# Indigenous knowledge of a changing environment:

## An ethnoecological perspective from Bolivian Amazonia

PhD thesis | September 2015

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PhD Dissertation


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With all its sham, drudgery and broken dreams,
it is still a beautiful world

Max Ehrmann, *Desiderata* (1927)

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# PREFACE

This dissertation is the result of a three-year PhD project based at the Institut de Ciència i Tecnologia Ambientals of the Universitat Autònoma de Barcelona (UAB), in Spain. This thesis has been supervised by Dr. Victoria Reyes-García and Dr. Aili Pyhälä.

This work included 15 months of fieldwork in the Tsimane' Territory, in Bolivian Amazonia, as well as a one-year doctoral stay at the Metapopulation Research Centre, in the Department of Biosciences of the University of Helsinki, in Finland, under the supervision of Dr. Mar Cabeza.

This work was funded by a scholarship from a Starting Grant of the European Research Council (FP7-261971-LEK) to Dr. Victoria-Reyes-García, as well as two visiting fellowships from the Centre for International Mobility (CIMO) of Finland.

This thesis includes six chapters: a general introduction, four research chapters, and an overall conclusion. At the time of submission of this thesis, from the four research chapters, two of them were published in scientific journals and the two remaining were under review.

Additional publications complementary to this PhD project are listed in the Appendices, alongside with further supplementary information.

# SUMMARY


Indigenous peoples are increasingly facing threats resulting from a changing global environment. Given the unprecedented rates of ongoing Global Environmental Change, there is scholarly debate on whether these threats might also undermine the adaptive capacity of indigenous knowledge. Due to its strategic position bridging the natural and social sciences, ethnoecology is well-placed to examine to what extent indigenous knowledge is adaptive in the face of rapid environmental changes.

This PhD thesis is the result of a three-year interdisciplinary study aiming to understand the relations between Global Environmental Change and the Local Environmental Knowledge held by a native society in Bolivian Amazonia: the Tsimane' hunter-gatherers. Facing rapidly changing social-ecological conditions and with the scientific discourse on anthropogenic global change still largely inaccessible to this group, the Tsimane' constitute a suitable case study for casting light on how local perceptions of Global Environmental Change are captured in the social memory of indigenous peoples.

The main argumentative line of this work is that Global Environmental Change has direct expressions at the local scale, including changes related to climate, the ecosystem and the availability of natural resources. In its four central chapters, this dissertation empirically investigates: (a) the potential use of indigenous knowledge for complementing scientific models assessing climate change; (b) the interplay between local observations of climate change and the uptake of scientific information; (c) the limits of the adaptive capacity of Local Environmental Knowledge in a context of rapid change; and (d) the role of local perceptions of change as drivers of adaptation to ecological shocks.

This research involved qualitative and quantitative data collection during 15 months of fieldwork in 23 villages of the Tsimane' Territory. I used a number of methods common to ethnoecological research, including participant observation, focus groups and systematic data collection. I specifically conducted semi-structured interviews on environmental change perceptions ($n$ = 300 adults), knowledge tests to assess individual levels of Local Environmental Knowledge ($n$ = 99) and a randomised controlled trial ($n$ = 442). Additional climate and ecological data were sourced to obtain scientific estimates of environmental changes in the study area.

The results of this dissertation show that the Tsimane' identify a wide array of local indicators of environmental change. Such indicators could help to fill gaps in instrumental records of Global Environmental Change. Moreover, this thesis finds a significant overlap between Tsimane' indigenous knowledge and scientific climate change records, as well as the instrumental role that local perceptions play in sparking collective responses for adapting to change. However, findings from this work also illustrate how Global Environmental Change challenges the adaptive capacity of Local Environmental Knowledge by widening the temporal gap between the rates of change in the ecosystem and the rates of change in the knowledge held by indigenous societies.

This thesis brings new insights to the theoretical discussion on the effectiveness of Local Environmental Knowledge in the context of rapid and unprecedented social-ecological changes. Results of this work stress the importance of devising strategic plans to support the resilience of indigenous knowledge in the face of ever encroaching environmental changes. This study also shows that building upon Local Environmental Knowledge is essential for informing and facilitating adaptive processes, particularly in areas inhabited by indigenous groups. Given these findings, I argue for an integration of indigenous peoples in global environmental policy fora, as well as for the recognition of their knowledge systems in scientific scholarship.

# RESUMEN

Los pueblos indígenas se enfrentan a un creciente número de amenazas causadas por el Cambio Ambiental Global. Dado el ritmo sin precedentes de los cambios ambientales actuales, los investigadores debaten si dichas amenazas podrían perjudicar también la capacidad de adaptación que confiere el conocimiento indígena. Al hallarse a caballo entre las ciencias naturales y sociales, la etnoecología cuenta con una posición estratégica para examinar hasta qué punto el conocimiento indígena puede ayudar a la adaptación ante cambios ambientales rápidos.

Esta tesis doctoral es el resultado de un estudio interdisciplinar de tres años que aborda las relaciones entre el Cambio Ambiental Global y el Conocimiento Ambiental Local de una sociedad nativa de la Amazonia boliviana: los cazadores-recolectores tsimane'. Al enfrentarse a condiciones socio-ecológicas cambiantes y estando aún muy alejados del discurso científico sobre el cambio global antropogénico, los Tsimane' constituyen un caso de estudio adecuado para entender cómo las percepciones locales del Cambio Ambiental Global son captadas en la memoria social de los pueblos indígenas.

La principal línea argumental del presente trabajo es que el Cambio Ambiental Global cuenta con manifestaciones directas a escala local, incluyendo cambios en el clima, el ecosistema y la disponibilidad de recursos naturales. En sus cuatro capítulos centrales, esta disertación investiga de forma empírica: (a) el uso potencial del conocimiento indígena para complementar los modelos científicos que evalúan el cambio climático; (b) la relación entre las observaciones locales de cambio climático y la asimilación de información científica; (c) los límites de la capacidad adaptativa del Conocimiento Ambiental Local en un contexto de cambio rápido; y (d) el papel de las percepciones locales de cambio como estímulo de adaptación a los impactos ecológicos.

Esta investigación incluyó la recolección de datos cualitativos y cuantitativos durante 15 meses de trabajo de campo en 23 comunidades del Territorio Tsimane'. Utilicé métodos comunes en investigación etnoecológica tales como la observación participativa, los grupos focales, y la recogida sistemática de datos. Realicé específicamente entrevistas semi-estructuradas sobre la percepción de cambio ambiental ($n$ = 300 adultos), pruebas de conocimiento para evaluar los niveles individuales de Conocimiento Ambiental Local ($n$ = 99) y una prueba controlada aleatorizada ($n$ = 442). Adicionalmente, se recogieron datos climáticos y ecológicos para obtener estimaciones científicas de los cambios ambientales en el área de estudio.

Los resultados de esta disertación muestran que los Tsimane' identifican un amplio número de indicadores locales de cambio ambiental. Dichos indicadores podrían ayudar a completar vacíos en los registros instrumentales de Cambio Ambiental Global. Así mismo, esta tesis demuestra la existencia de una superposición entre el conocimiento indígena Tsimane' y los registros científicos de cambio climático, así como el papel instrumental que juegan las percepciones locales en propiciar respuestas colectivas para adaptarse al cambio. Sin embargo, los hallazgos de esta tesis también ilustran cómo el Cambio Ambiental Global supone un desafío para la capacidad de adaptación del Conocimiento Ambiental Local, al ensanchar la brecha temporal entre la velocidad de cambio en el ecosistema y la velocidad de cambio del conocimiento de las sociedades indígenas.

La presente tesis aporta nuevos conocimientos a la discusión teórica sobre la efectividad del Conocimiento Ambiental Local en un contexto de cambios socio-ecológicos rápidos y sin precedentes. Los resultados de este trabajo destacan la importancia de trazar planes estratégicos para apoyar la adaptación del conocimiento indígena ante cambios ambientales cada vez más significativos. Esta investigación también muestra que el Conocimiento Ambiental Local es esencial para informar y facilitar procesos de adaptación, particularmente en áreas habitadas por grupos indígenas. Dados estos resultados, abogo por la integración de los pueblos indígenas en los foros globales de políticas ambientales, así como el reconocimiento de sus sistemas de conocimiento en el ámbito científico.

# MAIN ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACIA | Arctic Climate Impact Assessment |
| APCOB | *Apoyo para el Campesino-Indígena del Oriente Boliviano* |
| BBC | British Broadcasting Corporation |
| BBVA | *Banco Bilbao Vizcaya Argentaria* |
| CBD | Convention on Biological Diversity |
| CBIDSI | *Centro Boliviano de Investigación y Desarrollo Socio Integral* |
| CEEAH | *Comissió d'Ètica en l'Experimentació Animal i Humana* (of UAB) |
| CIFOR | Centre for International Forestry Research |
| CIMO | Centre for International Mobility (of Finland) |
| CRU | Climate Research Unit |
| DOB | Decade Of Birth |
| ENSO | El Niño Southern Oscillation |
| ERC | European Research Council |
| FPIC | Free, Prior and Informed Consent |
| GCT | *Gran Consejo Tsimane'* |
| ICDS | *Iniciativa de Comunicación para el Desarrollo Sostenible (*of Bolivia) |
| IIPFC | International Indigenous Peoples Forum on Climate Change |
| INE | *Instituto Nacional de Estadística* (of Bolivia) |
| INRA | *Instituto Nacional de la Reforma Agraria* (of Bolivia) |
| IPCC | Intergovernmental Panel on Climate Change |
| ISE | International Society for Ethnobiology |
| ISI | Institute for Scientific Information |
| ISSC | International Social Science Council |
| IUCN | International Union for Conservation of Nature |
| GC | Global Change |
| GEC | Global Environmental Change |
| GFW | Global Forest Watch |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| LEK | Local Environmental Knowledge |
| MA | Millennium Ecosystem Assessment |
| MMA | *Ministerio de Medio Ambiente* (of Bolivia) |
| NASA | National Aeronautics and Space Administration (of the United States) |
| NGO | Non-Governmental Organisation |
| OLS | Ordinary Least Square |
| PNUD | *Programa de las Naciones Unidas para el Desarrollo* |
| PPP | Purchasing Parity Power |

| | |
|---|---|
| REDD+ | Reducing Emissions from Deforestation and Forest Degradation |
| REDESMA | *Red de Desarrollo Sostenible y Medio Ambiente* (of Bolivia) |
| RLI | Red List Index |
| SBS | Shifting Baseline Syndrome |
| SD | Standard Deviation |
| SE | Standard Error |
| SENAHMI | *Servicio Nacional de Meteorología e Hidrología* (of Bolivia) |
| TAPS | Tsimane' Amazonian Panel Study |
| TCO | *Tierra Comunitaria de Origen* |
| TEEB | The Economics of Ecosystems and Biodiversity |
| TICH | *Territorio Indígena Chimane* |
| TIM | *Territorio Indígena Multiétnico* |
| TIOC | *Territorio Indígena Originario Campesino* |
| TIPNIS | *Territorio Indígena Parque Nacional Isiboro Sécure* |
| UAB | *Universitat Autònoma de Barcelona* |
| UNCCD | United Nations Convention to Combat Desertification |
| UNESCO | United Nations Educational, Scientific and Cultural Organisation |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VIF | Variance Inflation Factor |

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# Chapter I

## Introduction

### 1.1. Background and motivation

Indigenous peoples worldwide are confronted by the pressing and increasing threat of a changing global environment (Salick and Ross 2007; Boillat and Berkes 2013; Wildcat et al. 2013). On the one hand, studies from different corners of the world have documented the high vulnerability of indigenous peoples to the impacts of Global Environmental Change (hereinafter GEC) (Ford 2012; Hofmeijer et al. 2012). Yet, on the other hand, the significant resilience of indigenous societies in front of GEC is receiving more and more attention, at least partly as an attribution to their rich and detailed systems of local knowledge (Marin 2010; Klein et al. 2014). However, the pace at which GEC operates has raised concerns regarding the validity and effectiveness of local knowledge to continue safeguarding indigenous peoples' livelihoods (Cox 2000; Kameda and Nakanishi 2002), with some authors expressing severe concerns about the adaptive capacity of indigenous peoples, which could possibly be undermined (Turner and Clifton 2009; Valdivia et al. 2010; Naess 2013).

Understanding the relation between GEC and the local knowledge of indigenous peoples is the main concern of this PhD work. Specifically, this dissertation aims to understand how the Tsimane' –a native society of foragers and horticulturalists living in Bolivian Amazonia– perceive and interpret GEC, and how their local observations of GEC define their strategies for coping with change and for ultimately contributing to social-ecological resilience. The main argumentative lines of this work are that: (a) the complex interrelations between environmental, social and economic processes and drivers of GEC have direct expressions at the local scale; and (b) such expressions can be evaluated through the study of Local Environmental Knowledge (hereinafter LEK). From all the local manifestations of GEC, I specifically address climate change, ecosystem change, and changes in the availability of natural resources. In contrast to studies examining the impacts of GEC upon societies and cultures from a top-down perspective (e.g., Adger et al. 2013), in this dissertation, I emphasise the local dimension of the impacts of GEC, using a bottom-up approach, i.e., examining the local interpretation and knowledge held of an otherwise global phenomenon.

Nature-culture interactions are inherently co-evolutionary (Posey 1985; Gadgil et al. 1993; Berkes et al. 2000). Research shows that there is a continuous interplay between cultural practices and environmental transformations: while cultures co-evolve with their surrounding environments, the environment itself is shaped by cultural processes (Heckenberger et al. 2007; Pilgrim and Pretty 2010; Guèze et al. 2015). As such, the complexity of this relation calls for place-specific analyses and therefore also for real-life case studies in the present-day (Berkes and Jolly 2001). To meet this need, the work presented within the scope of this thesis is a compilation of social and ecological data collected during 15 months of in-depth fieldwork amongst the Tsimane' hunter-gatherers in Bolivian Amazonia.

The Tsimane' constitute an excellent case study for addressing local observations of GEC for at least three reasons. First, the Tsimane' hold a great deal of LEK, which is at the basis of their subsistence-based livelihoods (Reyes-García et al. 2003, 2005). Second, the scientific discourse on anthropogenic GEC remains largely inaccessible to this society. And third, Tsimane' observations of GEC are most probably conferred to local manifestations of such phenomenon and based on their LEK. In this work, I empirically investigate Tsimane' local observations of GEC, i.e., how they are captured in LEK and how they determine the ability of the entire social-ecological system to respond and adapt to GEC.

This study brings significant insights to the current global change literature both at the theoretical and the methodological levels. At the theoretical level, it contributes to: (a) the growing body of literature discussing the effects of GEC on indigenous societies; and (b) the ongoing discussion on whether or not LEK is efficient in the face of GEC and, similarly, whether it continues to hold the capacity to help societies adapt to changing environments. I also explore the potential for the use of LEK for complementing existing models of GEC assessment in Bolivian Amazonia, by empirically testing for possible overlaps between indigenous observations and scientific records of climate change. Overall, the different chapters are intended to offer an overview of the extent to which LEK can contribute to the endeavours of GEC research, and how the merging of multiple epistemologies could help to improve our understanding of GEC processes, particularly in data-deficient regions. As such, this work expands the theoretical discussion on: (a) what counts (or not) as legitimate knowledge in the context of GEC (see Moore 2001); and (b) the to-date general tendency of the natural sciences to underrate indigenous sources of knowledge (as pointed out by Simpson 2004).

At the methodological level, this dissertation offers a fresh interdisciplinary take on indigenous knowledge of GEC. This work emerges from the broader base of work that refers to the *dialogue of the deaf* (i.e., a discussion in which each party is unresponsive to what the others say) that has long characterised the interactions between social and natural scientists (Mascia et al. 2003; Agrawal and Ostrom 2006). Several authors have underlined the need for more interdisciplinary collaborations –both in terms of quantity and scope− to put global change research on its trajectory (Holm et al. 2013; Mauser et al. 2013; Victor 2015). Answering that call, this thesis builds on concepts, approaches and methods developed in and derived from a range of disciplines, including and intermingling climatology (Chapter II), communication studies (Chapter III), conservation biology (Chapter IV), ethnoecology (Chapters II-V), psychology (Chapters IV and V) and sustainability science (Chapter V). Overall, this works draws on a place-based and culture-specific case study of local realities of a changing global environment, involving: (a) documenting indigenous knowledge of GEC; (b) contrasting this knowledge with scientific observations; and (c) tying up both streams of knowledge to generate insights about GEC adaptation and social-ecological resilience.

## 1.2. State-of-the-art

### 1.2.1. Indigenous peoples in the Anthropocene

Growing evidence about the impacts of anthropogenic activities on the Earth system has led some researchers to propose the term *Anthropocene* to define a new geological era (Crutzen 2002; Zalasiewicz et al. 2008; Steffen et al. 2011). Although the term has not yet been adopted by the Geological Society of London as a formal unit of the geological time scale, it is widely used in the scientific literature to refer to the temporal period characterised by Global Environmental Change (GEC), i.e., a set of planetary-scale changes in the global geosphere and biosphere systems, driven by an interwoven system of human and natural processes (Zalasiewicz et al. 2010; Ruddiman 2013; Dirzo et al. 2014).

Researchers disagree on the Anthropocene's onset date (Crutzen and Steffen 2003; Doughty et al. 2010; Smith and Zeder 2013). While some research proposes that significant anthropogenic changes started with the advent of the Industrial Revolution (Crutzen 2002; Zalasiewicz et al. 2011; Lewis and Maslin 2015), a growing body of archaeological and stratigraphic evidence suggests that the Anthropocene could extend back millennia, at least to the origin of agriculture (Hong et al. 1994; Certini and Scalenghe 2011; Erlandson and Braje 2014). However, a common denominator across these varying positions is the recognition of humanity as a major force of currently experienced GEC (Vitousek 1994; Kirch 2005; Barnosky et al. 2012; Helmus et al. 2014). GEC is a broad concept without easily-defined boundaries, but research documents its intimate engagement with processes of socio-economic and cultural globalisation (e.g., Liverman 2004; Soares-Filho et al. 2006; Lambin and Meyfroidt 2011).

The study of human interactions with the global environment has used two different terms to refer to human-induced planetary-scale changes: Global Change (GC) and Global Environmental Change (GEC). The distinction between these two terms is subtle and only partly explained by the different analytical angles of the research undertaken on the topic. Broadly speaking, human actions and environmental changes have two main points of encounter: (a) where human actions cause environmental changes (e.g., Grübler 1998); and (b) where environmental changes affect human actions (e.g., O'Brien and Barnett 2013). In general –but with some exceptions– research examining human causes of environmental change has tended to use more frequently the term GC (e.g., Wuebbles and Hayhoe 2002; Grimm et al. 2008), while research examining the impacts of environmental changes upon humans has been more prone to use the term GEC (e.g., Ericksen et al. 2009; Warner 2010). As such, GEC mostly refers to the biophysical transformations of the Earth system, while GC includes large-scale changes in society (i.e., globalisation). However, with the increasing recognition of the complex interconnection of human-environment interactions, nowadays both terms are used rather indistinctively in the literature (e.g., Reid et al. 2010). In this dissertation, I prioritise the term GEC over GC in order to emphasise that my research focus is on understanding how environmental changes affect humans rather than how humans affect their environment.

Precisely because the driver of the Anthropocene is the unprecedented scale and impact of human behaviour, a force so significant that it progressively shapes the dynamics of ecosystems from the local to the biosphere as a whole (Steffen et al. 2004; Hardesty 2007; Rockström et al. 2009), there is urgent need to examine beyond the physical manifestations and understand also the social contexts and human dimensions of GEC (Jasanoff 2010; Adger et al. 2013; Barnes et al. 2013; Castree et al. 2014). However, while there is a growing body of knowledge about the impacts of GEC on the biosphere (e.g., Dirzo et al. 2014; Helmus et al. 2014), the understanding of its impacts upon the ethnosphere (i.e., the variety of cultures, ethnic groups, languages and traditions in the planet; Davis 2001, 2009) is still meagre at best (see Strauss 2012). Despite this fragmented evidence, we know that, just as the biosphere is being severely eroded by GEC, so too is the ethnosphere, most probably at a far greater rate (Harmon 1996; Sutherland 2003; Gorenflo et al. 2012). For example, some studies show that the diversity of the world's indigenous languages (often used as a proxy for cultural diversity; e.g., Stepp et al. 2004) has declined by 21% at global level over the period 1970-2005[1] (Lewis 2009; Harmon and Loh 2010; Moseley 2010). In this context, researchers argue that loss of biological and cultural diversity: (a) are inextricably linked (Moore et al. 2002; Tershy et al. 2015); (b) are driven by the same common forces, threats and pressures (Pretty et al. 2009; Amano et al. 2014); and (c) have profound implications for the maintenance of life on Earth (Loh and Harmon 2005; Maffi 2005). Thus, accepting the interconnectedness between biological and cultural diversity is fundamental in order to understand the nature of GEC and facilitate the adaptation in the face of accelerating GEC (Harmon and Maffi 2002; Reyes-García 2013; Turvey and Pettorelli 2014).

Arguably for these reasons, GEC is increasingly discussed amongst the social sciences[2] (ISSC and UNESCO 2013; Stern and Dietz 2015; Victor 2015), especially as evidence of its pervasive impacts upon different societies and cultures continues to emerge from all over the world (Foley et al. 2005; Black et al. 2011; Wheeler and von Braun 2013). By exploring the linkages between ecological, social and economic systems, the social sciences are well-positioned to further our understanding on the human causes, vulnerabilities and impacts of GEC, as well as to inform potentially effective strategies to either guide or respond to GEC in context-sensitive ways (Agrawal et al. 2012; Palsson et al. 2013; Granderson 2014). In particular, with regard to the study of the ethnosphere, a number of cultural anthropologists are starting to examine the irrevocable transformations that GEC brings to the peoples, societies and places traditionally studied within the discipline (Roncoli et al. 2009; Crate 2011; Strauss 2012; Barnes et al. 2013).

Numerous scientific studies have identified indigenous peoples[3] as being particularly vulnerable to the impacts of GEC (Ford 2012; Hofmeijer et al. 2012;

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[1] At the regional level, estimates of indigenous linguistic diversity loss for the period 1970-2005 reach over 60% in the Americas, 30% in the Pacific and almost 20% in Africa (Harmon and Loh 2010).

[2] In line with the International Social Science Council (ISSC) scientific membership base, reference to the *social sciences* is understood as including the social, behavioural and economic sciences.

[3] There is to date no internationally agreed upon legal definition of *indigenous peoples*, although most definitions agree that the concept implies: (a) priority with respect to the occupation and use of a specific territory; (b) a set of specific rights based on their historical ties to a particular territory; (c) cultural and/or historical distinctiveness from other populations; (d) self-identification and recognition by others as a

Wildcat et al. 2013). Paradoxically, despite having contributed the least to GEC (e.g., by traditionally leading carbon-neutral lifestyles or having a low ecological footprint), indigenous peoples carry a disproportionate share of its burden (Green and Raygorodetsky 2010; Abate and Kronk Warner 2013). This injustice is explained by several interrelated reasons. First, many indigenous societies inhabit ecosystems that are today increasingly prone to the effects of GEC, e.g., marginal environments or high-risk areas (Macchi et al. 2008; Lefale 2010; Bardsley and Wiseman 2012). Second, they are directly dependent on their surrounding lands and resources for meeting their basic livelihood needs (Krupnik and Jolly 2002; Brondizio and Moran 2008; Wenzel 2009). And third, their current social and economic conditions are the consequence of historical exclusion and continued marginalisation, which limit their capacity to defend their rights and negotiate strategies to adapt to GEC based on these rights (Morton 2007; Maldonado et al. 2013; Maru et al. 2014).

While GEC alone creates major challenges for indigenous peoples to continue their traditional ways of life, its effects can be aggravated by other socio-economic stressors (Kronik and Verner 2010; McDowell and Hess 2012; Dinero 2013). GEC is only one of the many drivers of change impacting upon indigenous peoples today. Forces of globalisation other than GEC, such as market integration, colonisation, land-grabbing, and the advance of destructive extractive industries into indigenous territories, not to mention the commodification of their resource systems, may interact synergistically with environmental changes to produce more severe impacts (e.g., Perz et al. 2008; Schwartzman et al. 2013). Indeed, these impacts often induce exacerbating effects (Galloway et al. 2011; Nakashima et al. 2012; Sherman et al. 2015). For example, current research on vulnerability to climate change suggests that indigenous communities are amongst those who suffer the most not only from the environmental pressures triggered by climate change itself, but also from the economic and social implications related to this change (Ribot et al. 1996; Adger and Kelly 1999; Ford et al. 2010). Particularly the absence of recognised rights of indigenous peoples over their territories and

different group; and (e) experience of subjugation, marginalisation, dispossession, exclusion or discrimination (Sanders 1999; Coates 2004; Stavenhagen 2005).

resources contributes to further their vulnerability (Tsosie 2007; Castro et al. 2012). Thus, the effects of GEC cannot be isolated from the multiple social, political, legal, economic and cultural changes (Cameron 2012; Byg and Herslund 2014; Ribot 2014).

### 1.2.2. Local Environmental Knowledge and perceptions of a changing environment

In contrast to the narrative about indigenous peoples as being particularly vulnerable to GEC (e.g., Pearce et al. 2010; Berrang-Ford et al. 2012), there is a wealth of literature highlighting the rich and extensive systems of local knowledge that indigenous peoples hold about their environment[4], which is a result of, and continues to be the source of, adaptive strategies to changing social-ecological conditions (Moller et al. 2004; Marin 2010; Aswani and Lauer 2014). Such narratives emphasise the potential of actively drawing upon local knowledge systems for increasing social-ecological resilience in a changing global environment (Lebel 2013; Naess 2013). In other terms, this literature proposes that indigenous peoples should not be viewed as *helpless victims* of a changing global environment, but rather as experts that can actively contribute to developing original coping and adaptation strategies at the local level (Salick and Byg 2007; Boillat and Berkes 2013).

Cultural evolution theory acknowledges that indigenous peoples with a long history of interaction with their environment have developed complex and detailed systems of first-hand knowledge about local ecosystems and their dynamics, as well as associated management practices, beliefs, traditions and institutions (Berkes 1999; Toledo 2002; Gadgil et al. 2003). Such knowledge

[4] Such knowledge systems are by no means exclusive of indigenous peoples. There is a great deal of literature examining local knowledge also amongst non-indigenous rural societies and local communities (e.g., von Glasenapp and Thornton 2011; Anik et al. 2012; Oteros-Rozas et al. 2013; Iniesta-Arandia et al. 2014), but for the purposes of this dissertation, I only focus on the literature specifically addressing indigenous peoples.

systems are widely referred to as Local Environmental Knowledge[5] (LEK): '*a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment*' (Berkes et al. 2000:1252). LEK is thus a holistic system for understanding the world, embedded in the culture of a group (including local institutions) and borne from continued periods of observation on an empirical basis and a longstanding interaction between people and their environment (Huntington 2000; Toledo 2001; Gagnon and Berteaux 2009). Researchers argue that, to remain effective, LEK requires that indigenous peoples remain close to the production of knowledge, through well-connected social networks and robust institutional frameworks (Berkes et al. 2003; Gómez-Baggethun and Reyes-García 2013). In this context, place attachment and long-term time continuity enable indigenous peoples to acquire a great deal of LEK on environmental changes, which is at the basis of their adaptive responses to face GEC (Stigter et al. 2006; Monastersky 2009; Klein et al. 2014). Such place-based identity is increasingly being emphasised in discourses on indigenous sovereignty and empowerment (see Castree 2004; Greenop 2009; Thornton 2010).

Indigenous observations of environmental change can therefore be considered a tacit and situated knowledge form, reflecting a depth of embodied experience unlikely to be derived through structured and formalised processes (Fazey et al. 2005; Huntington 2011). Because local observations of environmental changes are an intrinsic part of the traditional livelihoods of indigenous peoples, the latter are being recognised as potential allies in the quest to better understand

[5] There is ongoing debate on the most appropriate term to define such a body of cultural knowledge. The term *Local Environmental Knowledge* is well-established in the literature (e.g., Karjalainen and Habeck 2004; Reyes-García et al. 2010a), although other terms are also often used and referred to, such as *Traditional Ecological Knowledge* (e.g., Berkes et al. 2000; Drew 2005; Rist et al. 2010), *Traditional Environmental Knowledge* (e.g., Sherry and Myers 2002; Lyver et al. 2009), *Local Ecological Knowledge* (e.g., Gilchrist et al. 2005; García-Quijano 2007; Turvey et al. 2014), *Indigenous Knowledge* (e.g., Stevenson 1996; Ziembicki et al. 2013), *Indigenous Ecological Knowledge* (e.g., Spooh 2014), *Rural Peoples' Knowledge* (e.g., Kothari 2002) or *Folk Knowledge* (e.g., Berkes 1999). Without dwelling excessively on semantic controversies (see Ellen and Harris 2000 for more details), this dissertation mostly uses the term *Local Environmental Knowledge* to: (a) avoid the static and rigid vision that the word *traditional* entails (Woodward and Lewis 1998); and (b) stress that this body encompasses not only *ecological* features of the local context, but also other physical settings of the environment, such as climate (Garay-Barayazarra and Puri 2011). *Indigenous knowledge* is also referred to in some passages of the dissertation, but mostly for stylistic reasons and because this work addresses the local knowledge system specific to an indigenous society.

GEC (Salick and Ross 2009; Klein et al. 2014). Not surprisingly, in the last decades, an increasing number of scientists have begun to tap into local knowledge as a starting point for their scientific studies[6] (Riedlinger and Berkes 2001; Lykke et al. 2004; King et al. 2007). Similarly, I subscribe to Yeh's (2015:3) claims that considering the experience of local peoples as a form of knowledge '*should be a non-negotiable starting point for interdisciplinary "human dimensions" of global climate change research*'. Research has shown the potential of LEK to further our understanding of a handful of environmental changes, including climate (Green et al. 2010; Alexander et al. 2011), vegetation composition (Wezel and Lykke 2006; Sop and Oldeland 2011), animal distribution (Mallory et al. 2003; Danielsen et al. 2014a,b; Parry and Peres 2015), hydrology (Alessa et al. 2008; Jones et al. 2015), phenology (Lantz and Turner 2003; Prober et al. 2011), or even geomorphic processes (Cuomo et al. 2008; Eisner et al. 2009). The main developments in the scientific study of indigenous knowledge of a changing environment are briefly summarised in Table 1.1, including influential publications, and special issues (based on a Web of Science bibliographic database search).

Indigenous knowledge of environmental change is a complex and multi-faceted concept (Berkes 2009; Orlove et al. 2010). On the one hand, it is based on factual and direct *knowledge* or continued observations of biophysical phenomena (e.g., Gearheard et al. 2009; Marin 2010; Aswani and Lauer 2014). On the other hand, it also encompasses embodied experience directly acquired through *perceptual* information drawn from personal experience (e.g., Garay-Barayazarra and Puri 2011; Leclerc et al. 2013). As a result, the literature has to date interchangeably used the terms *perception* (e.g., Oldekop et al. 2013; Da Silva et al. 2014) and *knowledge* (e.g., Couzin 2007; Riseth et al. 2011) to refer to accounts of environmental changes reported by indigenous peoples[7]. Actually, whether

[6] While the use of local knowledge for academic purposes has become increasingly common in the last decades (e.g., Danielsen 2005, 2014a,b), some research has also expressed concerns about the limitations of local knowledge in detecting changes in populations, habitats, patterns of resource use or climatic trends (e.g., Meze-Hausken 2004; Gilchrist et al. 2005; Daw 2010). Some of the limitations of LEK in detecting environmental changes are specifically discussed in Chapters IV and V. Additionally the challenges of integrating local and scientific knowledge in a single research framework are explored in Chapters II and III.

[7] Other terms that are referred to in the literature are *belief* (Salick et al. 2012), *detection* (Aswani and Lauer 2014), *interpretation* (Boillat and Berkes 2013), *observation* (Huntington et al. 2004) and *understanding* (Wolf and Moser 2011).

**Table 1.1 |** 'Indigenous peoples and environmental changes' in the research agenda.

| Year | Event |
|---|---|
| 1990 | A.E. Sollod publishes 'Rainfall variability and Twareg perceptions of climate impacts in Niger' in the journal *Human Ecology*, arguably one of the first works examining indigenous perceptions of climate impacts (Sollod 1990) |
| 1993 | R. Nelson publishes 'Understanding Eskimo Science' where he draws the attention to Inuit knowledge as a source of science (Nelson 1993) |
| 2000 | B. Orlove and colleagues publish 'Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility' in the journal *Nature*, which sparks a wave of interest from the physical sciences on ethnoclimatology and indigenous knowledge systems (Orlove et al. 2000) |
| 2001 | J. Cruikshank publishes 'Glaciers and climate change: perspectives from oral tradition' in the journal *Arctic*, currently the most cited paper on indigenous peoples and environmental change (Cruikshank 2001) |
| 2002 | I. Krupnik and D. Jolly publish their book 'The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change', one of the first collections of essays describing contemporary efforts to document indigenous knowledge of environmental change (Krupnik and Jolly 2002) |
| 2005 | The 2005 Arctic Climate Impact Assessment, organised through the Arctic Council, marks a watershed in the consideration of indigenous contributions both to science and policy-making (ACIA 2005) |
| 2007 | The 4th Assessment Report of IPCC notes that indigenous knowledge is an invaluable basis for developing adaptation in response to environmental change (Anisimov et al. 2007; Yohe et al. 2007) |
| | The International Polar Year 2007-2008 lists the perspectives of indigenous societies as one of six themes shaping its research agenda. 30 projects sought to tap into traditional knowledge of the Arctic are supported (Monastersky 2009) |
| 2009 | Two Special Issues on indigenous peoples and climate change are published in scientific journals: 'Climate change impacts, adaptation and vulnerability in the Arctic' in *Polar Research* (Ford and Furgal 2009) and 'Traditional Peoples and Climate Change' in *Global Environmental Change* (Salick and Ross 2009) |
| | The Anchorage Declaration is signed by over 400 indigenous peoples from 80 countries at the 'Indigenous Peoples' Global Summit on Climate Change', held in Anchorage, Alaska, calling for respect to indigenous peoples in the global climate change policy fora and in scientific research |
| | S.A. Crate and M. Nuttal publish the book 'Anthropology and Climate Change: From Encounters to Actions', the first work to comprehensively assess cultural anthropology's engagement with climate change research (Crate and Nuttal 2009) |
| 2010 | A Special Issue on 'Indigenous Knowledge of a Changing Climate' is published in the journal *Climatic Change* (Green and Raygorodetsky 2010) |
| 2011 | Several scholars highlight the low prominence given to indigenous research in IPCC assessment reports (Galloway et al. 2011; Hulme 2011; Huntington 2011) |
| | The meeting 'Indigenous Peoples, Marginalized Populations and Climate Change' is held in Mexico City, sponsored by IPCC (Galloway et al. 2011) |
| 2013 | A Special Issue on 'Traditional Ecological Knowledge and Global Environmental Change' is published in the journal *Ecology and Society* (Gómez-Baggethun et al. 2013) |
| | The International Social Science Council (ISSC) issues its World Social Science Report, entirely dedicated to develop a social science framing of Global Environmental Change (ISSC and UNESCO 2013) |
| 2014 | The 5th Assessment Report of IPCC reaffirms the importance of indigenous knowledge for more comprehensively addressing the impacts of climate change and developing effective adaptation strategies (Adger et al. 2014; Noble et al. 2014) |

indigenous peoples' experience of environmental changes can be considered as knowledge or perception is still debated[8] (see Yeh 2015), because a great deal of indigenous knowledge is inherently tacit and held in embodied experiential forms (i.e., not articulated in a form easily accessible to others; Raymond et al. 2010).

In the present dissertation, I take Berkes' (2009) approach and consider indigenous perceptions of environmental change as part of a larger system of knowledge, developed locally, passed down through generations, and integrating with both local values and information from external sources, as well as experiential and belief systems (Ingold and Kurtilla 2000; Rudiak-Gould 2014). In absence of written records, perceptions of environmental change are captured in LEK, which is stored, revived and transmitted as social memory (Berkes et al. 2000; Barthel et al. 2013). For the purposes of this thesis, I have developed an operational definition of *environmental change perception* as an individual's evaluation of changes in the environment over time. Such evaluation is constructed and appraised based on the wider context of observation, interpretation and appreciation of different information sources, ranging from own personal experience and cultural values to externally-built awareness of environmental change (Verweij et al. 2010). Specifically, the definition used here is structured around five components (Table 1.2), each one explored in a different chapter of this dissertation and described according to the works of Houde (2007) and Orlove et al. (2010).

[8] Human perceptibility of Global Environmental Change (and particularly climate change) has been somewhat disputed in the last decades (see Rudiak-Gould 2013 for a thorough review). While some argue that most environmental changes are beyond the threshold of human perception over the course of a lifetime (Doyle 2009; Swim et al. 2009), others claim that the effects of GEC can be tracked based on personal experience (Howe and Leiserowitz 2013; Weber 2013). I address this debate in detail in Chapter III.

**Table 1.2 |** The multiple components of environmental change perceptions

| Component | Description | Chapters |
|---|---|---|
| Direct observations of the environment | Experiential knowledge of the environmental, acquired through daily observation of the current state of the environment (e.g., resource status, land use, animal stocks). These observations correspond to physical rather than symbolic understandings of environmental changes. They are inferred from personal experience of the current environment (including uses, knowledge and skills). | Chapter II<br>Chapter III<br>Chapter IV<br>Chapter V |
| Historical patterns, system dynamics and past baselines | Experiential knowledge of past baselines against which variability and change are measured. This knowledge is issued from the longstanding familiarity with seasonal patterns, environmental system dynamics, and variability therein. At the community level, these observations form the collective memory of local environmental change. | Chapter II<br>Chapter III<br>Chapter IV<br>Chapter V |
| Cultural and symbolic values | Awareness of a set of local traditional indicators or signs that have cultural, religious and/or cosmological significance, and that are useful to interpret particular changes (e.g., ethnoclimatic indicators). Most of these indicators provide symbolic value rather than material or causal links to the environment. This set of values determines how change is converted into a culturally-relevant form at the local level. | Chapter III<br>Chapter V |
| Peer information | Environmental change observations from local peers that serve as complementary to the own personal experience of changes. Extended social networks and local institutions (e.g., assemblies) facilitate the exchange of information about environmental changes occurred. | Chapter V |
| External information (media, science, NGOs) | Uptake of scientific or externally-built information about environmental change, via scientific, technical or institutional networks (e.g., through mass media or workshops). Amongst indigenous peoples, its influence has been argued to be minimal, due to very limited access to external sources of information. | Chapter III |

Note: Adapted from Houde (2007) and Orlove et al. (2010)

There is increasing recognition that LEK, encompassing environmental change perceptions (see Table 1.2), strengthens community resilience to respond to the multiple stressors of GEC and to deal with disturbances under conditions of high uncertainty and change (Colding et al. 2003; Tengö and Hammer 2003; Berkes and Turner 2006; Brännlund and Axelsson 2011). LEK systems constitute an important reservoir of experiential knowledge that can provide practical insights for the elaboration of adaptation and mitigation measures to cope with a changing environment[9] (Cochran et al. 2013; Ignatowski and Rosales 2013; Turner

[9] For instance, the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) noted that there is *robust evidence* and *high agreement* of the positive impacts of integrating indigenous and scientific knowledge for adaptation (Adger et al. 2014; Niang et al. 2014). Different studies worldwide have also concluded that mutual integration and co-production of indigenous and scientific knowledge increase adaptive capacity and reduce vulnerability (e.g., Vogel et al. 2007; Flint et al. 2011; Eira et al. 2013).

and Spalding 2013). It is based on this knowledge that many indigenous peoples determine whether or not change merits a certain response or adaptation (e.g., Ostrom 1999; Oldekop et al. 2012). Several studies have shown that local perceptions of change have sometimes led to the adoption of self-governed institutional arrangements and management regimes to deal with change (e.g., Rudel et al. 2002; Sirén 2006; Salo et al. 2014).

In general, LEK-based responses to change provide considerable buffering capacity when dealing with perturbations and include strategies to spread risks over space (mobility), time (rationing), asset classes (diversification, innovation and revitalisation), and households or communities (exchange and resource pooling) (Gómez-Baggethun et al. 2010; Thornton and Manasfi 2010). Moreover, these adaptive processes illustrate the myriads of ways in which indigenous peoples have learned to adapt to social-ecological changes across a wide range of environments (Berkes and Jolly 2001; Ishaya and Abaje 2008; Kansiime et al. 2013). However, when these processes are interrupted, obstructed or hampered, vulnerabilities emerge and the resilience of the system can be severely undermined (Davies 2008; Hovelsrud and Smit 2010).

With the onset of rapid cultural transformations experienced by indigenous peoples worldwide, due to the multiple socio-political stressors mentioned above, there are concerns over the relevance of LEK for future adaptation amidst other challenges, with some authors pointing at the limitations of LEK even in confronting GEC (Briggs 2005; Naess 2013; Valdivia et al. 2010). There have been recurrent calls for further research to understand how indigenous LEK-based adaptation strategies might be affected by other socio-political processes at different scales, and ultimately, how adaptive LEK continues to be in the face of GEC (e.g., Thornton and Manasfi 2010; Ruiz-Mallén and Corbera 2013). In the following section I elaborate on the role of ethnobiological research, and in particular ethnoecology, to contribute to this challenge, due to its strategic position bridging the natural and social sciences (Reyes-García and Martí 2007).

### 1.2.3. An Ethnoecology of Change?

Ethnoecology is generally described as the scientific study of how different groups of people –living in different locations– understand the ecosystems around them, and how they relate with their surrounding environments (Hunn 1989; Toledo 1992). It consolidated as a discipline in the early 1990s, after two decades of widely expressed scholar discomfort with the limitations of ethnobiology, which did not emphasised sufficiently the broader ecological context and the dynamic nature of the relation between peoples, biota and the environment (Nazarea 1999; Hunn 2007; D'Ambrosio 2014). Indeed, the dynamics of nature-culture interactions was neglected in most ethnobiological research of the 20th century (Gómez-Baggethun and Reyes-García 2013; Reyes-García et al. 2014a). Until the 1990s, modern ethnobiology was mostly devoted to describe cultural systems of classification of the environment, from an emic perspective (Frake 1962; Berlin 1973; Hunn 1977). Such research drew from the historical and intergenerational continuity in resource use management and tended to view LEK systems as static and hermetically isolated from other forms of knowledge (Berkes et al. 2000), a framing largely in consonance with a tradition in anthropology of conceptualising local and indigenous peoples as *people without history* (Wolf 1982).

Yet, the 1990s and the entrance into the new millennium set the foundations of a new era of ethnobiological research, with ethnoecology burgeoning as an independent discipline (Toledo 1992; Agrawal 1995; Gragson 1999). Ethnoecology shifted from a static approach centred on the description of LEK systems as *atemporal* towards the understanding of LEK as a complex form of adaptation, resulting from the co-evolutionary dynamics of nature and culture (see Berkes et al. 2000). Several researchers started to emphasise that LEK systems should neither be considered static nor in isolation from other knowledge systems (Agrawal 1995; Olsson et al. 2004; Leonti 2011). Rather, local knowledge systems should be understood as being in constant change, in a type of process that anthropologists have noted to involve simultaneously *continuity and change* (Reenberg et al. 2008).

Such paradigm shift catalysed the emergence of the first studies on changes in local knowledge systems (Benz et al. 2000; Kingsbury 2001; Pieroni et al. 2004). Much of this body of research was centred in documenting fading local knowledge (Ferguson and Messier 1997), understanding the parallel decrease of biological and cultural diversity (Sutherland 2003; Maffi 2005), estimating knowledge loss rates (Brosi et al. 2007; Reyes-García et al. 2013a), or assessing the drivers of change leading to the loss of LEK (Cetinkaya 2009; Gómez-Baggethun et al. 2010). The thread in all this literature has been the analysis of the changes in LEK systems in terms of *loss* of knowledge. Without neglecting the importance of such a process, by focusing only on knowledge losses, the understanding of other processes of change has often been overshadowed, and consequently, ethnoecology has tended to downplay the dynamic nature of LEK (McCarter and Gavin 2013).

Some recent works are starting to move the spotlight from the specific bodies of knowledge that are lost and/or eroded to the capacity of local knowledge systems to absorb changes and adapt to new social and environmental conditions (Eyssartier et al. 2011; Leonti and Casu 2013). For example, in a study amongst the Tsimane', Reyes-García et al. (2013b) found that while particular domains of knowledge that are less frequently used (e.g., wild edibles) are decreasing, there are other domains of knowledge (e.g., house building) that seem to be increasing due to new social contexts (e.g., increasing sedentarisation and the need to make more permanent houses). Some of these studies also highlight the process of the hybridisation of local knowledge with other forms of knowledge (Dove et al. 2007; Reyes-García et al. 2014a; Tengö et al. 2014). For example, in a study in Oaxaca, Mexico, Giovannini et al. (2011) showed that individual knowledge of pharmaceuticals does not necessarily displace knowledge of medicinal plants, but rather that the two knowledge systems co-exist in a complementary way. Similar results have been found for the ethnomedicinal system of the Tsimane' (Calvet-Mir et al. 2008), as well as other indigenous communities in Peru and Bolivia (Mathez-Stiefel et al. 2012).

