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Rapid ecosystem change challenges the adaptive capacity of Local Environmental Knowledge

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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 on-going 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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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, 2014).

However, the increase in the pace at which GEC operates has raised skepticism 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-analog 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 behavior 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.

2. Theoretical section

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., desensitization 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).

2.2. A conceptual framework for the analysis of SBS

Despite the implications that the erosion of LEK on past ecosystems 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 vs. 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 life

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span 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.

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 (Fig. 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, 2005).The forest is the main source and sustenance of the Tsimane' livelihood, providing an essential basis for subsistence activities such as hunting and gathering (Chicchon, 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, 2007a).

To carry out this study, we first obtained Free Prior and Informed Consent of each village and individual participating, as well as the agreement of the Tsimane' political organization, the Great Tsimane' Council (*Gran Consejo Tsimane'*). In addition, this research adhered to the Code of Ethics of the International Society of Ethnobiology. 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 (Fig. 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 (see Table 2). 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 data set relates to measures of ecosystem change (Section 3.1), the second to age-related differences in the perception of ecosystem change (Section 3.2), and the third to intergenerational communication with regard to ecosystem change (Section 3.3). In Table 1 we summarize our Research Design.

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

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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.

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 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).

We asked about individual perceptions of environmental changes in wildlife (bird and game species), taking the informant's childhood (i.e., the decade of birth, hereinafter DOB) as an individual baseline. In line with the literature mentioned in Section 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 Table 5 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 recognized 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.

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 2 summarizes 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 contextualize 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 contextualize our free-listing data. The discussion narratives were analyzed by extracting dominant themes under the interview topic of intergenerational communication (see Bernard and Bernard, 2013).

4. Results

We structure our results below around the three units of evidence we used for analysing generational amnesia: ecosystem change (Section 4.1), age-related differences in the perception of ecosystem change (Section 4.2), and intergenerational communication within the study population (Section 4.3).

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 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 (Chicchon, 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 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.

4.2. 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 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.

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*-value = 0.036; Fig. 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*-value = 0.021; Fig. 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 Table S1, 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 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

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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 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.

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 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 amongst the factors explaining the decreasing LEK acquisition among 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 (Fig. 3A), on average, older respondents report significantly higher numbers of locally-extinct species than younger respondents ($R^2 = 0.775$; p-value = 0.009). The same was found for fish diversity (Fig. 3B), with older Tsimane' reporting higher numbers of locally-extinct species than younger Tsimane' ($R^2 = 0.602$; p-value = 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.

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

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(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 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 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,

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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., 2007c, 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

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issues of (a) revitalizing 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.

6. Conclusion

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 desensitization 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 revitalization 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.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- We develop a conceptual framework for empirically measuring shifting baselines.
- Empirical evidence of the shifting baseline syndrome found amongst native Amazonians.
- Local knowledge does not match the temporal rates of environmental change.
- Rapid ecosystem changes defy local knowledge adaptation timescales.

