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

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### 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 behavior 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 analyzed whether perceptions of availability match estimates of abundance obtained from ecological data and whether differences in perception help to explain harvesting behavior 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 scrutinized 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.

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## 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 emphasized 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).

Perceptions of environmental change can therefore be considered a form of tacit and situated knowledge, reflecting a depth of embodied experience unlikely to be derived through structured and formalized processes (Fazey et al. 2005). On the one hand, perceptions of environmental change are based on factual and direct knowledge or continued observation of biophysical phenomena (Gearheard et al. 2009; Orlove et al. 2010). On the other hand, they also encompass embodied experience directly acquired through perceptual information (Leclerc et al. 2013). Given this dual character, the literature has to date interchangeably used the terms *perception* (e.g. Oldekop et al. 2013) and *knowledge* (e.g., Riseth et al. 2011) to refer to accounts of environmental changes reported by small-scale societies. Actually, whether local people's experience of environmental changes can be considered as knowledge or perception is still debated (see Yeh 2015), because many of these perceptions are inherently tacit (i.e., not articulated in a form easily accessible to others; Raymond et al. 2010). Such experiential character echoes the nature of Local Environmental Knowledge, a holistic cumulative body of knowledge, practice and belief, embedded in the culture of a group (including local institutions) and borne from continued periods of observation (Berkes et al. 2000; Gagnon and Berteaux 2009).

In any case, based on such perceptual information (be it theorized or referred to as perception or local knowledge), local resource users often determine whether change merits a certain response, including shifts in management strategies (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 internalized 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 localized depletion of resources has often led to individuals maximizing 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 behavior 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* (Poit Kunth.) 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. It is important to note that we consider perceptions 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 (Berkes 2009), as well as experiential and based on the belief systems (Ingold and Kurtilla 2000; Fernández-Llamazares et al. 2015a). In absence of written records, perceptions of the status and change of natural resources are captured in Local Environmental Knowledge, which is stored, revived and transmitted as social memory (Berkes et al. 2000; Barthel et al. 2013).

Our research pursues three specific objectives: (1) to describe the Tsimane' management regime of *G. deversa* as currently practiced; (2) 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 (3) to analyze whether different perceptions of *G. deversa* availability and change explain harvesting behavior 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.

## 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 (Fig. 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 m (Guèze et al. 2014a).

### Thatch palm *Geonoma deversa*

*Geonoma deversa* (known as '*jatata*' in Spanish or '*cajtafa*' in Tsimane') is an understory 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 meters tall), its trifoliolate 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).

### 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<sup>2</sup> (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 (Morales 1999). Although the leaves of other palm species are also used by the Tsimane' for the thatching of their houses (see Reyes-García 2001 for an exhaustive list of palm species used), *G. deversa* is by far the most valued species by the Tsimane' 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).

### 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 specialized in sourcing, transporting, and commercializing 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 one of the cheapest alternatives to corrugated iron, thatch palm panes (including *G. deversa*, as well as other palm species) became highly valued throughout the Bolivian lowlands, particularly in touristic venues, due to its rustic look. Thus, it is hardly surprising that the commercialization 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 commercialization of *G. deversa* in the market town of Yucumo (Fig. 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. 2014b).

## Methods

We conducted fieldwork between January 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 of each village and individual participating in the study, as well as the agreement of the Tsimane' political organization, the Great Tsimane' Council (*Gran Consejo Tsimane'*). In addition, this research adheres to the Code of Ethics of the International Society of Ethnobiology.

All adults (defined as people of 16 years of age or older) 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.

### 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 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 contextualize results from quantitative data collection methods.

### 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 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 on 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 (see Appendix 1). Based on previous research in the area, we transformed the time reported to kilometers 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 vs. present state. We used the informant's childhood (i.e., the decade of birth, hereinafter 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.  $\pm 15\%$ ), 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 (Fig. 1). In all cases, this distance was calculated from the village school (which the Tsimane' consider their village center), 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 farther from the main market town (i.e., less or more than 90 km, respectively). To contextualize 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.

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

Accurately measuring *G. deversa* harvesting behavior 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 Yucumo, Fig. 1) and the one furthest from the market town (a three-day canoe trip from Yucumo). 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 behavior regarding *G. deversa* harvesting and management (see Table 1 for descriptive statistics of sample composition).

With regard to individual behaviors in thatch palm harvesting and management, we used different quantitative methods (see Appendix 1). First, individual harvesting behavior 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 behavior with regard to thatch palm management was further measured with the help of two standard proxies (see Appendix 1): (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 OLS and Poisson regressions to test the association between individual harvesting and management behavior 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 closer and further from town village, 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).