### 1.2.4. Examining the adaptive nature of LEK

Nourishing from resilience theory, an original and innovative body of research in ethnoecology points towards the adaptive capacity of LEK systems and their ability to generate, transmit, and discard knowledge according to the particular needs of a society. Without denying the rapid loss of knowledge, such an approach does not necessarily address all changes in LEK as a loss, but rather as part of the general self-organising process of the knowledge systems (Boyd and Richerson 2005; Reyes-García et al. 2014a). Indeed, this dynamic nature of LEK is valuable for adapting to the also changing social conditions (Folke et al. 1998; Berkes et al. 2000) and for providing strategies for adaptive management in the face of GEC (Turnhout et al. 2012; Noble et al. 2014). In this context, LEK is argued to be *adaptive* because it reacts to the ever-changing nature of social and environmental conditions (Gómez-Baggethun and Reyes-García 2013). This potential of LEK systems to absorb change can contribute to the long-term resilience of social-ecological systems (Gómez-Baggethun et al. 2013; Ruiz-Mallén and Corbera 2013).

In the same line, ethnoecologists have also started to explore the structural constraints of LEK adaptation in the context of GEC (e.g., Berkes 2009; Gómez-Baggethun 2009; McCarter et al. 2014). The increasing pace at which GEC takes place has raised scepticism regarding LEK endurance and/or efficiency (Cox 2000; Kameda and Nakanishi 2002). For instance, with regard to climate change, the IPCC 4$^{th}$ Assessment Report notes that LEK may not always be sufficient to meet impacts originated from the rapid changes in climate, because changing climatic conditions are often beyond the knowledge range of the cultural repertoire (Adger et al. 2014). In general, because rapid ecosystem changes deriving from GEC are often abrupt and unprecedented, they might be hard to forestall by applying LEK (Berkes 2009; Turner and Clifton 2009; Valdivia et al. 2010). Furthermore, in many cases, these changes are not only faster but also nonlinear, with new thresholds of irreversible change, which could possibly shape a novel or no-analogue future (*sensu* Ruhl 2010, i.e., completely dissimilar to past and/or present conditions). In such contexts, LEK could lose its effectiveness (Macchi et al. 2008;

Ford et al. 2010; McNeeley and Shulski 2011), thereby jeopardising local adaptive capacity (Eakin 2000; West et al. 2008; Newsham and Thomas 2011).

Thus, a critical task for the research agenda in ethnoecology is to identify and understand the factors underlying the capacity of communities with historical continuity in the use of natural resources to keep their capacity to adapt and regenerate LEK (Mercer et al. 2010; Weatherhead et al. 2010; Simelton et al. 2013). While LEK systems have throughout history shown great resilience and adaptability (e.g., through flexibility in traditional practices or close social networks), some traditional responses to absorb change have already been compromised by socio-political and environmental changes (Kesavan and Swanminathan 2006; Homann et al. 2008; Yeh et al. 2014). For example, in some communities in the Arctic, current social, economic and cultural trends towards adopting Western lifestyles have eroded the cycle of traditional knowledge transfer upon which adaptive capacity is built (e.g., Ford et al. 2006, 2010). Disruption of LEK transmission, decreasing engagement between youth and older generations, and degradation of social networks may therefore all contribute to the already vulnerable indigenous communities facing GEC (Ford et al. 2006; Alessa et al. 2008).

In such contexts, the constituent element ensuring the adaptation of LEK systems is the maintenance of the socio-economic, cultural and environmental conditions that allow indigenous peoples to experiment with knowledge (Rautela 2005; Pérez et al. 2010; Maldonado et al. 2013). The ability of indigenous peoples to cope with substantial changes in the future cannot be considered as unlimited, unless their knowledge systems adapt to these changes and/or people keep the ability to continue developing, testing and updating indigenous knowledge. In other terms, bodies of LEK remaining in indigenous, peasant and other types of semi-autarkic societies are bound to either change and adapt (e.g., through hybridisation) or disappear (Gómez-Baggethun and Reyes-García 2013). Ethnoecological research is thus urgently needed to better understand the adaptive capacity of LEK under change conditions and the factors facilitating the resilience of knowledge systems in the face of new global scenarios. In order to contribute to this goal, in the present dissertation I examine the adaptive capacity of LEK –both in terms of strengths and limitations– in a rapidly changing social-ecological system of Bolivian Amazonia.

## 1.3. Case study: the Tsimane' of Bolivian Amazonia

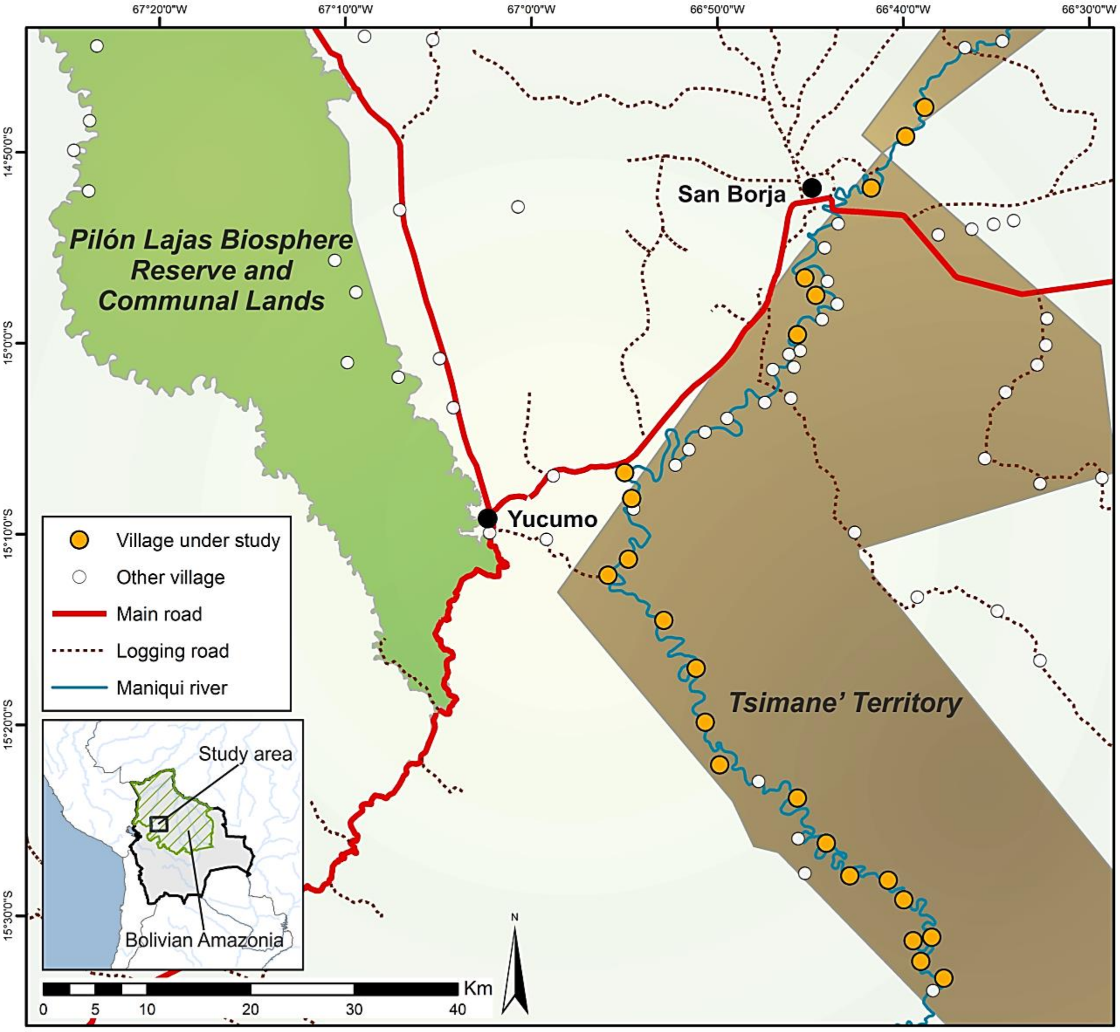
### 1.3.1. Study area

The Tsimane' are a native Amazonian society of hunter-gatherers and small-scale horticulturalists living in the south-western department of Beni, mainly in the Ballivián and Yacuma provinces of Bolivian Amazonia. Nowadays, they number approximately 14,000 people (Undurraga et al. 2014) living in some 125 villages of commonly ca. 20 households per village, mostly concentrated along riverbanks and logging roads (Reyes-García et al. 2012).

Tsimane' settlements are nowadays scattered across an array of land tenure systems as a result of different policies deployed in successive laws, agrarian and forestry reforms. Specifically, Tsimane' villages are now settled within: (a) three protected areas (Beni Biological Station, Pilón Lajas Biosphere Reserve, and Isiboro-Securé National Park); (b) several logging concessions; (c) four indigenous titled territories or communal original lands (TCOs for the Spanish acronym referred to *Tierras Comunitarias de Origen*: Tsimane' Indigenous Territory, Multiethnic Indigenous Territory, Pilón Lajas Communal Lands, and Isiboro-Sécure Indigenous Territory); and (d) private lands, including colonisation areas (see Reyes-García et al. 2014b for a review). In the present dissertation, I worked only with villages within the Tsimane' Indigenous Territory (TICH, *Territorio Indígena Chimane*), also referred to as Tsimane' Territory, a communal land comprising ca. 400,000 hectares (14°10' – 15°40'S, 66°20' – 67°20'W) granted to the Tsimane' in 1990 (Figure 1.1). San Borja, a town of ca. 40,000 people (INE 2012) is the primary economic centre of the area, where the municipal government and the *Gran Consejo Tsimane'* (Great Tsimane' Council, GCT, i.e., the Tsimane' legitimate political organisation) are based. The town of Yucumo (Figure 1.1) is also an important market centre for the Tsimane'.

The Tsimane' Territory extends from the Andean piedmont to the vast planes of the savannahs of Moxos (Guèze et al. 2014a). Elevation in the area varies

**Figure 1.1 |** Study area.




between 150 to 1500 metres above sea level (m.a.s.l.) around the Cara Cara Mountains, but Tsimane' villages are only settled up to 500 m.a.s.l. in the upstream Maniqui River. Most of the territory is covered by *terra firme* lowland Amazonian rainforests with a high semi-deciduous canopy reaching 40 metres (Guèze et al. 2014a,b). These forests support a rich faunal diversity, with about 30 game vertebrate species, including ungulates, primates, caviomorph rodents, cracids, tinamous and tortoises (Chicchón 1992; Luz 2013). The climate of the region is thermotropical with summer rains from October to April and a cold season from June to August, when polar winds from the South Pacific sweep through the area and trigger punctual cold spells, locally known as *surazos* (Ronchail 1989). The mean annual temperature is 25.8°C (Navarro and Maldonado 2002) and the mean annual rainfall is 1743 mm, ranging from 1000 to 4000 mm depending on the year (Godoy et al. 2008).

### 1.3.2. Cultural and historical context

The Tsimane' are traditionally and essentially hunter-gatherers, but nowadays they also practise small-scale shifting agriculture (Vadez and Fernández-Llamazares 2014). Some Tsimane' (particularly those in villages close to the main market towns) are starting to engage in market-oriented activities such as cash cropping, sale of forest products (e.g., thatch palm, *Geonoma deversa*) or wage labour in logging camps, cattle ranches and in the homesteads of colonist farmers (Reyes-García et al. 2014c). However, despite this increasing market integration, the Tsimane' society continues to be highly autarkic and self-sufficient, with only ca. 16% of Tsimane' households having monetary earnings (Godoy et al. 2010).

The Tsimane' social organisation is largely kinship-based. Residence is generally matrilocal (i.e., the immediate family living with or near the wife's parents) and most Tsimane' still practise cross-cousin marriage, meaning that a man can marry the daughter of his mother's brother or that of his father's sister (Daillant 2003), despite a growing tendency for exogamous unions, particularly in villages closer to town. Household patterns reflect clan groups (i.e., extended family units) and social life is embedded in relations around subsistence activities, particularly fishing, hunting and gathering, which provide links to the ancestors, land and cultural identity of the Tsimane' (Huanca 2014). Traditionally, the Tsimane' were animists and believed in the existence of supernatural spirits who owned trees, stones, animals and ancestors, towards which they showed reverential attitudes (Riester 1976; Reyes-García 2001). They also counted on shamans who were simultaneously religious leaders and folk healers, responsible for mediating between humans and the supernatural world (Huanca 2008). Nowadays, their belief system represents a syncretic blend of animist beliefs and those brought by Christian missionaries in the 1950s (Ellis 1996; Fessler et al. 2015).

A summary of the (known) history of the Tsimane' is provided in Table 1.3, adapted from the work of Reyes-García et al. (2014b). Historical accounts of the Tsimane' depict them as a particularly elusive ethnic group (Nordenskiöld 1924; Pauly 1928; Chicchón 1992). Escaping from the violence and abuses of the Hispanic conquests, the Tsimane' confined themselves to the remote upper parts of the Apere and Maniqui rivers (Reyes-García et al. 2014c). Hidden in the '*almost impenetrable forests*' (Pauly 1928:116) of the furthest reaches of these rivers, the Tsimane' succeeded in resisting Catholic and Protestant proselytes' incursions from the early seventeenth century up until the 1950s (Pérez-Díez 1983; Martínez-Rodríguez 2009). The first record of contact assigned to the Tsimane' was in 1621, when the Franciscan priest Gregorio de Bolívar attempted and failed to settle the Tsimane' into missions (Chicchón 1992; Huanca 2008). Ethnographic works describe the Tsimane' traditionally being a highly mobile society, with dispersed settlement patterns and lacking a hierarchical system of authority (Califano 1975; Ellis 1996; Daillant 2003), possibly explaining why they managed to withstand the evangelisation process and remain relatively isolated until the mid-20$^{th}$ century. Moreover, with none of the commercial resources valued by Europeans in that era (i.e., gold, silver and rubber trees), the Maniqui and Apere Basins provided the perfect hideout for the Tsimane' to resist to the whirlpool of conquest, evangelisation and illnesses brought by the arrival of colonists elsewhere in the region.

Up until the late 1930s, the Tsimane' maintained a traditional, semi-nomadic and self-sufficient lifestyle, keeping occasional and selective contact with outsiders (Nordenskiöld 1924; Pauly 1928). Such contacts were very limited and spasmodic, mostly explained by the Tsimane' incipient taste for market goods such as clothes and metal utensils like axes, knives and fishhooks (Nordenskiöld 1924). Apparently, the Tsimane' had continued to use hafted stone adzes into the twentieth century (Métraux 1942). However, Tsimane' interactions with the

**Table 1.3 |** Historical timeline of the Tsimane' Territory.

| Period | Phase | Year | Highlight | Reference |
|---|---|---|---|---|
| Until 1952 | Indigenous territories as marginal lands | 1621 | The Franciscan priest Gregorio de Bolívar provides the first known reference to the Tsimane' | Chicchón (1992), Daillant (2003) |
| | | 1693 | Foundation of the Mission San Francisco de Borja | |
| | | 1805 | Foundation of two small missions with the Tsimane' villages along the Maniqui river | Pérez Díez (1983) |
| | | 1860s | Violent confrontations: Tsimane' resistance to settle in missions | Daillant (2003), Huanca (2008) |
| | | 1910s | Arrival of new migrants to the area (mostly attracted by the rubber economy) | Reyes-García et al. (2014b) |
| | | 1930s | Some Tsimane' start working as ranch labourers, becoming entangled in the debt-peonage system | Martínez-Rodríguez (2003) |
| | | 1950s | Arrival of the first traders to the Tsimane' Territory: expansion of debt-peonage systems | Riester (1993), Huanca (2008) |
| 1952-1980s | Forest frontier expansion | 1952 | National Revolution in Bolivia: huge migration waves to the Bolivian lowlands | Pacheco et al. (2010) |
| | | 1957 | Establishment of the Catholic Fátima mission and arrival of the Protestant New Tribes Mission | Huanca (1999) |
| | | 1970s | Illegal logging operations in the Chimane Forest (largest mahogany reserve in South America) | Jones 1980 |
| | | 1975 | Road opened between San Borja and Trinidad | Bottazzi (2008) |
| | | 1979 | Road opened between Rurrenabaque and Yucumo: rapid increase of permanent migration | |
| | | 1980s | Land conflicts force many Tsimane' families to migrate to the Maniqui and Quiquibey rivers | |
| | | 1982 | Creation of the Beni Biological Station (135,000 ha) in the lower section of the Maniqui river | Paneque-Gálvez et al. (2013) |
| 1985-1994 | Indigenous peoples' political awakening | 1989 | Creation of the *Gran Consejo Tsimane'* (GCT), political organisation representing the Tsimane' | Reyes-García et al. (2014b) |
| | | 1990 | March for Territory and Dignity: claims for indigenous territorial rights | Jones (1993) |
| | | | The Tsimane' are granted a communal land of ca. 400,000 ha: Tsimane' Indigenous Territory | Reyes-García et al. (2014b) |
| | | 1990s | The Tsimane' living in Pilón Lajas, TIM and TIPNIS are also granted territorial rights | |
| 1994-2005 | Neoliberal multicultural reforms | 1994 | Popular participation law: decentralisation and recognition of indigenous authorities | Chumacero (2011) |
| | | 1996 | Agrarian Reform Law: TCOs are created and the land titling process (*saneamiento*) starts | Assies and Salman (2000) |
| | | | Forestry Law: logging concessions are regularised and given priority over TCOs | Hunnisett (1996), Pacheco (2007) |
| | | | The opening up of a logging road destroys an important Tsimane' petroglyph site | Daillant (1997) |
| | | 1999 | National halt of the land titling process (including Tsimane' Territory) due to land conflicts | Martínez (2000) |
| | | 2000 | March for Lands, Territories and Natural Resources: claims to accelerate the titling process | INRA (2005) |
| 2005-2015 | Indigenous autonomies in the Plurinational State of Bolivia | 2005 | Election of Evo Morales as the first indigenous Bolivian president | Reyes-García et al. (2014b) |
| | | 2006 | Agrarian Reform Law: provisions for the acceleration of indigenous land titling | Chumacero (2011) |
| | | 2007 | National Development Plan with the goal of reducing social inequality in Bolivia | Pacheco et al. (2010) |
| | | 2009 | New Bolivian Constitution: more political autonomy to indigenous peoples | Reyes-García et al. (2014b) |
| | | 2010 | TCOs are reconverted to TIOCs (Indigenous Originary Peasant Territories) | |
| | | | Jorge Añes becomes the first Tsimane' major of San Borja: enforcing local Tsimane' governance | |
| | | 2015 | The Tsimane' land titling process is yet to be concluded (GCT aiming to recover logging concessions) | |

Note: the contents of this table are a summary of the main historical developments in the Tsimane' Territory, adapted from Reyes-García et al. (2014)

broader Bolivian society started to increase with the first settlement of cattle ranchers in the area, who began to engage the local indigenous groups –including the Tsimane'– as wage labourers under debt peonage systems[10] (Martínez-Rodríguez 2009; Fernández-Llamazares et al. 2014a). Similarly traders started to move into the Tsimane' Territory around the 1950s (Chicchón 1992; Huanca 2008) and soon the Tsimane' started to regularly barter non-timber forest products with traders in exchange for commercial items such as tools, salt or alcohol (Riester 1993). At first, the main products entering this trade were animal pelts (Roca 2001), later to be followed by what continues to be the most important non-timber forest product traded by the Tsimane': thatch palm (*G. deversa*). The latter is an understorey palm whose leaves are used for the roofing of houses in many rural and urban dwellings throughout the Bolivian lowlands. With the regional boom of its demand, *G. deversa* became the primary source of income for the Tsimane' (Godoy et al. 2001) and the main contributing factor to the articulation of the Tsimane' within the regional economy.

The National Revolution of 1952, with the construction of new roads in the region, the logging boom, the different land tenure reforms and its subsequent waves of government-planned Andean colonisation of the Bolivian lowlands[11], pushed the Tsimane' into increasing contact with other segments of the national society (Reyes-García et al. 2012, 2014b). Such processes gradually transformed the Tsimane' at all levels: social, economic, political and cultural (Chicchón 1992; Godoy et al. 2005; Reyes-García et al. 2014c). Moreover, by that time, the Evangelic group New Tribes Mission had managed to permanently settle within the Tsimane' Territory, achieving a large influence in the area mostly through the establishment of two educational centres and a biblical radio station. The evangelic missionaries created a Tsimane' alphabet and dictionary, in order to be able to translate the

[10] Debt peonage systems (*sistemas de habilito* or *sistemas de enganche*, in Spanish) became very common throughout Amazonia at the end of the 19th century, mostly during the rubber tapping period (Herrera et al. 2005). Such patron-peon systems are a form of servitude akin to bonded labour, where a patron provides commercial goods or money to a peon as an advance for her/his future labour (e.g., collection of forest products). Until the debt (including interest rates) is paid off by the debtor, the patron has the use of her/his labour. Nowadys, such labour systems remain prevalent in the Tsimane' Territory, despite them being prohibited by international law (Bales 2004; Martínez-Cantero 2012; Fernández-Llamazares et al. 2014a).

[11] Different government laws were approved to encourage migration to Bolivian Amazonia in an attempt to reduce demographic pressure in the densely populated Bolivian highlands and valleys (Reyes-García et al. 2014b)

Bible to Tsimane' language for indoctrination (Huanca 2008). The arrival of missionaries had profound impacts upon the local culture, including changing the traditional communal structure by clustering many households in more permanent settlements, diminishing the shamans' cultural status until their ulterior disappearance[12], and replacing many native cultural rituals with Christian practices (Reyes-García 2001; Huanca 2008, 2014). In the absence of effective state services in the area, through schooling and basic biomedical services, the New Tribes Mission achieved a prominent role within the Tsimane' society. The Mission became responsible for the application of bilingual education in Tsimane' schools and for the empowerment and formation of an entire cohort of Tsimane' teachers and political leaders (Reyes-García et al. 2010a).

In 1989, under the auspices and coaching of evangelic missionaries, the *Gran Consejo Tsimane'* (GCT), the first political representative authority of the Tsimane', was formally created. Their first task was to put forward a territorial claim requesting control over an area that includes the Maniqui River, the Eva Eva mountain range, and part of the pampas (Bottazzi 2009). In 1990, a supreme decree (Ds No. 23611) recognised Tsimane' rights to land, by assigning them an area of 392,220 hectares, named Tsimane' Indigenous Territory (Reyes-García et al. 2012). In the following years, other Tsimane' living in different areas were also granted territorial rights over different neighbouring lands (Chumacero 2011), which resulted in a substantial fragmentation of the Tsimane' territorial and institutional unity (Reyes-García et al. 2014c). In 2005 the national election of Evo Morales as the first indigenous president of Bolivia led to several improvements for the Tsimane', including advances in the recognition of indigenous rights and significant steps forward in the process of land titling (Chumacero 2011; Fernández-Llamazares et al. 2014a). Additionally, in 2010, Jorge Añes, the then-President of the GCT, was elected mayor of the town of San Borja, giving even stronger political influence to the Tsimane' at the local and regional levels and

[12] Due to religious pressures and cultural change, the traditional shamans (locally known as *cocojsi'*) do not exist anymore. The last shaman died three decades ago. However, their descendants, assistants and some local elders still exercise their functions sporadically (Huanca 2014). Some of them are still referred to as shamans, and while they hold some of the traditional knowledge and practices of the former shamans, their function of mediating between the natural and spiritual world has substantially diminished. Their practices are mostly limited to plant treatments for sorcery, particularly in villages further from town.

contributing to the defence of the Tsimane' Territory against land encroachers (Reyes-García et al. 2012).

The history of the Tsimane' suggests that their interactions with other sectors of the Bolivian society are rapidly increasing. However, research shows that there is great heterogeneity with regard to how the Tsimane' engage in these interactions (Godoy et al. 2001, 2008; Reyes-García et al. 2005). Tsimane' villages present a gradient of cultural change as they experiment different levels of contact with outsiders (Godoy et al. 2004; Guèze et al. 2015). Several historical, social and geographical factors (e.g., remoteness from main towns) partly explain this gradient. For example, traders visit villages close to market towns on an almost daily basis, while visits to the more remote villages are much more infrequent, arguably because they take up to four days to reach by canoe. Similarly, villages closer to town have easier access to modern schooling and health care facilities than the more remote villages. As a result, the Tsimane' display a large variation in their dependence on market-economic activities, in their contacts with the wider national society and in their levels of cultural change (Vadez et al. 2008; Reyes-García et al. 2005, 2014c). Yet, these different degrees of market integration and cultural change are not only to be found between villages, but also between individuals within a village. While some Tsimane' individuals rely heavily on forest products for their subsistence, do not speak any Spanish (this being the most widely spoken of the 37 national languages of Bolivia), and choose to live according to traditional norms and customs, others have received formal education, speak fluent Spanish, and have become reliant on cash income from wage labour, cash cropping or illegal logging (Luz 2013; Paneque-Gálvez 2013). These variations, both between villages and between individuals, create an interesting pattern to study the different ways in which the Tsimane' adapt to the new social-ecological scenarios shaped by GEC.

### 1.3.3. Tsimane' Local Environmental Knowledge

As with other native Amazonian societies, the close relation of the Tsimane' with their environment has resulted in them holding a great deal of LEK across different domains, such as wildlife ecology and distribution (Apaza et al. 2003; Ringhofer 2010), hunting (Chicchón 1992; Luz 2013), fishing (Pérez 2001), landscape management (Riu-Bosoms et al. 2014), agriculture and home-gardening (Vadez et al. 2004; Díaz-Reviriego et al. *accepted*), and ethnobotany (Ticona-Contreras 2007; Guèze et al. 2014a).

Not surprisingly, Tsimane' LEK has been extensively examined in the last 15 years (see Luz et al. 2014 for a review). Research amongst the Tsimane' suggests that LEK is widely shared amongst all members of the society (Reyes-García et al. 2003; Paneque-Gálvez 2012) supporting the idea that the generation of knowledge is a social effort (Berkes et al. 2000; Stone 2004). However, some studies have also explored the intra-cultural distribution of LEK amongst the Tsimane', showing that even if a certain LEK basis is shared by all members of the society, individual LEK levels might differ, due to the influence of individual level characteristics such as gender (Díaz-Reviriego et al. *accepted*), market participation (Reyes-García et al. 2005, 2007a) or formal education (Reyes-García et al. 2010a). In view of these intra-cultural LEK differences, a number of studies have tested the association between Tsimane' LEK and particular social and environmental variables. Some of these works have shown that individual levels of LEK are positively associated with: (a) effective habitat management (Reyes-García et al. 2008a); (b) decrease in forest clearance (Reyes-García et al. 2007b, 2011); (c) individual nutritional status (Reyes-García et al. 2008b); and (d) offspring health status (McDade et al. 2007). Similarly, at the community level, Tsimane' villages with higher levels of LEK show, in general, decreased deforestation rates (Paneque-Gálvez 2012).

From previous research, we know that –as with other societies– the drivers of change in LEK amongst the Tsimane' are complex and partially contextual. Some of these factors include: (a) the influence of schooling (Reyes-García et al. 2010a); (b) land-use changes (Paneque-Gálvez 2012, Pérez-Llorente et al. 2013); (c) community integration into the market economy (Reyes-García et al. 2005, 2007a); and (d) changes regarding traditional beliefs and values (Luz 2013; Reyes-García et al. 2014c). In general, all these works coincide in pointing to globalisation as currently posing a serious threat to the local knowledge systems to the extent that cultural and economic changes devaluate the use of LEK, prioritising alternative sources of information and new modes of subsistence (Reyes-García et al. 2005; Luz 2013). With the Tsimane' being increasingly exposed to Western cultural and economic norms and patterns, there are numerous concerns on potential LEK losses in the near future (Godoy et al. 2010; Reyes-García et al. 2014c).

Notwithstanding, research examining Tsimane' LEK trends reveals contradictory findings, with some studies showing a net loss of LEK (Reyes-García et al. 2007a, 2013a) and others suggesting an overall maintenance of LEK even as the Tsimane' undergo cultural, economic and environmental changes (Godoy et al. 2009; Reyes-García et al. 2013b). Analysing cross-sectional data from Tsimane' adults, Godoy et al. (2009) found no evidence of secular loss of theoretical knowledge of useful plants since the 1920s. These results were later challenged by Reyes-García et al. (2013a) who found that between 2000 and 2009, Tsimane' adults experienced a net decrease in the report of plant uses equivalent to a 1% to 3% per year. According to these authors, the Tsimane' could be abandoning their LEK as they perceive that this form of knowledge does not equip them well to deal with the rapidly changing socio-economic, political and environmental conditions that they currently face. However, with the aim of reconciling this contradictory evidence, a third study was set by Reyes-García et al. (2013b) to closely examine if different knowledge domains could show distinct vulnerability to the process of socio-economic and environmental change. Indeed, the authors found that not all LEK domains follow the same secular trends, each of them paralleling other social changes with uneven effects upon each knowledge type.

Understanding changes in the LEK system is crucial to determine how this society can become more resilient in the face of growing social-ecological challenges. The role of LEK in adapting to current environmental changes will be generally discussed in this work, and particularly in Chapter IV.

## 1.3.4. Social-ecological changes amongst the Tsimane'

Several social-ecological transformations have recently put Bolivian Amazonia in the spotlight of GEC research (Bottazzi and Dao 2013; Fernández-Llamazares and Rocha 2015). While environmental changes have been relatively well-documented in Brazilian Amazonia for the past two decades (e.g., Laurance 2001; Soares-Filho et al. 2006; Satyamurty et al. 2010), studies for the remaining 37% of the cross-national basin have been scant (e.g., Perz et al. 2005; Espinoza-Villar et al. 2009). This is particularly the case for Bolivian Amazonia, covering 12% of the Amazonian Basin.

Formerly known for its low deforestation rates (Kaimowitz 1997), Bolivia has nowadays the fourth highest forest cover loss rate of Latin America (GFW 2015), due to economic growth, changes in agriculture practices and colonisation schemes. These same trends are steadily increasing throughout Bolivian Amazonia (Killeen et al. 2007, 2008), with oil, gas and road development having intesified in the region, causing major ecological and social impacts (Finer et al. 2008, 2015; Bottazzi and Dao 2013). Moreover, several studies document the effects of anthropogenic climate change in the region (Ronchail 2005; Seiler 2009), as well as the alarming trends of biodiversity loss (Ibisch 2005; MMA 2009; Herzog et al. 2011), despite it being considered amongst the top conservation priorities in the world (Myers et al. 2000). All this represents an increasing threat for the 31 native indigenous groups inhabiting Bolivian Amazonia (Ferreira 2011; PNUD 2013).

Within this broader context, the Tsimane' Territory is also facing substantial ecological changes (Ringhofer 2010; Pérez-Llorente et al. 2013; Guèze et al. 2015). Rapid declines in biodiversity, mostly stemming from significantly high levels of deforestation, habitat degradation and hunting pressures, have been recurrently reported in the area (Apaza et al. 2002; Paneque-Gálvez et al. 2013; Luz 2013). Moreover, climate change is likely to have disrupted –and likely to continue disrupting– the ecosystems of the Tsimane' Territory (Fernández-Llamazares et al. 2014b), considering also that climate change interacts synergistically with pre-existing deforestation and forest fragmentation, both of which have been reported in the area (Paneque-Gálvez 2012; Pérez-Llorente et al. 2013; Guèze et al. 2014b).

All these environmental changes intersect with broader socio-economic and cultural transformations, which generally exacerbate effects and create major challenges for the Tsimane' livelihoods and culture (e.g., Reyes-García et al. 2013a; Zycherman 2013). For example, despite increasing market opportunities (e.g., Vadez and Fernández-Llamazares 2014), the Tsimane' continue to suffer economic disadvantages, as illustrated by the extended prevalence of systems of debt peonage in their Territory (Martínez-Cantero 2012; Fernández-Llamazares et al. 2014a). Moreover, the increasing fragmentation of Tsimane' institutions (Reyes-García et al. 2014b), together with their still-limited influence on regional governance issues (Reyes-García et al. 2010b), facilitates the presence of encroachers invading their Territory and exploiting their natural resources (Bottazzi 2009; Reyes-García et al. 2012). This broader socio-political context is most probably compounding the threats caused by GEC to increase vulnerability in the area, for instance raising the levels of food insecurity amongst the Tsimane' (Qureshi 2007; Zycherman 2014, 2015).

Notwithstanding, the literature also highlights different social attributes of the Tsimane' that could contribute to their resilience and adaptability to GEC. For example, LEK continues to be at the core of Tsimane' livelihood (Reyes-García et al. 2003, 2013b), most probably conferring them adaptive capacity in the light of new scenarios (Luz et al. 2014). Such adaptive capacity might in turn be enhanced by diversified livelihood options (Godoy et al. 2005, 2010), a culture of strong social support –with dynamic social networks– (Daillant 2003; Reyes-García et al. 2006), and the relative sovereignty that the Tsimane' have over their territory (Bottazzi 2009; Chumacero 2011). Moreover, in the current context of the Plurinational State of Bolivia (e.g., with a New Constitution recognising the rights of indigenous peoples and reflecting a plural and inclusive state), the Tsimane' are experiencing a wave of increasing cultural self-esteem, a stronger sense of self-determination, and a general willingness to preserve their culture, language and knowledge (Godoy et al. 2007; Fernández-Llamazares et al. 2014a).

## 1.4. Structure and aims of the dissertation

This PhD dissertation is a hybrid between a monograph and a compilation of scientific papers. It contains a comprehensive introduction to the research topic and a final chapter with the main conclusions, but it also includes four research chapters in the format of scientific articles: two of them published (Chapters III and IV) and two submitted (Chapters II and V). As such, some of the chapters present some similarities in their description of the study area and the methodological approach. However, I have chosen to preserve each chapter in its intact article format in order to respect their respective internal cohesion, even if the reader will find some duplicated information between chapters.

This thesis has four specific aims:

1. to assess the potential use of indigenous knowledge for complementing climate models assessing climate change (Chapter II);
2. to investigate the interplay between local observations of climate change and the uptake of media information (Chapter III);
3. to examine the adaptive capacity of LEK in a context of rapid ecosystem change (Chapter IV); and
4. to explore the role of local perceptions as drivers of adaptation (Chapter V).

The work presented within the scope of this thesis is a compilation of social-ecological data collected over 15 months of fieldwork and examined from the theoretical framework of ethnoecology. Chapters II and III specifically deal with observations of climate change, while Chapters IV and V are devoted to examine perceptions of ecological change. The cross-cutting theme across all four chapters is the study of local knowledge and perceptions of GEC.

Given the complexity of working with indigenous knowledge and local perceptions (Raymond et al. 2010; Yeh 2015), many different approaches have been used to term, define and apply these multi-faceted concepts (see also Section 1.2.2). In general, the terminology used differs from one discipline to another.

Climatological studies mostly use terms such as *indigenous observations* or *indigenous knowledge*, arguably because a great number of these works have been conducted amongst indigenous societies, particularly in Arctic regions (e.g., Gearheard et al. 2006; Cochran et al. 2013). Contrarily, conservation scientists and ecologists mostly focus their research on *local environmental knowledge* for understanding changes in the ecosystem (e.g., Moller et al. 2004; Drew 2005; Gilchrist et al. 2005; Pan et al. 2015). Meanwhile, studies on natural resource management and psychology prefer to use the term *local perceptions*, emphasising the tacit and sensory component of any representation of the environment (e.g., Patt and Schröter 2008; Weber 2010; Oldekop et al. 2013).

When reading this thesis, it is important to keep in mind that each of its chapters is addressed to a particular audience through a concrete scientific journal with specific lexical and stylistic requirements. As a result, the reader might find that these terms are somewhat interchangeably used across the chapters of this dissertation. In any case, I want to stress that while these terms differ from one another conceptually, in this dissertation they are always understood in the wider context of observation, perception, interpretation, successive evaluation and appreciation of all information on environmental change captured by an individual, both from her/his own personal experience, as well as from other external sources of information (see Table 1.2 for further details).

This introductory chapter (Chapter I) has presented the topics addressed through an extensive annotated literature review, placing the scope of this work within the wider context of the current state of the research. It has also described the main objectives and motivations of the thesis, as well as the case study used to approach my research questions. The following four chapters cover the results of the thesis.

Chapter II documents Tsimane' observations of climate change, investigating whether these are consistent or not with scientific records and whether consistency is higher for individuals with higher levels of LEK. Based on the results, I discuss whether indigenous knowledge could help to fill gaps in instrumental records of climate change in Bolivian Amazonia, where current climate data are limited. This chapter corresponds to the article 'An empirically-tested overlap between indigenous and scientific knowledge of a changing climate', submitted to the journal *Proceedings of the National Academy of Sciences of the United States of America* in September 2015.

Chapter III tests to what degree the Tsimane' local accounts of climate change are influenced by externally driven awareness-raising, or –rather– are mainly a result of local observations. I extensively document Tsimane' ethnoclimatological knowledge, with a focus on climate change perceptions, and I study the possible effects of media communication on such knowledge by conducting a randomised controlled evaluation[13]. I discuss the challenges involved in translating between local and scientific framings of climate change. This chapter corresponds to the article 'Links between media communication and local perceptions of climate change in an indigenous society', published in the journal *Climatic Change* in July 2015.

Chapter IV targets the core discussion of the limits of the adaptive capacity of local knowledge systems. Using the concept of the shifting baseline syndrome and drawing on Tsimane' perceptions of wildlife change I develop a conceptual framework to examine the structural constraints of using LEK in the context of GEC. On the basis of my results, I discuss different mechanisms to support the resilience of LEK in the face of ever encroaching environmental change. This chapter corresponds to the article 'Rapid ecosystem change challenges the adaptive capacity of Local Environmental Knowledge', published in the journal *Global Environmental Change* in March 2015.

Chapter V explores the roles of local perceptions as drivers of harvesting and management behaviour, focusing on the study of thatch palm (*G. deversa*). I analyse whether Tsimane' perceptions of availability of the resource match estimates of abundance issued from ecological data and whether differences in perception help

[13] This chapter draws on a database from previous research in the area (Tsimane' Amazonian Panel Study, TAPS; see Leonard et al. 2015), combined with my own ethnographic data collection.

to explain harvesting behaviour and local management of thatch palm. I discuss the role that local perceptions play in promoting collective responses for the sustainable management of dwindling natural resources. This chapter corresponds to the article 'Local perceptions as a guide for the sustainable management of natural resources: empirical evidence from a small-scale society in Bolivian Amazonia', submitted to the journal *Ecology and Society* in July 2015.

Chapter VI presents a general discussion of the results of this research. In this final chapter, I integrate the main results of the four research chapters of the thesis and draw from these a broader perspective on the main questions addressed. I also outline the policy implications of this research, the main methodological caveats and contributions, and suggest potential areas for further study.

Finally, I present a list of publications complementary to this PhD project (Appendix I) alongside with further supplementary information as a background to the chapters of this thesis (Appendices II-V).

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# Chapter II

## An empirically-tested overlap between indigenous and scientific knowledge of a changing climate


### Abstract

Current climate models in Bolivian Amazonia rely on data from a few sparse weather stations, interpolated on coarse-resolution grids. At the same time, the region hosts numerous indigenous groups with rich knowledge systems that are hitherto untapped in the quest to understand local climate change. Drawing on an empirical dataset of climate change observations by an Amazonian native society, we assess the potential use of indigenous knowledge for complementing climate models. We find indigenous observations to be robustly associated with local station data for climatic changes over the last five decades. By contrast, there are discrepancies between global climate models and both indigenous observations and local station data. Indigenous knowledge can be instrumental to enhance our understanding of local climate in data-deficient regions. Indigenous observations offer a tool to ground-truth modelled descriptions of climatic changes, thereby making adaptation strategies more robust at local scales.



**Keywords:** ethnoclimatology; indigenous observations; local climate change; Local Environmental Knowledge.


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## 2.1. Introduction

Most models currently used to describe past or project future climate change are being developed at the global level, with coarse spatial resolution (Bindoff et al. 2013; Flato et al. 2013). Since the normative use of a number of these models is to assess impacts at more localised scales, climate models are increasingly being downscaled to resolutions that are relevant for policy-making in general and adaptation planning in particular (Fowler et al. 2007; Maraun et al. 2010). However, the resulting downscaled products are constrained by the uncertainty of the coarse-scale data that drive them, as well as by the new uncertainties introduced by the downscaling techniques (Zou et al. 2010; Chen et al. 2011). Moreover, since current climate models rely on spatially interpolated gridded data from a number of weather stations, with some geographically heterogeneous areas poorly covered, they generally show lower performance and decreased reliability from global to local scales (Hijmans et al. 2005; Fernández et al. 2013). Arguably for these reasons, the ability of global models to describe climatic changes at the local level has been widely questioned (Hawkins et al. 2009; Zou et al. 2010; Potter et al. 2007). Here we explore the potential for the use of indigenous knowledge to address the above challenges in local assessments of climatic changes. We contrast local observations of climate change held by indigenous peoples in Bolivian Amazonia with commonly used metrics of climate change (Garcia et al. 2014) based on spatially interpolated gridded climate data for the past 50 years.

Partly in response to calls to explicitly address uncertainty in climate observations in areas such as Bolivian Amazonia (e.g., Soria-Auza et al. 2010), some authors are starting to use indigenous knowledge as a place-based tool to scrutinise local indicators of climate change (Hulme 2011; Smith 2011; Barnes et al. 2013). Local Environmental Knowledge (LEK) is one of the multiple dimensions of indigenous knowledge: a cumulative body of knowledge, skills and beliefs held by a specific group of people, handed down through generations by cultural transmission (Berkes et al. 2000). LEK is a holistic system for understanding the world, embedded in the culture of a group and borne from long periods of observation, experimentation and continued interaction between people and their environment (Berkes et al. 2000; Gagnon and Berteaux 2009; Laborde et al. 2012). Place attachment and long-term time continuity in resource use enable LEK holders to recognise local indicators not only of weather, but also of climate change (Monastersky 2009; Huntington et al. 2011; Klein et al. 2014).

Indigenous observations of climate change can therefore be considered a tacit and situated understanding of local climate change, reflecting a depth of embodied experience unlikely to be derived through structured and formalised processes (Fazey et al. 2005; Huntington et al. 2011; Klein et al. 2014). It has been argued that the strength of LEK systems lies in their long-term local-scale observations (Couzin 2007; Whipple 2008; Rosenzweig and Neofotis 2013). Some studies have already attempted to compare scientific data with indigenous observations of climate change (Monastersky 2009; Klein et al. 2014). While informative, most of these works are limited in that: (a) they have been conducted on the basis of narratives rather than systematically collected individual knowledge data (e.g., Alexander et al. 2011); (b) they often compare indigenous and scientific data at different spatial resolution (e.g., Chaudhary and Bawa 2011); and (c) they have focused almost entirely on the Arctic and Himalayan regions (e.g., Vedwan and Rhoades 2001; Couzin 2007). Due to this relative lack of experimental work, IPCC has recently called scientists to further develop the evidence base for the effectiveness of indigenous knowledge, particularly LEK (Niang et al. 2014).

Evidence on the effectiveness of indigenous knowledge to advance climate science is still largely lacking in tropical regions such as Bolivian Amazonia. Yet, the intricate relationship between Bolivian native Amazonians and their surrounding environment has resulted in detailed bodies of LEK, including ethnoclimatological knowledge, which are at the basis of their subsistence practices (e.g., Reyes-García et al. 2003, 2013; McDade et al. 2007; Cámara-Leret 2014). Moreover, this knowledge is independent from the scientific discourse on anthropogenic climate change, which remains still largely inaccessible in many areas (Fernández-Llamazares et al. 2015a). In other words, indigenous observations of climate change are most probably conferred to local manifestations of such phenomenon and based on their LEK. Here, we: (a) empirically investigate if indigenous observations of climate change by native Bolivian Amazonians are consistent with scientific knowledge; and (b) whether consistency is higher for individuals with higher levels of LEK.