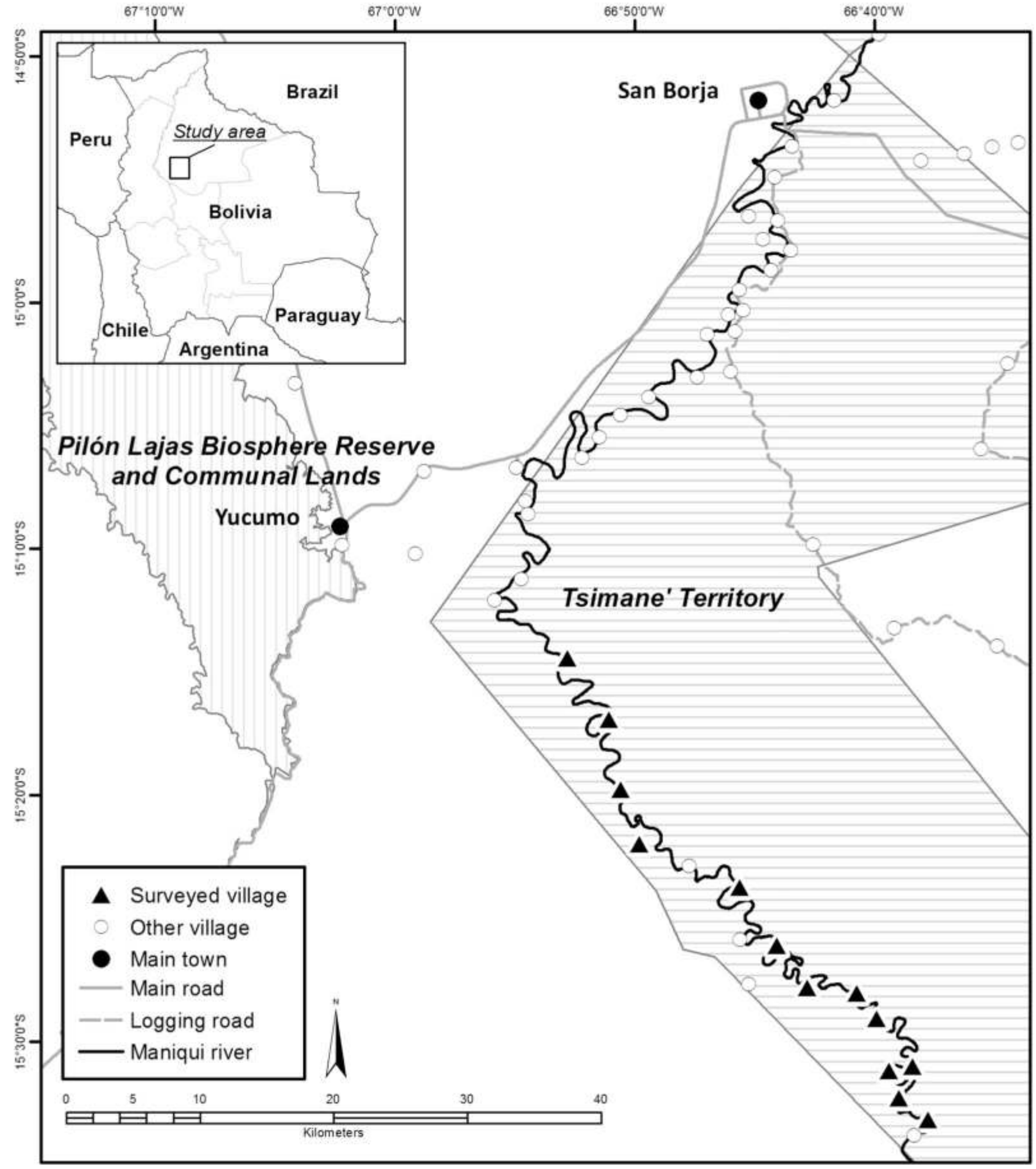

Fig. 1.
Region under study

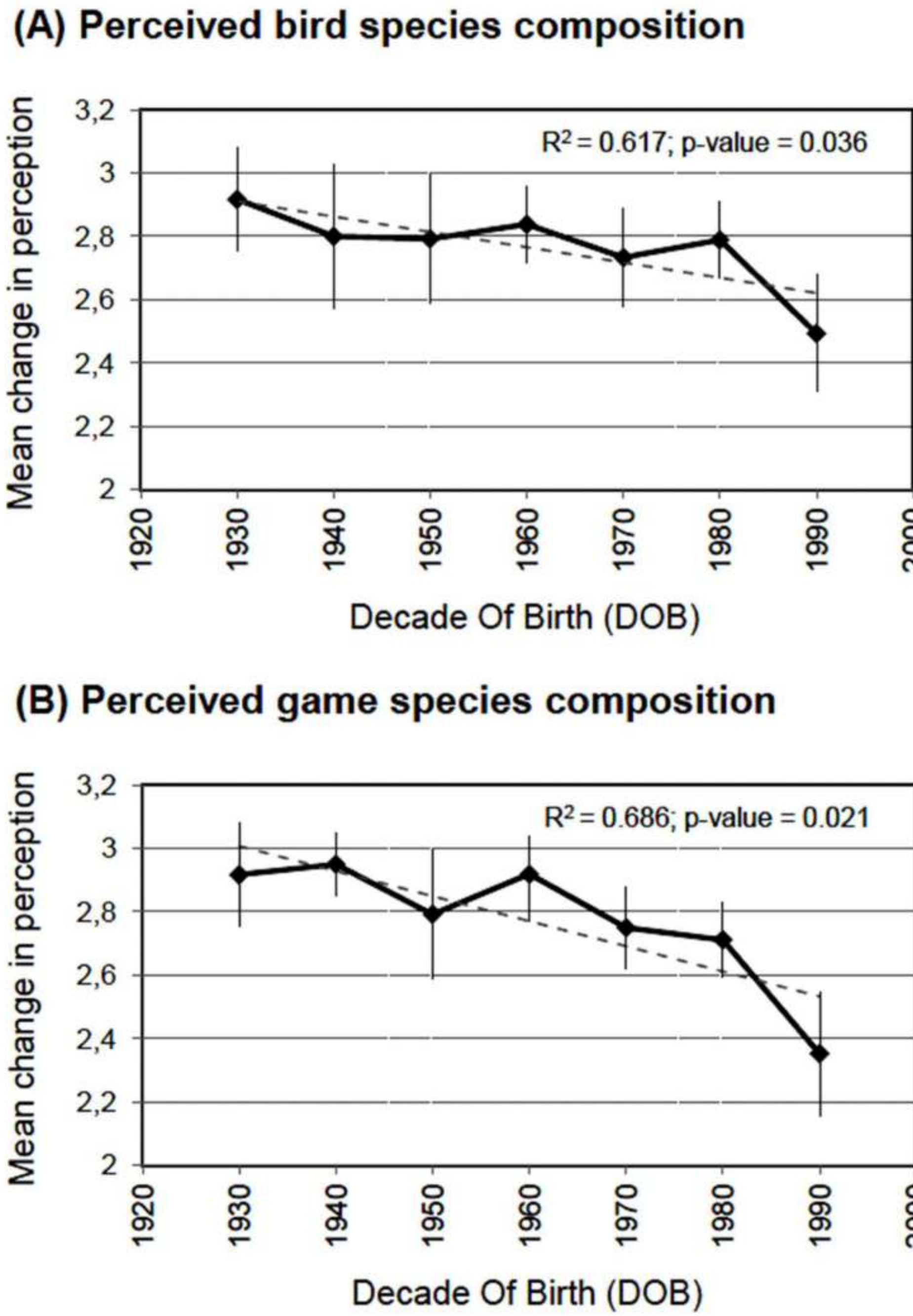

Fig. 2.

Evidence of age-related differences in the perception of environmental changes. Subplot (A) shows the mean change perception regarding composition of bird species reported by groups of individuals born in the same DOB. Subplot (B) shows the mean change perception regarding the composition of 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 equaling three, and minimum change perceived equaling zero. The dashed grey lines show the fitted regression models. The bars indicate the Standard Error (SE) of the mean change perception.