## Results and Discussion

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

The Tsimane' legally hold communal land titles since 1996, although the land demarcation process is yet to be finalized (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' recognize 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 organization 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' organization 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 authorization 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 (Morales 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 m 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, Morales 1999).

Interestingly, we did not find any strong evidence of a recognized 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, 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*.

### Measurement and validation of local perceptions

Table 2 provides descriptive statistics of the variables measuring change and availability perceptions of *G. deversa*. The average value for our measure of change perception ( $3.46 \pm 1.78$  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*" (woman, 65, June 2013). 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*" (man, 33, April 2013).

Fig. 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 farther 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 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 farther from town seem to overestimate the walking distance to reach the closest thatch palm grove, hence also underestimating *G. deversa* availability.

The results of the t-tests comparing change perceptions between younger and older individuals both in villages closer to and farther from town suggest that the changes in thatch palm availability happened at different timescales along the Maniqui River (see Table 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 2 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*” (woman, 60, March 2013) or “*First they (the traders) ended with the thatch palm near the town and now that it is over, they come here to steal ours*” (man, 91, October 2013).

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). Same than Local Environmental Knowledge, local perceptions of environmental change encompass not only experiential knowledge of the environment, but also symbolic dimensions and/or traditional beliefs (Berkes et al. 2000; Houde 2007). This set of cultural values and beliefs is critical to determine how change is interpreted at the local level (Orlove et al. 2010). 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*” (woman, 44, May 2013) or “*What will our children sell when our thatch palm is over?*” (man, 40, April 2013). 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. 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 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  $3.28 \pm 1.90$  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 (Fig. 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 internalized these perceptions as a threatening reality.

### Local harvesting and management behavior

Table 4 shows significant differences in harvesting and management behavior between the two villages studied. In the village farther 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 farther 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 farther from town ( $P < 0.01$  and  $P < 0.1$ , 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 behavior 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 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 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 behaviors was found to be in detriment to pro-social behavior (Godoy et al. 2007, Gurven et al. 2008).

The results of the regressions of individual harvesting and management behavior against individual perceptions of *G. deversa* availability and change show some paradoxical findings (Table 5). In the village closer to town, we found (a) negative associations between harvesting proxies and availability perception ( $P < 0.001$  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 farther from town, no significant relation was found between perceptions and harvesting behavior. However, in the village farther 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 behavior proxies and change perception ( $P < 0.001$  and  $P < 0.05$ , respectively). Contrarily, no association was found between perceptions and management behavior 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.

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 behaviors 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 behavior disposition have widely examined socio-economic factors affecting pro-social behavior (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 organizing users to sustainably manage the resource might be perceived as unnecessarily high and unlikely to generate benefits. In contrast, such self-organization 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!*" (man, 33, April 2013).