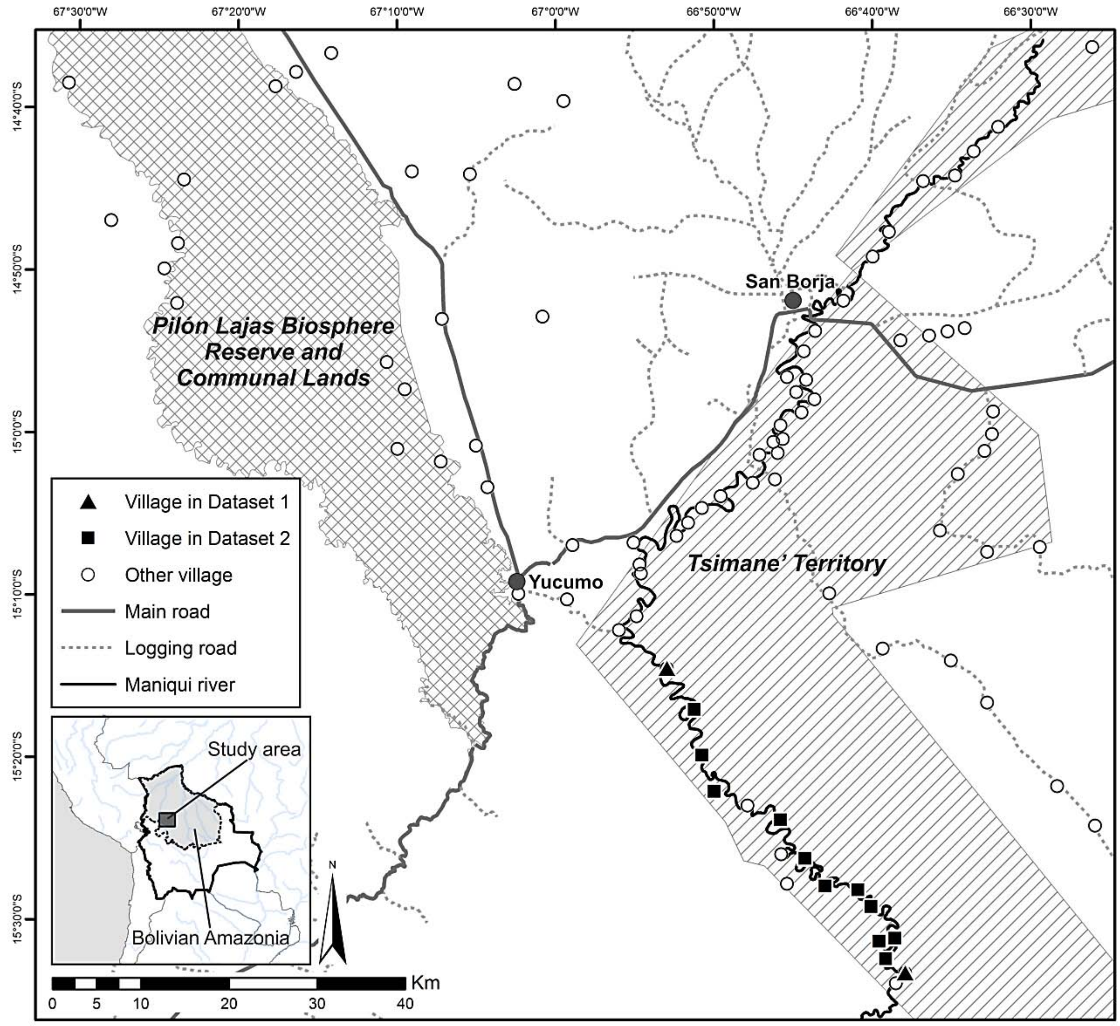
## 2.2. Methods

### 2.2.1. Study area

Amazonia is generally recognised as one of the world's emblems of Global Environmental Change (e.g., Mahli et al. 2008; Espinoza-Villar et al. 2009). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) compiles unequivocal evidence of climatic changes in the Amazon Basin over the last six decades, such as increased decadal variability in rainfall and increased frequency of heavy rainfall events, floods and dry spells (Mahli et al. 2008; Marengo et al. 2009; Satyamurty et al. 2010). However, it has been argued that knowledge of climate change in Amazonia is geographically biased (e.g., Espinoza-Villar et al. 2009). Moreover, existing efforts to understand climate change in the region are crippled by the low degree of spatial coherence and certainty in climate data due to limited or low-quality climate records (Hijmans et al. 2005; Soria-Auza et al. 2010). For example, while the spatio-temporal patterns of precipitation and temperature have been well-documented in Brazilian Amazonia (e.g., Satyamurty et al. 2010), studies for the remaining 37% of the cross-national Basin are meagre. This is of concern for adaptation planning, particularly considering that most adaptation strategies are developed under the national level (Adger et al. 2005).

Bolivian Amazonia covers 12% of the Basin and hosts 31 native indigenous groups (Appendix II.a) whose resource-based livelihoods are increasingly threatened by climate change (e.g., Fernández-Llamazares et al. 2015a,b). Amongst these, we work with the Tsimane', an indigenous hunter-gatherer society mostly inhabiting a communal territory comprising ca. 400,000 ha of *terra firme* rainforests, known as Tsimane' Territory (Figure 2.1). The climate of the region is thermotropical, with a rainy season from November to March and a dry season from April to October with punctual cold spells from June to August, when polar winds from the South Pacific sweep through the area (Fernández-Llamazares et al. 2015a).

**Figure 2.1 |** Study area and villages surveyed.




## 2.2.2. Climatic data

Four climate variables were sourced from the TS3.22 gridded climate dataset (0.5° x 0.5°) available from the Climatic Research Unit (CRU), one of the most used databases in IPCC assessment reports and numerous scientific studies (Harris et al. 2009). These included: (a) monthly mean temperature; (b) monthly minimum temperature; (c) total monthly precipitation; and (d) number of rain days per month. The available data are interpolated from local weather station records and undergo several corrections. We gathered data for 1963–2012, a period chosen to approximate the temporal focus of indigenous observations (see Section 2.2.3). The same four climate variables, for the same period, were sourced from the local weather station of the Bolivian National Service of Meteorology and Hydrology (SENAHMI) in the town of San Borja.

We used a set of climate change metrics (Garcia et al. 2014) to describe changes in temperature and precipitation during the 50-year study period in each cell (at half-degree resolution) across Bolivian Amazonia using regional climate data and in the town of San Borja (Figure 2.1) using local station climate data. Metrics were selected that corresponded most closely to the questions in the interviews to the Tsimane' (see Section 2.2.3). All calculations were performed using the R programming language and environment version 3.01 (R 2010).

For comparison with local observations of changes in temperature and rainy season precipitation, we analysed the gradual trends in annual mean temperature and in mean intensity of precipitation in the rainy season (October to April). As an indication of changes in the length of dry season, we analysed the temporal trend in the total intensity of precipitation in the dry season (May to September). Changes in the frequency of cold spells were assessed based on the trend in the mean of the monthly minimum temperatures of the cold season (June to August). Changes in both the length of the dry season and the frequency of cold spells would ideally be analysed using daily precipitation and temperature, respectively, but such data were unavailable for Bolivian Amazonia. Temporal trends were estimated using the Theil-Sen slope implemented in the *openair* package in R (Carslaw and Ropkins 2012).

Quantifying the occurrence of droughts and floods would require data at finer temporal resolution and additional climatic and other abiotic parameters. Notwithstanding, with the data available we were able to assess changes in the frequency of extreme dry and wet conditions, which are seen as proxies for the occurrence of droughts and floods, respectively. We followed three steps to analyse changes in the probability of occurrence of extreme climates. First, we divided our study period into two 25-year segments, and identified, for a given cell, the extreme climatic values of the first segment (1963–1987) as the 5$^{th}$ or 95$^{th}$ percentiles of the distribution of climatic values for that cell during the first segment. Second, we calculated the percentile of the distribution of values during the second segment that corresponded to a given extreme value. This percentile was interpreted as the probability that such extremes were exceeded. Third, to assess changes in the frequency of extreme climates, we subtracted the probabilities in the first segment from those in the second segment: positive values indicated increased probability of extremes in the second segment. We applied this procedure to monthly total precipitation values to obtain an indication of the frequency of droughts (5$^{th}$ quantile) and floods (95$^{th}$ quantile).

### 2.2.3. Indigenous observations of climate change

During 15 months (September 2012 to November 2013) we collected individual-level data amongst the Tsimane' (Figure 2.1). These data included: (a) climate change observations; (b) Local Environmental Knowledge; and (c) socio-demographic and economic attributes. We obtained Free Prior and Informed Consent (FPIC) from villages and individuals participating in this study and the agreement of the political organisation representing the Tsimane'. In addition, this research adhered to the Code of Ethics of the International Society of Ethnobiology (ISE). The Ethics Committee of the Universitat Autònoma de Barcelona (UAB) approved the research (CEEAH-04102010; LEK Project 2014). Two datasets were used in this study. Dataset 1 includes panel data collected in two Tsimane' villages ($n$ = 99 adults, ≥ 16 years old) over the course of 18 months of fieldwork. Dataset 2 includes cross-sectional data collected in 13 Tsimane' villages ($n$ = 308; Figure 2.1) over the course of three months of fieldwork.

To capture consistency with scientific records, we conducted individual structured interviews (Dataset 1) about all changes observed since Decade Of Birth

(DOB; Fernández-Llamazares et al. 2015b) for six climate variables (temperature, precipitation in rainy season, length of dry conditions, frequency of cold spells, flood frequency and drought frequency; see Appendix II.b). Changes perceived were coded as increase, decrease or invariant. We then assessed the consistency of individual observations with scientific records by calculating the number of answers in which the individual observations of the six aforementioned variables were in agreement with the climatic trends calculated for the area, based on: (a) spatially interpolated climatic values from the CRU TS3.22 dataset; and (b) records from the local weather station in San Borja (see Section 2.2.2).

We also examined change blindness, or the failure to observe local indicators of climate change (that is, desensitisation to change; Simons and Rensink 2005; Fernández-Llamazares et al. 2015b). To do so, we conducted individual structured interviews (Dataset 2) about static *versus* dynamic observations of climate since DOB, in relation to four climate variables (temperature, precipitation, frequency of cold spells and flood frequency). Our index measures the number of times that the observation of each of the climate variables was static (that is, to what extent the individual was unable to observe local indicators of climate change).

Additionally, we constructed a composite measure of LEK related to hunting, medicinal plants and wild edibles, using data collected from three different methods for each domain (Reyes-García et al. 2015): an identification task, a self-reported skills questionnaire and peer ratings (Appendix II.c). For Dataset 2, the construction of the LEK index was performed with shorter questionnaires and only for two knowledge domains (medicinal plants and hunting; Appendix II.c). We explored the consistency of our scores by calculating the Cronbach's alpha coefficient for each domain (Reyes-García et al. 2015).

Controls in our models include sex, age, village of residence and fluency in the national language (Spanish). Additionally we created indices proxying education, integration into the market economy, and forest dependence for both datasets (the variables included in these indices are listed in Appendix II.c; Reyes-García et al. 2015).

### 2.2.4. Data analysis

We assessed the association between consistency of climate change observations and LEK by running: (a) a Poisson correlation; and (b) a Poisson multivariate regression with consistency as dependent variable and LEK as explanatory variable, a set of controls and clustering by village of residence. As the Variance Inflation Factor (VIF) values were smaller than 1.5, we dismissed the possibility of strong collinearity between LEK and other variables.

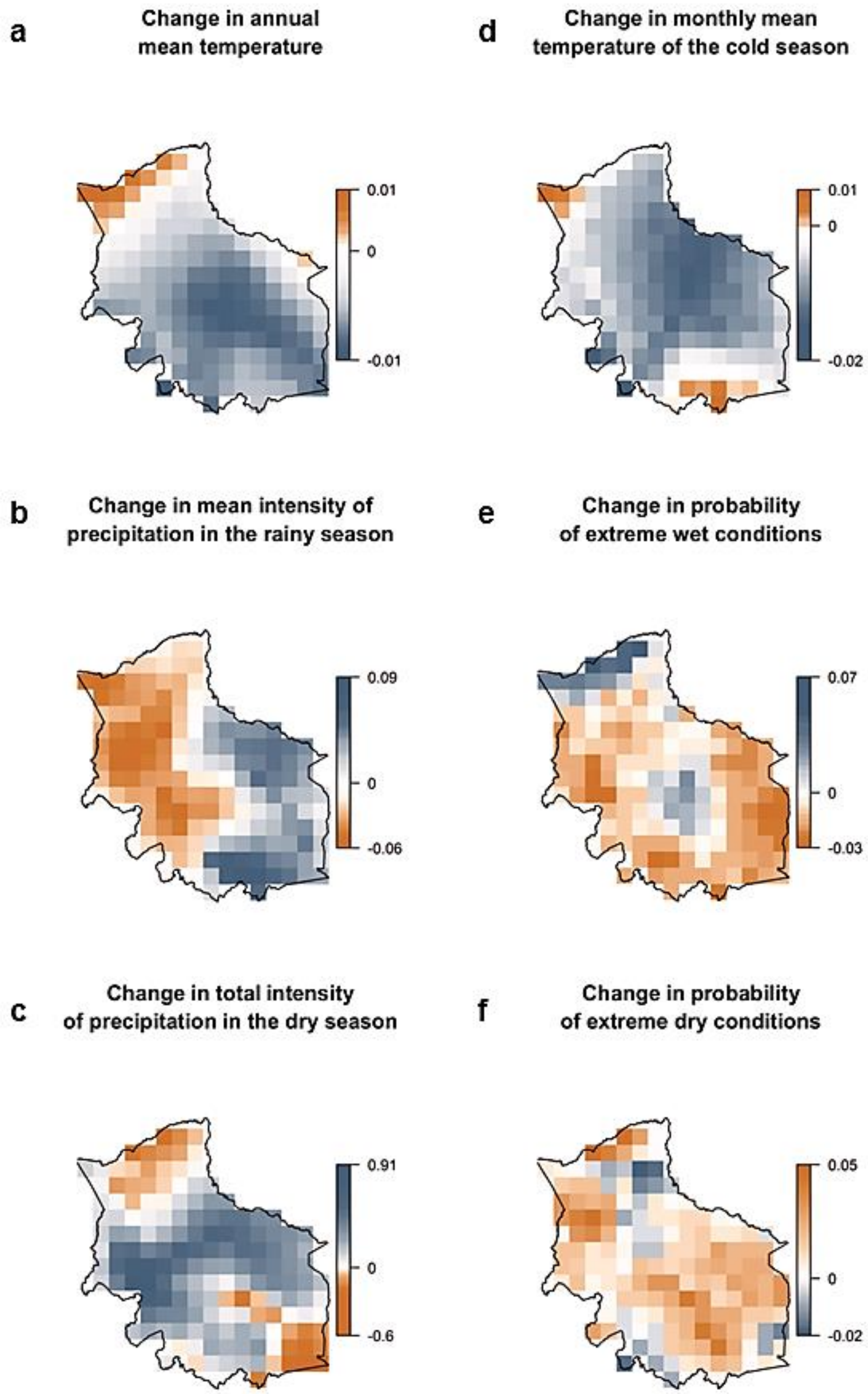
To assess trends in the association between change blindness and LEK, we performed a hierarchical cluster analysis classifying interviewees according to their scores in the variables measuring change blindness and LEK levels. We used the Ward's algorithm as agglomerative technique (see Appendix II.d). Then, we used Kruskal-Wallis and Chi-square tests to characterise the groups obtained with the hierarchical cluster analysis according to different socio-cultural and demographic variables. For all the statistical analyses we used Stata 12.1 (StataCorp 2011).

## 2.3. Results

### 2.3.1. Climate change in Bolivian Amazonia

Based on available climate coarse-resolution data from CRU, climatic trends for Bolivian Amazonia between 1963 and 2012 show extended variation across space and across multiple climate change metrics (Figure 2.2). Decreasing mean annual temperature trends (Figure 2.2a) and decreased monthly mean temperatures during the cold season (used as an indicator of frequency of cold spells, Figure 2.2d) seem to be the norm across the region. By contrast, precipitation trends in the rainy season show more pronounced spatial variation, with increasing trends in the southeast and decreasing trends in the

**Figure 2.2 |** Climatic changes in Bolivian Amazonia, 1963–2012.




Note: Theil-Sen slopes based on CRU data (Harris et al. 2009) illustrating the temporal trends in mean annual temperature (a), mean intensity of precipitation in the rainy season (b), total intensity of precipitation in the dry season (c), monthly mean temperature of the cold season (d) and changes in the probability of extreme monthly precipitation (95$^{th}$ and 5$^{th}$ quantiles, e and f). Positive values indicate increasing trends or probabilities of extremes; negative values indicate decreasing trends or probabilities of extremes. The scales were defined using quantiles and reflect a gradient from blue (changes towards cooler or wetter conditions) to orange (changes towards warmer or drier conditions). See Section 2.2.2 for details.

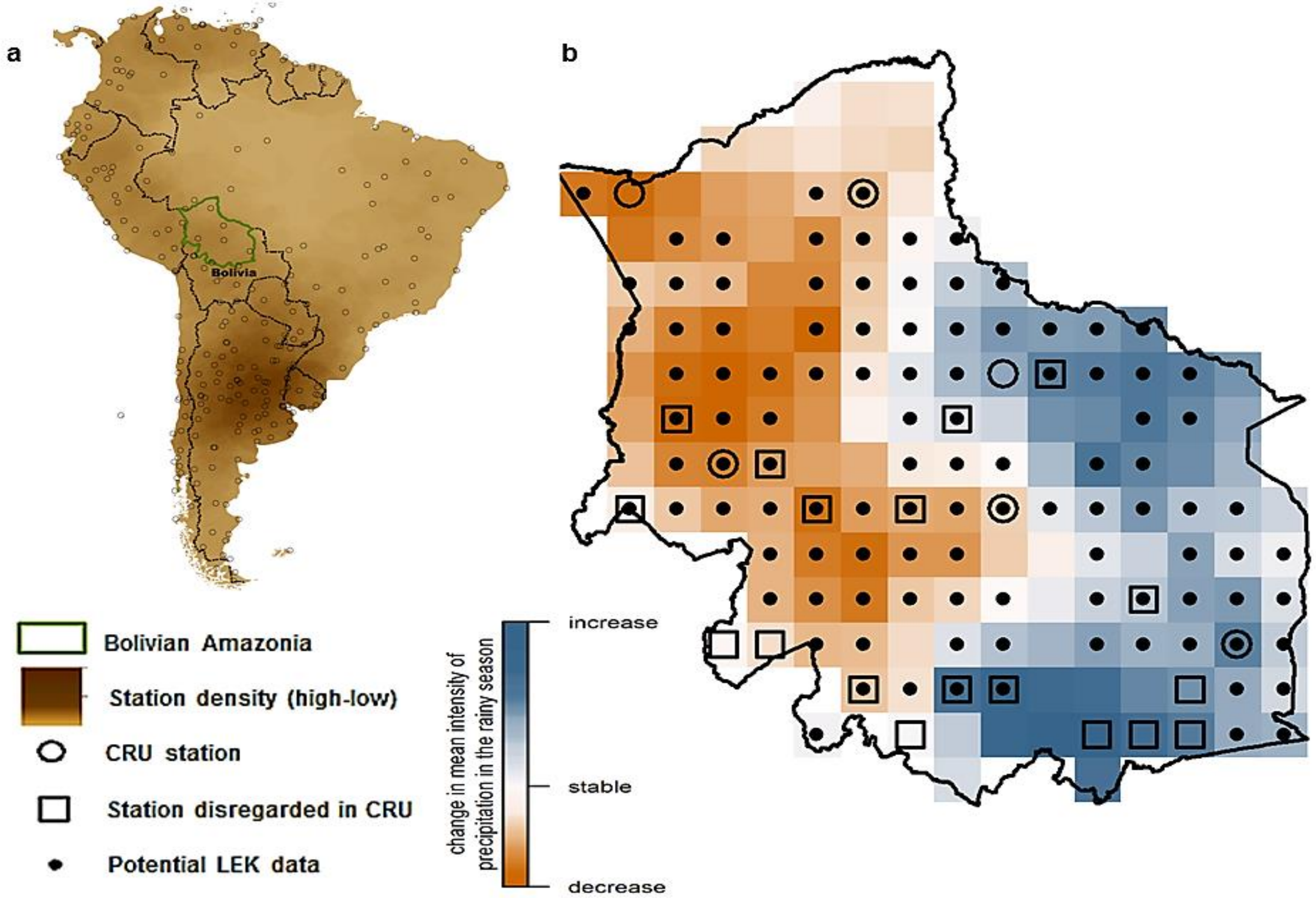
northwest (Figure 2.2b). As an indication of the potential occurrence of floods, extreme wet conditions become more frequent in the central and northwest areas (Figure 2.2e). At the same time, the frequency of extreme dry conditions, an indicator of the potential occurrence of droughts, shows a general increasing trend (Figure 2.2f), while the total intensity of precipitation in the dry season seems to be increasing in all the central part of Bolivian Amazonia (Fig 2.2c).

Notwithstanding the availability of coarse-resolution data, weather station density in Bolivian Amazonia is low (Appendix II.e) and the climate records gathered are often incomplete. The database from CRU relies on a mere six stations out of 39 existing within Bolivian Amazonia (Figure 2.3a-b). Although often capturing the general climatic trend (Muller et al. 2013), stations are disregarded by CRU due to poor-quality data, gaps in records, or incomplete coverage of the full period targeted (from 1961 onwards; Harris et al. 2009). Climate interpolations based on the selected six stations might thus not be able to capture all the regional heterogeneity. A case in point is the analysis of climatic trends for a cell in mid-Bolivian Amazonia that contains the local weather station of San Borja. For four out of the six climate change metrics, the trends estimated with CRU data for this cell are in clear contradiction with those calculated with data from the given weather station (Figure 2.4a-b).

## 2.3.2. Overlap between LEK and local scientific records

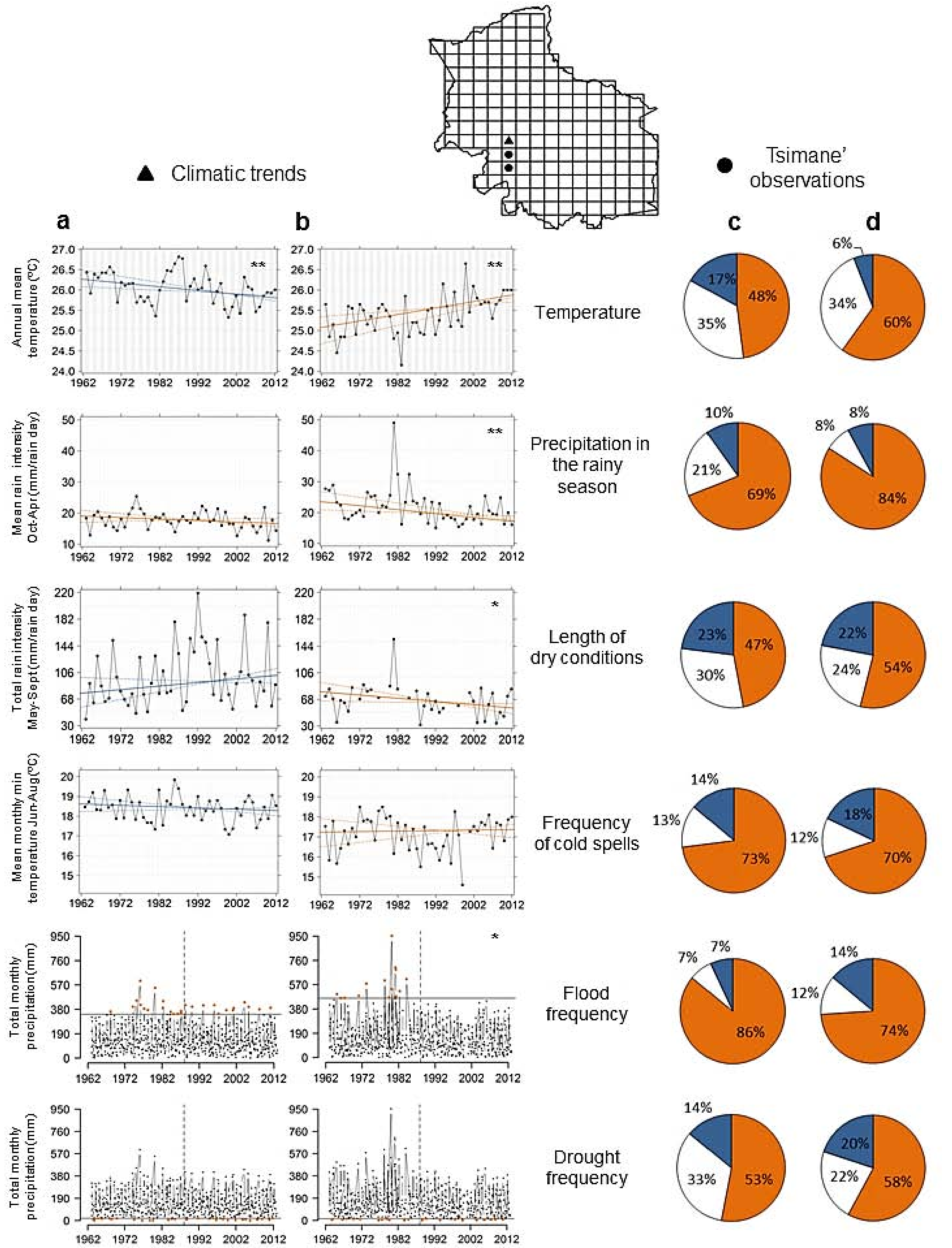
Based on interpolated data from the CRU at half-degree resolution (see Section 2.2.2), the climatic trends between 1963 and 2012 for the region enclosing the Tsimane' Territory show decreased mean temperatures and, remarkably, no significant changes in either the mean intensity of precipitation in the rainy season or the length of dry conditions (Figure 2.4a). Yet, these trends are inconsistent with those estimated from records from the local weather station of San Borja (Figure 2.4b), which reveal a steady increase in temperature, a pronounced

**Figure 2.3 |** Potential complementarity of climate data with indigenous knowledge in Bolivian Amazonia.




Note: (a) Kernel density analysis applied to the weather stations in Latin America used in the CRU dataset (Appendix II.e; Harris et al. 2009). (b) Comparison of the grid cells in Bolivian Amazonia containing source climate data (either from the 6 stations underpinning the CRU dataset or from the 33 stations disregarded, some of which overlap in the same grid cells) and grid cells inhabited by indigenous peoples (Appendix II.a). In cells inhabited by indigenous peoples, information issued from LEK systems could help assisting the downscaling process.

**Figure 2.4 |** Comparison of climate data with indigenous observations.



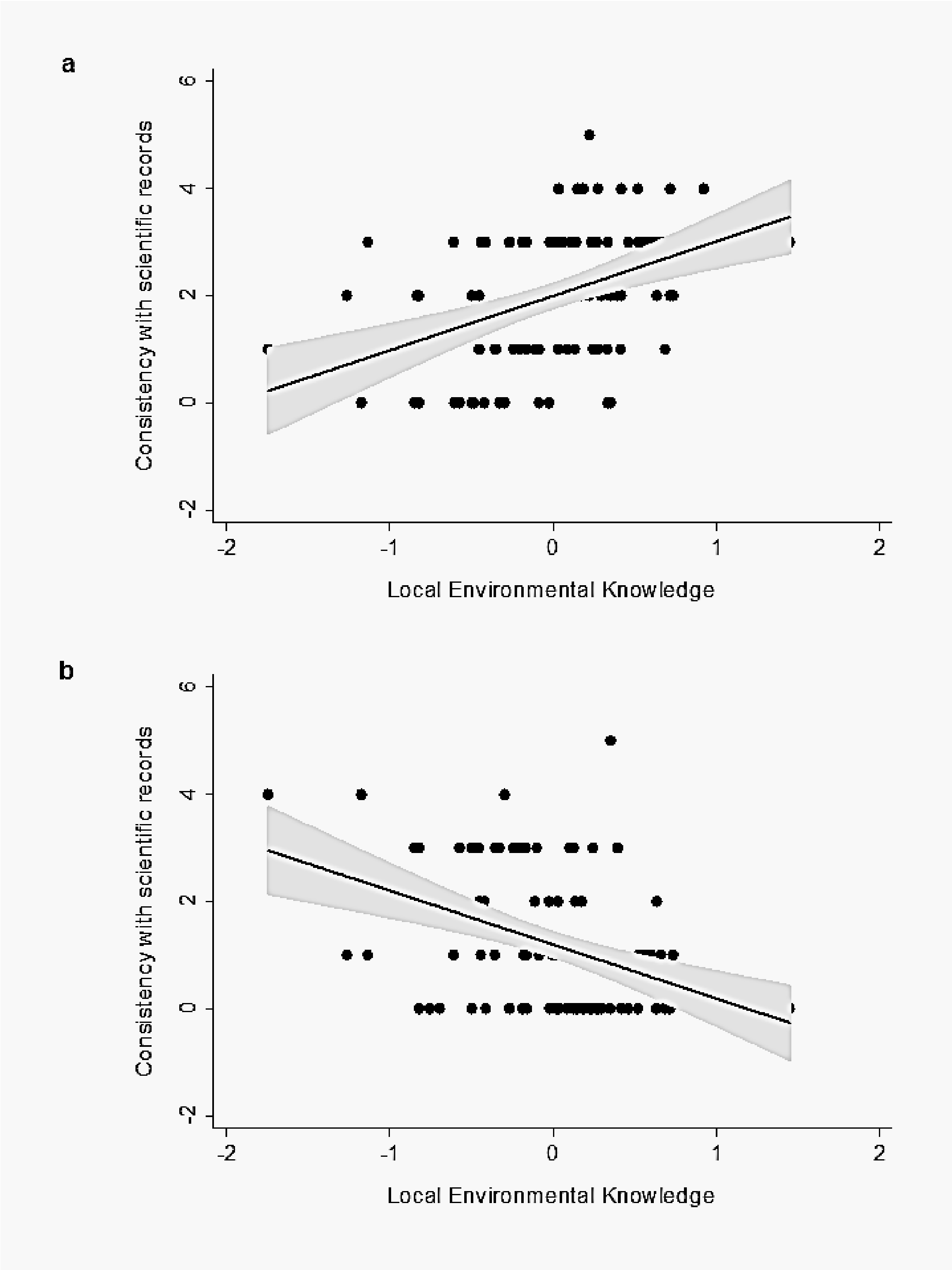

Note: For the grid cell containing the local station, climatic trends calculated with CRU data (a) or station records (b) are compared with Tsimane' observations (proportion of the entire sample ($n$ = 99, c) or LEK holders ($n$ = 50, d) reporting increase, decrease or invariance in climatic parameters). Solid and dashed lines in scatterplots correspond to slope and confidence intervals at 95% (first three rows) and to baseline extreme and middle year (remaining rows), respectively. Blue, orange and white denote changes towards cooler/wetter, warmer/drier, or invariant. * $p < 0.05$ and ** $p < 0.01$. See Appendices II.b, II.e, II.f and II.g for further details.

decrease in the mean intensity of precipitation in the rainy season, and an increase in the length of dry conditions for the same time period. In turn, most Tsimane' interviewed ($n$ = 99) report climate change during the last four decades (Figure 2.4c-d), including increased temperatures and overall drier conditions reflected in decreased precipitation and increased drought frequency (Figure 2.4c). The local observations for the subsample of people with high levels of LEK ($n$ = 50), including local experts, elders, and traditional healers (see Section 2.2.3), show an even higher group consensus on a decrease in precipitation, higher temperatures and a pronounced increase in the length of dry conditions, amongst other metrics (Figure 2.4d).

Tsimane' observations are thus in higher accordance with the scientific records from the local station (Figure 2.4b) than with the scientific records from the CRU dataset (Figure 2.4a). Bivariate analysis suggests a positive and statistically significant association between individual LEK scores and the degree to which individual climate change observations are consistent with climatic data from the local station. In other words, the higher an individual's LEK, the more accordance we find between her/his climate change observations and the climatic trends calculated for the local station (Figure 2.5a, $r$ = 0.537, $p$ = 0.000). By contrast, the association is negative when individual climate change observations are compared with trends calculated from the spatially interpolated climatic values (Figure 2.5b, $r$ = -0.757, $p$ = 0.000).

The positive association between an individual's LEK and the consistency of her/his climate change observations with the local climate data is corroborated in multivariate regression analysis controlling for potential covariates (age, sex, fluency in the national language, village of residency, education, integration into the market economy and forest dependency; Table 2.1a-d). Here too, the association becomes negative when the consistency is measured in relation to spatially interpolated values (Table 2.1e-h).

**Figure 2.5 |** Association between LEK and consistency of climate change observations with scientific records.




Note: The vertical axis represents the degree to which individual indigenous observations of climate change ($n$ = 99) are consistent with the scientific records of the local weather station (a) or with the spatially interpolated climatic values from CRU (b). The horizontal axis represents the level of LEK held by an individual. The line shows the fitted regression models. The grey area denotes the confidence intervals at 95%. See Section 2.2 for details on the construction of the variables.

**Table 2.1 |** Poisson regression assessing the association between LEK and the consistency of the indigenous observations of climate change with both local station climate data and spatially interpolated climatic values.

| | **Dependent Variable:** ***Consistency with scientific records*** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Local station climate data** | | | | **Spatially interpolated climatic values** | | | |
| | **Std. Model** | **Robustness Analysis** | | | **Std. Model** | **Robustness Analysis** | | |
| | **a** | **b** | **c** | **d** | **a** | **b** | **c** | **d** |
| **Explanatory** | | | | | | | | |
| LEK | 0.468 (0.032) ** | 0.386 (0.061) ** | 0.445 (0.072) ** | 0.464 (0.084) ** | -0.692 (0.187)** | -0.602 (0.094)** | -0.685 (0.129)** | -0.651 (0.108)** |
| **Control** | | | | | | | | |
| Age | 0.004 (0.004) | 0.001 (0.004) | 0.005 (0.005) | 0.005 (0.004) | -0.005 (0.011) | 0.003 (0.012) | -0.006 (0.013) | -0.008 (0.012) |
| Sex (*Male* = 1) | 0.106 (0.002)** | 0.202 (0.051)** | -0.022 (0.055) | 0.008 (0.025) | 0.242 (0.282) | -0.367 (0.192) | -0.025 (0.122) | 0.075 (0.130) |
| National language (*totally fluent omitted*) | | | | | | | | |
| *Not fluent* | 0.116 (0.073) | ---- | ---- | ---- | -0.853 (0.142)** | ---- | ---- | ---- |
| *Moderately fluent* | -0.074 (0.109) | ---- | ---- | ---- | -0.175 (0.020)** | ---- | ---- | ---- |
| Education | ----- | -0.203 (0.002)** | ---- | ---- | ----- | 0.363 (0.066)** | ---- | ---- |
| Integration into the market economy | ---- | ---- | 0.072 (0.026)** | ---- | ---- | ---- | -0.010 (0.104) | ---- |
| Forest dependence | ---- | ---- | ---- | 0.000 (0.000)** | ---- | ---- | ---- | -0.001 (0.000)** |
| ***n*** | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |

Note: The table reports the Poisson regression coefficients with robust standard errors in parentheses. a-d, Regressions testing consistency with climate data from the local weather station of San Borja. e-f, Regressions testing consistency with spatially interpolated climatic values. All regressions are clustered based on the village of residency of the informants. * $p < 0.05$ and ** $p < 0.01$. For definitions of variables see Appendix II.c.

A hierarchical cluster analysis to address change blindness (see Section 2.2.3) shows that people with higher LEK levels are more immune to change blindness than individuals with lower LEK levels (Table 2.2). To some extent, LEK seems to attenuate blindness to climate change, with people with higher LEK being comparatively more change-aware than people with lower LEK.

**Table 2.2 |** Characterisation of Tsimane' respondents resulting from the hierarchical cluster analysis.

| **Variables** | $\chi^2$ | $p$ | ***Change-aware*** | | ***Change-blind*** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | | | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** |
| Change blindness (average) | 183.933 | 0.000 | 0.44 | 0.03 | 2.26 | 0.06 | 0.85 | 0.05 |
| LEK (average) | 9.152 | 0.002 | 0.06 | 0.04 | -0.16 | 0.06 | 0.01 | 0.03 |
| Age (average) | 7.129 | 0.008 | 39.78 | 1.16 | 34.26 | 2.01 | 38.52 | 1.01 |
| Male (%) | 0.587 | 0.444 | 48.72 | 3.27 | 43.48 | 6.01 | 47.52 | 2.87 |
| National language (%) | | | | | | | | |
| *Not fluent* | 0.675 | 0.411 | 33.76 | 3.10 | 39.13 | 5.92 | 34.98 | 2.74 |
| *Moderately fluent* | 0.312 | 0.576 | 55.98 | 3.25 | 52.17 | 6.06 | 55.11 | 2.86 |
| *Totally fluent* | 0.145 | 0.703 | 10.26 | 1.99 | 8.70 | 3.42 | 9.90 | 1.72 |
| Education (average) | 2.190 | 0.139 | -0.02 | 0.07 | 0.05 | 0.08 | 0.00 | 0.06 |
| Integration into the market economy (average) | 0.017 | 0.895 | 0.04 | 0.07 | -0.12 | 0.44 | 0.00 | 0.06 |
| Forest dependence (average) | 1.325 | 0.250 | 51.39 | 15.28 | 22.19 | 7.20 | 44.73 | 11.92 |
| *n* | | | 238 | | 70 | | 308 | |

Note: For definitions of variables see Appendix II.c. For clustering distribution see Appendix II.d.

## 2.4. Discussion

Most efforts to reduce uncertainties in models assessing climate change have centred on improving modelling techniques and applying new mathematical processes (Kay et al. 2009). Yet, circumventing uncertainties rests also on improving climate data (Hijmans et al. 2005; Joseph et al. 2009). Significant, albeit insufficient, progress is being made to improve spatial coverage of climate data, with the launching of new weather observation sites and the development of high-resolution satellite-derived climate datasets (Joseph et al. 2009). Nonetheless, uncertainties prevail and the exploration of more data sources, including harnessing new disciplines and knowledge systems, is strongly encouraged to increase the precision and accuracy of current climate models, particularly in the tropics (Rosenzweig and Neofotis 2013).

The results of this work show both connection (Figure 2.5a) and discrepancy (Figure 2.5b) between scientific data and indigenous knowledge of climate change. On the one hand, we find dissonance between indigenous knowledge and spatially interpolated values, a measure widely used global scientific models. We argue that this discrepancy can be due to different spatial resolutions of the two bodies of data. Although some authors have previously made the same claim (Berkes et al. 2000; Gagnon and Berteaux 2009; Laborde et al. 2012), this is, to the best of our knowledge, the first work to empirically show this incongruence. On the other hand, our work is arguably also the first to empirically show a significant overlap between indigenous knowledge and scientific climate change records matched at the same spatial scale of observation (Figure 2.5a).

A finer analysis revealed, however, that not all indigenous observations of climate change are always well-suited to detect local climate change. Rather, the consistency of LEK with scientific records (both at local and regional level) is partly shaped by an individual's fluency in the national language, education, market integration and forest dependence (Table 1.1a-h). Although more research is needed to fully understand the effects of these complex and multi-faceted factors on climate change observations, we contend that they might be possibly linked to LEK erosion. Recent work amongst the Tsimane' has shown that due to age-related change in perceptions and decreasing intergenerational passing of knowledge, LEK is increasingly jeopardised (Reyes-García et al. 2013; Fernández-Llamazares et al. 2015b). Consequently, change blindness, might be on the rise, potentially distorting local people's observations of climate change and thus undermining their reliability (Smith 2011; Fernández-Llamazares et al. 2015b).

Based on our results for Bolivian Amazonia, we advocate that indigenous knowledge is well-suited to fill gaps in instrumental records of climate change, for areas where climate data are meagre at best (Figure 2.3b). Nevertheless, we also recommend caution when considering indigenous observations of climate change, since not all observations are well-suited to contribute to climate research. Filtering indigenous observations of climate change based on individual LEK levels is thus advisable. There are several possible tools to minimise sources of error when documenting indigenous knowledge. These include careful selection of participants (Davis et al. 2003), peer evaluation for a rapid assessment of individual LEK levels (Reyes-García et al. 2015), or community verification of data (Gagnon and Berteaux 2009). Such measures, though not infallible, ensure a standard of credibility and validation of the information collected. Additionally, the careful development of interview questions so as to match the metrics of climate change under analysis (Figure 2.4) constitutes a first step towards the development of a more systematic and critical analysis of indigenous knowledge of a changing climate.

If regional interpolations were complemented with information on local climate change trends as observed by LEK holders, a greater proportion of local climate peculiarities, idiosyncrasies and anomalies could be captured in the generalised models with interpolated gridded data. Indigenous observations can provide information with higher resolution that can be used to assist in the downscaling of global models. Specific outcomes of practical and direct application (for example, production of geo-referenced datasets of LEK-based climate change observations; Figure 2.3b) could be useful for the systematic ground-truthing of spatially interpolated climate values, thus making climate change impact assessments and adaptation plans more robust at the local scale (Barnes et al. 2013; Niang et al. 2014). Yet, it is essential that such products take into account the social, situated and dynamic nature of LEK (Berkes et al. 2000).

Attempts to portray a precise and measured picture of climate change within an acceptable range of evidence and agreement should consider indigenous observations of climate change as a valuable proxy for monitoring the accuracy of current climate models, narrowing their geographic uncertainty and assisting the downscaling process. Indigenous knowledge, through cumulative experience and oral history, can also complement time-series of climate data to piece together regional climate history and provide more close-up diachronic information on climate baselines. However, more empirical work is needed to address the impediments of matching observations with station records at the same spatial resolution, but probably different temporal resolution (Whipple 2008).

## 2.5. Concluding remarks

The results of this work reveal a significant association between indigenous observations of climate change and scientific records at the local scale in Bolivian Amazonia. As additional empirical tests of overlap in other geographical areas become available to the scientific community, as well as innovative ways to address uncertainty in indigenous observations (Smith 2011), the gaps between scientific inquiry and indigenous knowledge systems might gradually become bridged. In our opinion, such converging evidence challenges the dichotomisation between indigenous and scientific knowledge that, in confining them to discrete categories, pits the one against the other.

We contend that future climate research will substantially benefit from new partnerships and collaborations with indigenous peoples to capture local indicators of climate change in some of the world's most data-deficient regions. Yet, such efforts bring to the fore issues about intellectual property and control over information (Couzin 2007). In this context, the formulation of protocols and guidelines for a diligent and respectful use of indigenous knowledge for scientific endeavours remains a critical step (Huntington 2011). In addition, examining the ways in which discrepancy between and uncertainty within different knowledge systems can be addressed in such a collaborative research framework is an important avenue for further climate research (Whipple 2008; Klein et al. 2014). Indigenous peoples, as close observers of local climatic changes, could for instance engage with research projects and consortia to address knowledge gaps identified in IPCC scoping or in assessments of local climatic impacts.

Nonetheless, if such aspirations are to be reflected in practice, there is an urgent need to formulate strategic plans to document indigenous knowledge before it vanishes (e.g., Cámara-Leret 2014). Due to the cultural changes brought by globalisation, LEK is suffering worldwide decline at alarming rates (Maffi 2005; Reyes-García et al. 2013). Hence, exploring the promising new frontiers opened by indigenous knowledge is a pressing task in the climate research agenda for the forthcoming years. While specific to Bolivian Amazonia, our results are likely to be relevant at the global scale, given that the regions in the world with the lowest density of weather stations (see Appendix II.e) are generally inhabited by indigenous peoples with rich, detailed and, in many cases, threatened LEK systems (Maffi 2005).

## Acknowledgements

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# Chapter III

## Links between media communication and local perceptions of climate change in an indigenous society


### Abstract

Indigenous societies hold a great deal of ethnoclimatological knowledge that could potentially be of key importance for both climate change science and local adaptation; yet, we lack studies examining how such knowledge might be shaped by media communication. This study systematically investigates the interplay between local observations of climate change and the reception of media information amongst the Tsimane', an indigenous society of Bolivian Amazonia where the scientific discourse of anthropogenic climate change has barely reached. Specifically, we conducted a Randomised Evaluation with a sample of 424 household heads in 12 villages to test to what degree local accounts of climate change are influenced by externally influenced awareness. We randomly assigned villages to a treatment and control group, conducted workshops on climate change with villages in the treatment group, and evaluated the effects of information dissemination on individual climate change perceptions. Results of this work suggest that providing climate change information through participatory workshops does not noticeably influence individual perceptions of climate change. Such findings stress the challenges involved in translating between local and scientific framings of climate change, and gives cause for concern about how to integrate indigenous peoples and local knowledge with global climate change policy debates.



**Keywords:** climate change communication; climate change perceptions; ethnoclimatology; experiments in social sciences; indigenous peoples; local knowledge.


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## 3.1. Introduction

*'The temperatures are rising, because the Government is selling the wind'*

Tsimane' elder, Bolivian Amazonia

Indigenous and rural societies have developed first-hand, unique, and complex systems of empirical knowledge about climate variability and strategies for responding to it (Moran et al. 2006; Stigter et al. 2006). Such knowledge is of great importance in the planning of livelihood activities such as hunting, planting or harvesting (Orlove et al. 2000; Godoy et al. 2009) and may situate indigenous and rural peoples as potential allies in our quest to better understand anthropogenic climate change and its effects at local and regional scales (Salick and Ross 2009; Cochran et al. 2013). However, because the trends of climatic variability may be beyond the threshold of human perception over the course of a lifetime –at least without instrumental records (Spence et al. 2011; Weber 2013)–, indigenous peoples might not necessarily be aware of current climatic change.

Indeed, there are two predominant schools of thought with regard to the human perceptibility of climate change. On the one side, the *invisibilists* assume climatic change to be undetectable to the lay observer and invisible to the naked eye (Doyle 2009; Swim et al. 2009). They argue that local understandings of climate change are the product of the dissemination of climatic information via scientific, technical or institutional networks (e.g., through mass media or workshops) rather than based on actual observations (Mormont and Dasnoy 1995). In contrast, the *visibilists* claim that the effects of anthropogenic climate change are visible and have already been reported by local people worldwide (Riedlinger and Berkes 2001; Green et al. 2010). For these scholars, climate change can be tracked based on personal experience (Howe and Leiserowitz 2013; Weber et al. 2013). Meanwhile, a third school of thought is emerging with the argument that local reports of climate change reflect a combination of both observation and reception of climate information (Rudiak-Gould 2013). This third claim, coined *constructive visibilism*, assumes climate change not to be inherently visible or invisible, but made visible through its tangible features and/or external knowledge of it (Marin and Berkes 2012).