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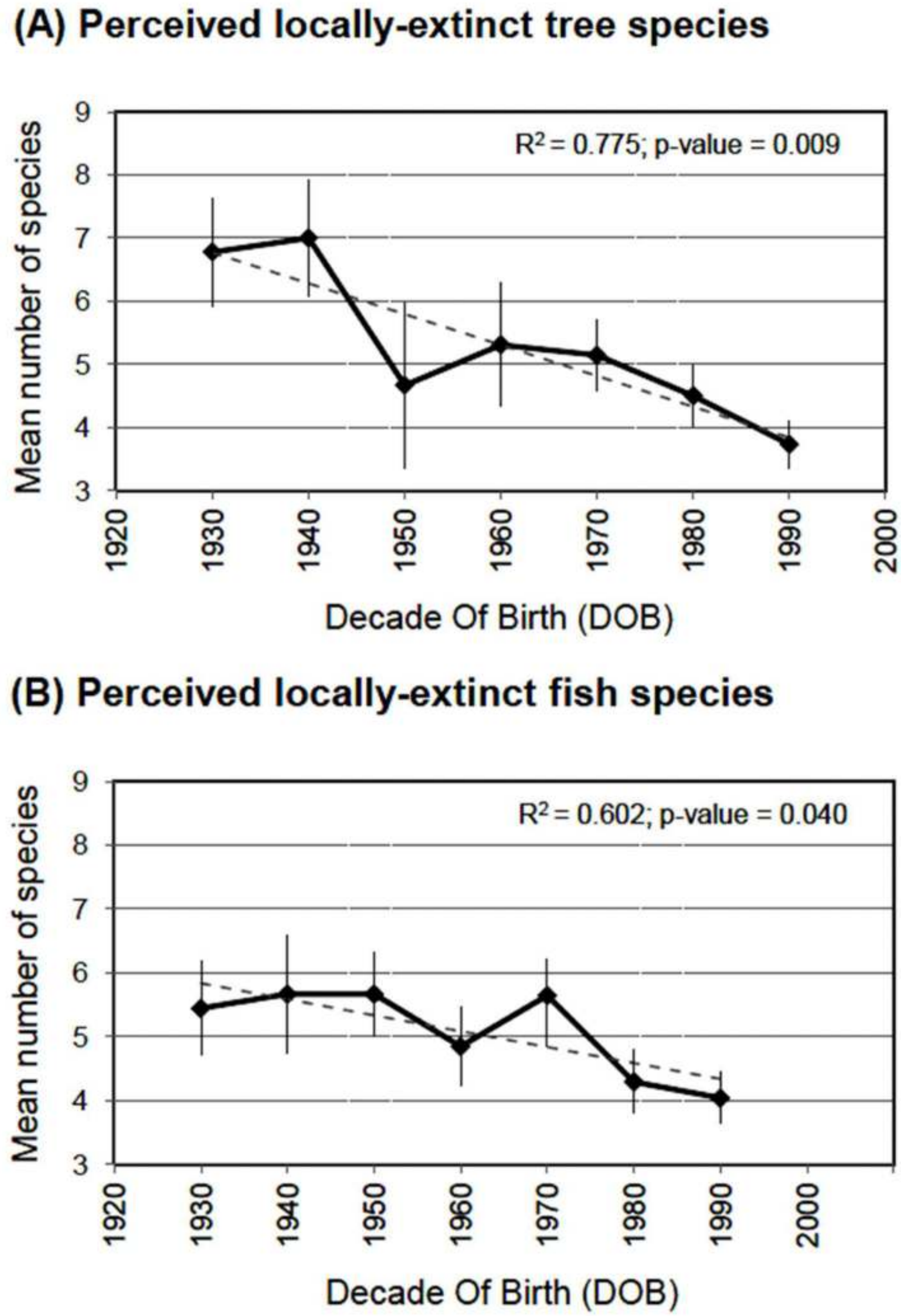

Fig. 3.

Evidence of low levels of intergenerational communication. Subplot (A) shows the mean number of locally-extinct tree species free-listed by groups of individuals born in the same DOB. Subplot (B) shows the mean number of 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.

Table 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]

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Table 2

Summary descriptive statistics of the sample composition

Sample	Variable name	Description	Descriptive statistics				
			n	Mean	SD	Min	Max
Sample 1	Age	Age of the interviewee	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	Male: 47.33% Female: 52.67%				
			n	Mean	SD	Min	Max
Sample 2	Age	Age of the interviewee	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	Male: 51.79% Female: 48.21%				
			n	Mean	SD	Min	Max
Sample 3	Age	Age of the interviewee	16	36.53	15.58	19	70
	Sex	Sex of the interviewee	Male: 56.25% Female: 43.75%				

Table 3

Local manifestations of Global Environmental Change in the Tsimane' social-ecological system

Main change	Description	Scale[1]	Methods[2]	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 and 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 (2005), 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 structure of populations	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 (2005), Castañeda-Menacho (2013)
Climatic 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 behavior (e.g. increased deforestation rates, decreasing adherence to traditional hunting norms)	L	SE	Chicchon (1992), Wilkie and Godoy (2001), Vadez et al. (2004, 2008), Godoy et al. (2005,2010), Reyes-García et al. (2007b, 2010), Luz (2013), Bottazzi et al. (2014)
	Increasing fragmentation of indigenous institutions for the governance of natural resources	L	S	Huanca (2005), Reyes-García and TAPS Bolivian Study Team (2012), Reyes-García et al. (2014c)

[1] *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. areas neighboring the Tsimane' Territory.

[2] *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*.

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Table 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

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Table 5

Tsimane' perceptions in threatened and non-threatened game species trends over the respondent's lifetimes

Species classification	Red List Index (IUCN, 2014)	Vernacular name	Scientific name	IUCN status (MMA, 2009)	Population trend (IUCN 2014)	Total number of reports [a]	% of reports as abundant in the past	% of reports as abundant in the present	Probability of change in abundance report [b]
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

[a] 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;

[b] *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).

* Significant at ≤0.05.

** Significant at ≤0.01.