pasamos nuestras tardes libres de domingo frente a la Rockola cantando viejas canciones y disfrutando acaí o pescado fresco. Estoy muy agradecida de que hayamos podido pasar estos momentos instructivos, bellos, interesantes y sobre todo aventureros juntos y estoy segura de que algún día volveremos. Dos más y nos vamos 😉.

Ale, muchísimas gracias a vos por tu enorme ayuda y compromiso en la segunda parte de la recolección de datos.

I am also very glad that I had the opportunity to get to know you, **Benno (Pokorny)** and **Pablo (Pacheco)**; thank you so much for your reflections and critical discussions on methodological parts and policies, but not to forget also the laughs and nice time we shared at the workshops.

Walter y **Mario**, mis dos queridos amigos bolivianos, compañeros de mi tesis desde hace mucho tiempo que admiro mucho! Para mí, ambos son ejemplos de científicos dedicados con una tremenda experiencia de campo, diligencia y profesionalidad - pero - sin olvidar su buen sentido del humor, para el baile y los lados agradables de la vida – y que me enseñaron que lo uno no excluye al otro. Les agradezco de todo corazón que me hayan permitido aprender tanto de ustedes, de Bolivia, del contexto político y de la pasión por los bosques que ambos comparten. Estoy seguro de que nuestros caminos se cruzarán de nuevo.

Lieber **André**, meinen herzlichsten Dank an Dich für Deine große Unterstützung in meinen ersten Doktorandenjahren und Deine langjährige Freundschaft. Dein kritisches und allzeit konstruktives Feedback, sowie Deine innovativen Ideen (die sich bevorzugt bei dem ein oder anderen Abendbierchen in unserem Garten in Tharandt entwickelten) haben diese Dissertation nachhaltig geprägt. Mein Dank gilt ebenfalls dem **PhD-Kollegium** und **Institut für Tropische Forstwirtschaft** in Tharandt, wo diese lange Reise begann.

Personally, we met only once, dear **Charlotte**, – yet our meeting had a lasting impact on my life as a researcher. We share the passion and work for forest communities in the Congo Basin and the Amazon, particularly for the Tacanas in Bolivia. Your work has inspired me in many ways, and it is mainly thanks to you that I have had the courage to apply at FNP Wageningen, which turned out to be a life changer.

Marieke, thank you for your friendship and hospitality, especially the wonderful time we spent together in Lima, Pucallpa and Freiburg. We did not only share the remote PhD life, far from Wageningen, often struggling with the daily challenges of the sometimes rather adventurous life in Peru, but also the passion for nature conservation. We shared lots of beautiful moments, some difficult ones as well, but most importantly, the certainty to encourage each that we can face all challenges and never give up.

Lieber **Ueli**, Du warst einer der wenigen in meinem Arbeitsumfeld, dem ich das Projekt meiner Doktorarbeit anvertraut habe und der mich fortwährend darin bestärkt hat. Du hast mich damals nach Kinshasa geholt, trotz des Wissens, dass ich noch promoviere, dass diese Doppelbelastung ein Stressfaktor sein könnte (war) und dennoch hast Du immer an mich geglaubt und mir Mut gemacht, die Arbeit (neben der Arbeit) zu beenden. Ich danke Dir von ganzem Herzen dafür – Dein Glaube an mich, hat mich immer begleitet und bestärkt.

Rubén, mi querido amigo. Nunca voy a olvidar el momento cuando por varias veces consecutivos el vuelo desde La Paz hacia Rurrenabaque no se realizó y después haber pasado una noche en el frio de El Alto me llevaste a tu casa y te aseguraste de que llegaria sana y salva nuevamente al aeropuerto. También te debo un cordial agradecimiento por ayudarme con muchos contactos, consejos y la traducción del resumen.

Liebe **Sondra**, Deine wegbereitenden Forschungsarbeiten und Texte zu den Tacanas haben mich sehr inspiriert. Herzlichen Dank für den allzeit guten Austausch in Peru und Dein tiefes Interesse an meiner Forschung.