Research addressing this debate has been mostly conducted using data of a non-experimental nature (e.g., Leduc 2007; Green et al. 2010); furthermore, as pointed out by Rudiak-Gould (2014), to date, most local reports of climate change have been predominantly qualitative. To provide a complementary view to further our understanding of how climate change perceptions are constructed and reappraised, in this work, we set an experimental design. Analysing to what extent climate information reported by local people is based on their direct experience of the environment, *versus* the adoption of a discourse framed by scientific and media accounts, is of relevance for scientists using local knowledge to understand climate change at the local scale (e.g., Green and Raygorodetsky 2010).

The work presented here seeks to systematically investigate the confluence of climate change observation and reception amongst the Tsimane', a highly autarkic society of foragers-farmers in Bolivian Amazonia where the scientific discourse on anthropogenic climate change has barely reached. Specifically, this work has two objectives. First, we extensively document Tsimane' ethnoclimatological knowledge, with a focus on climate change perceptions. Second, we study the possible effects of media communication on such knowledge by conducting a controlled experiment to assess changes in Tsimane' climate change perceptions before and after participating in a workshop on climate change. With up to 65% of the Tsimane' being monolingual in their own language (Godoy et al. 2007) and with very limited –if any– access to mass media, externally-sourced information on anthropogenic climate change is almost completely absent. This sets an ideal test-case scenario to examine if information dissemination is likely to transform local understandings of climate change as a reproduction of science popularised through the media. The setup of the experiment allowed for testing to what degree the Tsimane' local accounts of climate change are influenced by externally built awareness around it, or –rather– are purely a result of local observations.

## 3.2. Materials and Methods

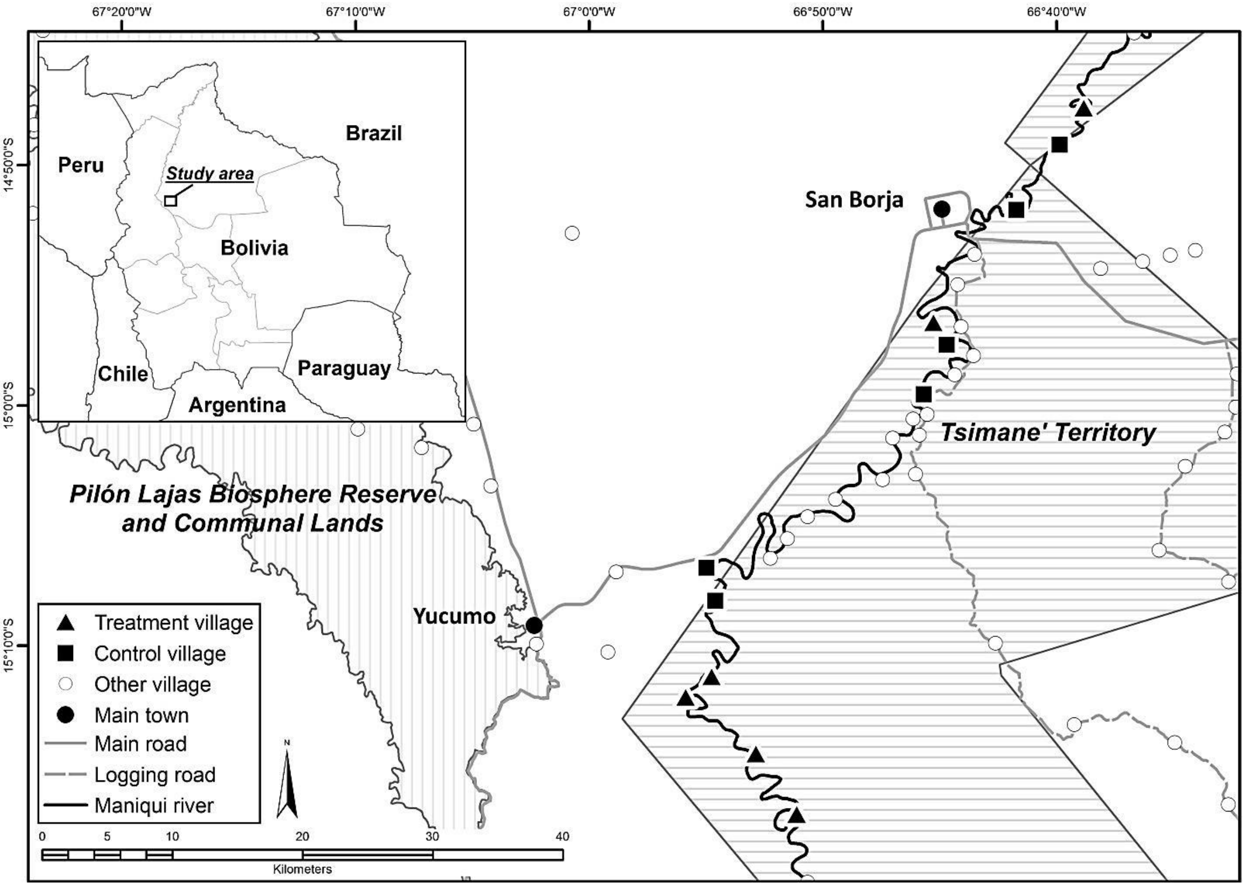
### 3.2.1. Case study

Scientific evidence documents the effects of anthropogenic climate change in Bolivian Amazonia. Several studies report an increase in the mean temperatures in the region of more than 0.08°C per decade from 1900 to 2001 (Mahli and Wrigth 2004; Seiler 2009) and decreases in the average annual rainfall (Kamiguchi et al. 2006; Wenhong et al. 2008). The latter are argued to be related to the *El Niño Southern Oscillation* (ENSO), which in turn could be responsible for increased frequencies of extreme events and increased cold season duration and strength (Ronchail 2005). The frequency of floods has also risen in several rivers of Bolivian Amazonia, with the whole area being increasingly vulnerable to flood risk (Quiroga et al. 2009).

These climatic impacts are believed to be a direct threat to local societies, particularly to native indigenous groups that rely directly on natural resources for their livelihoods (Nordgren 2011). Bolivian Amazonia hosts a large number of indigenous groups (INE 2012), amongst which we study the Tsimane', a society inhabiting a large territory in the southwestern Department of Beni. Predominantly hunter-gatherers, the Tsimane' also practise small-scale slash-and-burn agriculture. In this study, we worked only with villages within the Tsimane' Territory (*Tierra Comunitaria de Origen, TCO, Territorio Tsimane'*), a communal land comprising ca. 400,000 hectares (Figure 3.1). The climate of the region is thermotropical with rains from October to April and a cold season from June to August, when polar winds from the South Pacific sweep through the area (Ronchail 1989). Most of the territory is covered with *terra firme* rainforest (Guèze et al. 2014).

The Tsimane' political organisation, *Gran Consejo Tsimane'* (Great Tsimane' Council), gave its informed agreement to this research. The project was especially welcomed as it matched the aims of the *Initiative of Communication for the Sustainable Development of Bolivia*, promoting the application of communication strategies for climate change adaptation (ICDS 2008). We obtained Free Prior and Informed Consent (FPIC) from each village and individual participating in the study. Research adhered to the Code of Ethics of the International Society of Ethnobiology (ISE).

**Figure 3.1 |** Study area and villages surveyed.




## 3.2.2. Contextual ethnographic information

Accurate weather forecasting has long been important for the Tsimane' in order to better plan their subsistence activities. Indeed, daily weather forecasting has been shown to inform Tsimane' use of time (Godoy et al. 2009). For instance, rainfall seems to discourage hunting and fishing, due to its undermining effect on productivity. As such, accurate prediction of rainfall might increase the likelihood of successful hunting, fishing and wild plants gathering. Weather forecasting also serves a purpose in relation to agricultural activities: without irrigation systems, the Tsimane' are highly dependent on rainfall to produce crops.

Despite the number of works studying different domains of the Tsimane' Local Environmental Knowledge such as ethnobotany (e.g., Reyes-García et al. 2003; Guèze et al. 2014), accounts of their ethnoclimatological knowledge are rare. Godoy et al. (2009) provided the first and to date only descriptive account of the ethnoclimatological knowledge held by the Tsimane' assessing their ability to predict rainfall in relation to their livelihood strategies. However, records provided in this work were only partial and incomplete.

To fill these gaps and in order to thoroughly document Tsimane' ethnoclimatological knowledge, we conducted semi-structured interviews with 25 key informants (11 men and 14 women) of different ages (*min* = 17 and *max* = 91) in six villages. In each interview, we asked informants to explain how they forecasted weather and to describe the precise bio-temporal signals they used. We also asked them to describe any recent changes in the weather that render it difficult to predict. The interviews lasted 20 to 40 minutes each, during which we took detailed field notes. We used the responses given to inform the research design and to contextualise our results (see subsequent sections).

### 3.2.3. Research design

We used a Randomised Evaluation to assess the effects of information dissemination on the climate change perceptions of the Tsimane'. Randomised Evaluation is an experimental approach for evaluating the impact of an intervention (Duflo 2003). In our case, we aimed to assess the impact of disseminating information (through workshops) on the climate change perceptions of the Tsimane'. Several works have stressed that the individual climate change perceptions are sensitive to features of the judgement context at the moment of elicitation, such as transient local temperatures (Weber 2013; Zaval et al. 2014). In such a context, empirical studies with a randomised experimental design, such as ours, are less likely to be biased (Duflo 2003).

The sample consisted of 424 people in 12 villages in the Tsimane' Territory (Figure 3.1) other than the ones where we collected ethnoclimatological data. Villages participating in the study were assigned to two groups: treatment ($n$ = 6) and control ($n$ = 6). First, we conducted a baseline (or pre-intervention) survey (Table 3.1) between July and December 2008. The survey included questions on individual perceptions of climate change since childhood (see Section 3.2.4). After the baseline survey, we conducted a set of workshops providing information on anthropogenic climate change (i.e., intervention). The workshops took place in the six treatment villages only, between May-June 2009. Following the workshops, between April-September 2009, we conducted a post-intervention survey with identical questions to those in the baseline survey for all 12 villages, both control and treatment. For the sake of equity, following the post-intervention survey we conducted the same set of workshops in the six villages previously assigned to the control group (i.e., follow-ups). Thus, at the close of the project, we had conducted the workshops in all participant villages.

### 3.2.4. Pre- and post- intervention survey

We administered identical pre- and post-intervention surveys to 424 household heads (229 women and 195 men). We asked respondents to report if they had perceived changes in five specific climatic phenomena: rainfall, temperature, flood frequency, cold season duration, and cold season strength (Table 3.1). These phenomena were selected based on their saliency and cultural relevance, as well as on their higher probability of manifesting notable changes in the region due to anthropogenic climate change (Fernández-Llamazares et al. 2014). In all the surveys, we asked about changes that have occurred since the informant's childhood (i.e., Decade Of Birth, DOB). For each phenomenon, we coded responses categorically (*1* if the informants perceived an increase; *0* if they perceived no change; and -*1* if they perceived a decrease).

**Table 3.1 |** Research Design and summary statistics of variables.

| **A. Outcome variables** | **Description** | Frequency table | | |
|---|---|---|---|---|
| | | Decrease | Same | Increase |
| Rainfall | Reported change in rainfall | 50% | 42% | 8% |
| Temperature | Reported change in temperature | 20% | 45% | 35% |
| Flood frequency | Reported change in flood frequency | 59% | 27% | 14% |
| Cold season duration | Reported change in the cold season duration | 42% | 43% | 15% |
| Cold season strength | Reported change in the cold season strength | 45% | 40% | 15% |

| **B. Other variables of interest** | **Description** | Descriptive statistics | | | |
|---|---|---|---|---|---|
| | | Mean | SD | *min* | *max* |
| Age | Age of the interviewee | 36.98 | 16.17 | 16 | 85 |
| Sex | Sex of the interviewee | 195 men (46%)<br>229 women (54%) | | | |
| Village | Village where the interviewee lives | | | | |
| Treatment | Treatment group (*0* = Control; *1* = Treatment) | | | | |
| After | Interviewed before (*0*) or after (*1*) the intervention | | | | |

| **C. Schedule** | **Date** |
|---|---|
| Baseline Survey | July – December 2008 |
| Intervention: *workshops in treatment villages* | May – June 2009 |
| Post-intervention Survey | |
| In *control* villages | April – June 2009 |
| In *treatment* villages | July – September 2009 |
| Follow-up: *workshops in control villages* | September – November 2009 |

| **D. Sample size** | **Control** | **Treatment** |
|---|---|---|
| Villages (*N* = 12 total) | 6 | 6 |
| Individuals (*n* = 424 total) | 350 | 74 |

Note: For all the outcome variables: *-1* = decrease; *0* = same; *1* = increase. All information refers to changes since the age of childhood (i.e., Decade of Birth, DOB).

## 3.2.5. The intervention: workshops on climate change

The intervention consisted of a village workshop on climate change carried out initially only in the six treatment villages. The workshops provided up-to-date information on climate change and were both designed and led by a team composed of a researcher and a Tsimane' technician, who also served as translator. The workshops were first pilot-tested in a Tsimane' village not participating in this study. The team rehearsed the delivery of the workshop to ensure that the same message was consistently conveyed. Attendance to the workshops was free, informed and voluntary.

Climate change communication research identifies three steps when shaping climate change communications: *framing*, *targeting* and *tailoring* (see Bostrom et al. 2013 for definitions). The communication strategy employed here included framing and targeting, but not tailoring. We framed climate change as in the media (e.g., explaining the global and anthropogenic dimensions of the phenomenon) and we targeted the Tsimane' with the aim of reaching them directly with pertinent, salient and understandable messages. However, to emulate the media coverage of the topic, the information provided was not tailored to the Tsimane' cultural context, i.e., we did not link the information provided to their cultural values, local knowledge or belief system. While the contents of the intervention were conceived to emulate the mass media, the communication channel (i.e., workshops) was designed to mimic communication strategies launched by government agencies and NGOs in developing nations, often involving workshops (ICDS 2008; Wall et al. 2008; Godfrey et al. 2010). In this sense, the communication channel consisted on a single one-off intervention in each village, based on *in vivo* communication without relying on local understandings of the concept (Nisbet 2009).

The workshops involved three stages (see Appendix III.a): (a) introduction; (b) definition of key concepts; and (c) technical information on the topic of climate change. The two first stages were devoted to discussing the importance of weather forecasting and to facilitate participation (see Chambers 2002 for more details). They also enabled us to collect contextual information for use in interpreting the results. The third stage consisted entirely of presenting up-to-date information on climate change as framed by the media.

The presentation of the climate change information was interactive (with the aid of simple games and discussions; see Appendix III.a for details on the workshop contents). The explanation of anthropogenic climate change as communicated through the media was done with the aid of different graphs and images obtained from mass communication media (e.g., Gore 2006). These were shown to the audience and presented in a popular language and style. After providing some insights into the notion of global warming as an anthropogenic phenomenon, we focused on the climatic changes reported in the area. In accordance with the scientific evidence of climate change in Bolivian Amazonia, the information provided for the five selected variables being assessed specified the following: (a) decreased rainfall; (b) increased temperatures; (c) increased flood frequency; (d) increased cold season duration; and (e) increased cold season strength. Each workshop lasted on average three hours. All in all, 74 people (40 men and 34 women; 17.5% of the total sample) in the six treatment villages attended the workshops.

### 3.2.6. Data analysis

To analyse the effect of the intervention, we created a binary variable called *agreement* that captured whether the individual perception of the informant matched the information presented in the workshop (coded as *1*) or not (coded as *0*). With this variable, we analysed the effect of information dissemination on climate change perceptions using bivariate and multivariate statistics, taking the individual –not the village– as the unit of analysis (see Appendix III.b for the validation of the method).

The bivariate analysis was used for obtaining preliminary estimates of the magnitude of effect of the intervention. We also ran difference-in-difference estimations using multivariate techniques. The difference-in-difference estimation consisted of a set of logistic (i.e., *logit*) regressions of our outcome variables (one at a time) against: (a) a dummy for treatment [*1* = treatment; *0* = control]; (b) a dummy for the time of the survey [*1* = after intervention; *0* = before the intervention]; and (c) an interaction term [treatment*after]. The estimations were used to test the statistical significance of the trends observed. Even though the experimental design did not require the incorporation of any control (due to the randomisation), we decided to include villages of residency to control for geographical biases. We ran the regressions using robust standard errors with clustering by village and also controlling for village of residency (with a set of dummy variables). Statistical analyses were performed with Stata 12.1 (StataCorp 2011).

## 3.3. Results

### 3.3.1. Tsimane' ethnoclimatological knowledge

The Tsimane' reported to rely on up to 43 converging biotemporal signals, defined as determining events upon which people have acquired capacity to anticipate climate fluctuations and to make short-term decisions on time investment (Appendix III.c). The Tsimane' rely on such signals –be they visual (67%), auditory (30%) or tactile (3%)– to organise their livelihood activities through the year. Various sources of biotemporal signals relevant to weather prediction were also reported, mainly phyto-indicators (44%), zoo-indicators (42%), atmospheric indicators (7%), and astronomical indicators (7%). In concordance with Godoy et al. (2009), we found that about half (54%) of the *rule-of-thumb* methods that the Tsimane' use to forecast weather are for the short-term, i.e., from one to three days into the future. In addition, certain bio-indicators (9%) are used to predict long-term weather oscillations (e.g., interannual weather variation) while others (37%) are used for the medium-term (e.g., seasonal variation; delays in season onset). Up to ca. 26% of the indicators reported by the Tsimane' have also been reported by other indigenous groups, both in Amazonia and in the Andean highlands (Appendix III.c).

### 3.3.2. Tsimane' perceptions of climate change

Results from the semi-structured interviews indicate that the Tsimane' perceive a number of different changes in the climate. Many Tsimane' expressed concern over the climate trends in the area and their potential impacts on their livelihoods. One local informant stated that '*Streams are drying; even the trees die because of the drought. We will lose our harvests.*' In fact, we found that the reduction in rainfall is perceived by the Tsimane' as the biggest challenge for their livelihoods, since hunting, gathering and farming are crucially dependent on it. That said, not all the Tsimane' perceive drought as negative. As one Tsimane' woman reported: '*Now we live much better, because there are almost no floods. Long ago, we had to climb over the rooftops of our house not to drown.*'

Irrespective of whether change is viewed as positive or negative, the most commonly held perception seems to be that weather patterns are changing and that accurate weather forecasting is getting harder. As one local elder from one of the villages said, '*Times are changing. Now it is much more difficult to know when the rainy season will start.*' In general, the Tsimane' do not necessarily attribute these changes to a global-scale anthropogenic phenomenon, although they recognise different human-induced dimensions of it. For instance, local peoples tend to link the recent increases in temperature with deforestation, as illustrated in some of their statements: '*Trees retain the water and cool the forest*' or '*There are less trees, and therefore less shadows; that is why it is warmer now.*' Moreover, interpretations anchored in the cultural belief system, such as anger by the spirits for '*felling too many trees*', also seem to be very common.

Table 3.1 contains summary statistics for the weather variables measured before the intervention. Although there is considerable variation amongst individual perceptions, overall, the Tsimane' consider that: (a) rainfall has decreased; (b) temperatures have slightly increased; (c) flood frequency has decreased; (d) the cold season duration has shortened; and (e) the cold season strength has remained unchanged. The perceptions reported by the Tsimane' did not always match the changes documented in the available scientific literature. For instance, while local perceptions of temperature and rainfall aligned with reported scientific evidence, mismatches were found for flood frequency, cold season duration and cold season strength, which, in contrast to local perceptions, appear to have been increasing in the last 30 years. Furthermore, during the workshops, many informants showed scepticism and incredulity towards some of the scientific data presented, particularly for information at odds with local perceptions.

### 3.3.3. Difference-in-difference multivariate estimates

Table 3.2 presents the results of the difference-in-difference multivariate estimate of the effect of the intervention on the climate change perceptions of the workshop attendees (see Appendix III.d for the results of the bivariate analysis). Cells show the coefficient for the interaction term (treatment*after), which captures whether the intervention (i.e., the workshop) has an effect on the individual perception of change in the outcome variables. We first conducted the analysis without accounting for village differences (Table 3.2a). To test the robustness of our findings, we then repeated our analysis with the inclusion of a set of village dummy variables (Table 3.2b).

**Table 3.2 |** Difference-in-Difference multivariate estimates: Effects of intervention on outcome variables (*n* = 848).

| **Outcome Variable** | **Robustness** | |
|---|---|---|
| | **a** | **b** |
| Rainfall | -0.185 (±0.371) | -0.273 (±0.454) |
| Temperature | 0.431 (±0.390) | 0.523 (±0.648) |
| Flood frequency | -0.691 (±0.622) | -0.106 (±0.466) |
| Cold season duration | -1.022 (±0.559) | -1.142 (±0.501)* |
| Cold season strength | -0.308 (±0.462) | -0.353 (±0.536) |

Note: Outcome variables (previously transformed into *agreement* measures, see Section 3.2.6) logistically regressed against *treatment* and *after* binary dummy variables, and interaction of treatment*after. Coefficient reported (Standard Error in parenthesis) refers to the difference-in-difference coefficient (treatment*after). *Treatment* = 1 if the person received treatment; *treatment* = 0 if the person was control. *After* = 1 if *year* = 2009 (after intervention); *after* = 0 if *year* = 2008 (before intervention). (a) Raw model. Controls for (b) A full set of village dummy variables. * $p < 0.05$ and ** $p < 0.01$. See Table 3.1 for definition of variables.

The most important finding is that the intervention had no significant effect on perceptions of change. After the workshop, the response of the interaction variable (treatment*after) with the outcome variables amongst respondents who had and had not attended the workshop was not significant for any of the climate variables measured ($p > 0.05$). This indicates that the perceptions of change do not vary significantly with increased externally-obtained scientific information. With the exception of cold season duration (for which a slightly significant effect was found when controlling for a set of village dummies; $p < 0.05$), our robustness analysis suggests consistency in the main finding, as the results found in the core model (Table 3.2a) were reproduced in several robustness tests (Table 3.2b).

## 3.4. Discussion

We structure the discussion around the main findings related to our two objectives: (a) reporting Tsimane' ethnoclimatological knowledge; and (b) testing the effects of media communication on such knowledge.

### 3.4.1. Ethnographic insights on climate change observation

Results from the ethnographic phase suggest that the Tsimane' have a long tradition of close monitoring of climatic conditions, probably because such knowledge helps them in planning their subsistence activities (in concordance with Godoy et al. 2009). The Tsimane' hold a great deal of ethnoclimatological knowledge that: (a) has both qualitative and quantitative features: some indicators are only descriptive (e.g., the fructification of a tree signals the end of the rainy season), while others are quantitatively measured (e.g., the altitude of a particular bird species flying over the river indicates the height of an upcoming flood); and (b) provides an integrative and holistic forecast: bio-temporal signals are interpreted jointly, suggesting an interlinkage and convergence of different indicators, and framed in their traditional belief system. These results refute some previous assumptions underrating local reports of climate change as compromised or unreliable. The fact that individuals completely unaware of the scientific notion of climate change can nonetheless report change consistent with it –at least some of the time– has deep theoretical implications and calls for additional research to understand this further.

### 3.4.2. Effects of information dissemination on climate change perceptions

To our knowledge, this work is the first to empirically assess the effects of information dissemination on the climate change perceptions of an indigenous society. Our results suggest that providing climate change information to individuals, through a one-off workshop, does not noticeably influence their perceptions of climate change. Thus, local reports of climate change by indigenous peoples –at least for our test-case– do not seem to be re-shaped in the light of information provided by media or scientific accounts.

Before discussing our main finding, we highlight four methodological limitations of our experimental design. The first relates to pseudo replication (i.e., multiple samples from a single treatment unit), as the unit of analysis chosen (individual) differed from the randomisation unit (village). To avoid pseudo replication we would have needed to run the experiment at a larger scale (e.g., with a randomised sample of some 100 villages), which was beyond our budget. The second caveat relates to measurement error, since our proxy figures only account for overall quantitative agreement with trends reported in scientific studies. A more refined analysis would have also included qualitative elements and scales, which are generally of great value for the local interpretation of climatic changes. The third limitation arises from the self-selection bias occurring when participation in the intervention is voluntary (Ziliak and McCloskey 2008). We accounted for this by not stating *a priori* the topic of the workshops, in order not to bias participation by attracting only concerned individuals. However, we cannot disregard the possibility that only people with particular characteristics chose to participate in the workshops. The final caveat relates to the two month delay between the intervention and the post-intervention surveys. Ideally, to assess information retention complications, we should have assessed climate change perceptions both immediately after the workshop and two months later, but we could not do so for budgetary reasons. Yet, our study is still meaningful as it shows it is possible to assess the impact of a climate change communication at the medium term, in line with Howell (2014). To our knowledge, this approach has never been tried before, so our study opens the way for promising future research in this field. It is important to note that the results found in this research cannot be extrapolated to other types of intervention than that here presented (see Section 3.2.5), nor do they directly inform about the effectiveness of other types of interventions, such as those composed of multiple exposures to new information.

Despite these potential biases, our results sit well within the growing bulk of the literature devoted to investigating media framings of climate change (Lorenzoni and Pidgeon 2006; Goodwin and Dahlstrom 2014; Moser 2014). According to such work, media communications often fail to present climate change information in a locally salient and credible way (i.e., tailored to the local context). As a result, media framings are unlikely to distort local observations of climate change because their coverage of the topic is usually too general or decontextualised from local realities, failing to penetrate the wide epistemological gap between the information portrayed and the one perceived, particularly in indigenous cultures (Hulme 2009; Marin and Berkes 2012). Other than the epistemological gap between the two knowledge systems, another factor influencing uptake of science is trust (Hmielowski et al. 2013). For example, Rudiak-Gould (2011) notes that trust in scientific experts may be as important in determining how communications about climate change are received as whether or not the information presented is integrated into local beliefs. This aligns well with the more general research on climate change communication, which has shown that people's trust (or lack thereof) in scientific experts hold considerably more sway over their beliefs in climate change than previously thought (Goodwin and Dahlstrom 2014). Thus, if externally-generated knowledge on climate change is perceived as at odds with local understandings and the convener is perceived as an outsider, this might lead to a lack of credibility amongst stakeholders (Cash et al. 2003). Such a hypothesis is consistent with our results for the variables where local perceptions of change did not match the information presented and agreement was low (e.g., flood frequency or cold season strength).

The climate change information provided did not seem to have reached the targeted population. Potential explanations for this result could be the lack of trust between the audience and the convener or a certain degree of epistemic vigilance (*sensu* Sperber et al. 2010) from the people attending the workshops, who might have been sceptical about purported experts pressing their views upon them. The term *climate change*, as presented in the workshop, stood for different local climate changes that the Tsimane' did not necessarily interpret as part of the same phenomenon. This epistemological misfit is an important extension of the debates on: (a) what counts (and what does not) as legitimate knowledge in the context of global anthropogenic climate change (see Moore 2001); and (b) the well-recognised tendency of climate change studies to underrate traditional sources of knowledge (as pointed out by Simpson 2004).

Given these results, we posit the need to distinguish between the experiential knowledge acquired through daily observation and the descriptive knowledge that one gains through the uptake of scientific information. Our results align with those of previous studies depicting how experiential knowledge will often override descriptive knowledge (Weber et al. 2013; Zaval et al. 2014; Patt and Weber 2014). For example, reporting in the workshops that the patterns of extreme events had increased globally did not prevent people from showing scepticism towards this information, or from later describing a local decline in the frequency of floods. Two issues are relevant here: whether externally given information: (a) is converted into a locally relevant form; and (b) corresponds with local observations. Where external information and local perceptions are not consistent, reporting of change is likely to remain the same after information dissemination (e.g., flood frequency). Importantly, our finding provides evidence that, at least in this instance, claims of indigenous peoples mechanistically repeating a well-studied discourse as framed by science communication when they report local manifestations of anthropogenic climate change are not justified.

Moreover, these examples seem to confirm the profound and symptomatic mismatches between globally-framed media accounts and locally-detailed understandings of climate change by indigenous peoples (Marin and Berkes 2012). For instance, during one interview, a Tsimane' informant, when being asked about the reason behind the recent increase of temperatures, stated that the Bolivian

Government was '*selling the wind.*' Such a rhetoric affirmation, consonant with the carbon dioxide trading mechanisms and the REDD+ debate in Bolivia, proves to be illustrative of the challenge and difficulty of integrating concepts from the paradigm of scientific knowledge into other knowledge systems stemming from heterogeneous worldviews, mental models and epistemologies, and/or vice versa (Brodt 1999; Berkes 2009).

Along the lines of Rudiak-Gould's (2014) work, we posit that, while the Tsimane' perceive climate change, it may be beneficial for them to understand the scientific construct of such phenomenon. Scientific data predicts larger levels of climate change than what the Tsimane' observe. Furthermore, scientific and local understandings of the drivers of change differ, which may hamper local receptivity regarding adaptation strategies (Moser 2014). Results of this work open promising areas of research that can be of particular and immediate use in climate change communication practice. For instance, some questions rife for further study include: (a) How can climate change information be made locally relevant in different epistemic/cultural contexts?; (b) How do local peoples attribute causes to observed changes?; and (c) How can this attribution be used to benefit public engagement on adaptation in contexts where there is no pre-existing knowledge of the scientific discourse of climate change?

## 3.5. Concluding remarks

The role of indigenous peoples in global climate policy has already been widely discussed (see Thomas and Twyman 2005), yet if indigenous peoples are to be engaged in global climate negotiations (as proposed, see Schroeder 2010), a first step requires translating both local and scientific interpretations and understandings of climate change into a common language (Riedlinger and Berkes 2001). Previous research has shown that the way people perceive changes influences how they respond to them (Spence et al. 2011), and that in the context of climate change this means that people's perceptions can determine their behaviour towards proposed mitigation actions (Patt and Weber 2014). In this sense, if tailored knowledge (i.e., salient, legitimate and credible) is more likely to be influential (Bostrom et al. 2013), current framings of climate change in the media need to be rethought. As Cash et al. (2003) perceptively state, linking knowledge to action requires not only open channels of communication between the different stakeholders, but also that the participants in the resulting conversation actually *understand each other.* Attempts at successful translation between local and scientific framings of the concept of climate change –and its implications– need to be taken more seriously if we want to mobilise both scientific and local knowledge to the critical and compelling arena of climate change adaptation.

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# Chapter IV

## Rapid ecosystem change challenges the adaptive capacity of Local Environmental Knowledge


### Abstract

The use of Local Environmental Knowledge has been considered as an important strategy for adaptive management in the face of Global Environmental Change. However, the unprecedented rates at which global change occurs may pose a challenge to the adaptive capacity of local knowledge systems. In this paper, we use the concept of the shifting baseline syndrome to examine the limits in the adaptive capacity of the local knowledge of an indigenous society facing rapid ecosystem change. We conducted semi-structured interviews regarding perceptions of change in wildlife populations and in intergenerational transmission of knowledge amongst the Tsimane', a group of hunter-gatherers of Bolivian Amazonia ($n$ = 300 adults in 13 villages). We found that the natural baseline against which the Tsimane' measure ecosystem changes might be shifting with every generation as a result of: (a) age-related differences in the perception of change; and (b) a decrease in the intergenerational sharing of environmental knowledge. Such findings suggest that local knowledge systems might not change at a rate quick enough to adapt to conditions of rapid ecosystem change, hence potentially compromising the adaptive success of the entire social-ecological system. With the current pace of Global Environmental Change, widening the gap between the temporal rates of ongoing ecosystem change and the timescale needed for local knowledge systems to adjust to change, efforts to tackle the shifting baseline syndrome are urgent and critical for those who aim to use Local Environmental Knowledge as a tool for adaptive management.



**Keywords:** biocultural conservation; Bolivian Amazonia; change perceptions; generational amnesia; shifting baseline syndrome; Tsimane'


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## 4.1. Introduction

The idea that Local Environmental Knowledge (LEK) can provide strategies for adaptive management in the face of Global Environmental Change (GEC) is gaining worldwide credence and recognition (Berkes et al. 2000; Turnhout et al. 2012; Gómez-Baggethun et al. 2013a), not only in academic circles but also at the political level (CBD 1992; MA 2005; Reid et al. 2006). For instance, various agencies and bodies of the United Nations, including the Intergovernmental Panel on Climate Change (IPCC), recommend investigating local people's place-based knowledge for increasing resilience in a changing global environment (e.g., UNCCD 2005; UNESCO 2008; Noble et al. 2014). The intricate interaction between local peoples and their surrounding environments has resulted in detailed LEK that has proved to be pivotal in allowing societies to subsist in a wide range of environments and to adapt to social-ecological changes (Marin 2010; Brännlund and Axelsson 2011; Reyes-García et al. 2014a; Klein et al. 2014). In this context, LEK is argued to be *adaptive* because it reacts to the ever-changing nature of social and environmental conditions (Gómez-Baggethun et al. 2012, 2013a; Reyes-García 2013).

However, the increase in the pace at which GEC operates has raised scepticism regarding LEK persistence and effectiveness (Cox 2000; Kameda and Nakanishi 2002). Some authors argue that, because abrupt ecosystem changes deriving from GEC are new and unprecedented, they might be hard to anticipate using LEK systems (Berkes 2009; Turner and Clifton 2009; Valdivia et al. 2010). Furthermore, the nature of such changes is not only faster, but also nonlinear, generating feedback and forward loops along with new thresholds of irreversible change, all phenomena likely to lead to a novel or no-analogue future (*sensu* Ruhl 2010). In such context, LEK could potentially be outmoded and/or inefficient (Macchi et al. 2008; McNeeley and Shulski 2011), thereby undermining local adaptive capacity (West et al. 2007; Gilles and Valdivia 2009; Newsham and Thomas 2011). Several works underscore the need for LEK to adjust and evolve in parallel with GEC, i.e., complex ecosystems that undergo continual, rapid and nonlinear transformations (Ford et al. 2006; Gómez-Baggethun and Reyes-García

2013; Aswani and Lauer 2014). Such a challenge is illustrated by the concept of the shifting baseline syndrome (SBS) which suggests the potential limits of the adaptive capacity of LEK in rapidly changing environmental conditions (Pauly 1995). The term SBS refers to a socio-psychological phenomenon describing the inaccurate human perception of changes in the ecosystems, possibly resulting in serious implications for conservation behaviour and adaptive capacity.

Our research pursues two specific objectives. First, on a theoretical side, we aim to advance a conceptual framework for the study of SBS, discussing the definition and evolution of the concept and refining the methodology for its analysis. Second, on the empirical side, we apply the improved conceptual framework to test the existence of SBS in a rapidly changing social-ecological system of Bolivian Amazonia. On the basis of our results, we draw lessons on how to tackle the challenges that SBS poses, in order to support the resilience of LEK in the face of ever encroaching environmental change.

# 4.2. Theoretical section

## 4.2.1. Defining the shifting baseline syndrome (SBS)

For the past few decades, the physical and natural sciences have led the way in detecting and measuring the impacts of GEC on ecological systems (e.g., Vitousek 1994; Barnosky et al. 2012; Dirzo et al. 2014). To measure environmental changes, researchers have typically compared current with past conditions (the latter assumed to be the *natural* baseline). More recently, there have been different attempts to assess environmental changes by examining individual perceptions and information embedded in LEK systems (e.g., Dow et al. 2007; Patt and Schröter 2008; Petheram et al. 2010). However, when change is assessed through a social lens, there is risk that the baseline against which changes are measured might have drifted further from its departing point (Lozano-Montes et al. 2009; Turvey et al. 2010). This situation results in a cognitive ratchet known as the shifting baseline syndrome (SBS) describing perceptions of ecosystem change that are not matching the actual changes taking place in the environment (Pauly 1995).

The term *shifting baseline syndrome* has been used to refer to at least two types of socio-psychological phenomena (see Papworth et al. 2009). First, the term has been used to describe a form of *generational amnesia* occurring when knowledge of natural baselines is not passed on from one generation to the next (Huitric 2005; Sáenz-Arroyo et al. 2005). With scarce intergenerational communication, each new generation has a more biased conception of how much change has undergone the ecosystem, as they assess change relative to baselines that shift with each new generation (Steen and Jachowski 2013). Second, the term SBS has also been used to describe a type of *personal amnesia*, where individuals constantly (albeit unconsciously) update their own perception of normality over the course of their lifetime (Simons and Rensink 2005). In this case, baseline conditions observed long ago tend to be forgotten or hazed over and the new state becomes one's personal baseline, with this shift going unnoticed (Kahn 2002). In either case, the use of the word *amnesia* is important because any experience on shifting baselines involves an unperceived loss of knowledge (Roberts 2003; Bunce et al. 2008; Duarte et al. 2009).

SBS was originally observed in fisheries' sciences, when Pauly (1995) noticed how each generation of fisheries' scientists accepted the fish stock sizes occurring at the beginning of their careers as a baseline to evaluate change, with every new generation updating the baseline even when the stocks had further declined. The concept was rapidly picked up in a number of other disciplines, including cognitive science (Simons and Rensink 2005), environmental history (Sáenz-Arroyo et al. 2006; Humphries and Winemiller 2009), restoration ecology (Whipple et al. 2010; Steen and Jachowsky 2013) and ethnobotany (Hanazaki et al. 2013). More recently, the concept has permeated beyond purely academic spheres and it is used even by environmental advocacy groups (Campbell et al. 2009; Shifting Baselines 2014). The importance of the concept in conservation practice is not surprising considering the bulk of research indicating that the way in which people perceive changes influences their responses to them (e.g., Stern 2000; Maule and

Hodgkinson 2002; Spence et al. 2011). In other words, if people do not acknowledge the existence of environmental change (i.e., desensitisation to change, *sensu* Robards and Alessa 2004), they might be less prone to engage in conservation initiatives (Papworth et al. 2009; Kai et al. 2014).

### 4.2.2. A conceptual framework for the analysis of SBS

Despite the implications that the erosion of LEK on past ecosystem states could entail, there are meagre empirical works showing evidence of the existence of SBS, particularly amongst indigenous societies. Because of the relative confusion around the term, with multiple definitions, interpretations and understandings, the conceptual framework for the study of SBS is still underdeveloped. Previous studies on SBS have received criticism due to the use of disparate datasets, inappropriate statistical techniques, and confusion around data on baselines perceptions *versus* change perceptions (see Papworth 2008). For example, in a study amongst fishers of the Gulf of California, Sáenz-Arroyo et al. (2005) found that the fish catches reported by older fishers were greater than those reported by younger fishers, from which they assumed the existence of SBS. However, these results are not completely reliable in demonstrating SBS because: (a) no evidence of environmental change is provided; and (b) intergenerational communication between young and old fishers is not taken into account. In other terms, although SBS is a logical explanation for anecdotal evidence of age-related differences in change perceptions, the latter alone cannot be taken as the ultimate confirmation of SBS existence (Papworth et al. 2009). Similar caveats are recurrent in much of the SBS literature to date (see Lozano-Montes et al. 2009; and Kai et al. 2014 for other examples).

In our study, we collected quantitative data amongst the Tsimane', an indigenous society of Bolivian Amazonia, to assess the possible existence of SBS with regard to environmental changes. The research setup was explicitly conceived to: (a) overcome the *change-of-standard* bias, a psychological process by which change perception entails that '*past times were always better*' (see Higgins and

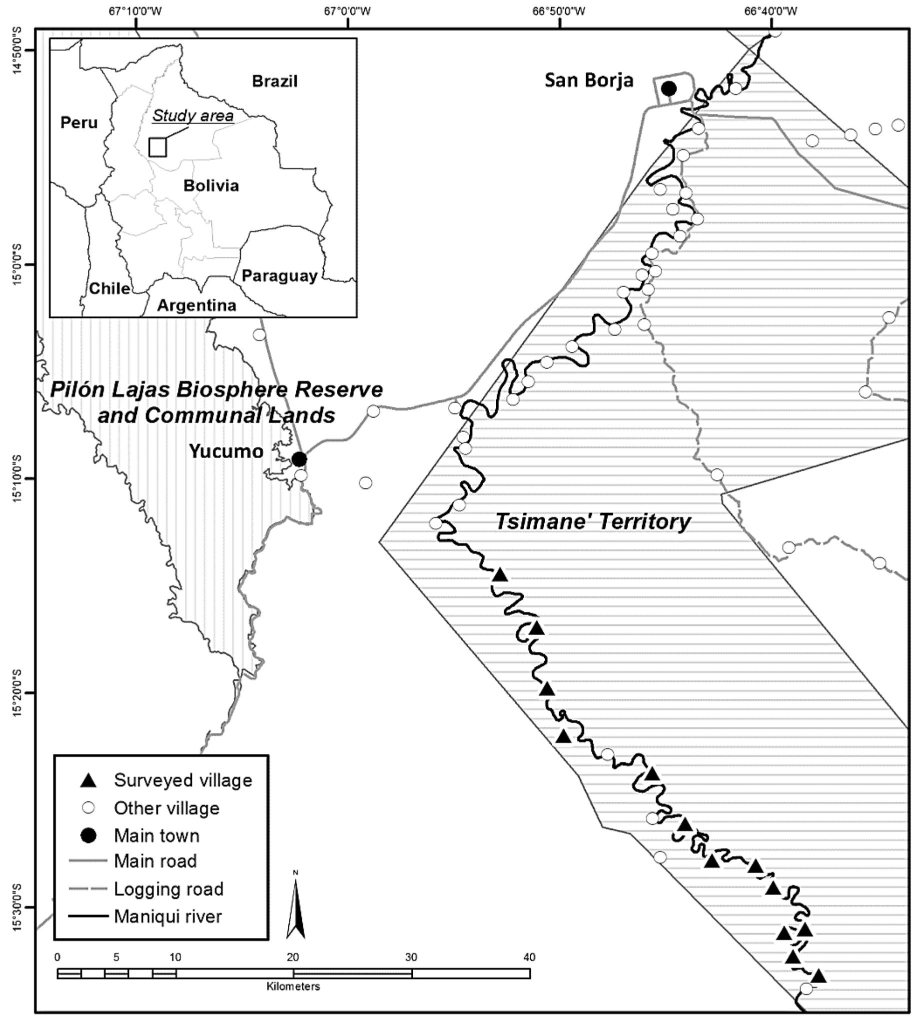
Stangor 1988); and (b) to avoid the over-reporting of environmental change that has clouded over some previous works on SBS (see Papworth et al. 2009 for more details). Following from the above, we propose that the existence of SBS could only be confirmed if we find evidence of all of the following: (a) a perceivable and locally-relevant ecosystem change; (b) age-related differences in the perception of ecosystem change; and (c) scarce intergenerational communication. While points (a) and (b) have been covered by Papworth et al. (2009), to our best knowledge, no work to date has explicitly taken into account intergenerational communication in order to demonstrate SBS. Hence, our present work contributes a new angle to the study of SBS. For the purpose of this work, we focus on generational rather than personal amnesia, as the latter requires longitudinal cohort-type datasets over a long period of time (currently unavailable to us).

We focus our study on indigenous peoples for two main reasons. First, unlike industrial societies, indigenous groups typically rely on oral memory. Second, they hold accounts of environmental change that are less likely to be distorted by scientific or media framings of GEC (due to limited access to mass media and/or Western scientific reports; Fernández-Llamazares et al. 2015). In indigenous societies, accounts of environmental change are captured in LEK, which is stored, revived and transmitted as social memory (Barthel et al. 2013). LEK has the potential to expand the knowledge basis of a group at least to the lifespan of the oldest of its members, and potentially longer, as long as the knowledge held by an individual is transmitted from generation to generation (Berkes et al. 2000; Alessa et al. 2008). Thus, the study of indigenous peoples proves very useful to empirically test the existence of SBS.

## 4.3. Material and methods

The Tsimane' are a foraging-horticulturalist group of about 12,000 people living in the Department of Beni, Bolivian Amazonia (for a detailed ethnography on the Tsimane', see Huanca 1999; Reyes-García 2001). Tsimane' settlements are currently scattered across different areas and land tenure regimes (Reyes-García et al. 2014c). In the present study, we worked only with villages within the Tsimane' Territory (*Tierra Comunitaria de Origen, TCO, Territorio Tsimane'*), a communal land comprising ca. 400,000 ha (Figure 4.1). The Tsimane' Territory is mostly covered by *terra firme* Amazonian rainforests, home to more than 30 game vertebrate species (Luz 2013; Guèze et al. 2014) which are deeply intertwined with the Tsimane' culture (Huanca 1999, 2008). The forest is the main source and sustenance of the Tsimane' livelihood, providing an essential basis for subsistence activities such as hunting and gathering (Chicchón 1992; Reyes-García 2001). As with other native Amazonians, this close human-nature relation has resulted in the Tsimane' holding a great deal of LEK on wildlife ecology and distribution (Ringhofer 2010; Luz 2013), ethnoclimatology (Fernández-Llamazares et al. 2015), landscape management (Riu-Bosoms et al. 2014), and ethnobotany (Reyes-García et al. 2003, 2007b).

**Figure 4.1 |** Study area and villages surveyed.



To carry out this study, we first obtained Free Prior and Informed Consent (FPIC) of each village and individual participating, as well as the agreement of the Tsimane' political organisation, the *Gran Consejo Tsimane'* (Great Tsimane' Council). In addition, this research adhered to the Code of Ethics of the International Society of Ethnobiology (ISE). The Ethics Committee of the Universitat Autònoma de Barcelona (UAB) approved the research (CEEAH-04102010; LEK Project 2014). Study villages were selected according to their size and location in order to capture differences on their cultural change (Figure 4.1). All adults (defined as people of 16 years of age or older) were invited to participate in the research. We encouraged both women and men to participate in the study with the aim to ensure equal representation in the final sample. Overall, we had a participation rate over a total of 80% of the population of all the villages, capturing a sound representation of potential variability on environmental change perceptions.