## Conclusions

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.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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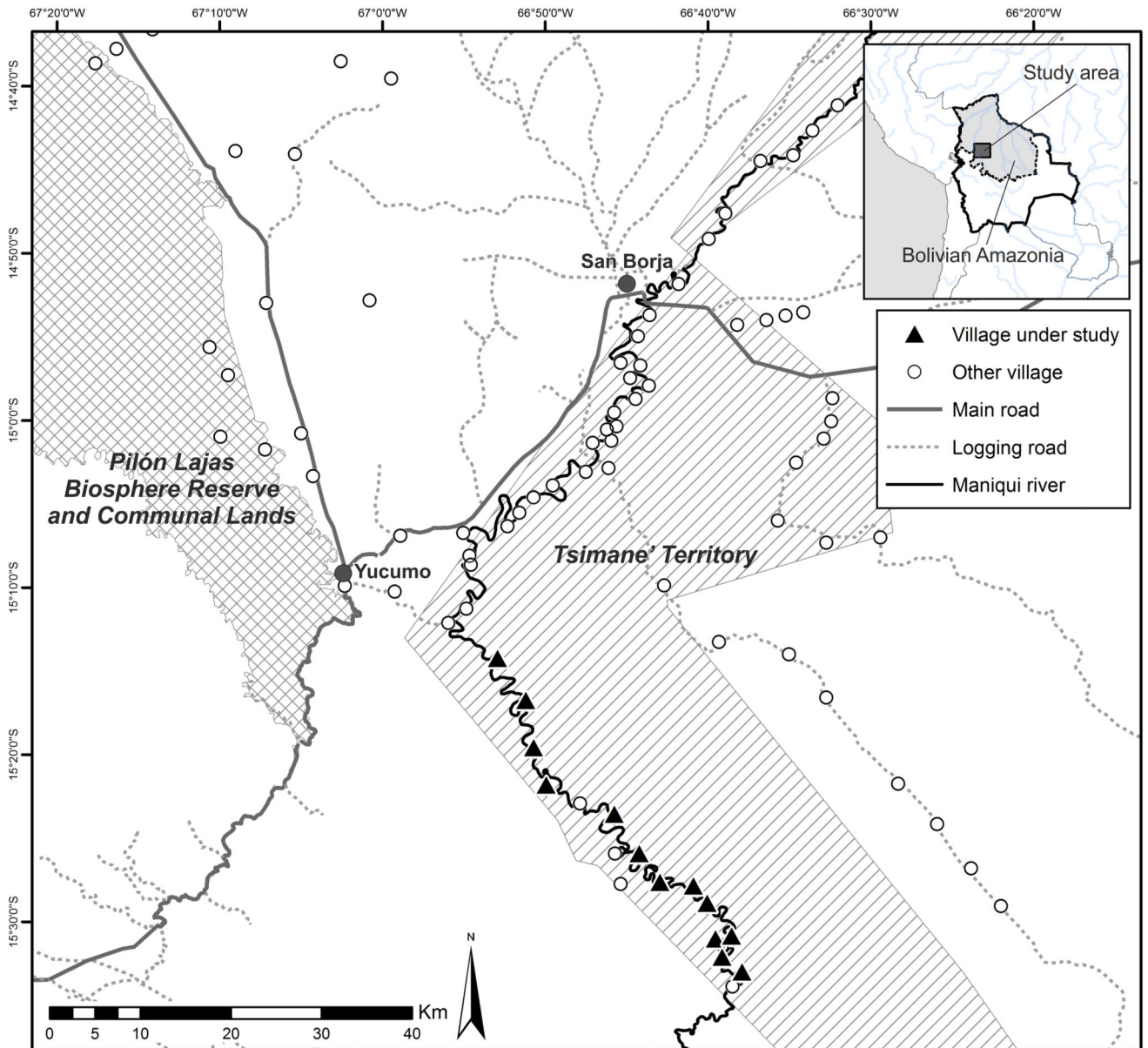


Fig. 1.