My dear constant companions during all those years, my **friends all over the world** – some of you knew of my ‘small hobby’, others never knew. That does not matter. What did matter is the fact that all of you supported me with your friendship and helped me to put things in perspective. I wish to express many thanks to my dear **Mela**, the one who knows me the longest and best; **Lisa, Hansi, Tim, Arne** and the entire international group of friends from Tharandt; the friends I made in Kinshasa, first and foremost **Isabell, Ousman, Ueli, Henrike, Jens, Anne-Lise**; in Bolivia, **Bachi, Fabo, Edgar, Omar, Ceci, Ruben, Renee, Walter, Mario, Valeria, Susan, Kristina and Dirk** and so many more; my dear friends and colleagues from Peru, **Malena, Hannes, Lino, Liz, Iliana, Henri, Frank, Withman** and all my dearest friends from **OSINFOR** and **GIZ**; all my friends from GNE & Witzenhausen, especially **Tanja, Jenny, Georg and Johanna**. And not to forget my four(eight)-legged and (partly) fluffy friends who were mental supporters, most loyal friends and who purred me up, and protected me, in difficult times. Thanks for being there.

Ein besonderer Dank gilt meinen lieben **Eltern** und meiner **Familie**. Ich danke euch von Herzen für das Fundament dieser Arbeit, welches lang vor dem Beginn dieser Forschung gelegt wurde: Ihr habt mir das Studium ermöglicht und mich immer ermutigt, meinen eigenen Weg zu gehen, bescheiden zu bleiben und für das zu kämpfen, was einem am Herzen liegt.

Mutti und Vati, mir ist durchaus bewusst, dass meine Sturköpfigkeit und Beharrlichkeit in Verbindung mit meiner manchmal tragischen Vorliebe für abenteuerliche und abgelegene Forschungsgebiete in tropischen Wäldern für euch nicht immer leicht zu ertragen waren – aber ohne diese tollen Gene wäre meine Doktorarbeit – nebst Vollzeitjob - wahrscheinlich nie zu einem Ende gekommen 😉.

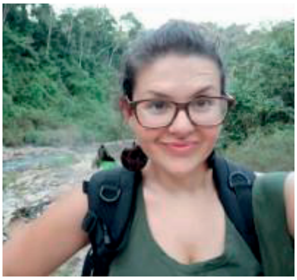
Ik zou ook graag mijn hartelijke dank willen betuigen aan mijn lieve **Nederlandse familie**, die altijd begrip toonde als ik veel te vaak moest schrijven in plaats van bij het gezin te zijn. Dank jullie kindjes voor de leuke tijden samen, die me veel energie hebben gegeven.

And last but most importantly, my dearest love **Appie**, I know the time was far from being easy for us – combining a full-time job and PhD was not always a good idea, and opportunity costs were incredibly high. Thank you for your patience, understanding, support, occasional and motivational pale ales, inspiring walks & talks, and your love throughout this long-lasting journey. Today is the day the word soon is being replaced with finally.

Many places and moments have provided me with lasting inspiration for writing this thesis. In the course of my dissertation, I moved ten times over three different continents, where I lived in large cities like Kinshasa, Pucallpa and Lima, and spent as much time backpacking and camping in rural communities of the Bolivian Chiquitania and the Amazon forest. Besides at home, I read and wrote papers, presentations and chapters in airports, on buses, and on planes during lunch breaks, in the mornings, late evenings and at weekends. All these experiences have left lasting traces and have shaped me forever.

About the author

CURRICULUM VITAE



Tina Bauer was born on November 9, 1983, in Zschopau, former East Germany, and very much enjoyed growing up on a farm in a small mountain village called Schönbrunn. The surrounding forest and animals sparked her keen interest in nature, which has not left her since.