Our analysis draws on three different datasets, each one addressing one of the three conditions previously mentioned to prove the existence of SBS. The first dataset relates to measures of ecosystem change (Section 4.3.1), the second to age-related differences in the perception of ecosystem change (Section 4.3.2), and the third to intergenerational communication with regard to ecosystem change (Section 4.3.3). In Table 4.1 we summarise our Research Design.

**Table 4.1 |** Research design.

| Unit of evidence | Date | Method | Sample |
|---|---|---|---|
| Ecosystem change | October 2012 – July 2014 | Literature review | 69 Publications |
| Age-related differences in the perception of ecosystem change | October 2012 – November 2013 | Semi-structured interviews | 300 Adults in 13 villages [i.e., Sample 1] |
| Intergenerational communication | October 2012 – July 2013 | Free-listings | 113 Adults in 2 villages [i.e., Sample 2] |
| | September – November 2013 | Focus groups | 16 Adults in 2 villages [i.e., Sample 3] |

### 4.3.1. Measurement of ecosystem change

Many scientific works have situated Amazonia as one of the world's emblems of GEC (e.g., Laurance 1998; Mahli et al. 2008). However, while global models provide a comprehensive picture of the biophysical effects of GEC at a regional scale, there is a surprising lack of scientific data at local scales, particularly with regard to baselines. Because of this lack of comprehensive data sources with which to establish environmental baselines, to assess ecosystem changes we drew instead on a systematic review of literature documenting local environmental changes in the Tsimane' Territory. Such review was complemented with regional evidences for Bolivian Amazonia.

For the last 15 years, the Tsimane' have been the subjects of a panel study focusing on how global change (including market economy and environmental transformations) affects their economy, health and knowledge system (Tsimane' Amazonian Panel Study, TAPS; Leonard and Godoy 2008). The research team has had continued presence in the area since 1999; hence, a systematic review of TAPS publications provides some insight into environmental changes at the local scale. We also used the bibliography compiled in the Ethnoecology Virtual Library (2014). Out of 130 publications surveyed (including articles, books, and PhD dissertations), 36 contained references to environmental changes in the Tsimane' Territory and were hence examined here.

To complement these local accounts with regional evidences, we also conducted a systematic keyword search in the ISI Web of Science using the terms *Bolivian Amazonia* and *environmental change*. The search yielded a list of 33 peer-reviewed publications that we also reviewed (included in the Reference list).

### 4.3.2. Measurement of age-related differences in the perception of ecosystem change

From October 2012 to November 2013, we conducted structured interviews with 300 adults (≥ 16 years old) in 13 villages. Table 4.2 contains summary descriptive statistics of the sample. In our research design the sample sizes per age group are intended to mimic the current population pyramid of the Tsimane' (Saidi et al. 2013; Undurraga et al. 2014).

**Table 4.2 |** Summary descriptive statistics of the sample composition.

| Sample | Variable name | Description | Descriptive statistics | | | | |
|---|---|---|---|---|---|---|---|
| Sample 1 | Age | Age of the interviewee | *n* | Mean | SD | *min* | *max* |
| | | | 300 | 37.75 | 16.97 | 16 | 84 |
| | DOB 1930 | Interviewees born in the 1930s | 12 | 80.00 | 3.19 | 75 | 84 |
| | DOB 1940 | Interviewees born in the 1940s | 20 | 67.85 | 2.52 | 65 | 73 |
| | DOB 1950 | Interviewees born in the 1950s | 24 | 58.71 | 2.31 | 55 | 63 |
| | DOB 1960 | Interviewees born in the 1960s | 37 | 47.13 | 2.38 | 44 | 52 |
| | DOB 1970 | Interviewees born in the 1970s | 60 | 38.55 | 3.02 | 34 | 43 |
| | DOB 1980 | Interviewees born in the 1980s | 76 | 28.62 | 2.90 | 24 | 33 |
| | DOB 1990 | Interviewees born in the 1990s | 71 | 19.27 | 2.38 | 16 | 23 |
| | Sex | Sex of the interviewee | 142 men (47.33%)<br>158 women (52.67%) | | | | |
| Sample 2 | Age | Age of the interviewee | *n* | Mean | SD | *min* | *max* |
| | | | 113 | 39.29 | 18.82 | 16 | 84 |
| | DOB 1930 | Interviewees born in the 1930s | 9 | 80.78 | 3.11 | 75 | 84 |
| | DOB 1940 | Interviewees born in the 1940s | 9 | 68.89 | 2.85 | 65 | 73 |
| | DOB 1950 | Interviewees born in the 1950s | 3 | 60.00 | 0.00 | 60 | 60 |
| | DOB 1960 | Interviewees born in the 1960s | 13 | 46.61 | 2.47 | 44 | 52 |
| | DOB 1970 | Interviewees born in the 1970s | 28 | 39.07 | 3.37 | 34 | 43 |
| | DOB 1980 | Interviewees born in the 1980s | 24 | 28.83 | 3.00 | 24 | 33 |
| | DOB 1990 | Interviewees born in the 1990s | 26 | 19.31 | 2.51 | 16 | 23 |
| | Sex | Sex of the interviewee | 59 men (52.21%)<br>54 women (47.79%) | | | | |
| Sample 3 | Age | Age of the interviewee | *n* | Mean | SD | *min* | *max* |
| | | | 16 | 36.53 | 15.58 | 19 | 70 |
| | Sex | Sex of the interviewee | 9 men (56.25%)<br>7 women (43.75%) | | | | |

We asked about individual perceptions of environmental changes in wildlife (bird and game species), taking the informant's childhood (i.e., Decade Of Birth, DOB) as an individual baseline. In line with the literature mentioned in Section 4.2.2, we did not directly ask about change perceived in the course of a lifetime, but rather about baselines and present state. We then obtained surrogate individual measures of change by comparing current with past situation. Specifically, we asked our informants to report the three most abundant bird and game species both now and at childhood.

Following Papworth (2008), we then developed a measure to describe the perception of change in bird and game species composition for each individual. The resulting variable, which we call *change perception*, measures the difference between the species perceived as most abundant in the DOB and the species perceived as most abundant in the present. In a range from zero to three, this variable counts the number of species reported as abundant in the DOB but not in the present. For instance, if the three bird species perceived as most abundant in the DOB were all different from those three in the present, the variable would be at its highest (three, i.e., a difference of three species between the present and the past), whereas the contrary would happen when the DOB and the present species were the same (zero, i.e., no different species between the present and the DOB).

Then, we calculated the mean change perception of species composition reported by all the individuals born in the same DOB. Finally, to estimate age-related differences in the perceptions of change, we ran an Ordinary Least Square (OLS) regression model of the mean change perception against DOB.

Additionally, we examined: (a) the perceived baselines of abundance for the five game and bird species reported as most abundant both in the past (i.e., DOB) and at the time of interviewing; and (b) the trends in the perceived abundance of both the five most reported threatened and non-threatened game species, based on the Bolivian IUCN Red List of Threatened Species (MMA 2009). For the latter point, we ran a *logit* regression to measure the probability of change in the abundance report between past and present both for threatened and non-threatened species (see section 4.4.2 for more details). Moreover, we used the Red List Index (RLI) to measure trends in the extinction risk of the reported species over time, i.e., changes in the threat status of the species reported in our study. Following Butchart et al. (2007) we calculated the RLI for all the reported species in our study that are classified as threatened (six species, according to MMA 2009) and the same number of non-threatened species, i.e., the six most reported non-threatened species in our study. We were only able to conduct this analysis for the selected game species, but not bird species, as most of the bird species found in the Tsimane' Territory have to date not been assessed by the IUCN Red List or are data-deficient. The calculation of RLI was based on data from the global IUCN Red List (IUCN 2014), because there are not recognised IUCN National Assessments for Bolivia prior to MMA (2009) and therefore, it is impossible to compute the RLI at the national, regional or local level.

### 4.3.3. Measurement of intergenerational communication regarding ecosystem change

To capture intergenerational communication, we conducted: (a) structured interviews with a sub-sample of 113 adults in two of the studied villages; and (b) focus group discussion with two groups (with a total of 16 adults participating). Table 4.2 summarises the descriptive statistics of the sample.

The interviews addressed individual perceptions of locally-extinct species, defined here as species that were locally-abundant in the past but not locally-found anymore. Our underlying argument goes as follows. In the absence of written records and lack of access to scientific or media information (see Fernández-Llamazares et al. 2015), we assume that if young generations are able to free-list locally-extinct species, they are able to do so because older people have told them about past presence of the species in the area; otherwise, conditions that existed prior to their lifetime would be unknown. If so, the difference in the mean number of all the perceived locally-extinct species free-listed by individuals of each generation is a good proxy for the level of intergenerational communication with regard to ecosystem change. Research results on the current erosion of LEK amongst the Tsimane' (Reyes-García et al. 2013a,b) validate the selected approach.

The interviews consisted of a free-listing of all the perceived locally-extinct tree and fish species known by each individual. We decided not to conduct the free-listing with game and bird species, because we had already asked about perceived baselines for those groups of animals and responses related to those groups would have probably been biased, thus weakening our measure of intergenerational communication. Rather, we chose to conduct the free-listings with fish and tree species because, like game and birds, they are central elements to the Tsimane' livelihood and culture (see Reyes-García and TAPS Bolivian Study Team 2012). We calculated the mean number of locally-extinct species free-listed by all the individuals born in the same DOB and we used an OLS regression model to detect trends in the mean number of locally-extinct species free-listed by individuals belonging to different generations.

In order to contextualise our free-listings on the intergenerational transmission of knowledge, we also conducted focus group discussions in the two villages where we had collected the free-listings. All in all, sixteen adults (9 men and 7 women) of different ages (*min* = 19 and *max* = 70) attended the meetings. During the focus group discussions we asked participants about their perceptions of intergenerational communication. The open discussion allowed us to obtain qualitative narratives to complement and contextualise our free-listing data. The discussion narratives were analysed by extracting dominant themes under the interview topic of intergenerational communication (see Bernard and Bernard 2013).

## 4.4. Results

We structure our results below around the three units of evidence we used for analysing generational amnesia: ecosystem change (Section 4.4.1), age-related differences in the perception of ecosystem change (Section 4.4.2), and intergenerational communication within the study population (Section 4.4.3).

### 4.4.1. Evidence of ecosystem change

While a lack of baseline ecological data about the Tsimane' Territory hampers a full understanding of the impacts of GEC in the area, there is enough evidence to suggest a significant degree of environmental change that is altering the nature and functionality of the ecosystems as well as the faunal composition and distribution. Table 4.3 provides a list of the local manifestations of GEC in the studied social-ecological system derived from the available literature.

As explained below, the existing and potential impacts of GEC on the Tsimane' social-ecological system are predominantly reflected in three aspects. First, the Tsimane' are undoubtedly facing substantial changes as their ecosystem is undergoing a rapid decline in biodiversity, mostly stemming from significantly high levels of deforestation, habitat degradation and hunting pressures (Apaza et al. 2002; Ringhofer 2010; Paneque-Gálvez et al. 2013; Luz 2013). Second, climate change is likely to have disrupted –and likely to continue to disrupt– the ecosystems upon which the Tsimane' traditions and livelihoods depend, seeing that climate change interacts synergistically with pre-existing deforestation, forest fragmentation and exogenous pressures (e.g., market integration), all of which have been documented in the area (Paneque-Gálvez 2012; Pérez-Llorente et al. 2013). And thirdly, as environmental changes impact the ecosystem, they also affect local culture and livelihood (Reyes-García et al. 2013a; Fernández-Llamazares et al. 2014a,b). For example, the observed changes might compromise the ability of the Tsimane' to secure the species upon which they have historically relied for subsistence (Luz 2013; Zycherman 2013).

The analysis of research work in the area yields evidence of substantial faunal changes at the local level (Chicchón 1992; Pérez 2001; Ringhofer 2010; Zycherman 2013). Luz (2013) found that overall, the vertebrate fauna in the Tsimane' Territory is less diverse, in terms of number of species, than in other *terra firme* Amazonian forests also subject to hunting pressure (Peres 1997; Endo et al. 2010). Moreover, the same author finds that encounter rates of large-bodied

**Table 4.3 |** Local manifestations of Global Environmental Change in the Tsimane' social-ecological system.

| Change | Description | Scale[14] | Methods[15] | References |
|---|---|---|---|---|
| Ecosystem change | Net old-growth forest loss | R | E | Steininger et al. (2000, 2001), Pachecho (2002,2006), Perz et al. (2005), Killeen et al. (2007, 2008), Müller et al. (2012) |
| | | L | SE | Paneque-Gálvez (2012), Paneque-Gálvez et al. (2013) |
| | Increased landscape fragmentation | R | E | Millington et al. (2003) |
| | | L | SE | Paneque-Gálvez (2012), Pérez-Llorente et al. (2013) |
| | Habitat loss and reduction of wildlife diversity / abundance | L-R | E | Peres et al. (2000, 2001, 2010), Vargas and Simonetti (2005), Santivañez (2007), Mercado and Wallace (2010) |
| | | L | SE | Huanca (1999), Apaza (2001), Apaza et al. (2002, 2003), Bottazzi (2009) Ringhofer (2010), Guèze (2011), Luz (2013) |
| | Local extirpation of valued game, tree and fish species | L | SE | Godoy et al. (1998), Herrera-MacBryde et al. (2000), Apaza et al. (2003), Gutiérrez (2005), Huanca (2008), Reyes-García and TAPS Bolivian Study Team (2012), Luz (2013), Fernández-Llamazares et al. (2014b) |
| | Changes in freshwater communities: reduction of fish population sizes and alteration of age structures | L-R | E | Van Damme et al. (2009), Anderson et al. (2011) |
| | | L | S | Pérez (2001), Ringhofer (2010), Zycherman (2013), Fernández-Llamazares et al. (2014b) |
| | Increased levels of water pollution (e.g., mercury, waste mills from logging firms) | L-R | E | Maurice-Bourgoin et al. (2000, 2001, 2002) |
| | | L | SE | Huanca (2008), Castañeda-Menacho (2013) |
| Climate change | Increase in the mean temperatures and decrease in the average annual rainfall | R | E | Mahli and Wrigth (2004,2008), Nepstad et al. (2004), Seiler (2009), Magrin et al. (2014) |
| | Increased frequency and intensity of ENSO-related droughts | R | E | Betts et al. (2004), Ronchail (2005), Wenhong et al. (2007), Mayle and Power (2007), Li et al. (2011) |
| | Hydrological changes | R | E | Marengo (2003), Li et al. (2008), Quiroga et al. (2009) |
| | Increased temperatures, more irregular rainfall patterns, and increased frequency of long dry spells | L | SE | Méndez-López (2009), Fernández-Llamazares et al. (2014a) |
| Cultural change | Rapid erosion and loss of LEK | L | S | Reyes-García et al. (2013a,b, 2014b) |
| | Reduced food yields, diet changes and increasing food insecurity | L | SE | Qureshi (2007), Luz (2013), Zycherman (2013) |
| | Increasing cultural change and integration into the market economy, modification of conservation behaviour (e.g., increased deforestation rates, decreasing adherence to traditional hunting norms) | L | SE | Chicchón (1992), Wilkie and Godoy (2001), Vadez et al. (2004, 2008), Godoy et al. (2005, 2010), Reyes-García et al. (2007, 2010), Luz (2013), Bottazzi et al. (2014) |
| | Increasing fragmentation of indigenous institutions for the governance of natural resources | L | S | Huanca (2008), Reyes-García and TAPS Bolivian Study Team (2012), Reyes-García et al. (2014c) |

[14] *R* indicates *Regional Evidence*, i.e., Bolivian Amazonia; *L* indicates *Local Evidence*, i.e., Tsimane' Territory; and *L-R* indicates *Local-Regional Evidence*, i.e., neighboring areas.

[15] *E* indicates *Ecological Science Methods*, including biological monitoring, transects, field surveys, satellite imagery analysis, climate trend detection, climate modeling and soil and water analysis; *S* indicates *Social Science Methods*, including structured and semi-structured interviews, knowledge questionnaires, participant observation, classic ethnography and oral histories; and *SE* indicates *Social-Ecological Methods*, integrating elements from both *Ecological* and *Social Science Methods*.

game species (e.g., *Tayassu pecari*) assessed in 2.6 km transects in 40 Tsimane' villages were on average lower than the ranges reported for other hunting forest sites in Amazonia (Luz 2013). The current faunal distribution in the Tsimane' Territory, particularly the composition and structure of vertebrate communities, suggests the presence of selective hunting and habitat degradation, a trend consistent with those found elsewhere in the Neotropics (Peres 2000, 2001; Luz 2013; Zycherman 2013). Regarding bird species, it is important to note that up to 93.4% of Tsimane' households hunt birds regularly (Gutiérrez 2005), directly impacting bird species composition and diversity.

### 4.4.2. Evidence of age-related differences in change perception

The second element examined relates to the evidence of age-related differences in the perception of ecosystem changes. Table 4.4 provides descriptive statistics of variables measuring change perception in the composition of bird and game species. The average value for our measure of the change perception (above 2.5 species for both measures) suggests the existence of large differences between the composition of those bird and game species perceived as more abundant in the past and those perceived as more abundant in the present.

**Table 4.4 |** Definition and summary statistics of the outcome variables.

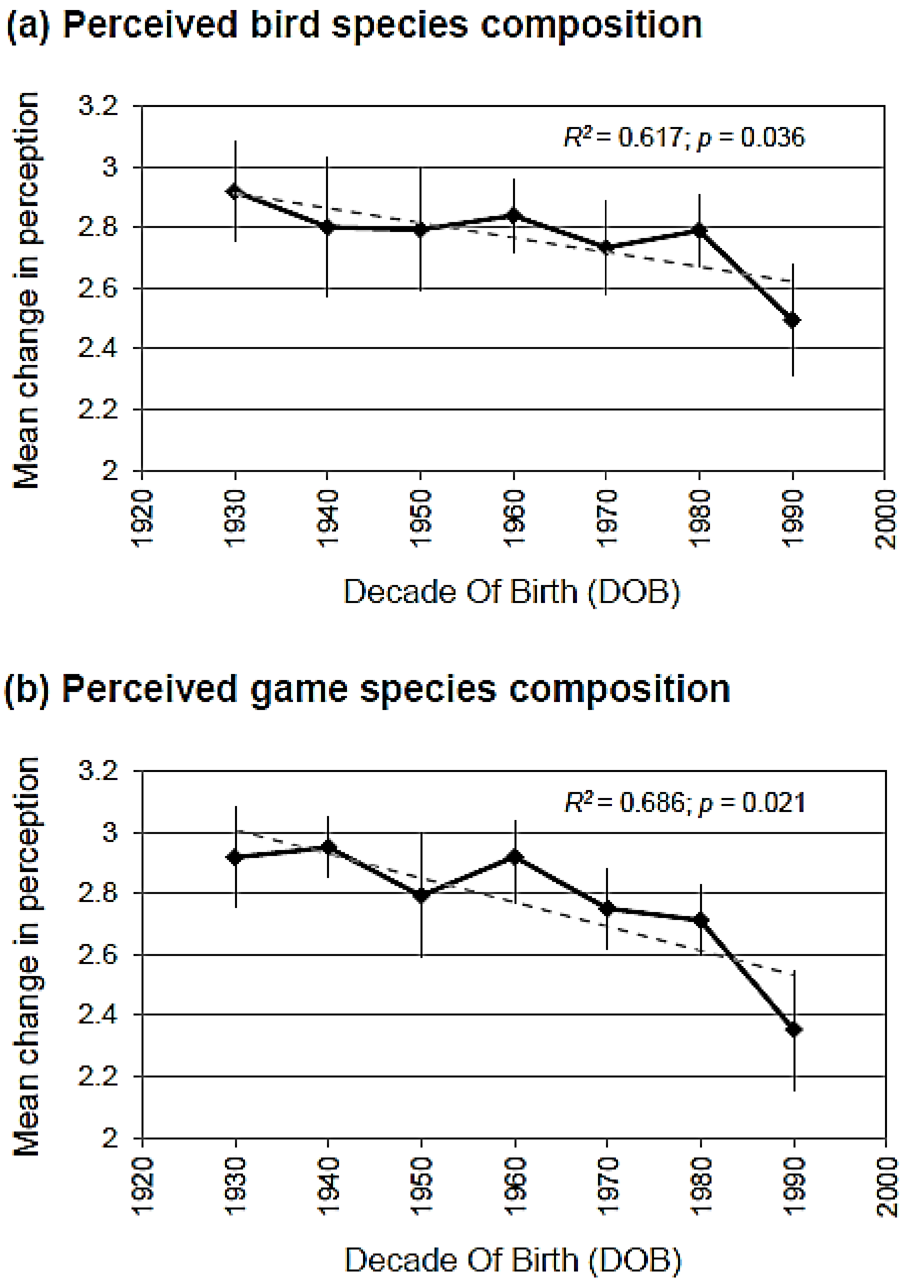
| **Variable name** | **Description** | **Descriptive statistics** | | | | |
|---|---|---|---|---|---|---|
| | | *n* | Mean | SD | *min* | *max* |
| Change perception in the composition of bird species | Difference in the three bird species perceived as most abundant in the past compared to the three ones perceived as most abundant in the present | 300 | 2.72 | 0.60 | 0 | 3 |
| Change perception in the composition of game species | Difference in the three game species perceived as most abundant in the past compared to the three ones perceived as most abundant in the present | 300 | 2.69 | 0.61 | 0 | 3 |
| Locally-extinct tree species reported | Number of locally-extinct tree species free-listed | 113 | 4.96 | 1.65 | 2 | 9 |
| Locally-extinct fish species reported | Number of locally-extinct fish species free-listed | 113 | 4.87 | 1.41 | 2 | 8 |

The results of the regression of the mean change perception reported per age group against the DOB show that, for bird species composition, on average, older respondents report changes of significantly greater magnitude than younger respondents ($R^2$ = 0.617; $p$ = 0.036; Figure 4.2a). The same result was found for game species composition, with older Tsimane' reporting changes of significantly greater magnitude than younger Tsimane' ($R^2$ = 0.686; $p$ = 0.021; Figure 4.2b). These results provide evidence of significant differences in the perception of change in bird and game species composition between people of different ages.

Such differences in perception are presented in more detail in Appendix IV, where the perceived baselines of abundance for the five game and bird species reported as most abundant, both in the past (i.e., DOB) and at the time of interviewing, are shown. Our calculation of RLI separately for the six threatened and non-threatened species (Table 4.5) shows that while the threatened species have a smaller and decreasing RLI (0.87 in previous assessments, to 0.70 in the latest global mammal assessment), the non-threatened species show a stable RLI of 1. This indicates that the status of the threatened species in the area has deteriorated since the previous IUCN assessments (i.e., further evidence of ecosystem change). Yet, for the non-threatened species, a RLI of 1 in both periods can be interpreted as a sign of no substantial change in the species status, i.e., remaining in the Least Concern category. We note that the use of RLI calculations here is only indicatory, as the amount of data remains low, and the years of assessment vary greatly from one species to another (see Butchart et al. 2007).

When examining separately the threatened and non-threatened game species (Table 4.5), we found that current threatened species were significantly reported as more abundant in the past than are current non-threatened species, while the latter were significantly reported as more abundant in the present than are current threatened species.

**Figure 4.2 |** Evidence of age-related differences in the perception of environmental changes.




Note: Mean change perception regarding composition of: (a) bird species reported by groups of individuals born in the same DOB; and (b) game species reported by groups of individuals born in the same DOB. The mean change perception is measured in a range scale counting from zero to three, i.e., maximum change perceived equalling three, and minimum change perceived equalling zero. The dashed grey lines show the fitted regression models. The bars indicate the Standard Error (SE) of the mean change perception.

**Table 4.5 |** Tsimane' perceptions of threatened and non-threatened game species trends over the respondent's lifetimes.

| Species classification | Red List Index (IUCN 2014) | Local name | Scientific name | IUCN status (MMA 2009) | Population trend (IUCN 2014) | Total number of reports[16] | % of reports as abundant in the past | % of reports as abundant in the present | Probability of change in abundance report[17] |
|---|---|---|---|---|---|---|---|---|---|
| Threatened | 0.87 – 0.70 | Quiti | *Pecari tajacu* | NT | Stable | 228 | 59.2% | 40.8% | Decreasing ** |
| | | Mumujñi' | *Tayassu pecari* | NT | Decreasing | 157 | 93.6% | 6.4% | Decreasing ** |
| | | Shi' | *Tapirus terrestris* | VU | Decreasing | 157 | 93.6% | 6.4% | Decreasing ** |
| | | Odoj | *Ateles chamek* | VU | Decreasing | 125 | 75.2% | 24.8% | Decreasing ** |
| | | Uru' | *Alouatta sara* | NT | Decreasing | 104 | 91.3% | 8.7% | Decreasing ** |
| | | Yushi | *Myrmecophaga tridactyla* | VU | Decreasing | 13 | 53.8% | 46.2% | Stable |
| Non-threatened | 1 | Naca' | *Cuniculus paca* | LC | Stable | 215 | 7.1% | 92.9% | Increasing ** |
| | | Nej | *Mazama americana* | NA | Unknown | 206 | 34.0% | 66.0% | Increasing ** |
| | | Oyoj | *Sapajus libidinosus* | LC | Unknown | 162 | 57.4% | 42.6% | Decreasing * |
| | | Chu' | *Nasua nasua* | LC | Decreasing | 119 | 25.2% | 74.8% | Increasing ** |
| | | Väsh | *Dasypus novemcinctus* | LC | Stable | 85 | 5.9% | 94.1% | Increasing ** |
| | | Isvara | *Saimiri boliviensis* | LC | Decreasing | 44 | 43.2% | 56.8% | Stable |

Note: * $p < 0.05$ and ** $p < 0.01$.

[16] The total number of reports is the addition of the individual reports of the species as both abundant in the past and in the present.

[17] *Logit* regression: probability of change in the abundance report of a species (i.e., *decreasing* if people report a species as more abundant in the past than in the present; *increasing* if people report a species as more abundant in the present than in the past; *stable* if there is no significant change in the abundance report between past and present).

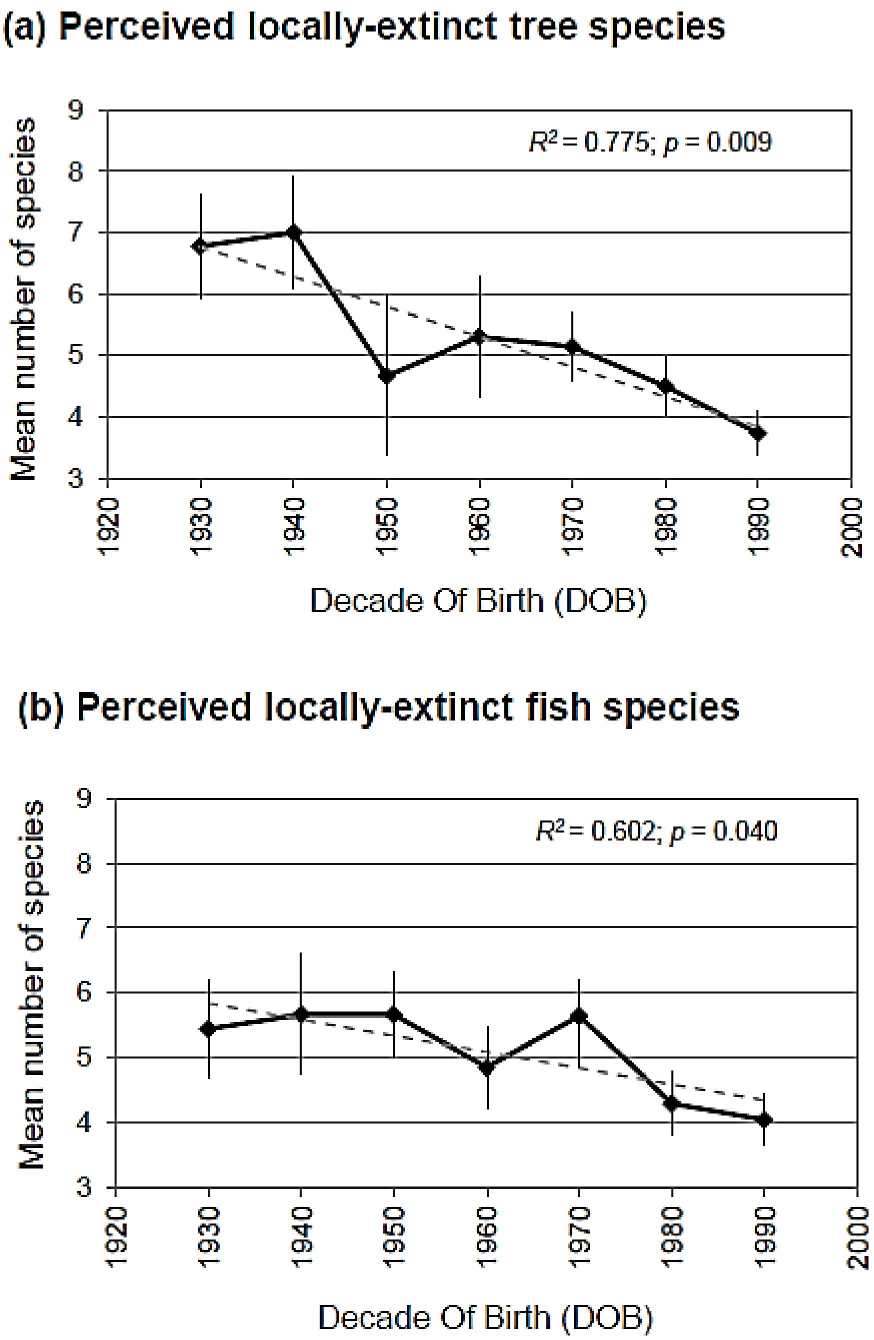
## 4.3. Evidence of scarce intergenerational communication

The third condition we use to test the existence of generational amnesia relates to intergenerational communication regarding ecosystem change. Table 4.4 provides descriptive statistics of variables measuring the number of locally-extinct tree and fish species reported. The average number of locally-extinct species reported (above 4.7 species for both measures) suggests the existence of a relatively high knowledge of species having gone extinct in the area.

Results from the focus groups reveal that many Tsimane' informants are seriously concerned about different barriers for a successful LEK intergenerational transmission. According to them, such barriers include: (a) lack of communication between old and young generations mainly due to the increasing disregard by young generations for their elders; (b) rapid loosening of the traditional norms regulating the process of cultural transmission (e.g., weakening importance and practice of different rites and beliefs, which are intrinsically associated with the transmission of knowledge); (c) changing patterns in certain subsistence practices, as exposure to market integration grows, preventing young generations from spending long and continued periods of time with their elders; and (d) increasing exposure of young generations to formal schooling, discouraging experiential learning of Local Environmental Knowledge. The ripple effects of these phenomena, according to most of our informants, strains the capacity of sharing and transmission of LEK systems amongst the Tsimane'. Moreover, the gradual disappearance of the current knowledgeable elders is also cited as one of the factors explaining the decreasing LEK acquisition amongst the young Tsimane'.

The results of the regression of the mean number of locally-extinct species reported per each age group against the DOB show that, for tree diversity (Figure 4.3a), on average, older respondents report significantly higher numbers of locally-extinct species than younger respondents ($R^2$ = 0.775; $p$ = 0.009). The same was found for fish diversity (Figure 4.3b), with older Tsimane' reporting higher numbers of locally-extinct species than younger Tsimane' ($R^2$ = 0.602; $p$ = 0.040). These results suggest that not all environmental knowledge on ecosystem change is being shared between different generations, as young generations do not seem to be learning about all locally-extinct species from older generations.

**Figure 4.3 |** Evidence of low levels of intergenerational communication.




Note: Mean number of: (a) locally-extinct tree species free-listed by groups of individuals born in the same DOB; and (b) locally-extinct fish species free-listed by groups of individuals born in the same DOB. The dashed grey lines show the fitted regression models. The bars indicate the Standard Error (SE) of the mean number of species reported.

## 4.5. Discussion

Our analysis of the three characteristics associated with the existence of SBS, (a) locally-relevant environmental change, (b) age-related differences in the perceptions of change, and (c) decreasing intergenerational transfer of knowledge, suggests that they are all simultaneously taking place amongst the Tsimane'. Together, our results provide enough evidence to assert the existence of SBS amongst the population studied, at least with regard to wildlife diversity. In other words, the baseline against which Tsimane' measure ecosystem change seems to be shifting with every new generation, rising from age-related differences in the perception of change and the decreasing intergenerational environmental knowledge sharing. As a result, the younger Tsimane' generations have a relatively inaccurate and poor conception (at least compared to their elders) of past ecosystems and the changes undergone in their surrounding environment.

This study is amongst the first to provide a complete conceptual framework to empirically demonstrate SBS within an indigenous society. Our methodological design stresses the complexity of LEK change across time and provides a useful starting point for examining the resilience of LEK systems in a context of GEC, especially where longitudinal data on LEK are not available (Kumar 2002; Godoy et al. 2009). While an important development in itself, the methodology proposed has at least three limitations that might have biased our results. The first relates to personal amnesia (see Section 4.2.1). While our data do not allow us to test the existence of personal amnesia amongst the Tsimane' (due to unavailability of data comparing one generation at different points in time), we cannot dismiss its possible occurrence. The second caveat relates to the free-listings designed to measure intergenerational communication. Ideally, we would have conducted the free-listings for the same species groups for which we measured the age-related differences in change perception (i.e., game and birds). This would have allowed testing for intergenerational communication on those groups. However, such a measure would have generated potential biases derived from immediate recall in our results. We therefore decided to conduct the free-listings with other elements equally central to the Tsimane' livelihood and culture (i.e., fish and tree species;

see Section 4.3.3). Further research could avoid such biases by doing the free-listings and the interviews on change perceptions with the same species groups, but in two distinct fieldwork periods with a sufficient time gap in between to avoid information retention (see Fernández-Llamazares et al. 2015). The third limitation relates to ecosystem change, as our results do not allow us to draw causal connections between ecosystem change and change perceptions.

We argue that future studies using the proposed framework would benefit greatly from: (a) the use of longitudinal or diachronic observations of changes in LEK (see Greenfield et al. 2000 or Reyes-García et al. 2013a for examples); and (b) the integration of quantitative ecological data directly linkable to data on local change perceptions. As suggested by Papworth et al. (2009), such long-term datasets would substantially improve the analysis of SBS. While our analysis based on the RLI proves to be a useful approach to directly link interview and biological data, its validity is hampered by the limited data available, especially due to highly scattered distributions and with years of assessment varying substantially from one species to another. Yet, even with these limitations, RLI can serve as an evidence of the changing state of biodiversity. With the gradual aid of longer sets of biological data, the use of indicators such as RLI will probably become an increasingly used tool in research on social-ecological change (see Vidal-Abarca et al. 2014). Furthermore, the type of research presented here provides an example of the complementarity of data collected from the social and the natural sciences in answering questions, not only of profound theoretical relevance, but also with practical applications.

Despite these potential biases, our findings dovetail with the growing body of literature addressing the structural constraints of using LEK in the context of GEC (Naess 2013; Saslis-Lagoudakis et al. 2014). The failure to detect, understand, interpret and respond to change undermines resilience and exacerbates vulnerability to GEC (Lauer and Aswani 2010; Mercer et al. 2010; Simelton et al. 2013), even if SBS could eventually help diminish psychological distress stemming from yearning for a lost *ideal* past (see Doherty and Clayton 2011). In this context, SBS could be considered an indicator of the mismatch between the temporal rates of environmental change on the one hand, and adaptation of LEK systems on the other, as advanced in previous literature (Kameda and Nakanishi 2002; Berkes 2009; Gómez-Baggethun et al. 2013b). While some authors have showed that LEK is well-suited to detect sudden, abrupt ecosystem changes in the short term (e.g., changes in benthos after a tsunami, see Aswani and Lauer 2014), most research suggests decreasing effectiveness of LEK systems to account for gradual changes over long periods of time (Hanazaki et al. 2013; Kai et al. 2014). For example, Pahl et al. (2014) discussed misfits between the human mind, surrounding social dynamics, and climate change. Reviewing concepts from the sociology of time (e.g., Bergmann 1992; Trope and Liberman 2003), they observed a number of fundamental constraints that made challenging for peoples and societies to deal with the timescales of environmental change. Our findings support the idea that the temporal dimensions inherent in the physical phenomena of GEC are not well-suited to the timescales of local knowledge systems (Armitage and Plummer 2010; Pahl et al. 2014).

An alternative reading of our findings could be that LEK is changing very fast over time, which is why in the course of a few years people can lose sight of the magnitude of the ecosystem changes undergone. In other words, LEK systems might be changing quickly in order to parallel rapid ecosystem changes, most likely resulting in knowledge loss and/or erosion (as pointed out by Reyes-García et al. 2013a,b, 2014b). Yet, while LEK might be trying to adapt to match the changing realities, this does not mean that the changes are adaptive in the evolutionary sense. It is important to note that the results presented here do not necessarily imply that LEK systems do not have capacity to adapt to changing environments, but rather that the timescale needed for environmental changes to be captured in social memory may be longer than the timeframe at which GEC is currently taking place (see Held 2001 or Weatherhead et al. 2010 for other examples). Since multigenerational LEK is an instrumental element for dealing with current and projected environmental changes, SBS could represent a significant setback to the fostering and strengthening of adaptive capacity (van Densen 2001; Robards and Alessa 2004), leading to slow societal change and delay in implementing effective policies with regard to ecosystem change.

The implications of the results presented in this paper are, in our opinion, profound. The difference between perceived and actual change contributes to the ability of a social-ecological system to respond and adapt to GEC (Stamm et al. 2000; Davidson-Hunt and Berkes 2003; Byg and Salick 2009). The magnitude of such a gap has been implicated amongst the main barriers to successful GEC adaptation (Tyler et al. 2007; Salick and Ross 2009; Patt and Weber 2014) and strongly defines how adaptive, flexible and, ultimately, efficient a society's LEK is under conditions of rapid environmental change (Alessa et al. 2008; Turvey et al. 2010). This study suggests the existence of SBS affecting LEK and originating from generational amnesia. Yet, the Tsimane' society could only respond effectively to ecosystem change if their perceived changes were in accordance with the actual changes occurring in the ecosystem, considering that decisions regarding natural resources are often based on the local perception of their availability (Oba and Kotile 2001; Voyer et al. 2012). If we take into account that the Tsimane' are increasingly shifting towards younger decision-makers (with skills in the national language, in order to channel demands to the national society; see Reyes-García et al. 2008, 2014b), questions arise regarding whether the difference between perceived and actual change may undermine the likelihood of adaptive responses promoting sustainability over time.

The Tsimane' seem to agree that there is a gradual disappearance of traditional institutions that used to help them to transfer knowledge from generation to generation. This is generally attributed to a decline in direct interactions between elders and young generations. Such perception contrasts with the work of Reyes-García et al. (2009) showing that the transmission of ethnobotanical knowledge and skills amongst the Tsimane' continues to take place and is mostly oblique (i.e., from older to younger generations, excluding parents). However, it is important to note that change in LEK is a complex process (see Gómez-Baggethun and Reyes-García 2013) and rapid social-ecological changes can have a different impact on the various domains and dimensions of LEK (Reyes-García et al. 2007a, 2013b; McCarter and Gavin 2013). Knowledge of ecosystem change is more likely to be vulnerable to fast-changing ecological conditions than other LEK domains of a more practical and tacit nature and directly tied to the meeting of imminent subsistence needs, which in turn are likely to be more adaptive (Berkes and Jolly 2001; Ford et al. 2006; Reyes-García et al. 2013b).

Although the results presented here are case-specific, we believe that they yield insights applicable to other contemporary social-ecological systems exposed to rapid change. It is important to note that SBS has a strong relevance for conservation science. SBS can distort data on biophysical conditions obtained using LEK (e.g., for assessment of ecosystem long-term dynamics; see Daw 2010 or O'Donnell et al. 2010) and should therefore be taken into account particularly where conservation target-setting for species or habitat regeneration is informed by human perceptions of change (e.g., Sheil and Lawrence 2004; Anadón et al. 2009; Danielsen et al. 2014). This is particularly determining for community-based conservation or programs lacking long-term biological data (Lavides et al. 2009; Tesfamichael et al. 2014). In such cases, data issued through LEK need to be assessed as to whether they could be affected by SBS, in which case they should be used with particular caution (Dulvy and Polunin 2004; Ainsworth et al. 2008; Daw et al. 2011).

The associated lack of adaptive capacity entailed by SBS calls for developing and strengthening programs aimed at tackling this phenomenon and better engaging local peoples in the global conservation challenge (see Kai et al. 2014). For instance, by facilitating intergenerational transfer of local knowledge on natural baselines and establishing more accurate local narratives of change, we could contribute to the challenging issues of: (a) revitalising the biocultural systems of knowledge that have been significantly interrupted; and (b) co-generating insights that are practicable for novel realities, such as GEC, across generations. Both approaches can slow the process of SBS, build knowledge, and enhance cultural self-esteem and engagement with conservation, not just amongst the younger Tsimane' generations studied here, but also for other local peoples, indigenous and non-indigenous, who wish to better understand and adapt to the environmental changes occurring at both local and global scales.

## 4.6. Concluding remarks

Accurate perceptions of ecosystem change hold huge potential in furnishing collective and adaptive responses to GEC (e.g., Stern 2000). Therefore, cognitive processes such as SBS, which result in a loss of knowledge on past ecosystems, may have critical impacts on community resilience in the face of GEC. SBS shows that the gap between actual change and the change perceived by a given society is widening as GEC proceeds with ever increasing speed, and as the functions of collective longitudinal information transfer of LEK systems are disrupted. This desensitisation to ecosystem change may lead to an accumulation of shifts, potentially compromising the adaptive capacity of the social-ecological system. In order to prevent this, we argue that *in situ* LEK revitalisation efforts can play a crucial and positive role in GEC adaptation in small-scale societies. Yet, LEK is likely to be weaker and less adaptive in the absence of a flexible multigenerational mosaic allowing cultural transmission and providing practicable insights for novel realities such as rapid ecosystem change. The latter point is essential for enhancing adaptive processes, since GEC calls not for the resurrection of bodies of LEK in frozen forms, but rather for dynamic knowledge systems that are opportune to deal with the current new global scenarios (Gómez-Baggethun and Reyes-García 2013). Further research is needed to understand the cognitive underpinnings in local understandings of environmental change and local classifications of time and temporality of LEK systems, namely rates of temporal change in the local perceptions of GEC and personal amnesia. As SBS suggests, time is unquestionably of the essence if LEK is to persist amidst an era of GEC.

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# Chapter V

## Local perceptions as a guide for the sustainable management of natural resources: empirical evidence from a small-scale society in Bolivian Amazonia


### Abstract

Research on natural resource management suggests that local perceptions form the basis upon which many small-scale societies monitor availability and change in the stock of common-pool natural resources. In contrast, this literature debates whether local perceptions can be effective in guiding the sustainable management of natural resources. With empirical evidence on this matter still highly limited, this work explores the role of local perceptions as drivers of harvesting and management behaviour in a small-scale society in Bolivian Amazonia. We conducted structured interviews to capture local perceptions of availability and change in the stock of thatch palm (*Geonoma deversa*) amongst the Tsimane', an indigenous society of foragers-horticulturalists ($n$ = 296 adults in 13 villages). We analysed whether perceptions of availability match estimates of abundance obtained from ecological data and whether differences in perception help to explain harvesting behaviour and local management of thatch palm. Perceptions of availability of *G. deversa* are highly contingent upon the social, economic and cultural conditions within which the Tsimane' have experienced changes in the availability of the resource, thus giving a better reflection of the historical, rather than of the ecological, dimensions of the changes undergone. While local perceptions might fall short in precision when scrutinised from an ecological standpoint, their importance in informing sustainable management should not be underestimated. Our findings show that most of the harvesting and management actions that the Tsimane' undertake are, at least partially, shaped by their local perceptions. This paper contributes to the broader literature on natural resource management by providing empirical evidence of the critical role of local perceptions in promoting collective responses for the sustainable management of natural resources.



**Keywords:** collective action; common-pool resources; change perceptions; local peoples; overharvesting; Tsimane'.


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## 5.1. Introduction

Strong evidence suggests that small-scale societies are capable of designing robust institutional arrangements for managing natural resources sustainably (Ostrom 1999; Agrawal 2001; Basurto et al. 2013). Researchers have documented myriads of systems of communal ownership and collective management of common-pool natural resources (e.g., Ostrom 1990, 2010; Bodin and Crona 2008). These systems rely both on formal and informal institutions and are encoded in different rules, norms, conventions, sanctions, spiritual beliefs and taboos (Sirén 2006; Luz 2013; Salo et al. 2014).