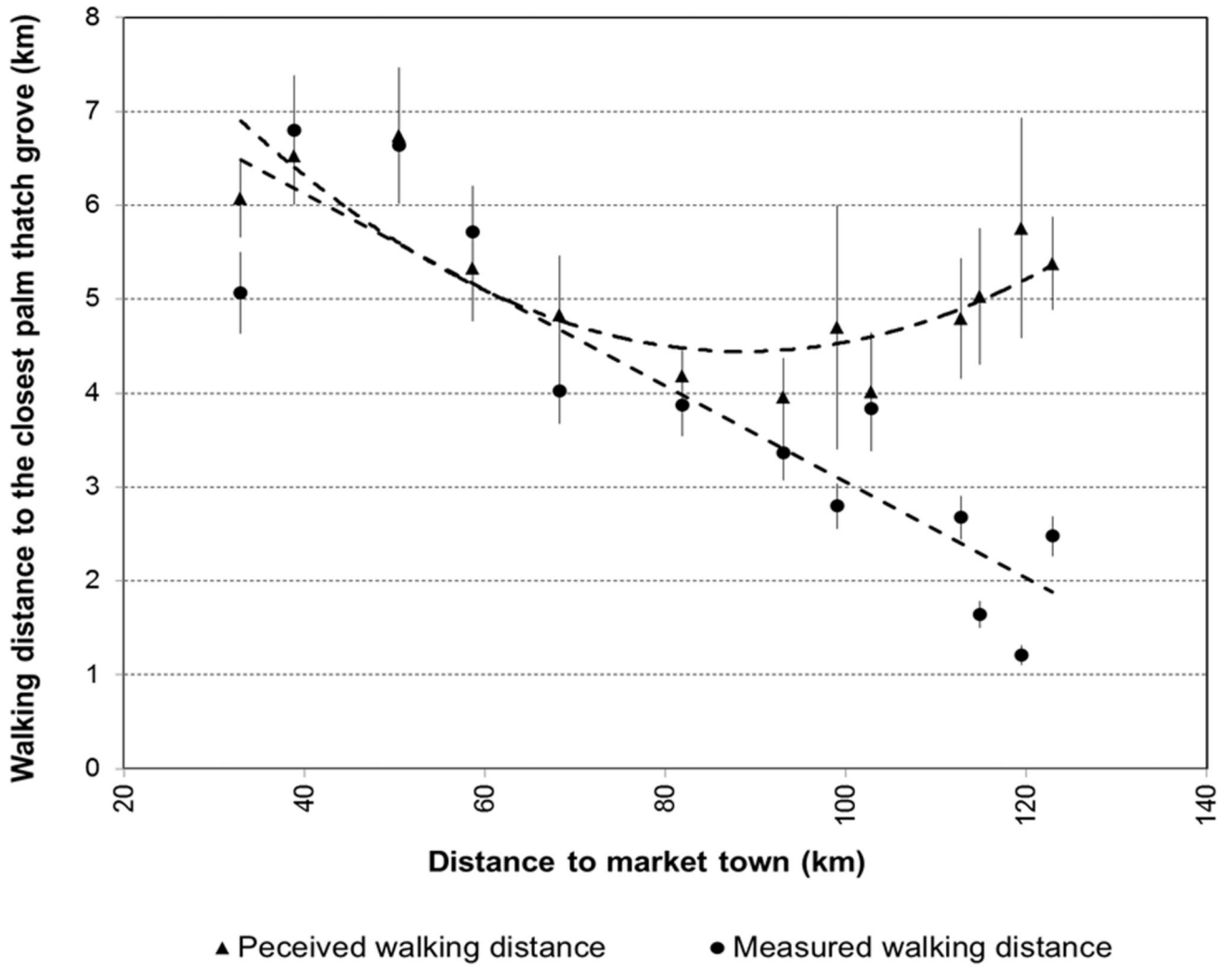


Fig. 2.

Table 1

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

Table 2

Variable name	Description	Villages <sup>†</sup>	Descriptive statistics				
			<i>n</i>	Mean	SD	Min	Max
Perception of <i>G. deversa</i> availability	Perceived walking distance to reach the closest thatch palm grove (km)	All ( <i>N</i> = 13)	296	5.31	1.77	2.34	11.70
		<90 km from town ( <i>N</i> = 6)	152	5.72	1.58	2.34	9.36
		>90 km from town ( <i>N</i> = 7)	144	4.88	1.85	2.34	11.70
Perception of <i>G. deversa</i> 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 ( <i>N</i> = 13)	296	3.46	1.78	0.00	9.36
		<90 km from town ( <i>N</i> = 6)	152	3.63	1.64	0.00	8.19
		>90 km from town ( <i>N</i> = 7)	124	3.28	1.90	0	9.36

<sup>†</sup>For village information, see Appendix S2.

**Table 3**

Variable	DOB of informants	<90 km from town			>90 km from town			p-value
		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 <sup>*</sup>
	p-value	--	0.052 <sup>*</sup>	--	--	0.012 <sup>**</sup>	--	--
Past walking distance	1920-1959	35	2.229	0.261	23	1.280	0.180	0.005 <sup>**</sup>
	1960-1999	117	2.060	0.995	121	1.679	0.117	0.007 <sup>***</sup>
	p-value	--	0.233	--	--	0.079 <sup>*</sup>	--	--
Current walking distance	1920-1959	35	6.251	0.275	23	5.375	0.355	0.027 <sup>**</sup>
	1960-1999	117	5.567	0.143	121	4.790	0.170	0.000 <sup>***</sup>
	p-value	--	0.012 <sup>**</sup>	--	--	0.082 <sup>*</sup>	--	--

<sup>\*</sup>, <sup>\*\*</sup> and <sup>\*\*\*</sup>, significant at <0.1, <0.05 and <0.01, respectively.



Table 4

Variable type	Variable name	Description	Village closer to town		Village farther 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 behavior	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 behavior	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

Table 5

Village	Explanatory variables	Dependent variable <sup>†</sup>			
		Harvesting <sup>‡</sup>		Management <sup>§</sup>	
		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 <sup>2</sup>	0.234	0.116	---	---
	Wald Chi <sup>2</sup>	---	---	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 <sup>2</sup>	0.210	0.153	---	---
Farther 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 <sup>2</sup>	0.087	0.060	---	---
	Wald Chi <sup>2</sup>	---	---	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 <sup>2</sup>	0.088	0.058	---	---
Wald Chi <sup>2</sup>	---	---	9.38	8.62	

<sup>†</sup> Coefficient reported (Standard Error in parenthesis); see Table 4 for definition of variables. No collinearity between variables (all Variance Inflation Factors (VIF) <1).

<sup>‡</sup> For harvesting behavior variables, these correspond to OLS Regression, including controls for age and sex, and clustering based on the household of the informant.

<sup>§</sup> For management variables, these correspond to Poisson regressions, including controls for age and sex, and clustering based on the household of the informants.

\*, \*\* and \*\*\*, significant at <0.1, <0.05 and <0.01, respectively.