After graduating from Gymnasium in 2002, she studied informatics but returned to nature and graduated with a Diploma in Geo-ecology and Ecosystem-Management from Tübingen University, University of Applied Forest Sciences Rottenburg, University Hohenheim. During her studies, she did an internship in Brazil and in the Ecuadorian rainforest that provided her with lasting inspiration to contribute to tropical forest conservation. She focused on forestry at Rottenburg and tropical forestry at the University of Applied Sciences Van Hall Larenstein in Arnhem during her studies and finished her MSc thesis on the topic of timber legality in community forests in Cameroon.

In 2012, after having worked for some time in an organic farming project in Panama and for Tropenbos International in Wageningen, she started to pursue a PhD to gain a deeper understanding of forest-dependent communities. To finance her studies, she began to work as a tutor for the MSc Tropical Forestry at TU Dresden. Then, as part of the INCA (International Network on Climate Change) research programme in 2013, she completed her first part of fieldwork in Bolivia's dry and wet tropical forests. In 2014, the research programme, her funding and her job ended. As a junior advisor for community forestry in the Democratic Republic of the Congo, she took up a new challenge as part of a GIZ project supporting Sustainable Forest Management and Biodiversity Conservation. The period in DRC introduced her to the world of development cooperation.

In early 2016, she joined the Forest and Nature Conservation Policy Group in Wageningen UR as an external PhD candidate where she continued researching forest communities and climate change in the Bolivian Amazon.

In 2017, she followed additional training at GNE Witzenhausen, Germany, to acquire more profound knowledge and skills and to become an international development project coordinator. In the same year, she moved back to the tropics to work as an advisor for Indigenous forest management and timber legality at the regional forest administration in Ucayali and later as part of the forest inspection agency OSINFOR in the frame of a GIZ project (ProAmbiente II) in Peru. Since 2020, she has been a planning advisor at GIZ headquarters in Eschborn, Germany and develops international forest projects for German ministries and international donors.

Training and Supervision Plan

Tina Nannette Bauer

Wageningen School of Social Sciences (WASS)

Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Writing of the research proposal	WUR	2016	6
WASS Introduction Course	WASS	2016	1
'Survival of the fittest: Differentiation in livelihood resilience - Bolivian indigenous forest communities in the wake of an extreme weather event'	IUFRO, Freiburg	2017	1
'Thriving in turbulent times: Livelihood resilience and vulnerability of Bolivian indigenous forest households after an extreme weather event'	IASC, Lima	2019	1
Review of scientific articles		2016-2019	3
Prior learning activities	TU Dresden and others	2013-2016	10
Presentation at research seminars	FNP, WUR	2016-2020	1,5
Latin America, Africa and Asia linkages in a Globalized Humanosphere: A Writing Workshop	Freiburg University and Center for Southeast Asian and Integrated Area Studies, Kyoto University	2017	1,5
Forest Ecosystem Services across the Pacific Rim: Comparing Tropical Asian and Tropical American perspectives, approaches and operationalization	Center for Southeast Asian and Integrated Area Studies, Kyoto University	2018	1
Scientific writing workshop	organized by Prof. Wil de Jong, Center for Southeast Asian and Integrated Area Studies, Kyoto University	2019	1,5
B) General research related competences			
The Essentials of Scientific Writing and Presenting	WGS	2016	1,2
Data Management Planning	WGS	2016	0,4
Scientific Publishing	WGS	2016	0,3
Reviewing a Scientific Paper	WGS	2017	0,1
C) Career related competences/personal development			
Coordinator in International Project Management (with a focus on development cooperation)	Gesellschaft für Nachhaltige Entwicklung mbH, Witzenhausen, Germany	2017	9
Organizational development	GIZ, Germany	2018	1,4
Moderation and Facilitation	GIZ, Peru	2019	0,8
Training of trainers	FomentoPeru, Peru	2019	0,3
Anatomic identification of timber species	Citeforestal, Peru	2019	0,7
Total			**41,7**

*One credit according to ECTS is on average equivalent to 28 hours of study load

A part of the field work for the research described in this thesis was financially supported by Deutscher Akademischer Austausch Dienst (DAAD).
Financial support from Wageningen University for printing this thesis is gratefully acknowledged.

Cover design by Ron Zijlmans
Printed by ProefschriftMaken