Besides institutions, the extensive theoretical and empirical research on the management of common-pool natural resources pays particular attention to the role of individuals as decision-makers and to the circumstances under which decisions are made (Ostrom 1999; Agrawal 2001; Aswani et al. 2013). Researchers argue that, in order to enable and maintain sustainable management of natural resources, a critical first component is that resource managers hold accurate, relevant, and effective information of the natural resource to be managed, including information on its state, availability, quality and change (Alessa et al. 2008; Ostrom 2010). For many small-scale societies, a common way to obtain such information is through constant and active monitoring of the status of local resources (Bodin and Crona 2008; McCarthy et al. 2014). While some authors have emphasised the importance of tapping into scientific knowledge for effective monitoring of resources (Noss et al. 2005; Ostrom 2010), in many parts of the world governance and management decisions regarding natural resources are not based on scientific knowledge, often because of its unavailability (Rist et al. 2010; Fernández-Llamazares et al. 2015a). On the contrary, local knowledge and individual perceptions often form the basis upon which many small-scale societies monitor availability and change in natural resources (Maule and Hodgkinson 2002; López-Hoffman et al. 2006). For this reason, local perceptions are considered critical in designing the success of the sustainable management of natural resources amongst small-scale societies (Oldekop et al. 2012; McCarthy et al. 2014).

In general, local peoples do not base decisions regarding natural resources on conventional cost-benefit analyses as defined by economists (Maule and Hodgkinson 2002). Rather, decisions are based on the accumulation of multiple and diverse sources of information, deriving from detailed and rich local knowledge of the environment, cultural values and/or peer information (López-Hoffman et al. 2006; Alessa et al. 2008). For example, to monitor resource population status, aboriginal fishers in California eyeball the numbers of salmon in upstream migration (Swezey and Heizer 1977), Cree hunters in Canada estimate the amount of geese noise in staging areas (Moller et al. 2004), and indigenous Kichwa in Ecuador count the walking time to the closest stand of *Pholidostachys synanthera* (Salo et al. 2014).

Based on this information, local resource users often determine whether or not change merits a certain response or action, or possibly even a shift in management strategy (Oldekop et al. 2012). In some cases, local perceptions of change in the availability of natural resources have led to the adoption of bottom-up self-governed arrangements to regulate and/or adjust harvesting activities to safeguard sustainability (e.g., Rudel et al. 2002; Sirén 2006; Salo et al. 2014). However, in other cases, the decreasing availability of natural resources might not be perceived as such and/or internalised as a communal problem, thus weakening possible initiatives of collective action (Lu 2005; Bodin and Crona 2008). For example, detailed ethnographic reports from various small-scale societies across the tropics show that localised depletion of resources has often led to individuals maximising their individual foraging efficiency and increasing harvesting effort, despite the potential ecological consequences of such decisions (Alvard et al. 1997; Peres 2000). Such examples thus show that local perceptions may not always be effective in preventing resource exhaustion and guiding a sustainable use of natural resources (Lu 2001; Peres 2010; Fernández-Llamazares et al. 2015b).

Why is it that local perceptions of availability and change in the stocks of natural resources do not always result in fostering their sustainable management? Empirical evidence on this matter is still highly ambiguous, largely due to a considerable lack of research exploring local perceptions as drivers of harvesting and management behaviour in the context of specific natural resource challenges. In order to fill this gap, this study investigates local perceptions of availability and change in the stocks of thatch palm *Geonoma deversa* amongst the Tsimane', a small-scale society in Bolivian Amazonia. Thatch palm is a cultural keystone species for the Tsimane' (*sensu* Garibaldi and Turner 2004), in that it has great symbolic value and cultural importance for Tsimane' identity (Huanca 2008).

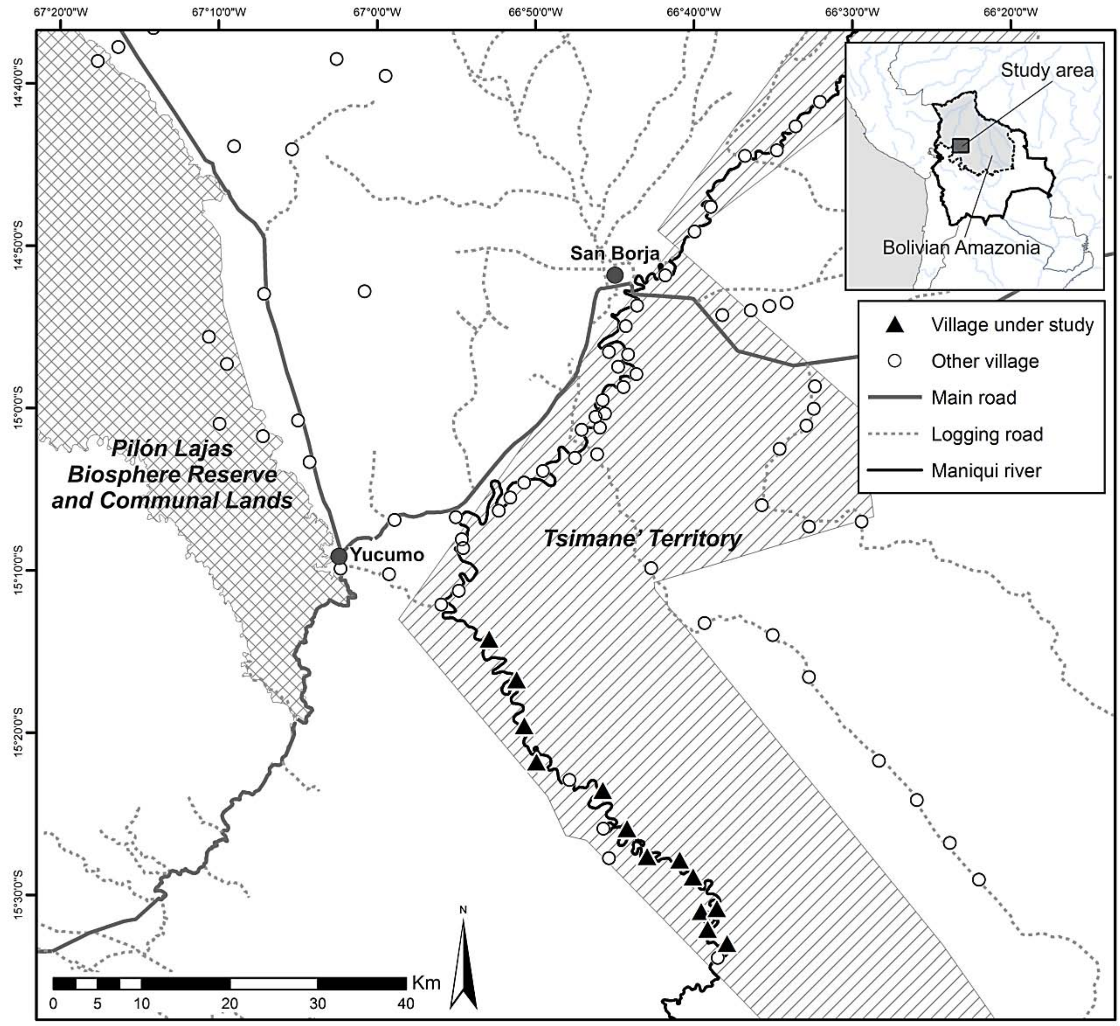
In the present work, we use the terms of *availability perception* and *change perception* as leading analytical concepts. Availability perception is defined as the individual evaluation of the available stocks of a given resource at the present moment, while change perception is defined as the individual evaluation of change in the stocks of a given resource over time. Following Verweij et al. (2010) both concepts are defined in the wider context of observation and successive evaluation, interpretation and appreciation of all information captured, i.e., both from personal experience and other sources.

Our research pursues three specific objectives: (a) to describe the Tsimane' management regime of *G. deversa* as currently practised; (b) to examine whether there is concordance between local perceptions of *G. deversa* availability and estimates of availability obtained from ecological data in the Tsimane' Territory; and (c) to analyse whether different perceptions of *G. deversa* availability and change explain harvesting behaviour and local management in general. On the basis of our results, we contribute to the broader literature on natural resource management by providing evidence of the critical role of local perceptions in promoting collective responses for the sustainable management of natural resources.

## 5.2. Case study

The Tsimane' are a foraging-horticulturalist society of about 12,000 people living in the Department of Beni, Bolivian Amazonia (see Huanca 2008). We conducted research in 13 villages of the Tsimane' Territory, an area of ca. 400,000 hectares lying between the eastern foothills of the Andes and the flooded pampas of Moxos (Figure 5.1). The area studied is communally owned by the Tsimane' (Reyes-García et al. 2014). Most of the Tsimane' Territory is covered by *terra firme* rainforests with a high semi-deciduous canopy reaching 40 metres (Guèze et al. 2014a).

**Figure 5.1 |** Study area and villages surveyed.




## 5.2.1. Thatch palm (*Geonoma deversa*)

*Geonoma deversa* (known as *jatata* in Spanish or *cajtafa'* in Tsimane') is an understorey palm species found in the lowland old-growth forests of Bolivian Amazonia. It has multiple stems (3-30 per plant) and can produce new stems from basal shoots even after one or several stems are cut (Paniagua-Zambrana 2005). Some of its characteristic features are its medium size (up to 3 metres tall), its trifoliate leaves (up to 75 cm length), and its flower pits (Moraes 1999).

*G. deversa* is largely distributed across the humid forests of the Amazonian Occidental Basin, including the Bolivian lowlands, although the density of the species varies from one site to another (Moraes 1999). The species has a patchy distribution (i.e., it typically grows in isolated, locally dense population patches), with densities ranging from 70 to 2000 individuals per hectare (Ergueta et al. 2006). It also has highly specific habitat requirements, restricted to humid *terra firme* old-growth forests mostly in the upper flanks of ridges, in well-drained soils (Paniagua-Zambrana 2005). Such stands are locally known as thatch palm groves and they provide rich habitat for wildlife. In the Tsimane' Territory, *G. deversa* is naturally abundant in the upper Maniqui River, but scarcer in the moist forests downstream of the Maniqui (Ergueta et al. 2006).

### 5.2.2. Traditional uses of *G. deversa* amongst the Tsimane'

*G. deversa* leaves are traditionally harvested for the use of thatch roofing of Tsimane' houses (Reyes-García 2001). Thatch palm harvesting occurs year round and is usually performed in collective expeditions involving all members of a household (including men, women and children) or, in many cases, several households from the same clan or extended family. These harvests are important social activities that provide links to the ancestors and to Tsimane' land and cultural identity (Huanca 2008). *G. deversa* stems are short, usually 1-3 m, such that their fronds can easily be harvested without felling the whole plant (Paniagua-Zambrana 2005). The fronds are then carried back to the village, where they are woven into roof panes, both by men and women. On average, 500 thatch palm panes, with ca. 300 leaves each, are needed for roofing a surface of 100 $m^2$ (Paniagua-Zambrana 2005).

Tightly woven thatch palm panes provide a leak-free and burn-tolerant roof that can last up to 20 years before needing replacement (Moraes 1999). Although the leaves of other palm species are also used by the Tsimane' for the thatching of their houses (see Reyes-García 2001), *G. deversa* is by far the most valued species due to its exceptionally longer durability. *G. deversa* roofs of the Tsimane' houses are amongst the most characteristic features of the communities along the Maniqui River (Pauly 1928). While tin roofs have begun to replace thatch roofs in some villages closer to town, *G. deversa* continues to be highly popular due to the coolness it provides. The cultural importance of *G. deversa* can be seen also in that it appears in many Tsimane' oral stories and traditions, including Tsimane' creation myth (Huanca 2008).

### 5.2.3. History and importance of thatch palm trade in the Tsimane' Territory

Thatch palm does not only serve an important function in local livelihoods, but has also long been an important cash product, with demand from urban and peri-urban areas. It has thus formed the basis of a specific market, with traders specialised in sourcing, transporting, and commercialising the product. Ethnographers situate the arrival of the first traders to the Tsimane' Territory around the 1950s (Riester 1993; Huanca 2008), but it was not until the early 1980s that the demand for the species experienced a regional boom (Guèze et al. 2014b). Being the cheapest alternative to corrugated iron, thatch palm panes became highly valued throughout the Bolivian lowlands, particularly in touristic venues, due to its rustic look. Thus, it is hardly surprising that the commercialisation of *G. deversa* became also a primary source of income for the Tsimane' (Godoy et al. 2001). Today, *G. deversa* is the most important non-timber product traded by the Tsimane', often used also as currency in barter when obtaining commercial products from traders (Luz 2013).

Traders acting as intermediaries are usually the ones responsible for the commercialisation of *G. deversa* in the market town of San Borja (Figure 5.1). These traders regularly visit Tsimane' villages in the upstream part of the Maniqui, where they deliver commercial items (e.g., salt, alcohol) en route up river, in exchange for future deliveries of woven thatch palm panes that they agree to collect during their trip downriver. If the deliveries of thatch palm are not ready when the traders return to the villages, the debts grow higher through the application of interest rates. Ethnographic reports show that traders often intimidate and exploit the Tsimane', and also take advantage of their limited mathematical skills to cheat them when making deals, further indebting them (Reyes-García et al. 2001; Huanca 2008).

Despite attempts to overturn the unfair productive system around thatch palm, even nowadays the barter with non-Tsimane' traders as described above continues to be the norm in the area. In the last years, the mounting extractive pressure of *G. deversa*, driven by market demand, has led to the region's thatch palm groves becoming ever more scarce, particularly in the vicinity of Tsimane' settlements (Moraes 1999). Apparently, during the 1970-80s, the harvesting of *G. deversa* did not cause a severe negative impact on the species, since the gathering was moderate and the palms regenerated quickly (Huanca 2008). Yet, following the regional boom of the 1980s, thatch palm has started to show clear signs of local depletion due to overharvesting (Ergueta et al. 2006; Guèze et al. 2014*b*).

## 5.3. Methods

We conducted fieldwork between September 2012 and November 2013 in 13 villages located in the upper Maniqui River where, according to Ergueta et al. (2006), *G. deversa* is present. To carry out this study, we first obtained Free Prior and Informed Consent (FPIC) of each village and individual participating in the study, as well as the agreement of the Tsimane' political organisation, the *Gran Consejo Tsimane'* (Great Tsimane' Council). In addition, this research adheres to the Code of Ethics of the International Society of Ethnobiology (ISE). The Ethics Committee of the Universitat Autònoma de Barcelona (UAB) approved the research (CEEAH-04102010; LEK Project 2014).

All adults (≥ 16 years) in the villages were invited to participate in the research. We encouraged both women and men to participate in the study with the aim of ensuring equal representation in the sample. Overall, we had a participation rate of more than 80% of the adult population of each village, across all villages. Our analysis draws on three different sources of information, each one addressing one of the three objectives of the work.

### 5.3.1. Ethnographic description of the Tsimane' management regime of *G. deversa*

Despite the number of works already describing the different domains of Tsimane' forest management practices (e.g., Reyes-García 2001; Godoy et al. 2001; Luz 2013), explicit accounts of rules regulating access, use and management of *G. deversa* are rare. We collected qualitative ethnographic information, complemented with participant observation in thatch palm harvesting expeditions. Overall, we conducted eight field visits to different thatch palm groves, accompanying different Tsimane' families in their harvesting of *G. deversa* (see Table 5.1 for descriptive statistics of the sample). In each visit, we carefully observed the actual harvesting technique. Once the harvest was performed, and before starting the way back to the village, we asked informants to explain the norms and practices related to the management of the species. Such *in situ* open-ended interviews lasted 15 to 30 minutes each, during which we took detailed field notes. We used the responses given and our field observations to inform the research design and to contextualise results from quantitative data collection methods.

**Table 5.1 |** Summary descriptive statistics of the sample composition.

| Objective | Data collection | Nr villages | Variable | Descriptive statistics | | | | |
|---|---|---|---|---|---|---|---|---|
| To describe the Tsimane' management regime of *G. deversa* as currently practised | Field visits and open-ended interviews | 3 villages | Age | *n* | Mean | SD | *min* | *max* |
| | | | | 15 | 35.00 | 10.38 | 21 | 49 |
| | | | Sex | 10 men (66.67%)<br>5 women (33.33%) | | | | |
| To examine whether there is concordance between local perceptions of *G. deversa* availability and estimates of availability obtained from ecological data in the Tsimane' Territory | Structured interviews | 13 villages | Age | *n* | Mean | SD | *min* | *max* |
| | | | | 296 | 38.35 | 17.80 | 14 | 88 |
| | | | Sex | 142 men (47.97%)<br>154 women (52.03%) | | | | |
| | Focus groups | 2 villages | Age | *n* | Mean | SD | *min* | *max* |
| | | | | 16 | 36.53 | 15.58 | 19 | 70 |
| | | | Sex | 9 men (56.25%)<br>7 women (43.75%) | | | | |
| To analyse whether different perceptions of *G. deversa* availability and change explain harvesting behaviour and local management in general | Semi-structured interviews | 2 villages | Age | *n* | Mean | SD | *min* | *max* |
| | | | | 97 | 40.07 | 20.32 | 16 | 84 |
| | | | Sex | 53 men (54.64%)<br>44 women (45.36%) | | | | |

### 5.3.2. Measurement and validation of local perceptions of *G. deversa* change and availability

To measure local perceptions of *G. deversa* change and availability, we conducted structured interviews with 296 adults (≥ 16 years old) in 13 villages (Table 5.1). Ethnographic evidence indicates that the Tsimane' perceive *G. deversa* availability in terms of walking distance (Fernández-Llamazares et al. 2014). Owing to the fact that *G. deversa* grows mostly in ridges and generally far from villages, the Tsimane' have to walk several hours, often climbing pronounced slopes, to reach the closest thatch palm groves. Carrying the harvests –of up to 20 kgs– back to their villages is also no easy feat. Thus, when asked about how much available *G. deversa* there is in the area, their answers generally refer to the walking time to the closest thatch palm grove.

In order to measure the individual perception of thatch palm availability, and based on our ethnographic observations, we asked about the amount of time that a person has to walk to reach the closest thatch palm grove. Based on previous research in the area, we transformed the time reported to kilometres at an average rate of 2.36 km/h (Luz 2013). In order to measure individual perceptions of thatch palm change, we followed a methodology used previously (see Fernández-Llamazares et al. 2015b), asking individuals about perceived baselines *versus* present state. We used the informant's childhood (i.e., Decade Of Birth, DOB) as an individual baseline. We first asked how long they had to walk to reach the closest thatch palm grove at present time (availability). We then asked how long they had to walk at their DOB (baseline). We transformed both times perceived into walking distances. We then obtained a surrogate measure of change perceived by each individual, comparing the current perceived walking distance with the perceived situation in the DOB.

Owing to the fact that clocks and watches are still quite inaccessible to most Tsimane', the measure of how long it takes someone walk to reach the closest thatch palm grove might be probably flawed. To assess the magnitude of the error, in each of the eight expeditions to gather thatch palm, we measured the time invested in walking until reaching the closest thatch palm grove. Upon arrival, we asked informants to estimate how much time they had walked. Results suggest that people interviewed are able to intuitively assess time with relative accuracy. Although all estimates were biased (ca. ±15%), the bias was similar between villages. So even if the temporal perceptions reported are actually flawed, the level of flaw is most certainly similar in all villages, thus not altering substantially our estimation results.

We also obtained ecological estimates of the availability of the species. First, from 2008 to 2012, a group of researchers carried out a project of participatory mapping of Tsimane' land use (Reyes-García et al. 2012). The team conducted communal workshops in the Tsimane' Territory where villagers sketched maps that included land-use features, such as thatch palm groves. Over the days following the workshop, researchers and village guides covered each village area on foot taking GPS readings of all the thatch palm groves. The data from the sketch maps and GPS readings were later processed in GIS, providing the most extensive distribution map available for *G. deversa* in the Tsimane' Territory. Second, as part of a floristic inventory from another project (see Guèze et al. 2014a for more details), we noted the presence of *G. deversa* in 48 0.1-ha old-growth forest plots established in the territory of six Tsimane' villages (eight plots per village) to cross-verify that *G. deversa* was abundant in the areas catalogued as thatch palm groves.

Drawing on the combination of both datasets and with the aid of GIS software, we could obtain a measure for the average distance to the closest thatch palm grove for each of the study villages (Figure 5.1). In all cases, this distance was calculated from the village school (which the Tsimane' consider their village centre), and with the walking route always following already established trails. To examine if local perceptions match estimates of the availability of *G. deversa*, we compared the village average measured distance with the village average perceived distance at present time (i.e., availability perception).

In order to examine if changes in the availability of *G. deversa* have taken place at different timescales along the Maniqui River, we ran a series of t-tests comparing the change perceptions of both older and younger individuals (i.e., born before or after 1970) living in both villages closer or further from the main market town (i.e., less or more than 90 km, respectively). To contextualise our results we also conducted focus group discussions in two of the villages. All in all, 16 adults (9 men and 7 women) of different ages (*min* = 19 and *max* = 70) attended the meetings. During the focus groups, we asked participants about the history of thatch palm trade in the area, the first signs of thatch palm depletion, and measures to prevent *G. deversa* overharvesting.

### 5.3.3. Measurement of the behaviour regarding *G. deversa* harvesting and management

Accurately measuring *G. deversa* harvesting behaviour and management decisions requires long periods of continued observation (e.g., to obtain reliable estimates of thatch palm extraction, controlling for seasonal variations). Conducting such detailed longitudinal research in all 13 villages along the upper Maniqui River was beyond the scope of our possibilities. Instead, we chose to focus this aspect of our study on the two potentially most contrasting villages: the one closest to the market town (a one-day canoe trip from San Borja, Figure 5.1) and the one furthest from the market town (a three-day canoe trip from San Borja). Due to their differences in distance from –and access to– the nearest market town, visits by thatch palm traders also differ drastically between the two villages. For instance, while traders have quite regularly visited the closer village for the last 40 years, their continued presence is relatively more recent in the isolated village. We interviewed a total of 97 adults (≥ 16 years old) in the two villages about individual behaviour regarding *G. deversa* harvesting and management (see Table 5.1 for descriptive statistics of sample composition).

With regard to individual behaviours in thatch palm harvesting and management, we used different quantitative methods. First, individual harvesting behaviour was measured with two standard proxies: (a) number of thatch palm panes produced; and (b) thatch palm productivity (panes/h), both in the course of one year. To collect these data, we used an anthropological technique known as scan observations (Reyes-García et al. 2009). Each week, on a randomly selected day, we visited each household in the village and asked the adult(s) present to tell us the amount of *G. deversa* (measured in panes) that they themselves had harvested in the previous two days. Over the course of 12 months, this method generated an average of 23.42 observations per person (*SD* = 6.73). We also asked those present in the household of the time they had invested in thatch palm harvesting. Based on these figures, we calculated individual thatch palm harvest productivity as the number of thatch palm panes produced per hour invested (panes/hour).

Individual behaviour with regard to thatch palm management was further measured with the help of two standard proxies: (a) rule compliance; and (b) involvement in informal institutions. To assess rule compliance, we created an index (ranging from 0 to 3) that captures the interviewee's self-reported degree of respect towards Tsimane' rules regulating the harvesting of *G. deversa*. This index, adapted from Luz (2013), was based on responses to three binary questions to which thatch palm harvesters could respond either that they adhered (*1*) or not (*0*) to the specified set of management norms or rules. The questions included three important aspects of management of the palm: (a) respect to the norms regarding harvesting intensity; (b) respect to the rules regulating no-take areas; and (c) respect to the thatch palm groves owned by other households. Thus, the resulting score comprises the number of times that the person reported rule compliance. With regard to individual involvement in informal institutions, attendance to the three meetings held in each village during June-August 2012 was used as a proxy measure. Since village meetings are one of the most important fora for addressing and discussing intra- and inter-village conflicts around use, access and management of thatch palm groves, our proxy is a directly relevant measure of involvement in collective action with regard to the management *G. deversa*.

We then ran a series of Ordinary Least Square (OLS) and Poisson regressions to test the association between individual harvesting and management behaviour on the one hand and individual perceptions of *G. deversa* availability and change on the other. All regressions were carried at the village level, to compare the village closer and further from town, included controls for age and sex, and were clustered based on the household of the informants. Statistical analyses were performed with Stata 12.1 (StataCorp 2011).

## 5.4. Results and discussion

### 5.4.1. Tsimane' management regime of *G. deversa*

The Tsimane' legally hold communal land titles since 1996, although the land demarcation process is yet to be finalised (Reyes-García et al. 2014). In fact, the Tsimane' do not traditionally adhere to a system of individual land tenure (Godoy et al. 2001). Natural resources in the Tsimane' Territory, including *G. deversa*, have generally been managed under common-property tenure (*sensu* Ostrom 1990).

Therefore, at least in the past, thatch palm was considered a common-pool resource and regulated through norms of customary access (Reyes-García et al. 2012). Most thatch palm groves in the area are governed by informal norms of access. Results from individual interviews suggest that today the Tsimane' recognise customary ownership of these thatch palm groves, i.e., specific households have access to and rights over specific thatch palm groves, meaning that these groves are for the designated household's use only. These user rights are generally defined according to the Tsimane' customary usufruct system, such that a stand of thatch palm belongs to the household or clan (i.e., group of households) who first harvested it and is generally the property of households with closest access (from their houses or agricultural plots), from which they generally trace their trails (Huanca 2008).

Although the Tsimane' Territory is communally owned by all Tsimane' inhabiting the area, and not by specific villages, villages have informal internal boundaries (Reyes-García et al. 2014). Villagers routinely trespass them in daily activities such as hunting and gathering, but over the years there have been reports of increasing inter-village conflicts when the trespassing involves the collection of resources with a market value such as *G. deversa* (Reyes-García et al. 2012). For this reason, the political organisation representing the Tsimane', the Great Tsimane' Council, has encouraged villages to agree on specific rules to avoid inter-village conflicts with regard to thatch palm harvest. On a series of radiophonic messages, the Tsimane' organisation has recurrently recommended that villages zone their thatch palm groves to ensure that harvest agreements and rules are respected. Tsimane' from other villages are expected to seek authorisation from the local community for extraction of *G. deversa* on their land. In practice, the villagers are responsible for the control and monitoring of access to the resource, as well as for rule compliance, both for their family thatch palm groves and at the village level. The rules are enforced through a variety of means, including peer pressure, public shaming, or monitoring by informal groups of villagers sporadically surveying the area to prevent land invasions.

Over the years, and based on empirical learning, the Tsimane' have developed a number of practices, norms and techniques to manage *G. deversa* (Guèze et al. 2014b). Concomitant to the high tolerance of *G. deversa* to defoliation (Moraes 1999), the general guiding principle of the Tsimane' when harvesting *G. deversa* is that at least one third of the leaves of the plant should be left intact (Ergueta et al. 2006). Typically, the Tsimane' first cut off the old leaves, leaving the youngest ones and avoiding damage to the adjacent leaves. The most mature palms (with flowers or fruits; locally known as *mother plants*) are generally left uncut. In fact, the Tsimane' harvest only leaves from individual palms with stems over 1.5 metres height (Ergueta et al. 2006). All these techniques have been described as constituting a sustainable form of management, enabling: (a) the maintenance of new leaf yield; (b) the safeguard of reproductive individuals as seed bearers; and (c) an increase in light availability for the remaining leaves, avoiding intra-clonal shade and taking advantage of the greater photosynthetic capacity of the younger leaves (Chazdon 1991; Moraes 1999).

Interestingly, we did not find any strong evidence of a recognised limit amongst the Tsimane' as to how much *G. deversa* can be extracted from a thatch palm grove. To our knowledge, at least one village attempted to establish a system of quotas for each family based on the state of the resource, but the regulations came from a development project in the area. That said, there are some informal norms of management, including restrictions on the frequency of harvest, although these tend to be rather vague. The Tsimane' generally plan their *G. deversa* harvesting in 2-year cycles. When a zone of a thatch palm grove has been intensively harvested for one year, it is left aside as a no-take area (*sensu* Salo et al. 2014) for another year, thus allowing the harvested plants to recover. No individual is allowed to cut leaves from no-take areas. Other than these norms and the above-mentioned restrictions on cutting reproductive individuals, we found no active management practices for the enhancement of the resource stock, e.g., by seeding or planting *G. deversa*.

In recent years, different actors, including thatch palm traders, have started to compete over *G. deversa* resources with the local Tsimane' (Huanca 2008).

Traders often set their camps close to the thatch palm groves and harvest the resource without the consent of villagers (Huanca 2008). This situation has led to increasing conflicts. Reyes-García et al. (2012) reports that from all outsiders in the area (e.g., loggers, cattle ranchers, colonist farmers, etc.) the Tsimane' tend to have the highest number of conflicts with thatch palm traders. In an open letter directed to the Great Tsimane' Council (see Appendix V.a), some villagers of the upper Maniqui River denounced the situation and requested the expulsion of all outsider thatch palm traders from the Tsimane' Territory (see Fernández-Llamazares et al. 2014). According to locals, restricting palm thatch harvest to only Tsimane' could reduce the amounts harvested, thus increasing the probability for the maintenance of the resource stock. Although there have been some recent attempts to ban entrance to outsiders, thatch palm traders continue to enter the Maniqui River and harvest *G. deversa*.

## 5.4.2. Measurement and validation of local perceptions

Table 5.2 provides descriptive statistics of the variables measuring change and availability perceptions of *G. deversa*. The average value for our measure of change perception (3.46 ± 1.78 km) suggests that most Tsimane' interviewed perceive changes in thatch palm availability. Many Tsimane' expressed concern over the decreasing availability of *G. deversa* in the area and the potential impacts this might have on their livelihoods. As one informant stated: '*Thatch palm is disappearing very quickly and soon we won't even have anything to roof our houses.*' Yet, most Tsimane' interviewed consider that the set of rules restricting the intensity and frequency of thatch palm harvest are efficient in preventing resource exhaustion and ensuring sustainability over time (see also Fernández-Llamazares et al. 2014). The problem for many Tsimane' is that even if they may comply with the rules, others may not. As a result, palm growth and regeneration are hampered by unsustainable harvesting practices of an increasing number of careless resource users breaking the rules, more importantly the traders. As one local elder said '*The traders do not respect our traditional rules: that's why thatch palm is not growing anymore.*'

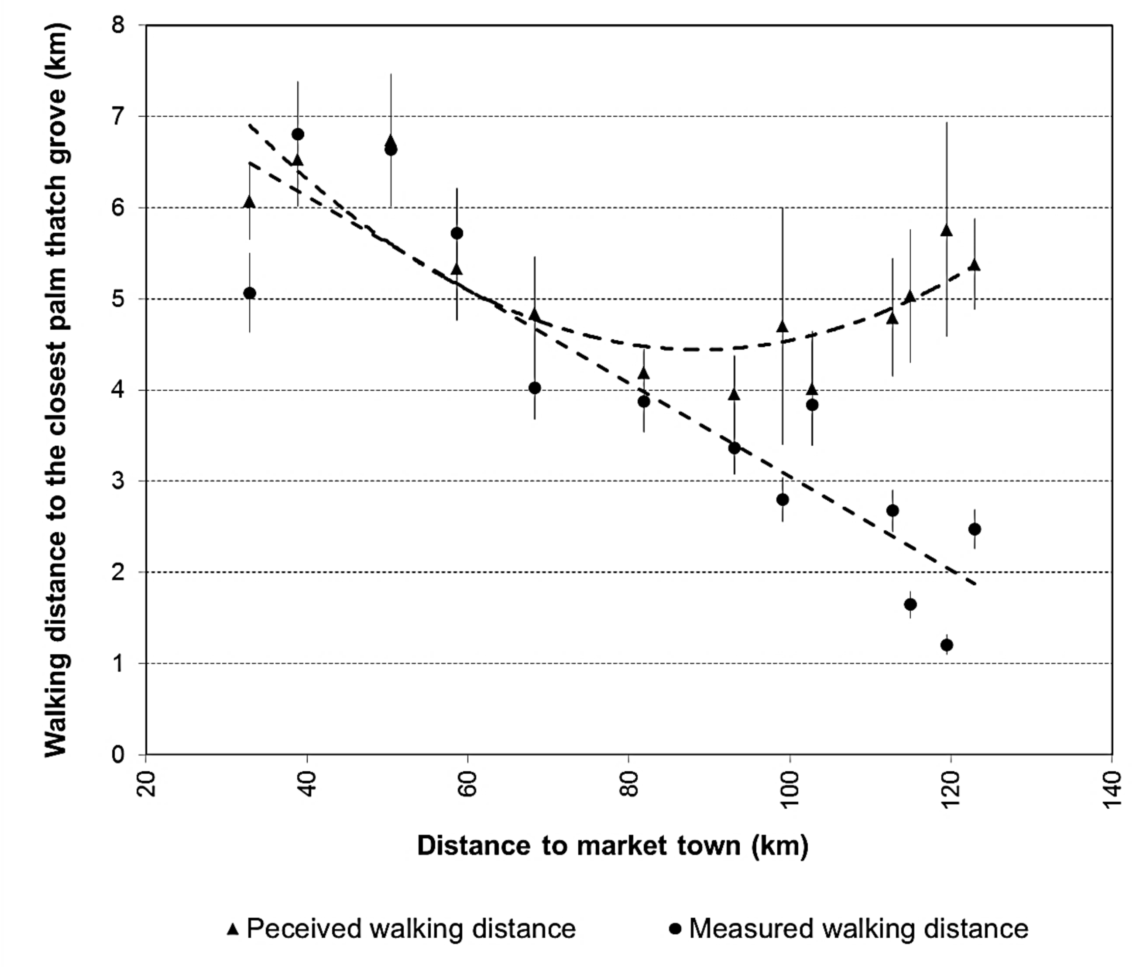
**Table 5.2 |** Definition and summary stastics of variables measuring perception of *G. deversa* change and availability amongst Tsimane' interviewees.

| Variable name | Description | Villages | Descriptive statistics | | | | |
|---|---|---|---|---|---|---|---|
| | | | *n* | Mean | SD | *min* | *max* |
| Perception of *G. deversa* availability | Perceived walking distance to reach the closest thatch palm grove (km) | All (*N* = 13) | 296 | 5.31 | 1.77 | 2.34 | 11.70 |
| | | <90 km from town (*N* = 6) | 152 | 5.72 | 1.58 | 2.34 | 9.36 |
| | | >90 km from town (*N* = 7) | 144 | 4.88 | 1.85 | 2.34 | 11.70 |
| Perception of *G. deversa* change | Difference in the perceived walking distance to reach the closest thatch palm grove in the past compared to the perceived walking distance to reach the closest thatch palm grove in the present (km) | All (*N* = 13) | 296 | 3.46 | 1.78 | 0.00 | 9.36 |
| | | <90 km from town (*N* = 6) | 152 | 3.63 | 1.64 | 0.00 | 8.19 |
| | | >90 km from town (*N* = 7) | 124 | 3.28 | 1.90 | 0 | 9.36 |

Note: For village information, see Appendix V.b.

Figure 5.2 shows a comparison between the average village-measured walking distance to the closest thatch palm grove and the average village-perceived walking distance (i.e., availability perception). *G. deversa* is still found in the vicinity of Tsimane' settlements (at less than 3.5 km distance), but only in those villages that are further away from town (i.e., more than 90 km). In other words, the measured walking distance to the closest thatch palm grove is shorter in villages further from town than in villages closer to town, most probably due to differences in accessibility also to thatch palm traders (see also Table 5.2). *G. deversa* availability estimates issued from ecological sampling match the local perceptions, but only partially. In villages closer to the market town, where *G. deversa* is only found further away from human settlements, local perceptions match ecological sampling data with relative accuracy. In contrast, the Tsimane' living in villages further from town seem to over-estimate the walking distance to reach the closest thatch palm grove, hence also under-estimating *G. deversa* availability.

**Figure 5.2 |** Mismatch between measured and perceived walking distance to the closest thatch palm groves.




Note: The dashed lines show the fitted regression models. The bars indicate the Standard Error (SE) of the mean walking distance (perceived and measured, respectively).

The results of the t-tests comparing change perceptions between younger and older individuals both in villages closer to and further from town suggest that the changes in thatch palm availability happened at different timescales along the Maniqui River (see Table 5.3). While older people seem to have witnessed more change in thatch palm availability during their lifetimes, change dates longer back in the villages closer to town than in the ones further upriver. This aligns well with the fact that the distance to the thatch palm grove is longer in villages closer to town, possibly indicating an advancing wave of harvesting pressure along the river. Considering that the topographical differences in the area under study are minor and that all the flanks and ridges in the upper Maniqui provide a suitable habitat for the species, as indicated by its presence (see Appendix V.b for more details), such decreasing trend is most likely the result of overharvesting. Furthermore, in the villages closer to the market town younger people report significantly greater past walking distances to the closest thatch palm groves than younger people in the villages further away ($p < 0.01$), implying a different timescale of changing conditions. Elders provided detailed complementary accounts of their temporal perspectives on *G. deversa* changes in the Maniqui River. According to them, in villages further from town, changes in *G. deversa* availability have been more abrupt and recent, whereas in villages closer to town, changes have been relatively more gradual and long-term due to the continued presence of traders, as illustrated by some of their statements: '*While the villages downriver depleted their thatch palm groves long ago, here we have worked to preserve our thatch palm*' or '*First they* (the traders) *ended with the thatch palm near San Borja and now that it is over, they come here to steal ours.*'

**Table 5.3 |** Differences in the perception of change per DOB between villages closer and further from town.

| **Variable** | **DOB of informants** | **< 90 km from town** | | | **> 90 km from town** | | | ***p*** |
|---|---|---|---|---|---|---|---|---|
| | | Obs | Mean | SE | Obs | Mean | SE | |
| Change perception | 1920-1959 | 35 | 4.023 | 0.276 | 23 | 4.095 | 0.338 | 0.565 |
| | 1960-1999 | 117 | 3.507 | 0.151 | 121 | 3.130 | 0.174 | 0.052* |
| | *p* | -- | 0.052* | -- | -- | 0.012** | -- | -- |
| Past walking distance | 1920-1959 | 35 | 2.229 | 0.261 | 23 | 1.280 | 0.180 | 0.005** |
| | 1960-1999 | 117 | 2.060 | 0.995 | 121 | 1.679 | 0.117 | 0.007*** |
| | *p* | -- | 0.233 | -- | -- | 0.079* | -- | -- |
| Current walking distance | 1920-1959 | 35 | 6.251 | 0.275 | 23 | 5.375 | 0.355 | 0.027** |
| | 1960-1999 | 117 | 5.567 | 0.143 | 121 | 4.790 | 0.170 | 0.000*** |
| | *p* | -- | 0.012** | -- | -- | 0.082* | -- | -- |

Note: * $p < 0.1$, ** $p < 0.05$ and *** $p < 0.01$

Our results sit well within the literature showing that perceptions of resource availability need to be interpreted not just from an ecological standpoint, but also as part of the broader context of historical changes, including an understanding of the complex relations between users, resources and livelihoods

(Sirén 2006; Alessa et al. 2008). If local perceptions of availability of *G. deversa* do not always match ecological estimates of local abundance, this is arguably because perceptions are highly contingent upon the social, economic and cultural conditions within which the Tsimane' have experienced changes in the availability of the resource. In villages further from town, where changes in thatch palm availability have been abrupt and perceivable at short-time scales, over-stated reports of resource unavailability may probably be signs of increased experience of risk by those Tsimane' whose livelihoods might be significantly threatened by *G. deversa* depletion. This is implicitly manifest in some of the statements raised by the villagers upriver: '*Very little thatch palm is left nowadays*' or '*What will our children sell when our thatch palm is over?*' Such risk perception is less manifest in the villages downriver, where there are plenty of alternative sources of monetary income (e.g., sell of timber or agricultural products) due to easier accessibility to the market town.

Additionally, such magnified claims on resource change may be the product of the higher cultural attachment to the resource in villages upriver (see Appendix V.a). It is noteworthy that in some villages upriver, *G. deversa* is sometimes named as *cajtafa' Tsimanes*, which translates to '*the thatch palm of the Tsimane' people*' (Ergueta et al. 2006), illustrating the strong cultural attachment of these villages to the resource. Since local perceptions are constructed based on arguably more subjective, procedural, spiritual, and sensory-oriented cognitive mechanisms (Moller et al. 2004), it is likely that the perceptions in villages upriver are magnified by a stronger cultural attachment to thatch palm as a resource shaping identity, social relations and local economies.

These results raise the multi-faceted and complex nature of local perceptions, interweaving the role of culture, power and history in understanding resource change, but at the same time, lead us to an important question. Could it be that the people in the villages upriver have perceived such a great change in thatch palm? Table 5.2 shows the people in villages upriver reported a change in the thatch palm groves of as much as an increase in walking distance of 3.28 ± 1.90 km in the last 30 years. However, in most of these villages, thatch palm groves are to be found nowadays within 3 km of the human settlements (Figure 5.2). Thus, according to locals, somewhere in the past, thatch palm would have been abundant in the vicinity of villages (i.e., less than 0.5km), in places other than the upper flank of ridges, which is apparently inconsistent with the ecological distribution of the species (Moraes 1999; Ergueta et al. 2006). A possible explanation for this misfit could be that the perceptions of people upriver are partially shaped by the resource trajectories undergone in villages closer to the market town, where the change seems to have been more critical. Ethnographic evidence shows that Tsimane' travel frequently along the Maniqui River, generally to visit kin (Reyes-García and TAPS 2012). In this context, it is likely that Tsimane' from villages closer to town might have transferred their change perceptions to the villagers from upriver who, in turn, might have internalised these perceptions as a threatening reality.

### 5.4.3. Local harvesting and management behaviour

Table 5.4 shows significant differences in harvesting and management behaviour between the two villages studied. In the village further from town, locals tend to harvest significantly higher amounts of thatch palm compared to the village closer to town ($p < 0.01$). Similarly, thatch palm harvesting productivity (panes/hour) is significantly higher in the village further from town than in the village closer to town ($p < 0.01$), where thatch palm is significantly less available, according to our ecological data ($p < 0.01$). In contrast, rule compliance and involvement in informal institutions are significantly lower in the village closer to town than in the village further from town ($p < 0.01$ and $p < 0.10$, respectively) where, despite the increased harvesting levels, there seems to be higher compliance with the Tsimane' management regime.

The fact that the management and harvesting behaviour are different in both villages is hardly surprising considering that the Tsimane' have been described as the indigenous group in Bolivia displaying the greatest variation in levels of both

**Table 5.4 |** Definition and summary statistics of variables measuring behaviour and perceptions in the two villages under study.

| Variable type | Variable name | Description | Village closer to town | | Village further from town | | t-test |
|---|---|---|---|---|---|---|---|
| | | | Mean | SE | Mean | SE | |
| Availability | Measured walking distance | Average measured walking distance to the closest thatch palm grove (km) | 5.065 | 0.221 | 2.478 | 0.108 | 0.000 |
| Perception | Availability perception | Average perceived walking distance to closest thatch palm grove (km) | 6.074 | 0.211 | 5.382 | 0.252 | 0.047 |
| | Change perception | Average perceived change of walking distance to the closest thatch palm grove over the respondent's lifetimes (km) | 4.321 | 0.234 | 4.104 | 0.266 | 0.538 |
| Harvesting behaviour | Panes | Mean individual number of thatch palm panes gathered in past two days (panes) | 2.622 | 0.421 | 5.355 | 0.661 | 0.001 |
| | Productivity | Average number of thatch palm panes gathered per hour invested in past two days (panes/hour) | 0.231 | 0.413 | 0.754 | 0.690 | 0.000 |
| Management behaviour | Rule compliance | Average individual self-reported respect of norms regulating thatch palm gathering (0-3) | 0.365 | 0.073 | 1.133 | 0.137 | 0.000 |
| | Involvement | Average number of communal meetings attended by an individual (0-3) | 1.904 | 0.153 | 2.355 | 0.199 | 0.071 |

integration into the market economy and cultural change (Godoy et al. 2001). In line with what is put forward in Salo et al. (2014) for the use of palm leaves by different Amazonian groups, we found significant differences regarding the extent to which there are community agreements and norms governing thatch palm management, and whether or not these are being followed and respected (Table 5.4). A possible explanation for these differences may lie in the degree of market integration, and its effects on eroding social capital (e.g., Basurto et al. 2013). In forest common-pool resources, market access has been found to reduce the durability of cooperative institutions for sustainable resource management (Young 1994; Agrawal 2001). Previous research amongst the Tsimane' has shown that integration into the market economy was negatively associated with investments in social capital; i.e., market economy promoting individualistic behaviours was found to be in detriment to pro-social behaviour (Godoy et al. 2007; Gurven et al. 2008).

The results of the regressions of individual harvesting and management behaviour against individual perceptions of *G. deversa* availability and change show some paradoxical findings (Table 5.5). In the village closer to town, we found: (a) negative associations between harvesting proxies and availability perception ($p < 0.01$ for panes and $p < 0.05$ for productivity); and (b) positive associations between harvesting proxies and change perception ($p < 0.05$ for both). In the village further from town, no significant relation was found between perceptions and harvesting behaviour. However, in the village further from town, we found: (a) a positive association between involvement in informal institutions and availability perception ($p < 0.05$); and (b) positive associations between our management behaviour proxies and change perception ($p < 0.01$ and $p < 0.05$, respectively). Contrarily, no association was found between perceptions and management behaviour in the village closer to town.

In the village further from town, where thatch palm is still relatively available, individuals display more attachment to the informal regime for managing thatch palm, probably because they have greater personal incentives to do so. Since thatch palm is still relatively available in these villages, individuals perceive that by investing time and effort in managing the resource at present (e.g., complying with management norms or attending meetings), they can reap personal benefits in the future. In other terms, individual investments in sustainable management might reflect a person's desire to have a safety net for the future. In contrast, in the village closer to town, where one has to walk up to 5 hours round trip (10.72 km) to harvest thatch palm, the payoffs to collective action are probably perceived to be lower.

**Table 5.5 |** Results of Ordinary Least Square (OLS) and Poisson Multivariate regressions of different individual harvesting and social behaviour variables against individual perceptions of *G. deversa* availability and change.

| Village | Explanatory variables | Dependent variable | | | |
|---|---|---|---|---|---|
| | | Harvesting | | Management | |
| | | Panes | Productivity | Rule compliance | Involvement |
| Closer from town | Availability perception | -0.741 (0.265)*** | -0.097 (0.042)** | 0.016 (0.042) | -0.012 (0.054) |
| | *n* | 52 | 52 | 52 | 52 |
| | $R^2$ | 0.234 | 0.116 | --- | --- |
| | *Wald* $Chi^2$ | --- | --- | 2.02 | 2.77 |
| | Change perception | 0.596 (0.242)** | 0.105 (0.039)** | 0.024 (0.041) | 0.034 (0.050) |
| | *n* | 52 | 52 | 52 | 52 |
| | $R^2$ | 0.210 | 0.153 | --- | --- |
| | *Wald* $Chi^2$ | --- | --- | 1.93 | 2.65 |
| Further from town | Availability perception | -0.109 (0.375) | 0.022 (0.068) | -0.033 (0.027) | -0.085 (0.036)** |
| | *n* | 45 | 45 | 45 | 45 |
| | $R^2$ | 0.087 | 0.060 | --- | --- |
| | *Wald* $Chi^2$ | --- | --- | 3.30 | 6.59 |
| | Change perception | 0.125 (0.391) | -0.011 (0.065) | 0.063 (0.022)*** | 0.103 (0.041)** |
| | *n* | 45 | 45 | 45 | 45 |
| | $R^2$ | 0.088 | 0.058 | --- | --- |
| | *Wald* $Chi^2$ | --- | --- | 9.38 | 8.62 |

Note: Coefficient reported (Standard Error in parenthesis); see Table 5.4 for definition of variables. No collinearity between variables (all Variance Inflation Factors (VIF) < 1). For harvesting behaviour variables, these correspond to OLS Regression, including controls for age and sex, and clustering based on the household of the informant. For management variables, these correspond to Poisson regressions, including controls for age and sex, and clustering based on the household of the informants. * $p < 0.1$, ** $p < 0.05$ and *** $p < 0.01$

Our findings dovetail with the bulk of research examining time preferences amongst natural resource users (Alvard et al. 1997; Reyes-García et al. 2007). Studies worldwide have shown that individuals with high discount rates, i.e., unwilling to sacrifice short-term benefits for potentially higher gains in the future, tend to have more impulsive behaviours and violate more often management regulations (Kirby et al. 2002; Akpalu 2008). However, this literature tends to neglect discount rates as largely contingent upon the perception of change in the availability of natural resources (Lu 2005; Suuronen et al. 2010). Studies on resource users' cooperative behaviour disposition have widely examined socio-economic factors affecting pro-social behaviour (e.g., Aswani et al. 2013; Teh et al.

2014), largely neglecting the role of perceptions of change and availability. Our research complements this body of literature by suggesting that perceptions of availability and change affect the benefits and costs of sustainably managing common-pool natural resources.

If the resource is already unavailable (e.g., village closer to town), the costs of organising users to sustainably manage the resource might be perceived as unnecessarily high and unlikely to generate benefits. In contrast, such self-organisation is likely to occur if the resource is still easily available, but only after the users have perceived some level of risk, for example observing substantial change in resource availability (Rudel et al. 2002; Potetee et al. 2010). Perceptions of resource change can therefore spark collective action for sustainable management (Ostrom 1999; Oldekop et al. 2012). The danger here, however, is that gradual changes in the availability of natural resources remain unnoticed to resource users until its availability is already severely compromised (Alessa et al. 2008; Fernández-Llamazares et al. 2015b).

Data obtained from our ethnographic observation methods provide evidence supporting our arguments. In the village closer to town, *G. deversa* is rarely a conversation topic and, when people are asked about it, they tend to feel quite hopeless about the state of the resource. Since *G. deversa* has become scarce, most people are not concerned with its management and it is largely considered a lost cause. Contrarily, in the village further from town, several discussions to better regulate access and use of thatch palm groves were witnessed. For example, in communal meetings, thatch palm tends to be a burning issue, often raising lively discussion amongst local villagers. Local people often expressed concern about the status of the resource and a wish for improved management strategies. As one Tsimane' man reported in one of the communal meetings: '*It is sad seeing how our thatch palm disappears and traders become rich, while we become poorer by losing our resources. We cannot allow that!*'

## 5.5. Concluding remarks

We conclude by highlighting some implications of our findings. The literature on environmental perceptions has already stressed that accurate perceptions of resource availability and change hold potential in furnishing collective responses to ensure sustainable management (e.g., Oldekop et al. 2012; McCarthy et al. 2014). Our study challenges this body of literature by evidencing that, regardless of whether local perceptions are accurate or not from an ecological standpoint, they are crucial in informing sustainable management of dwindling natural resources. It is clear that most of the harvesting and management actions that the Tsimane' undertake are, at least partially, shaped by local perceptions. Particularly in villages where claims over *G. deversa* unavailability were magnified, local perceptions seem to be an instrumental factor in ensuring collective action for its sustainable management. Such local perceptions reflect the multi-faceted complexity of cognition and, arguably, providing a better picture of the historical context of the changes undergone than of their ecological nature and extent.

Without denying the importance of accurately detecting, understanding and interpreting gradual changes in the ecosystem, our results show that local perceptions play an important role in creating or blocking incentives for societal change and sustainable management of natural resources. In addressing the overharvesting of natural resource, a better understanding of how local resource users perceive availability and change in the stock of these resources is critical. Local perceptions encompass cultural values, beliefs, and historical aspects that are essential for the endurance of any long-term sustainable management regime of natural resources.

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# Chapter VI

## Conclusions

I structure the conclusions below around six themes: theoretical contributions (Section 6.1); methodological contributions (Section 6.2); policy implications (Section 6.3); epistemological considerations (Section 6.4); limitations and caveats (Section 6.5); and future research (Section 6.6).

### 6.1. Theoretical contributions

With the analysis presented in this dissertation, I strive to contribute to the growing bulk of literature examining the effects of GEC upon indigenous peoples (e.g., Speranza et al. 2010; Eisner et al. 2013) and to the literature suggesting that LEK and local perceptions can be instrumental in building social-ecological resilience (e.g., Ostrom 1990; Berkes 2004). More specifically, this dissertation has sought: (a) to situate indigenous knowledge and local perceptions of environmental change in the broader context of GEC research (Chapters II and III); (b) to illustrate different examples in which GEC challenges the livelihoods and knowledge of indigenous peoples (Chapter IV and V); and (c) to identify what factors foster and/or undermine indigenous peoples' adaptive capacity in the face of GEC (Chapter II-V).

While this dissertation does not explore what constitutes GEC, my findings sit well within the current debate over its visibilism/invisibilism. As discussed in Chapter III, there is an ongoing discussion on whether or not GEC can be witnessed with the naked eye or not (see Rudiak-Gould 2013). While physical scientists and experimental psychologists argue that GEC –and particularly climate change– is inherently undetectable to the lay observer (e.g., Mormont and Dasnoy 1995), anthropologists and indigenous advocates have often claimed that the phenomenon is not only visible, but its effects and impacts can indeed be tracked based on personal experience (e.g., Reyes-García et al. *submitted*). This thesis compiles evidence supporting the idea that indigenous peoples are frontline observers of GEC. I found that, despite being unaware of the scientific notion of GEC, most Tsimane' report changes that are consistent with scientific records and that are based on their LEK (Chapters II and III), a finding that challenges the current definitions of what constitutes data and science (Adams 2007; Rudiak-Gould 2013; Beaudreau and Levin 2014)

Having emphasised that indigenous knowledge can indeed contribute to a better understanding of the local manifestations of GEC, it is important to also explore how this integration should take place in the research process itself (e.g., Gearheard et al. 2010; Turvey et al. 2013; Hiwasaki et al. 2014). Chapter II provides an embryonic framework for advancing on this dialogue. The keystone feature of my approach is to overlay indigenous observations with instrumentally-measured climatic changes, particularly in data-deficient regions. Although this approach can be considered relatively positivist and pragmatic, most probably reflecting the history of a power relation between indigenous and scientific knowledge (i.e., indigenous knowledge being only considered as a *complement* to science; Simpson 2004), it can open a pathway for an ever more constructive and equal exchange of information between the two knowledge systems.

The purpose here is not to assert one knowledge as more valid than another (e.g., Huntington et al. 2004; West et al. 2008), but rather to integrate them in such a way that indigenous knowledge can contribute to the endeavours of GEC research, and science, in turn, can inform adaptation efforts in areas inhabited by indigenous peoples or even contribute tools for tracking environmental changes (e.g., participatory mapping; Tremblay et al. 2006; Orta-Martínez 2010). Ultimately, and ideally, the outcome will be a knowledge base that is co-produced (*sensu* Armitage et al. 2011). Fostering linkages between both types of knowledge can therefore potentially lead to wide benefits both to indigenous peoples and researchers, for instance to improve local environmental management (Maynard et al. 2011; Cochran et al. 2013).

Results presented in this thesis also raise concerns about the vulnerable (albeit still adaptive) nature of indigenous knowledge and LEK, particularly amidst rapid social-ecological changes. By empirically testing the existence of the shifting baseline syndrome amongst the Tsimane' (Chapter IV), I have illustrated the profound gap between the temporal rates of GEC on the one hand, and on the other the timescales needed for environmental changes to be captured in culturally-built systems such as LEK. The Tsimane' are facing challenges to detect and interpret environmental changes, which in turn undermine their ability to respond to GEC. So far, studies examining change in LEK systems have mostly focused on social factors to explain these changes, such as market integration or cultural change (e.g., Iniesta-Arandia et al. 2014; Reyes-García et al. 2014). This thesis calls for broadening the analytical angle of this scholarly work to account for environmental changes as key drivers of knowledge erosion, e.g., shifting baseline syndrome (Chapter IV).

In general, the study of GEC and indigenous peoples has long been enveloped in deep polemics and controversies, perhaps as a result of it being a contentious political and human rights' issue (e.g., Cox 2000; Osofsky 2007; Marino and Ribot 2012). Through the chapters of this thesis, I have plunged into different and at times fierce scholarly debates, including: (a) the often-contested evidence of the effectiveness of indigenous knowledge (Chapter II); (b) the disagreement on the perceptibility of GEC (Chapter III); (c) the disputed limits of the adaptive capacity of LEK in the face of GEC (Chapter IV); and (d) the doubts on the role of local perceptions in guiding the sustainable management of natural resources (Chapter V). Other debates that converge with this research −although largely beyond its scope− include discussions on the dichotomist portrayal of indigenous peoples as either vulnerable or resilient to GEC (e.g., Maru et al. 2014), the potential ways forward to integrate indigenous and scientific knowledge (e.g., Gill and Lantz 2014), the uncertain impacts of GEC mitigation mechanisms upon indigenous cultures (e.g., Sandbrook et al. 2010) or the most effective strategies to protect LEK from the numerous impacts of GEC (e.g., McCarter et al. 2014).

## 6.2. Methodological contributions

One of the main reasons for the long list of controversies and caustic discussions described above is the lack of empirical research on the topic. With full recognition of the complexity involved in researching indigenous knowledge (Reid et al. 2006; Carothers et al. 2014), I argue that the field suffers important methodological weaknesses, mostly issued from a general lack of standards on how to successfully combine different knowledge paradigms. Deliberating and deciding on diverse methodologies useful for an ethnoecology of environmental change will most probably broaden the perspectives of this still-emerging and increasingly important field of enquiry.

This thesis brings forth three important methodological contributions to the field. First, the thesis explicitly attempts at linking social and climate data in a single operational framework in order to improve models assessing climate change (Chapter II). Although I am by no means the first to endeavour this (e.g., Alexander et al. 2011; Jones et al. 2015), to the best of my knowledge, there are no other studies with a systematic, quantitative and hybrid modelling approach such as the one put forward in this work. In particular, the construction of the climate change metrics in Chapter II, specifically designed to directly match the interview questions on indigenous observations, constitutes one of the methodological milestones of this dissertation.

Second, this thesis shows the benefits of Randomised Evaluation as a methodological approach to quantify the effects of a particular GEC adaptation project (e.g., climate change dissemination workshops; Chapter III). While Randomised Evaluations have become a popular tool in development studies (see Duflo 2003), its use has not been applied to climate adaptation planning before. I expect this methodological contribution to inspire new avenues for the evaluation of climate adaptation initiatives, with a stronger emphasis on assessing their level of tailoring to particular local contexts (Tyler et al. 2007; Agrawal 2010).

And third, in this thesis I advance an empirical method to examine the limits of the adaptive capacity of LEK (Chapter IV), drawing on the concept of the shifting baseline syndrome. This constitutes a step further in the study of LEK change, particularly when panel long-term data are unavailable.

## 6.3. Policy implications

My finding that GEC is impacting the Tsimane' knowledge system (Chapter IV) aligns well with the growing body of literature showing that the loss of biological and cultural diversity are inextricably linked and led by the same driving forces (e.g., Pretty et al. 2009; Tershy et al. 2015). For this reason, I stress the importance of re-designing strategic plans to support the resilience of LEK in the face of ever encroaching environmental changes. In other words, indigenous knowledge should be supported and strengthened to avert the negative consequences of GEC. However, in contrast to policy frameworks that focus only on *maintaining* LEK, my results point to the need of a *revitalisation* approach (Chapter IV), targeting the socio-political and environmental context in which knowledge is generated and transmitted rather than the preservation of biocultural heritage as a compilation of static practices (von Glasenapp and Thornton 2011; Gómez-Baggethun and Reyes-García 2013; Iniesta-Arandia et al. 2014).

In chapter IV, I have delineated some broad guidelines on how to promote *in situ* LEK revitalisation amongst the Tsimane'. In line with findings of Davidson-Hunt and Berkes (2003), my results point to the importance of maintaining intergenerational collective memory to facilitate the continuous adaptation of LEK to new social-ecological contexts. Projects seeking to reconnect elders with younger generations (e.g., Plotkin 1993), the establishment of LEK-based narratives (e.g., Kai et al. 2014) and efforts to realign more school curricula to LEK (e.g., Ruiz-Mallén et al. 2010) constitute promising avenues to ensure the vitality of

Tsimane' LEK in the years to come. However, it is important to stress that because LEK cannot be separated from its context (Simpson 2001), its revitalisation is likely to be best served by community-based approaches rather than top-down programmes (Brodt 2001; Singh et al. 2010). In this context, biocultural conservation approaches offer one of the most powerful ways to uphold LEK systems from the bottom-up, e.g., by supporting indigenous self-determination and inclusive governance mechanisms (Maffi and Woodley 2010; Gavin et al. 2015).

Findings from this thesis illustrate that not only do LEK contributes to a better local understanding of GEC (Chapter II), but also to more effective adaptation planning and decision-making (Chapter V). However, mainstream adaptation planning has traditionally tended to underplay considerations regarding the local contexts, including LEK (Hulme 2010; Thornton and Kitka 2015). Most often, authoritative knowledge shapes policy decisions not always reflecting local priorities (e.g., Leach and Mearns 1996; Moore 2001). As a result, poorly designed adaptation measures may exacerbate the impacts of GEC by undermining the livelihoods of indigenous groups or widening policy inequalities (Green and Raygorodetsky 2010; Brugnach et al. 2014). Documenting local perceptions of environmental change is therefore crucial from a policy perspective. Local perceptions reflect areas of immediate concern to indigenous peoples, thus offering interesting opportunities for tailoring adaptation strategies to the local contexts where they take place (Alcorn et al. 2003; Ignatowski and Rosales 2013). Moreover, understanding these perceptions can help us to make GEC communication strategies more effective (Chapter III).

Results of this thesis also show that historically-developed adaptation practices amongst indigenous peoples depend crucially on the existence of local institutions (both formal and informal) for environmental management (Chapter V). Institutional arrangements essentially affect the way in which people adapt to changes (Nyong et al. 2007; Tengö and von Heland 2012). For this reason, understanding how local institutions operate in relation to environmental change is a core component of the design of any successful adaptation strategies in indigenous territories and elsewhere (Bakker 1999; Young and Lipton 2006).

## 6.4. Epistemological considerations

Power imbalances in environmental decision-making bodies have legitimised certain knowledge forms at the expense of others (Tengö et al. 2014; Gavin et al. 2015). In general, indigenous knowledge has not been well-integrated into international platforms to govern GEC (e.g., IPCC, MA or TEEB), all of which focus almost exclusively on conventional science as the final arbiter of the validity of knowledge (Smith and Sharp 2012; Sutherland et al. 2013). As a result, several GEC mitigation programs have faced significant opposition and mistrust amongst indigenous peoples (e.g., IIPFC 2010; Long 2013). Although the debate is broad and complex (see Corbera and Schroeder 2010), one of the root causes for such scepticism is arguably the lack of recognition of indigenous epistemologies in environmental negotiation processes. For example, by putting a commercial value on forests or merely considering them as carbon sinks, the REDD+ program has repeatedly neglected the historical, cultural and spiritual values that forests hold for indigenous peoples (Gupta et al. 2012; Brugnach et al. 2014). Such epistemological mismatch represents an obstacle for the engagement of indigenous peoples in GEC negotiations (Brodt 1999; Berkes 2009). Their worldviews and cosmologies are often repressed by dominant scientific jargon, which is difficult to integrate into other knowledge systems stemming from heterogeneous mental models and logics (Chapter III).

The debate over the use of indigenous knowledge and its epistemological status in relation to mainstream scientific knowledge is not new (e.g., Brokensha et al. 1980). Yet, LEK and indigenous interpretations of GEC continue to be labelled as too local (Bellon et al. 2011), over-valued (Cleaver 1999), or parochial (discussed in Corburn 2003). For example, in 2008, not without controversy (Simpson 2010; Wesley-Esquimaux 2010), two Canadian scholars published an academic book discrediting indigenous knowledge as '*protoscientific*', '*junk science*' and '*neolithic*' (Widdowson and Howard 2008:234, 242 and 255, respectively). These claims are probably an outlier position, not fully reflecting the overall growing acceptance of indigenous knowledge (e.g., Turnhout et al. 2012; Tengö et al. 2014). However, what is glossed over in these criticisms is the failure to see use and/or value in integrating different knowledge systems, due to the epistemological gap between indigenous and scientific knowledge and the communication problems arising from this misfit.

My results call for a broader discussion on how to facilitate a meaningful intercultural discussion on GEC integrating different scales, epistemologies and bodies of knowledge. Based on the findings from Chapter III, I argue that the first step to advance in this dialogue is to attempt at improving translations between indigenous and scientific framings of GEC, in order to enable for better mutual understanding. This goes hand-in-hand with recognising that there are different types of knowledge, each associated with different needs for different human societies affected in different ways by GEC (Newton et al. 2005; Williams and Hardison 2013). Picking up on Mazzochi's (2006:464) metaphor '*Just as different maps can give accounts of the same territory, so too can different forms of knowledge about the material world.*' Following on this, the appraisal of indigenous knowledge should not be interpreted as an anathema to science, but rather as an opportunity to catalyse a more robust dialogue around GEC.

The conclusions of this thesis support the idea of a *co-production of knowledge*, i.e., striking a balance between science and others ways of knowing (Jasanoff 2004; Armitage et al. 2011). Chapter II has shown the potential of integrating different knowledge types for improving understanding of climate change in Bolivian Amazonia. However, as illustrated in Chapter V, co-producing knowledge is by no means free from challenges, especially where contradictions arise between –or within– scientific data and LEK. Additionally, Chapter III has evidenced that successful communication between scientific and indigenous knowledge holders is essential for the establishment of genuinely collaborative GEC research. In view of these results, I contend that the co-production of knowledge in response to GEC will require novel institutional arrangements providing larger community control of the research process and more meaningful partnerships (Dale and Armitage 2010; Brewer and Kronk Warner 2015). The formulation of protocols and guidelines for a diligent use of indigenous knowledge remains a critical for engaging indigenous communities in collaborative research.

## 6.5. Limitations and caveats

This dissertation has limitations and caveats. First, the dissertation would have benefitted from the integration of far more and better-quality independent ecological and climate data, in order to be able to have more precise recordings of the environmental changes taking place in the study area, to then be able to directly link them to the local perception data gathered. This is particularly relevant for Chapters IV and V, which would have benefitted significantly from more quantitative evidence of the environmental changes under scrutiny. Similarly, the climate metrics constructed in Chapter II would have been more robust had I counted on daily climate data (which were unavailable in the CRU dataset; see Harris et al. 2009).

Second, in studying the adaptive capacity of LEK systems, it would have been ideal to count on diachronic cohort-type data over a longer period of time. This is particularly the case for Chapter IV, where LEK erosion could have been assessed by comparing one generation at different points in time (see Reyes-García et al. 2013), i.e., providing an operative measure of the adaptive capacity of LEK.

Third, the data analysis would probably have been more solid had I carried out more in-depth ethnographic research examining, from a cognitive perspective, how the Tsimane' conceptualise change and time. Supplementary ethnographic data on these concepts would have allowed for a more nuanced interpretation of the epistemological gap found from the randomised controlled trial in Chapter III, adding more cultural meaning and cognitive depth to the thesis.

And finally, I am aware that some of the GEC perception data presented in this thesis might be affected by a measurement error. For instance, proxy figures in Chapters II and III only accounted for overall trends in climate variables (i.e., increase/decrease/invariant). This is most probably a very narrow approach, considering that the Tsimane' interpret changes based on far more fine-tuned, qualitative, and detailed observations. So, for example, in addition to the overall increasing or decreasing trends of rainfall over time, I could have accounted for qualitative aspects, such as the different types of rain, their intensity, their geographical extent or their different timing. Although this information was recorded in field notes, which gave me an overall understanding on how the Tsimane' interpret changes in local climate, it was not measured at the individual level, hence the exclusion from my analysis. Future studies should develop a refined analytical framework allowing for a broader construct of GEC perceptions, including qualitative elements and scales. How to do so remains an open question.

## 6.6. Future research

Overall, the limitations exposed illustrate the value that further investigation could have in filling the above gaps. To face the urgency and great challenge of mitigating and adapting to the severe impacts of GEC upon indigenous peoples, I have identified several questions rife for further study.

First, I call for more interdisciplinary and comprehensive research focusing on the role of LEK in reducing vulnerabilities and enhancing resilience in the face of GEC. It is crucial to understand how GEC is affecting LEK, i.e., not only whether the adaptive capacity of LEK is being lost (Chapter III), but also, if that is the case, how, where, why and at which rates. Such research could serve a purpose in identifying the implications that this knowledge loss has for indigenous peoples whose livelihoods are already impacted by GEC, as well as in informing strategies to reverse these trajectories, if appropriate. More attention should be paid to the indigenous climate indicators that could be losing their reliability due to climate change (Roncoli et al. 2002; Petheram et al. 2010).

Second, future research should be designed taking into account local framings and indigenous epistemologies (Descola 2005; Thornton 2010; Pyhälä et al. *submitted*). This thesis shows that there are many aspects that can go unnoticed as scientists remain limited by their own epistemological thinking. To recognise the original contribution of indigenous observations of GEC, we need further understanding of the epistemological foundations of indigenous ways of knowing

(Forbes et al. 2009; Marin and Berkes 2013). Particularly, further research should attempt at including embodied experiences in the study of GEC cognition, considering that LEK is often in tacit forms (see Raymond et al. 2010). Moreover, I stress that future research should consider the heterogeneity in GEC perceptions (e.g., Byg and Salick 2009). Chapters II, IV and V have shown that there are intra-cultural variations in GEC perception due, for instance, to different LEK levels. Future research should embrace this diversity and consider the choice of informants in order to capture the knowledge range of the group (see Chapter II).

And third, with these considerations in mind, it is time to devise new research tools that allow overcoming at least some of the structural challenges of integrating indigenous knowledge in GEC research. Here I argue that for such integration to resemble a symbiosis –instead of a host-parasite interaction nourished from years of colonising methodologies (see Smith 1999)– we need to prioritise bottom-up and collaborative research approaches not favouring one knowledge system in detriment of another (Chalmers and Fabricius 2007). Still, nowadays there are relatively few cases where scientists and indigenous communities have managed to work collaboratively in the co-creation of knowledge, involving cross-cultural dialogue and shifts in thinking across all stakeholders (e.g., Maynard et al. 2010; Thornton and Maciejewski Sheer 2012).

The cooperative and respectful alliances I propose above have an immense potential for empowering the disempowered and supporting the resilience of indigenous peoples in the face of GEC while also advancing scholarship. The pressing reality of GEC has dynamited all the classical reductionist scientific approaches, challenging the disciplinary compartmentalisation of science and calling for novel approaches to resolve complex issues. Ethnoecology blends far-ranging perspectives from different scholarly backgrounds, within and across cultures, which can contribute to: (a) connect global environmental changes to local contexts; and (b) facilitate the development of mutual learning strategies to confront GEC. Tailoring research questions and objectives to match the concerns of indigenous peoples, while also building upon their strengths and assets, should be a priority for future ethnoecological research addressing GEC.

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# APPENDIX I.

Besides the four chapters of this dissertation, during my PhD I have led or participated as co-author in the following 13 scientific publications (peer-reviewed articles and book chapters):


Díaz-Reviriego I, González-Segura L, Fernández-Llamazares Á, Howard PL, Molina JL, Reyes-García V (*accepted*) Social exchange networks and medicinal plant richness in Amazonian homegardens. Ecology and Society. Accepted (with minor revisions) 27.08.2015.

Díaz-Reviriego I, Fernández-Llamazares Á, Salpeteur M, Howard PL, Reyes-García V (*submitted*) Gendered medicinal plant knowledge contributions to adaptive capacity and health sovereignty in Amazonia. Ambio. Submitted 02.09.2015.

Fernández-Llamazares Á, Reyes-García V (*in press*) An Ethnobiology of Change. In: Albuquerque U (ed) Introduction to Ethnobiology. Springer-Verlag, Dordrecht, The Netherlands. Accepted 26.05.2015.

Fernández-Llamazares Á, Díaz-Reviriego I, Méndez-López ME, Sánchez IV, Pyhälä A, Reyes-García V (2014a) Cambio climático y pueblos indígenas: Estudio de caso entre los Tsimane', Amazonía boliviana. REDESMA Online Journal 7: 110-119.

Fernández-Llamazares Á, Díaz-Reviriego I, Sánchez IV (2014b) Las Voces del Cambio: percepciones de una sociedad ante el proceso de cambio. In: Reyes-García V, Huanca T (eds) Cambio global, cambio local. La sociedad tsimane' ante la globalización (pp. 355-380). Icaria Editorial, Barcelona, Spain.

Fernández-Llamazares Á, Rocha R (2015) Bolivia set to violate its protected areas. Nature 523(7559): 158.

Pyhälä A, Fernández-Llamazares Á, Lehvävirta H, Byg A, Ruiz-Mallén I, Salpeteur M, Thornton TF (*submitted*) Global Environmental Change: Local perceptions, understandings and explanations. Ecology and Society. Submitted 20.07.2015.

Reyes-García V, Díaz-Reviriego I, Duda R, Fernández-Llamazares Á, Gallois S, Guèze M, Napitupulu T, Pyhälä A (*accepted*) Peer evaluation reliably measures local ecological knowledge. Field Methods. Accepted 21.03.2015.

Reyes-García V, Guèze M, Díaz-Reviriego I, Duda R, Fernández-Llamazares Á, Gallois S, Napitupulu L, Orta-Martínez M, Pyhälä A (*under review*) The adaptive nature of culture. A cross-cultural analysis of the returns of local environmental knowledge in three indigenous societies. Current Anthropology. Revision sent 19.08.2015.

Reyes-García, V, Pyhälä A, Díaz-Reviriego I, Duda R, Fernández-Llamazares Á, Gallois S, Guèze M, Napitupulu T (*submitted*) The Impacts of Schooling and Local Knowledge on Working Memory: A Study among Three Contemporary Hunter-Gatherer Societies. PLoS ONE. Submitted 30.08.2015.

Reyes-García V, Fernández-Llamazares Á, Guèze M, Garcés A, Mallo M, Vila-Gómez M, Vilaseca M (*submitted*) Local indicators of climate change: The potential contribution of local knowledge to climate research. Wiley Interdisciplinary Reviews: Climate Change. Submitted 30.06.2015.

Riu-Bosoms C, Vidal T, Duane A, Fernández-Llamazares Á, Guèze M, Luz AC, Paneque-Gálvez J, Macía M, Reyes-García V (2014) Exploring Indigenous Landscape Classifications across Different Dimensions: A Case Study from the Bolivian Amazon. Landscape Research 40(3): 318-337.

Vadez V, Fernández-Llamazares Á (2014) De la agricultura de subsistencia a la comercialización. In: Reyes-García V, Huanca T (eds) Cambio global, cambio local. La sociedad tsimane' ante la globalización (pp. 147-175). Icaria Editorial, Barcelona, Spain.

Moreover, in order to disseminate some of the results of my work to a broader audience, I have participated in the publication of the following materials:

Fernández-Llamazares Á (2013) Una carretera a l'Amazònia divideix Bolívia. Diari Ara, 01.05.2013.

Fernández-Llamazares Á (2015) En los confines de lo distante y lo distinto. Espai Icària (Blog of the the Editorial Icària). 26.01.2015.

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LEK Project Team, *member* (2014) Rediscovering Wisdom. Short film selected at the Official Selection of the *Faces of Wisdom* Film Contest. Helsinki, Finland, 15.04.2014.

LEK Project Team, *member* (2014) The adaptive nature of culture. A dissemination video. Institut de Ciència i Tecnologia Ambientals (ICTA-UAB). 23.06.2014.

Reyes-García V, Fernández-Llamazares Á (2015) Los Tsimane' de Bolivia: paradojas de la sociedad del conocimiento. Altaïr Magazine, Voces, April 2015. Available online at http://www.altairmagazine.com/voces/lostsimanedebolivia [Accessed 30.08.2015].

Additionally, in exchange for the kind and generous hospitality I received from each of the communities I worked with, I participated in the two following outreach projects conceived to return scientific knowledge to the Tsimane':

Radio program: In agreement with the local communities, we recorded a radio program – in Tsimane' language– where we outlined various themes of Tsimane' tradition and culture, including traditional songs, the use of certain medicinal plants, some basic hygiene practices and different aspects of their Local Environmental Knowledge with regard to conservation practices, to cite just a few. The main objectives of the program were: (a) to provide information that helps improving the well-being and health of Tsimane' people; and (b) to help draw attention to the value of Tsimane' culture in the region, thereby increasing self-esteem of the Tsimane' as well. The topics of the 11 podcasts that composed the radio program were decided in partnership with local villagers and in coordination with the Great Tsimane' Council, the legitimate political organisation of the Tsimane'. The program aired every morning at 7.30am on Radio Horeb, a popular radio station listened to in all Tsimane' villages in the region. The program was broadcasted for –at least– three months and we received positive feedback from both Tsimane' people and political authorities in the area.

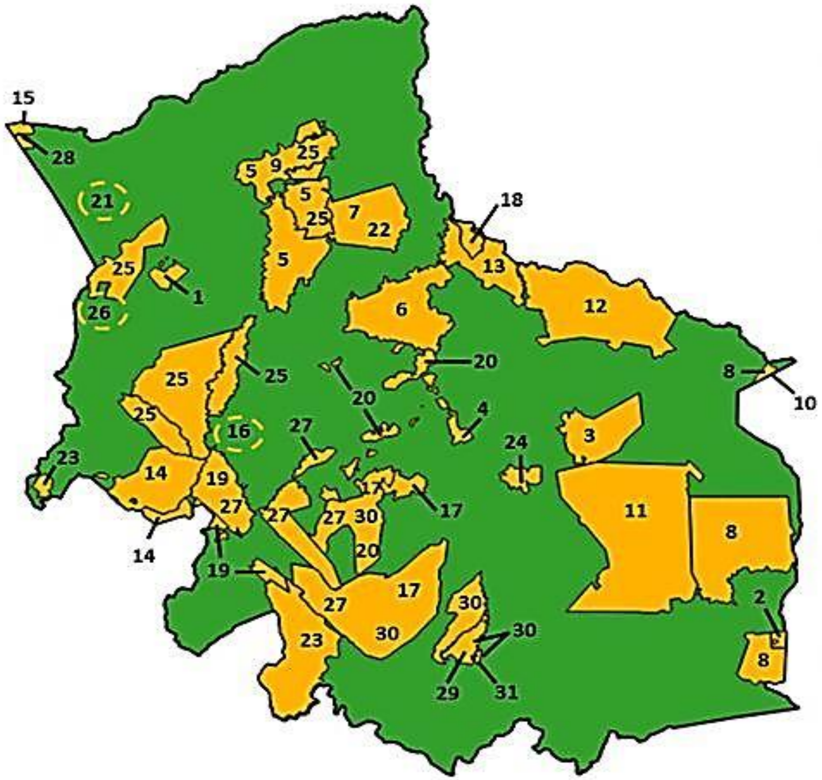
Tsimane' calendar: We produced a Tsimane' calendar for the year 2014, marked with the most important and prominent cultural events and seasons, lunar cycles, some Tsimane' sayings and curiosities, and some of the pictures taken during fieldwork. The calendar was produced with a bilingual approach, both in Tsimane' and Spanish. It is noteworthy that it was the first calendar ever to be printed in Tsimane' language, and also the first to respect the traditional Tsimane' calendar year, which starts in February (due to seasonal cycles of gathering of wild edibles). As with the radio program, the calendar planning and design, as well, as the topics included in it, were decided upon agreement with local peoples and the Great Tsimane' Council, with whom we worked in close collaboration. The goal of the calendar was to contribute to the transmission of the Tsimane' cultural identity both at the local and national levels. The Tsimane' were glad to receive them and were satisfied with the final product, which has been created in accordance with the Tsimane' cultural understandings.

Further activities carried out on site to benefit the local communities that I worked with are listed at: http://icta.uab.cat/Etnecologia/lek/

# APPENDIX II.

## Appendix II.a. Native indigenous peoples of Bolivian Amazonia

**Figure S2.1 |** Native indigenous peoples of Bolivian Amazonia.




| Code | Indigenous group | Estimated population |
|---|---|---|
| 1 | Araona | 910 |
| 2 | Ayoreo* | 931 |
| 3 | Baure | 2,319 |
| 4 | Canichana | 617 |
| 5 | Cavineño | 2,005 |
| 6 | Cayubaba | 1,424 |
| 7 | Chacobo | 826 |
| 8 | Chiquitano* | 43,942 |
| 9 | Esse Ejja* | 695 |
| 10 | Guarasugwe | 42 |
| 11 | Guarayo | 13,621 |
| 12 | Itonama | 10,275 |
| 13 | Joaquiniano | 2,797 |
| 14 | Leco | 9,006 |
| 15 | Machinerí* | 38 |
| 16 | Maropa | 2,857 |
| 17 | Mojeño | 31,078 |
| 18 | Moré | 155 |
| 19 | Mosetén | 1,989 |
| 20 | Movima | 12,213 |
| 21 | Nahua | *(uncontacted)* |
| 22 | Pachahuara* | 161 |
| 23 | Quechua* | 81,116 |
| 24 | Sirionó | 446 |
| 25 | Tacana | 11,173 |
| 26 | Toromona* | *(uncontacted)* |
| 27 | Tsimane' | 6,464 |
| 28 | Yaminahua* | 132 |
| 29 | Yuki | 202 |
| 30 | Yuracaré | 3,394 |
| 31 | Yuracaré – Mojeño | 292 |

Note: Indigenous territories were digitised based on maps of the communal indigenous territories titled by the Bolivian National Institute of the Agrarian Reform (INRA). * indicates that the group is not restricted to Bolivian Amazonia.

# Appendix II.b. Climate change questionnaires used in Chapter II

**Table S2.1 |** Climate change questionnaire for the structured interviews in Chapter II.

| **Coder:** | **Date:** | | **Coding** |
|---|---|---|---|
| **Village:** | **Informant id:** | **Age:** | |
| **Variable** | **Question** | ***Verbatim* answer (observations, comments)** | |
| Overall temperature | Compared to when you were a kid, nowadays, the temperatures are…? | | -1 = colder<br>0 = the same<br>1 = warmer |
| Precipitation in the rainy season | Compared to when you were a kid, nowadays in the rainy season it rains…? | | -1 = less than before<br>0 = the same than before<br>1 = more than before |
| Length of dry season | Last year, in which month did the dry season start?<br>When you were a kid, in which month did the dry season used to start?<br>Compared to when you were a child, the dry season is now…? | | -1 = shorter<br>0 = the same<br>1 = longer |
| Cold spell frequency | Compared to when you were a kid, do you think that cold spells (*surazos*) are nowadays…? | | -1 = less frequent than before<br>0 = the same than before<br>1 = more frequent than before |
| Flood frequency | Compared to when you were a kid, do you think that floods are nowadays…? | | -1 = less frequent than before<br>0 = the same than before<br>1 = more frequent than before |
| Drought frequency | Compared to when you were a kid, do you think that nowadays drought is…? | | -1 = less frequent than before<br>0 = the same<br>1 = more frequent than before |

# Appendix II.c. Descriptive statistics of variables used in Chapter II

**Table S2.2 |** Descriptive statistics of variables used in the regression analysis in Chapter II

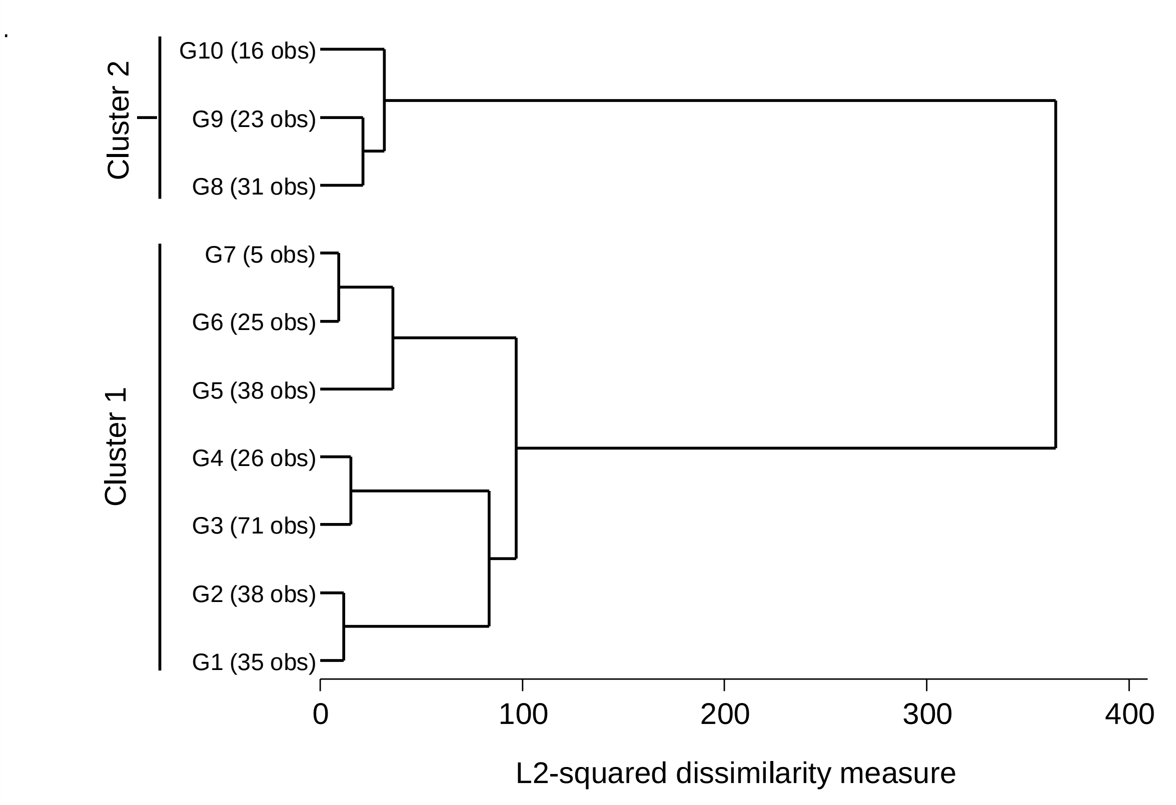
| Variables | | | Definition and Units | Panel Study (*n* = 99) | | | | Cross-Sectional Study (*n* = 308) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Mean** | **SD** | ***min*** | ***max*** | **Mean** | **SD** | ***min*** | ***max*** |
| **Dependent** | **Variables used to construct the variable *scientific consistency*** | | | | | | | | | | |
| | | Temperature | Reported change in temperature | 0.30 | 0.75 | -1.00 | 1.00 | 0.15 | 0.80 | -1.00 | 1.00 |
| | | Dry season length | Reported change in dry season length | 0.24 | 0.81 | -1.00 | 1.00 | --- | --- | --- | --- |
| | | Rainfall in rainy season | Reported change in rainfall in rainy season | -0.59 | 0.67 | -1.00 | 1.00 | 0.42 | 0.80 | -1.00 | 1.00 |
| | | Drought frequency | Reported change in drought frequency | 0.29 | 1.19 | -1.00 | 1.00 | --- | --- | --- | --- |
| | | Cold spells frequency | Reported change in cold spells frequency | -0.59 | 0.73 | -1.00 | 1.00 | -0.31 | 0.82 | -1.00 | 1.00 |
| | | Flood frequency | Reported change in flood frequency | 0.79 | 0.56 | -1.00 | 1.00 | -0.81 | 0.51 | -1.00 | 1.00 |
| | ***Scientific consistency*** | | ***Consistency of the observation with scientific records*** | | | | | --- | --- | --- | --- |
| | | With CRU dataset | Consistency measured based on Figure 2.4a | **1.20** | **1.26** | **0.00** | **5.00** | --- | --- | --- | --- |
| | | With local station data | Consistency measured based on Figure 2.4b | **1.99** | **1.24** | **0.00** | **5.00** | --- | --- | --- | --- |
| | ***Change blindness*** | | ***Inability to detect changes in the climate*** | **---** | **---** | **---** | **---** | **0.85** | **0.91** | **0.00** | **4.00** |
| **Explanatory** | **Variables used to construct the explanatory variable *LEK*** | | | | | | | | | | |
| | Hunting | | | *From a list of 10 species* | | | | *From a list of 3 species* | | | |
| | | Identification | Number of game stimuli recognised | 4.47 | 1.83 | 1.00 | 9.00 | 1.50 | 0.95 | 0.00 | 3.00 |
| | | Structured questionnaire | Agreement with the group regarding behaviour/ecology of different game species | 0.68 | 0.13 | 0.00 | 7.50 | 0.86 | 0.42 | 0.00 | 2.00 |
| | | Self-reported skills | Score on a test of hunting practices (ability to put hunting knowledge into practice) | 3.07 | 2.29 | 0.22 | 0.85 | 0.37 | 0.43 | 0.00 | 3.00 |
| | | | | *From a list of 6 evaluators* | | | | *From a list of 3 evaluators* | | | |
| | | Peer evaluation | Average rating provided by evaluators on subject's hunting knowledge | 1.63 | 1.25 | 0.00 | 3.83 | 1.83 | 1.32 | 0.00 | 4.00 |
| | Medicinal plant knowledge | | | *From a list of 10 species* | | | | *From a list of 6 species* | | | |
| | | Identification | Number of plants recognised as medicinal | 5.20 | 2.10 | 0.00 | 10.00 | 2.42 | 2.28 | 0.00 | 12.00 |
| | | Structured questionnaire | Agreement with the group regarding ailments that can be cured with the medicinal plants shown | 0.32 | 0.13 | 0.00 | 0.59 | 0.85 | 1.01 | 0.00 | 5.00 |
| | | Self-reported skills | Composite index that accounts for the total number of medicinal uses known (out of the selected medicinal plants) and the last time those were applied | 6.83 | 3.46 | 0.00 | 16.50 | 0.75 | 1.092 | 0.00 | 5.50 |
| | | | | *From a list of 6 evaluators* | | | | *From a list of 3 evaluators* | | | |
| | | Peer evaluation | Average rating provided by evaluators on subject's medicinal knowledge | 1.55 | 1.17 | 0.00 | 4.00 | 1.70 | 1.09 | 0.00 | 4.00 |
| | Wild edible knowledge | | | *From a list of 10 species* | | | | --- | | | |
| | | Identification | Number of wild plants recognised as edible | 3.03 | 1.36 | 0.00 | 7.00 | --- | --- | --- | --- |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Structured questionnaire | Agreement with the group regarding plant ecology (phenology, morphological traits, etc) of some wild edibles | 0.67 | 0.12 | 0.21 | 0.82 | --- | --- | --- | --- |
| | Self-reported skills | Score on a test of wild edible collection | 0.59 | 2.06 | 0.00 | 10.00 | --- | --- | --- | --- |
| | ***LEK*** | ***Overall Local Environmental Knowledge*** | **0.01** | **0.52** | **-1.72** | **1.46** | **0.01** | **0.57** | **-1.16** | **2.03** |
| Control | **Socio-demographic controls** | | | | | | | | | |
| | Male | Sex of the person (*1* = man; *0* = woman) | 0.53 | 0.50 | 0.00 | 1.00 | 0.47 | 0.50 | 0.00 | 1.00 |
| | Age | Estimated age of the person, in years | 39.32 | 18.73 | 16.00 | 91.00 | 38.52 | 17.63 | 16.00 | 111.00 |
| | Spanish fluency | Fluency on the national language (*0* = does not speak; *2* = speaks well) | 0.85 | 0.64 | 0.00 | 2.00 | 0.75 | 0.62 | 0.00 | 2.00 |
| | **Variables used to construct the *education* index** | | | | | | | | | |
| | Schooling | Maximum level of schooling completed | 1.52 | 1.67 | 0.00 | 5.00 | 1.75 | 2.35 | 0.00 | 13.00 |
| | Writing | Score in writing skills | 0.76 | 0.94 | 0.00 | 2.00 | --- | --- | --- | --- |
| | Math | Score in math test | 0.76 | 1.17 | 0.00 | 4.00 | --- | --- | --- | --- |
| | Literate_Ind | Score in indigenous language reading skills | 0.48 | 0.82 | 0.00 | 2.00 | --- | --- | --- | --- |
| | Monolingual | The person only speaks the indigenous language | 0.31 | 0.47 | 0.00 | 1.00 | 0.31 | 0.47 | 0.00 | 1.00 |
| | School_Now | The person is currently attending school (*1* = yes; *0* = no) | --- | --- | --- | --- | 0.03 | 0.17 | 0.00 | 1.00 |
| | ***Education*** | | **0.00** | **1.00** | **-1.10** | **2.46** | **0.00** | **1.00** | **-1.37** | **11.46** |
| | **Variables used to construct the *integration into the market economy* index** | | | | | | | | | |
| | Sales | Mean individual income from sales in past two weeks, in PPP values | 72.45 | 223.18 | 0.00 | 1214.71 | 56.99 | 340.85 | 0.00 | 5470.59 |
| | Expenditures | Individual expenditures, in PPP values | 41.05 | 134.40 | 0.00 | 1011.76 | --- | --- | --- | --- |
| | Wealth | Average individual wealth, in PPP values | 1038.81 | 1527.51 | 0.00 | 10011.76 | --- | --- | --- | --- |
| | Wage_Days | Number of days in wage labour in the past two weeks | --- | --- | --- | --- | 0.76 | 2.44 | 0.00 | 14.00 |
| | Wage | Individual income (in cash and kind) from wage labour in past two weeks, in PPP values | --- | --- | --- | --- | 24.35 | 186.83 | 0.00 | 3147.06 |
| | ***Market_integration*** | | **0.00** | **1.00** | **-0.48** | **5.59** | **0.00** | **1.00** | **-0.92** | **12.57** |
| | **Variables used to construct the *forest dependence* index** | | | | | | | | | |
| | Sale_Forest | Mean individual income from sales of forest products (wood, game and NTFP) in past two weeks, in PPP values | 36.30 | 165.80 | 0.00 | 1214.71 | 18.82 | 100.81 | 0.00 | 1214.71 |
| | Barter_forest | Mean individual income from barter of forest products (wood, game and NTFP), in past two weeks, in PPP values | 5.09 | 13.18 | 0.00 | 79.41 | 10.66 | 35.04 | 0.00 | 352.94 |
| | Wage_forest | Mean individual income from wage labour in forest activities (logging and NTFP extraction) in past two weeks, in PPP values | 45.27 | 316.82 | 0.00 | 3147.06 | 15.20 | 180.24 | 0.00 | 3147.06 |
| | ***Forest dependence*** | | **86.67** | **356.08** | **0.00** | **3153.14** | **44.73** | **208.94** | **0.00** | **3153.14** |

Note: More details on how the control data were collected and how the indices were constructed can be found in Reyes-García et al. (2015).

# Appendix II.d. Hierarchical cluster analysis details in Chapter II

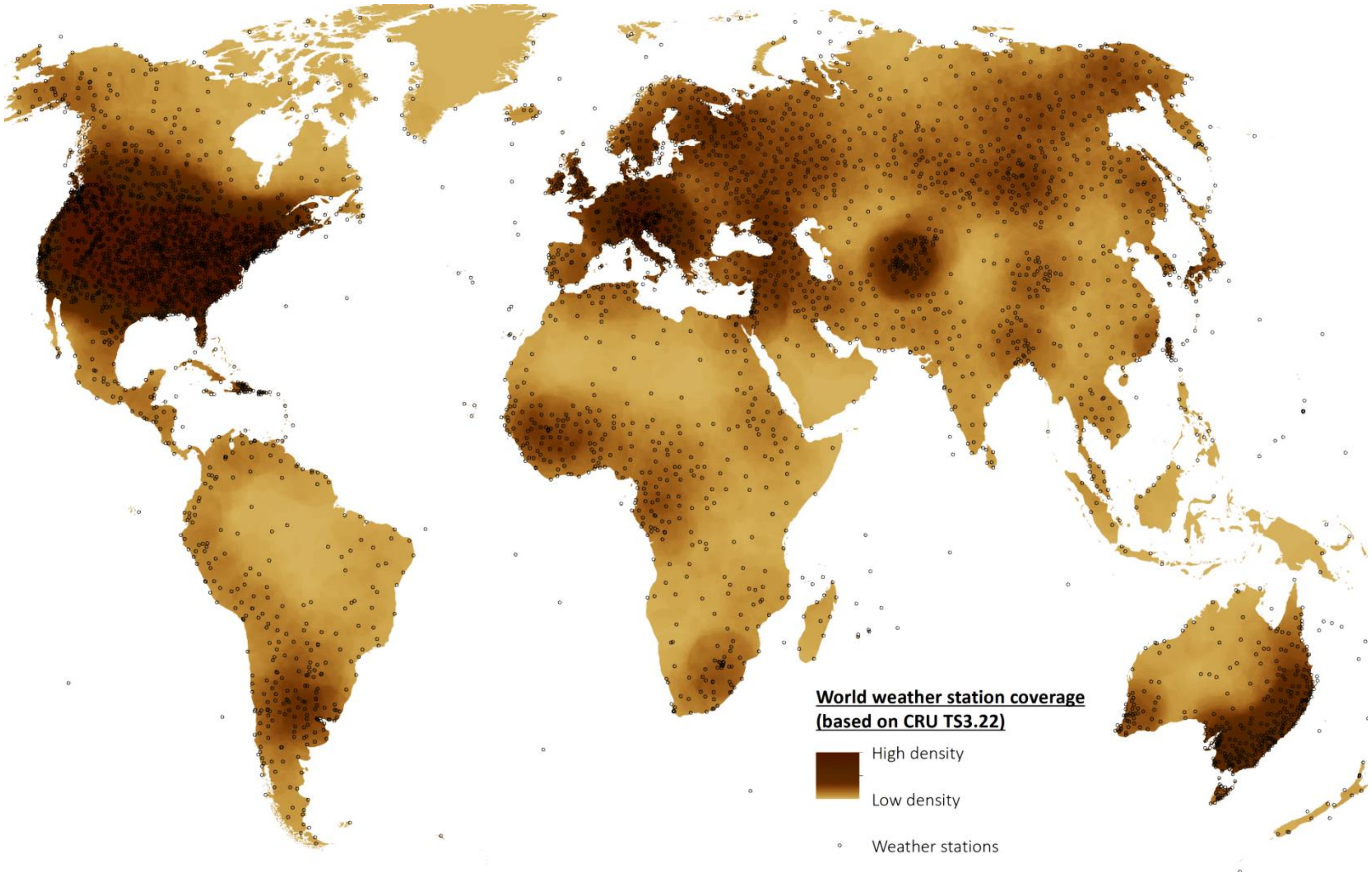
**Figure S2.2 |** Hierarchical cluster analysis of interviewees according to their change blindness and LEK levels.




Note: The vertical axis represents the different clusters of interviewees. The horizontal axis represents the $L^2$-squared dissimilarity measure. Hierarchical cluster analysis was done classifying interviewees according to their change blindness and LEK levels and using Ward's algorithm as agglomerative technique.

# Appendix II.e. Wold coverage of weather stations

**Figure S2.3 |** World coverage of weather stations.

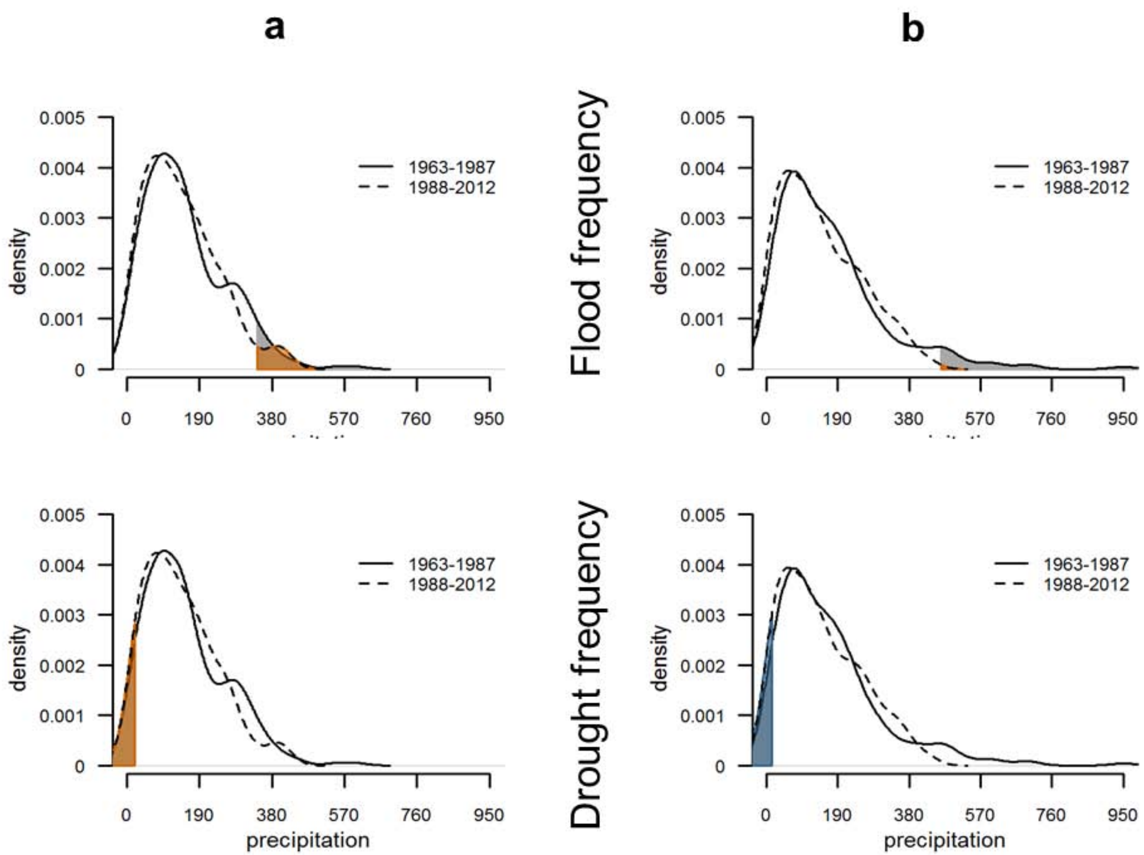





Note: Kernel density analysis applied to the weather stations used in the CRU TS3.22 dataset worldwide (Harris et al. 2009).

# Appendix II.f. Probability of extreme climates

**Figure S2.4 |** Comparison of changes in the probability of extreme climates between CRU and local climate data.




Note: The density plots illustrate the trends calculated with spatially interpolated values from the CRU TS3.22 dataset (a; Harris et al. 2009) and with local climate data from a weather station disregarded in the CRU dataset (b).

# Appendix II.g. Climatic trends for the Tsimane' Territory

**Table S2.3 |** Climatic trends for the Tsimane' Territory.

| Metrics | CRU estimates | | | | Station data estimates | | | |
|---|---|---|---|---|---|---|---|---|
| | **Mean value** | **95% confidence intervals** | | ***p*** | **Mean value** | **95% confidence intervals** | | ***p*** |
| Annual mean temperature | -0.00914 | -0.01506 | -0.00436 | 0.003 | 0.01590 | 0.07137 | 0.02271 | 0.003 |
| Mean intensity of precipitation in the rainy season (Oct-Apr) | -0.04719 | -0.10402 | 0.02724 | 0.184 | -0.12748 | -0.18611 | -0.03931 | 0.000 |
| Total intensity of precipitation in the dry season (May-Sept) | 0.50723 | -0.16666 | 1.09479 | 0.154 | -0.45771 | -0.88292 | -0.06675 | 0.020 |
| Monthly mean temperature of the cold season (June-August) | -0.00666 | -0.01903 | 0.00400 | 0.247 | 0.00256 | -0.01903 | 0.02221 | 0.736 |
| 95$^{th}$ quantile monthly precipitation | -0.01000 | -0.05701 | 0.01386 | 0.573 | -0.05000 | -0.14250 | -0.06601 | 0.025 |
| 5$^{th}$ quantile monthly precipitation | 0.01000 | -0.01918 | 0.05238 | 0.591 | 0.00862 | -0.02204 | 0.04956 | 0.647 |

Note: Estimates for six climate change metrics (see Section 2.2.2) for the grid cell containing the San Borja station, calculated either with CRU data (Harris et al. 2009) or station records. The six metrics are the Theil-Sen slopes illustrating the temporal trends in annual mean temperature, mean intensity of precipitation in the rainy season (October to April), total intensity of precipitation in the dry season (May to September) and monthly mean temperature of the cold season (June to August), and the changes in the probability of extreme monthly precipitation (95$^{th}$ and 5$^{th}$ quantiles). The 95% confidence intervals and *p*-values are also given.

# APPENDIX III.

## Appendix III.a. Description of the intervention in Chapter III

**Table S3.1 |** Description of the workshops performed in Chapter III.

| Stages | Objective | Tool | Time | Description |
|---|---|---|---|---|
| (i) Introduction | To break the ice and facilitate participation | Puzzle-solving | 15‘ | Each participant is given a piece of a jigsaw puzzle and directed to find other participants with pieces belonging to the same puzzle (out of a total of 6 puzzles). When complete, each puzzle produces a picture of the following: rainfall, sunshine, wind, river, tree and agricultural field. The participants then have to comment on the importance of these elements for their daily livelihoods. |
| (ii) Definition of key concepts | To define the concept of *climate* and introduce the notion of *climate change* | Brainstorming | 20’ | The audience is asked to define the concept of *climate*. All the ideas discussed are recorded on a flip chart. Once enough topics have been discussed to enable the concept to be defined, the notion of *climate change* is introduced in relation to the topics shown on the flip chart. |
| (iii) Technical information on the topic of climate change | To present up-to-date information on climate change as framed by the media | Exposition | 40’ | The scientific notion of climate change is introduced to the audience by showing a sequence of 20 pictures and graphs obtained from the mass media (e.g., Gore 2009). After providing some insights into the notion of global warming as an anthropogenic phenomenon, the audience is presented with information on the climatic changes reported in Bolivian Amazonia (specifically: decreased rainfall, increased temperatures, increased flood frequency, increased cold season duration and increased cold season strength). |
| | | Game about past-present scenarios | 20’ | Each participant is given a picture of a landscape and told to find another participant with a counterpart of the same picture (e.g., flooded *vs* non-flooded river; humid *vs* dry forest). Once the connected pairs of pictures are found, the audience is asked to discern between past and present image, and a possible link with climate change. |
| | | Brainstorming | 20’ | In order to summarise the contents of the presentation, the audience is asked to brainstorm on all the things learned about the concept of *climate change*. |
| | | Questions | 20’ | The audience is given the opportunity to pose questions to the convener about climate change and about the workshop. |

## Appendix III.b. Validation of the Randomised Evaluation in Chapter III

To validate the use of the Randomised Evaluation in Chapter III, we tested the random assignment of the villages (to either treatment or control groups) by running a logistic regression of each of the outcome variables against a dummy variable for the treatment, using only information from the pre-intervention survey (Table S3.2).

Because not all individuals assigned to the treatment village ended up attending the workshop, but they nonetheless undertook both surveys (post- and pre-), we analysed data in three ways: (a) all individuals not attending the workshop ($n$ = 350), regardless of whether from treatment or control villages, were considered as the *control* group against a *treatment* ($n$ = 74) including only people who attended the workshop; (b) all individuals in treatment villages not attending the workshop ($n$ = 167) were disregarded, and only the individuals originally assigned to the control villages ($n$ = 183) were considered as *controls*; and (c) all individuals in the treatment villages were considered the treatment group, both those who did and did not attend the workshops ($n$ = 241). Results did not differ significantly for the three options, which suggests that there was no significant information transmission or leakage in treatment villages from the people who attended the workshop to those who did not. For this reason, only results for option (a) are presented in the paper.

Since the number of people in the control and treatment groups differed, we also tested for sampling effects. Specifically, we conducted the same analysis with a randomly selected sub-sample of people in the control group ($n$ = 96). Results of both analyses did not differ significantly (see Table S3.3).

**Table S3.2 |** Test for the random assignment of treatments and controls in Chapter III.

| Outcome Variable | Coefficient | Standard Error | Pseudo-$R^2$ | $p$ |
|---|---|---|---|---|
| Rainfall | 0.390 | 0.281 | 0.0038 | 0.166 |
| Temperature | -0.362 | 0.303 | 0.0031 | 0.233 |
| Flood frequency | 0.426 | 0.362 | 0.0043 | 0.239 |
| Cold season duration | 0.516 | 0.354 | 0.0066 | 0.145 |
| Cold season strength | 0.506 | 0.353 | 0.0062 | 0.151 |

Note: Outcome variables (previously transformed into *agreement* measures, see Section 3.2.6) logistically regressed against a *treatment* dummy variable, using only information from the pre-intervention survey. * $p < 0.05$ and ** $p < 0.01$. See Table 3.1 for definition of variables.

**Table S3.3 |** Difference-in-Difference multivariate estimates: Effects of intervention on outcome variables ($n$ = 848) using other control-treatment groupings (Chapter III).

| **Results using other control-treatment groupings** | | | |
|---|---|---|---|
| | **Outcome Variable** | **Robustness** | |
| **Grouping (i)** | | **a** | **b** |
| | Rainfall | -0.185 (±0.371) | -0.273 (±0.454) |
| $n_{control}$ = 350 | Temperature | 0.431 (±0.390) | 0.523 (±0.648) |
| $n_{treatment}$ = 74 | Flood frequency | -0.691 (±0.622) | -0.106 (±0.466) |
| | Cold season duration | -1.022 (±0.559) | -1.142 (±0.501)* |
| | Cold season strength | -0.308 (±0.462) | -0.353 (±0.536) |
| | **Outcome Variable** | **Robustness** | |
| **Grouping (ii)** | | **a** | **b** |
| | Rainfall | -0.232 (±0.403) | -0.415 (±0.420) |
| $n_{control}$ = 183 | Temperature | 0.322 (±0.413) | 0.411 (±0.731) |
| $n_{treatment}$ = 74 | Flood frequency | -0.353 (±0.654) | -0.487 (±0.720) |
| | Cold season duration | -1.254 (±0.582)* | -1.455 (±0.514)** |
| | Cold season strength | -0.273 (±0.494) | -0.345 (±0.580) |
| | **Outcome Variable** | **Robustness** | |
| **Grouping (iii)** | | **a** | **b** |
| | Rainfall | -0.142 (±0.291) | -0.321 (±0.257) |
| $n_{control}$ = 183 | Temperature | -0.019 (±0.288) | 0.049 (±0.544) |
| $n_{treatment}$ = 241 | Flood frequency | -0.560 (±0.497) | -0.638 (±0.756) |
| | Cold season duration | -0.862 (±0.414)* | -0.967 (±0.567) |
| | Cold season strength | -0.056 (±0.367) | -0.207 (±0.597) |
| **Results using a sub-sample of controls** | | | |
| | **Outcome Variable** | **Robustness** | |
| **Grouping (iv)** | | **a** | **b** |
| | Rainfall | -0.149 (±0.433) | -0.263 (±0.434) |
| $n_{control}$ = 96 | Temperature | 0.760 (±0.447) | 0.762 (±0.704) |
| $n_{treatment}$ = 96 | Flood frequency | 1.237 (±0.798) | 1.395(±0.914) |
| | Cold season duration | -0.553 (±0.647) | -0.834 (±0.583) |
| | Cold season strength | 0.596 (±0.542) | 0.527 (±0.364) |

Note: Outcome variables (previously transformed into *agreement* measures, see Section 3.2.6) logistically regressed against *treatment* and *after* binary dummy variables, and interaction of treatment*after. Coefficient reported (Standard Error in parenthesis) refers to the difference-in-difference coefficient (treatment*after). *Treatment* = 1 if the person received treatment; *treatment* = 0 if the person was control. *After* = 1 if *year* = 2009 (after intervention); *after* = 0 if *year* = 2008 (before intervention). (a) Raw model. Controls for (b) A full set of village dummy variables. * $p < 0.05$ and ** $p < 0.01$. See Table 3.1 for definition of variables.

# Appendix III.c. Descriptive ethnoclimatological knowledge of the Tsimane'

**Table S3.4 |** Ethnoclimatological knowledge held by the Tsimane'.

| Generic use | Indicator type | Scientific name | Tsimane' name | English name | Description |
|---|---|---|---|---|---|
| Flood predictor | Phytoindicator | *Chorisia speciosa* | Vojshinaj | Silk Floss Tree | Its early fructification indicates that there will be a flood. |
| Flood predictor | Phytoindicator | *Citrus sinensis* | Maraca | Sweet Orange | Its early ripening indicates that there will be a flood. |
| Flood predictor | Zooindicator | *Amazilia saucerrottei* | Bista', chu'chu' | Steely-vented Hummingbird | The altitude of the flight of the bird (over the river) indicates the height of an upcoming flood. Other indigenous peoples in Bolivia are reported to predict the height of floods by looking at the behavior of birds (Claverías 2010). |
| Flood predictor | Zooindicator | *Atta* spp. | Bicoroi' | Leafcutter ants | Unusual concentrations of these ants flying in the forest indicate an upcoming flood in the short term (1-3 days). |
| Flood predictor | Zooindicator | *Panthera onca* | Itsiqui' | Jaguar | Its deep roar by night indicates that there will be a flood the day after. There is the extended belief that the jaguar actually invokes the flood. |
| Livelihood indicator | Phytoindicator | *Sapium marmieri* | Mujpe | Leche leche | The falling of its leaves indicates a good time to start clearing the agricultural plots. |
| Livelihood indicator | Phytoindicator | *Tetragastris altissima* | Na'fa | Isigo Tree | Its flowering indicates that the rainy-season honey is ready to be harvested. |
| Livelihood indicator | Zooindicator | Cicadidae spp. | Rojo' | Cicadas | The singing of the cicadas announces the timing for opening the agricultural plots. Mosetenes from Bolivian Amazonia share this belief (Ferreira 2011). Also the Kariñas in Venezuela use the Cicadas as a bioindicator for the same purpose (Olivares et al. 2012). |
| Rainfall predictor | Astronomical | --- | Cava'vare | Galactic halo | When a visible galactic halo called *cava' vare* appears around the stars, rains will arrive in the following 1-3 days. Similar halos are observed in the Andes with the Pleiades for rainfall forecasting (Orlove 2000). |
| Rainfall predictor | Astronomical | --- | Säñi | Moon eclipse | In the Tsimane' culture, a moon eclipse is perceived as a signal for an unusually dry year and poor agricultural yields. Such perception is shared with the Takana indigenous peoples from Bolivian Amazonia (Eibamaz 2010). |

| | | | | | |
|---|---|---|---|---|---|
| Rainfall predictor | Atmospheric | --- | Japacjoi' (ĉhibinmayedye') | Three-day continued heat | Three unusually hot days means that the fourth day will be rainy. |
| Rainfall predictor | Atmospheric | --- | Pururu | Night thunders | Hearing thunders by night means that the day after will be rainy. |
| Rainfall predictor | Phytoindicator | *Cecropia membranacea* | Tyej | Pumpwood | When it is going to rain, the leaves of this tree turn over. Such an observation has been also reported for the Takana indigenous group from Bolivian Amazonia (Eibamaz 2010). |
| Rainfall predictor | Phytoindicator | *Prunus* spp. | Iyason | --- | Spiritual beliefs indicate that the fell of the fruits of this tree calls for big rains to come. |
| Rainfall predictor | Zooindicator | *Alouatta sara* | U'ru | Bolivian red howler | According to spiritual beliefs, when many of them sing together, they are invocating the rain. Used to forecast rainfall in the short term (1-3 days). Such belief is shared with native peoples living in Escalera, Peru (Silva 2013). |
| Rainfall predictor | Zooindicator | *Rhinella marina* | Âbäbä | Cane toad | When toads are abundant in the dry season, it will be a rainy year. Such a belief is shared by many indigenous communities in the Andes (Claverías 2010). |
| Rainfall predictor | Zooindicator | Formicidae | Cahtyityij | Ants | When you see many holes on the ground made by ants, stormy rains will arrive in the following 1-3 days. |
| Rainfall predictor | Zooindicator | *Pachycondyla* spp. | Tyiquiqui' | Bulldog ants | When many bulldog ants walk very quickly in line in the forest, it will rain by night. The same behavior is reported as a bioindicator for the same generic use by the Nasua indigenous group (Colombia), but for a different ant, namely *Atta cephalotes* (Ramos-García et al. 2011). |
| Rainfall predictor | Zooindicator | *Ramphastos toco* | Yovijvi | Toco Toucan | When many of them sing together, it indicates that in some hours it will be rainy. Such an observation has also been reported for the Takana indigenous peoples of Bolivian Amazonia (Eibamaz 2010). |
| Rainfall predictor | Zooindicator | *Turdus amaurochalinus* | Oc' | Creamy-billed Thrush | When this bird sings, it calls the rain. |
| Seasonal indicator | Phytoindicator | *Acacia loretensis* | Shara' | CariCari Tree | Its flowering signals the onset of the rainy season. |
| Seasonal indicator | Phytoindicator | *Bactris gasipaes* | Vä'ij | Peach Palm | Its fructification signals the end of the rainy season and the start of the Tsimane' seasonal calendar. Many people signal that the fructification has been late in recent decades (Fernández-Llamazares et al. 2014). Phenological changes have also been reported by other Amazonian indigenous groups (Echeverri 2010). |

| | | | | | |
|---|---|---|---|---|---|
| Seasonal indicator | Phytoindicator | *Cecropia concolor* | Quiruru' | Pumpwood | Its flowering coincides with the arrival of the first migratory fishes in the Maniqui River (Fernández-Llamazares et al. 2014). |
| Seasonal indicator | Phytoindicator | Leguminosae | I'seji | --- | When its flowering occurs, the cold season is at its middle point. |
| Seasonal indicator | Phytoindicator | *Mauritia flexuosa* | Tyutyura' | Moriche Palm | Its flowering indicates the onset of the rainy season. |
| Seasonal indicator | Phytoindicator | *Pourouma cecropiifolia* | Movai | Amazon Tree-grape | Its flowering indicates that the rainy-season honey is ready to be harvested. |
| Seasonal indicator | Phytoindicator | *Salacia sp.* | Tiribui | Guapomo | Its flowering indicates the onset of the rainy season. |
| Seasonal indicator | Phytoindicator | *Swietenia macrophylla* | Chura' | Big-leaf Mahogany | Multi-indicator. Its flowering indicates the onset of the rainy season. When its seeds fly with the wind, the dry season starts. |
| Seasonal indicator | Phytoindicator | *Triplaris americana* | Chij | Ant Tree | Its flowering indicates the onset of the cold season. |
| Seasonal indicator | Zooindicator | *Columba subvinacea* | Oto' | Ruddy Pigeon | Its singing indicates the onset of the rainy season. |
| Seasonal indicator | Zooindicator | *Glaucidium brasilianum* | Cayovore | Ferruginous Pygmy Owl | Its singing indicates the onset of the rainy season. |
| Seasonal indicator | Zooindicator | Lumbricidae | Oya', shiri' | Earthworms | When there are few worms in the agricultural plots, it means that the arrival of the migratory fishes is approaching. |
| Seasonal indicator | Zooindicator | *Momotus momota* | Ururum, uaruv | Blue-crowned Motmot | Its singing indicates the onset of the rainy season. |
| Seasonal indicator | Zooindicator | *Pitangus sulphuratus* | Fidiri | Great Kiskadee | Its singing indicates the onset of the rainy season. |
| Storm predictor | Phytoindicator | *Ceiba pentandra* | O'ba | Great Kapok Tree | Its flowering is thought to attract big storms. Mosetenes from Bolivian Amazonia believe that this tree calls the water, because it has a puffed shape in its trunk. They also believe that when this tree does not flower, rice won't grow much (Ferreira 2011). |
| Storm predictor | Phytoindicator | *Heliocarpus americanus* | Mü' | Balsamillo Tree | Its flowering indicates that there will be a big storm in the following 3 days. |
| Storm predictor | Phytoindicator | *Ochroma pyramidale* | Cajñere' | Balsa Tree | Its flowering indicates a big storm coming. |
| Storm predictor | Zooindicator | *Ortalis motmot* | Mara'se | Little Chachalaca | Its singing indicates the arrival of a big storm in the short term (1-3 days). |

| | | | | | |
|---|---|---|---|---|---|
| Sunny weather predictor | Astronomical | --- | Dyidyista' ivaj | Smiling (U-shaped) moon | In the rainy season, when a quarter moon looks U-shaped (i.e., smiling), the following day will be sunny. In Hawaiian astrology, this moon is called the dry moon because '*it holds the water*' (NASA 2014). |
| Sunny weather predictor | Atmospheric | --- | Dyicba'babdye' | Morning fog over the river | A thick fog over the river at dawn means that the day will be sunny. |
| Sunny weather predictor | Phytoindicator | *Vernonia patens* | O'ojvi | Paichane | Its flowering indicates that the following day will be sunny. |
| Sunny weather predictor | Zooindicator | *Cerdocyon thous* | Va'ajva'aj | Crab-eating fox | When the fox signs in the night, the following day will be sunny. |
| Sunny weather predictor | Zooindicator | *Spizaetus tyrannus* | Ocoriyo | Black Haw Eagle | Its singing brings sunny weather. There is the extended belief of the singing of *Spizaetus tyrannus* as being a signal of good luck. |

**Note:** see the References section in Chapter II for the complete Reference List included in this table.

## Appendix III.d. Descriptive comparison of changes in climatic perceptions in Chapter III

The bivariate analysis of the outcome variable (i.e., agreement) allows us to get a preliminary assessment of the magnitude of effect of the intervention. Table S3.5 shows the results of this analysis for the five weather features, both before and after the workshop and for both treatment and control groups.

**Table S3.5 |** Analysis of change in outcome variables (*n* = 848 = 424 people*2 surveys) in Chapter III.

| **Outcome Variables** | **Groups** | | |
|---|---|---|---|
| | **a** | **b** | **c** |
| | **Control** (*n* = 350) | **Treatment** (*n* = 74) | **Δ (Treatment-Control)** |
| Rainfall | | | |
| Before Treatment | 48% | 58% | 10% |
| After Treatment | 64% | 69% | 5% |
| Δ (After – Before) | 16% | 11% | -5% |
| Temperature | | | |
| Before Treatment | 36% | 29% | -7% |
| After Treatment | 37% | 39% | 2% |
| Δ (After – Before) | 1% | 10% | 9% |
| Flood frequency | | | |
| Before Treatment | 13% | 19% | 6% |
| After Treatment | 5% | 7% | 2% |
| Δ (After – Before) | -8% | -12% | -4% |
| Cold season duration | | | |
| Before Treatment | 14% | 21% | 7% |
| After Treatment | 17% | 11% | -6% |
| Δ (After – Before) | 3% | -10% | -13% |
| Cold season strength | | | |
| Before Treatment | 13% | 21% | 8% |
| After Treatment | 20% | 24% | 4% |
| Δ (After – Before) | 7% | 3% | -4% |

Note: All the outcome variables have been transformed into binary surrogates for *agreement*, measuring if the individual perceptions reported matched the information presented in the workshop (coded as *1*) or not (coded as *0*). The numbers in each cell show the agreement both before and after the intervention, and in both control and treatment individuals.

# APPENDIX IV.

**Table S4.1 |** Descriptive summary of the Tsimane' perceptions in game and bird species' relative abundances over respondent's lifetimes (Chapter IV).

| | Vernacular name | Scientific name | Number of reports | 1930 (*n* = 12) | | 1940 (*n* = 20) | | 1950 (*n* = 24) | | 1960 (*n* = 37) | | 1970 (*n* = 60) | | 1980 (*n* = 76) | | 1990 (*n* = 71) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Game species** | **5 game species most reported as abundant in the past** | | | | | | | | | | | | | | | | |
| | Vernacular name | Scientific name | Number of reports (*past*) | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* |
| | Mumujñi' | *Tayassu pecari* | 168 | 66.67 | 0.00 | 50.00 | 0.00 | 66.67 | 4.17 | 62.16 | 8.11 | 68.33 | 1.67 | 50.00 | 2.63 | 45.07 | 4.23 |
| | Shi' | *Tapirus terrestris* | 147 | 83.33 | 0.00 | 50.00 | 5.00 | 50.00 | 0.00 | 56.76 | 2.70 | 55.00 | 6.67 | 43.42 | 3.95 | 39.44 | 1.41 |
| | Quiti | *Pecari tajacu* | 135 | 66.67 | 16.67 | 45.00 | 20.00 | 50.00 | 37.50 | 43.24 | 29.73 | 48.33 | 25.00 | 44.74 | 35.53 | 38.03 | 35.21 |
| | Odoj | *Ateles chamek* | 95 | 33.33 | 0.00 | 25.00 | 10.00 | 45.83 | 4.17 | 35.14 | 0.00 | 30.00 | 1.67 | 26.32 | 3.95 | 33.80 | 1.41 |
| | Uru' | *Alouatta sara* | 94 | 25.00 | 8.33 | 45.00 | 10.00 | 33.33 | 12.50 | 37.84 | 8.11 | 26.67 | 10.00 | 31.58 | 5.26 | 28.17 | 16.90 |
| | **5 game species most reported as abundant in the present** | | | | | | | | | | | | | | | | |
| | Vernacular name | Scientific name | Number of reports (*present*) | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* |
| | Naca' | *Cuniculus paca* | 209 | 0.00 | 91.67 | 0.00 | 80.00 | 0.00 | 66.67 | 5.41 | 64.86 | 1.67 | 66.67 | 9.21 | 80.26 | 8.45 | 57.75 |
| | Ñej | *Mazama americana* | 136 | 33.33 | 41.67 | 10.00 | 45.00 | 20.83 | 41.67 | 16.22 | 51.35 | 16.67 | 55.00 | 30.26 | 40.79 | 28.17 | 40.85 |
| | Quiti | *Pecari tajacu* | 93 | 66.67 | 16.67 | 45.00 | 20.00 | 50.00 | 37.50 | 43.24 | 29.73 | 48.33 | 25.00 | 44.74 | 35.53 | 38.03 | 35.21 |
| | Chu' | *Nasua nasua* | 89 | 0.00 | 75.00 | 15.00 | 20.00 | 12.50 | 37.50 | 13.51 | 24.32 | 6.67 | 18.33 | 10.53 | 31.58 | 9.86 | 32.39 |
| | Väsh | *Dasypus novemcinctus* | 80 | 0.00 | 58.33 | 0.00 | 25.00 | 0.00 | 33.33 | 0.00 | 32.43 | 0.00 | 18.33 | 3.95 | 28.95 | 2.82 | 21.13 |
| **Bird species** | **5 bird species most reported as abundant in the past** | | | | | | | | | | | | | | | | |
| | Vernacular name | Scientific name | Number of reports (*past*) | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* |
| | Emej | *Penelope jacquacu* | 190 | 83.33 | 8.33 | 70.00 | 10.00 | 58.33 | 25.00 | 70.27 | 21.62 | 68.33 | 18.33 | 60.53 | 14.47 | 54.93 | 15.49 |
| | Opaj | *Mitu tuberosum* | 165 | 91.67 | 0.00 | 70.00 | 5.00 | 58.33 | 0.00 | 48.65 | 5.41 | 60.00 | 5.00 | 56.58 | 3.95 | 40.85 | 7.04 |
| | U'va | *Ara chloropterus* | 129 | 41.67 | 8.33 | 25.00 | 15.00 | 50.00 | 4.17 | 51.35 | 8.11 | 45.00 | 8.33 | 38.16 | 13.16 | 45.07 | 8.45 |
| | Tobij | *Pipile cumanensis* | 121 | 91.67 | 0.00 | 45.00 | 10.00 | 45.83 | 0.00 | 32.43 | 5.41 | 41.67 | 3.33 | 48.68 | 1.32 | 22.54 | 0.00 |
| | Iya | *Ara ararauna* | 46 | 8.33 | 8.33 | 20.00 | 5.00 | 20.83 | 4.17 | 21.62 | 5.41 | 16.67 | 8.33 | 13.16 | 6.58 | 11.27 | 7.04 |
| | **5 bird species most reported as abundant in the present** | | | | | | | | | | | | | | | | |
| | Vernacular name | Scientific name | Number of reports (*present*) | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* | *DOB* | *now* |
| | Oi' | *Psarocolius viridis* | 110 | 0.00 | 33.33 | 5.00 | 25.00 | 0.00 | 25.00 | 0.00 | 37.84 | 0.00 | 35.00 | 7.89 | 35.53 | 14.08 | 46.48 |
| | Marase' | *Ortalis motmot* | 94 | 0.00 | 58.33 | 20.00 | 35.00 | 8.33 | 20.83 | 2.70 | 35.14 | 3.33 | 26.67 | 3.95 | 40.79 | 7.04 | 21.13 |
| | Yovivij | *Ramphastos toco* | 78 | 25.00 | 41.67 | 10.00 | 5.00 | 4.17 | 45.83 | 21.62 | 21.62 | 8.33 | 35.00 | 18.42 | 26.32 | 18.31 | 16.90 |
| | O'to' | *Columba subvinacea* | 62 | 0.00 | 25.00 | 5.00 | 45.00 | 16.67 | 16.67 | 5.41 | 10.81 | 5.00 | 18.33 | 11.84 | 15.79 | 14.08 | 26.76 |
| | Emej | *Penelope jacquacu* | 50 | 83.33 | 8.33 | 70.00 | 10.00 | 58.33 | 25.00 | 70.27 | 21.62 | 68.83 | 18.33 | 60.53 | 14.47 | 54.93 | 15.49 |

Note: Rows represent the percentage of people born in each decade reporting a particular species amongst the 3 most abundant both in their Decade Of Birth (DOB) and now.

# APPENDIX V.

## Appendix V.a. Open letter from the villagers of the Upper Maniqui River to the Great Tsimane' Council with regard to thatch palm gathering in the area.

Tsimane' Territory, 27th February 2013
Issue: Thach palm harvesting

Our Honourable President of the Great Tsimane' Council,

Of our utmost consideration:

It is a great pleasure for us to address you and all the members of the Great Tsimane' Council to convey our most cordial greetings and congratulate you for the commendable work done in the management of our Territory, wishing you every success in each of the activities that you are so eagerly developing.

The reason for this letter is to invite you, political authorities of the Tsimane' people, to reflect on the problematic situation and the countless challenges faced by thatch palm harvesting in our Territory, especially in communities upstream along the Maniqui River who are still trying to conserve and manage their thatch palm groves as a valuable resource of our forests.

The long history of traditional use of thatch palm in the Tsimane' Territory is well-known. Thatch palm harvesting constitutes an activity of great importance to our local economies, which has made it become a symbol of the Tsimane' people and culture. However, the continuity of thatch palm use is threatened by the growing presence of external thatch palm traders in our lands.

This situation poses a direct threat to our community and our thatch palm groves for the reasons set forth below:

1. Traders acquire thatch palm panes through unfair exchanges, generating a system of endless debts that lead to a cycle in which thatch palm harvesters are always indebted to traders.

2. For years, traders have been grown rich from our thatch palm but at the expense of our labour and resources, by buying it at low prices and selling it for far more expensive prices in Arenales, San Borja and Santa Cruz. This has been done without leaving any benefit for the community, making us work under an almost slavery-like system and without ever recognising the rights of the native communities originally settled here.

3. For quite a while, traders have been harvesting our thatch palm by themselves and taking it to own camps to be woven into panes. This is accomplished without even asking for our approval or permission, thus an unprecedented theft in the history of our Territory.

4. For hundreds of years, we have developed, through our ancestral knowledge, methods for harvesting thatch palm that are respectful with the forest, allowing the regeneration of thatch palm for generations to come. Our traditional regulations for harvest are completely ignored by traders intruding our lands, whose harmful extractive practices have led to the thatch palm groves to diminish, now found increasingly far away from our villages.

5. Some of the traders who come to our communities often display aggressive attitudes towards us, even threatening us to death, insulting us or pointing us with a gun when we do not follow their orders, despite being in our communities and our ancestral lands.

That is why we, the villagers of the Upper Maniqui, are forced to denounce this deplorable situation and ask the Great Tsimane' Council to take measures to definitively expel the traders from our lands, enabling us to manage our resources on our own.

Thatch palm panes are luxury items in the cities, where they can be sold for up to twenty bolivianos (Bs) per pane. How can it be that after all these years of harvesting thatch palm we have not seen any of this money? How can it be that we are like we were years ago? Where has gone all this wealth? The answer to these questions is clear: most of the benefits lie in the hands of outsiders. The current marketing system is completely unjust, with thatch palm harvesters being the least beneficiaries.

This situation causes us deep sadness. To see how our most important resources are disappearing at a frenetic pace while foreigners get rich is both saddening and frustrating. That is why we request aid from the Great Tsimane' Council to put an end to this bleak. Some villagers are organising and developing skills to better cope with the marketing of thatch palm, transporting panes themselves to San Borja or Arenales, where they are sold at fair prices. For this to be effective, we need the support of the Great Tsimane' Council.

We alone, without your help, cannot cope with the immense power held by thatch palm traders. We are seeing the frantic pace at which thatch palm is extracted without our consent and soon we will not even have any thatch palm to roof our own houses. We need to join our efforts to market our panes at fair prices and to preserve thatch palm for future generations.

Without further ado, we take this opportunity to send you our most cordial greetings. We thank you for all the time and attention put into considering our request and we look forward to your response, either via letter or by calling us to a meeting in the grounds of the Great Tsimane' Council.

Sincerely,

Villagers of the Upper Maniqui

# Appendix V.b. Further details on the villages surveyed in Chapter V

**Table S5.1 |** List of villages surveyed in Chapter V and corresponding characteristics along the Tsimane' Territory, Bolivian Amazonia.

| **Village** | **Number of informants** | **Distance to market town** (km)[18] | **Old-growth forest** ($km^2$)[19] | **Elevation** (m.a.s.l.) | **Annual precipitation** (mm)[20] | **Number of visits by thatch palm traders in the past month**[21] | **Average measured walking distance to the closest thatch palm grove** (km) | | **Average perceived walking distance to the closest thatch palm grove** (km) | | **Average perceived change of walking distance to the closest thatch palm grove** (km) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Mean | SD | Mean | SD | Mean | SD |
| 1 | 53 | 32.93 | 6.87 | 242 | 1868 | 6 | 5.065 | 0.221 | 6.074 | 1.538 | 4.321 | 0.234 |
| 2 | 26 | 38.89 | 6.81 | 236 | 1891 | 5 | 6.801 | 0.297 | 6.525 | 1.331 | 4.695 | 1.439 |
| 3 | 17 | 50.43 | 6.69 | 241 | 1912 | 3 | 6.641 | 0.290 | 6.745 | 1.521 | 2.684 | 1.225 |
| 4 | 21 | 58.62 | 5.99 | 247 | 1931 | 5 | 5.718 | 0.250 | 5.330 | 1.319 | 2.823 | 0.648 |
| 5 | 20 | 68.31 | 7.02 | 253 | 1962 | 3 | 4.023 | 0.176 | 4.836 | 1.434 | 2.964 | 1.642 |
| 6 | 19 | 81.85 | 6.28 | 259 | 1991 | 3 | 3.874 | 0.169 | 4.187 | 0.593 | 2.484 | 1.042 |
| 7 | 13 | 93.12 | 6.68 | 264 | 2013 | 3 | 3.364 | 0.147 | 3.960 | 0.761 | 2.484 | 1.188 |
| 8 | 18 | 99.05 | 7.30 | 262 | 2028 | 4 | 2.798 | 0.122 | 4.702 | 2.817 | 2.611 | 2.789 |
| 9 | 20 | 102.80 | 7.26 | 267 | 2042 | 5 | 3.837 | 0.168 | 4.017 | 1.432 | 2.588 | 1.317 |
| 10 | 20 | 112.78 | 7.23 | 277 | 2069 | 4 | 2.675 | 0.117 | 4.797 | 1.465 | 3.568 | 1.351 |
| 11 | 20 | 114.89 | 7.29 | 268 | 2062 | 4 | 1.646 | 0.072 | 5.031 | 1.659 | 2.164 | 1.484 |
| 12 | 13 | 119.45 | 7.21 | 270 | 2074 | 7 | 1.208 | 0.053 | 5.760 | 2.161 | 3.900 | 2.212 |
| 13 | 45 | 122.88 | 7.16 | 275 | 2091 | 4 | 2.478 | 0.108 | 5.383 | 1.692 | 4.104 | 0.266 |

[18] Accounting for river meanders.

[19] Estimates based on Landsate imagery for the year 2009, by applying a 5-km circular buffer to the centre of each village (Luz 2013).

[20] Estimates obtained from Worldclim dataset.

[21] Report from the village leader (*corregidor*) with information triangulated by other 2 village key informants.