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Adult knowledge of wild plants associated with limited delayed health and nutritional benefits for children or adults in the face of external change: A yearly panel (2003–2010) study among Tsimane', an indigenous Amazonian society in Bolivia

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ABSTRACT

Cross-sectional studies suggest that local ecological knowledge (LEK) helps humans cope with their environment. Among the forms of LEK, adult knowledge of wild plants has been associated with better child and adult health. We assess if the concurrent links between i) LEK and ii) health and nutritional status last and examine if LEK yields delayed benefits when societies face large socioeconomic and environmental changes. We use a yearly panel (2002–2010) from Tsimane', an Indigenous Amazonian society (Bolivia). All adults (~440) and children (~300) measured at baseline (2003) in 13 villages were followed yearly during 2004–2010 to estimate associations between a) baseline adult knowledge and skill about uses of wild plants and b) subsequent (2004–2010) anthropometric markers of nutritional status of themselves and the children (2y ≤ age ≤ 10y) living in the household at baseline. Among children, HAZ, BMI, and sum of four skinfolds were measured; among adults, BMI, sum of four skinfolds, and percent body fat with bioelectrical impedance were measured. Some skill losses increased by a large amount the likelihood of severe childhood stunting (HAZ < -3) for girls; the complete loss of these skills increased the share of severely stunted girls from 5% to 13%–20%. These are big numbers. The effects of LEK on other anthropometric indicators of children or adults were small. For example, if all adults in a household lost all their ethnobotanical knowledge, children's and women's BMI would decrease by only 3% and 11%, respectively.

Cross-sectional observational studies suggest that adults' local ecological knowledge (LEK) helps humans cope with their environment and correlates with improvements in own, offspring, and household well-being (Lavi & Friesem, 2019; Salim, Anuar, Omar, Tengku, & Snusi, 2023). Among forms of LEK in a variety of contexts in the Global South, parental knowledge (particularly mothers' knowledge) of medicinal plants has been associated with better child and adult health (Sibeko, Johns, & Cordeiro, 2021; Towns, Mengue, & Van Andel, 2014). So far, studies have focused on contemporaneous associations between LEK and individuals' well-being. Here we extend this line of research by estimating the health and nutritional benefits of LEK over time.

We argue that the delayed gains from LEK depend on three factors: [a] the stability of the socioeconomic and natural environment, [b] the lifecycle of individuals, and [c] the nature of LEK. [a] The use of local

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medicinal and edible wild plants (hereafter wild plants) might initially protect offspring and adult health in a rural setting, but the emergence of new diseases, changes in the local ecology, diet, and physical activity, coupled with migration, socioeconomic changes in village life, and the spread of biomedical public health services will combine to attenuate the benefits of yesterday's local knowledge of wild plants on today's health and nutritional status (Pires, Ferreira, & Albuquerque, 2022). [b] Even without environmental and socioeconomic change, parental knowledge of wild plants will protect less the health of infants as infants develop, begin to accumulate their own LEK (Pretelli, Borgerhoff Mulder, & McElreath, 2022; Quinlan et al., 2016), and become independent grown-ups. Effects may be most important in early life — during the sensitive period where childhood mortality from diarrheal diseases for example may be high — especially in environments with high parasitic and pathogen loads. [c] If local knowledge is flexible because it captures general principles, then it is likely to last longer. When confronted with a new illness, general knowledge of wild plants will facilitate experimentation and therefore will be more useful and last longer than knowledge leashed to specific plants for specific symptoms or illnesses.

The possible waning effects of past LEK on subsequent adults' own or offspring health and nutritional status could reflect a mix of the three factors. If LEK changes to help humans respond or cope with new local conditions (Fernández-Llamazares et al., 2021), tomorrow's parental LEK will likely protect the contemporaneous health of tomorrow's parents and their children, but here we focus instead in estimating the benefits of adult's past LEK embodied in knowledge of specific wild plants (rather than embodied in general principles) on the subsequent health of themselves and children. Thus, analyzing the effects of LEK over time is a gateway into a larger topic: Assessing how far the context in which LEK originally proved useful has changed and to what extent humans have to rediscover what works in new contexts (Fernández-Llamazares et al., 2015).

Until recently the question of whether past LEK improved later health — or measuring changes in the content of LEK over time (Pires et al., 2022) — was hard to answer owing to the absence of panel (longitudinal) datasets. Using a yearly panel (2003–2010) from Tsimane', a horticultural-foraging society of Indigenous native Amazonians in Bolivia, in this article we assess the association between baseline (2003) measurements of adults' local knowledge of wild plants and subsequent (2004–2010) anthropometric markers of nutritional status of themselves and the children who lived in the household at baseline. We focus on anthropometric data primarily because this provides a window into both short-term and long-term measures of nutritional status that allow for an examination of how people fare in marginal nutritional environments. These indicators of nutritional status are critical for understanding how children and adults respond to physiological, nutritional, and disease insults. Sufficient adipose tissue is a critical reserve of energy in marginal nutritional environments in dealing with illness especially during key growth time of children in which their bodies may have to make tradeoffs between growth and maintenance or for adults reproduction versus maintenance (McDade et al., 2007). Without this reserve, individuals may end up shorter and in severe cases, have stunted growth, which can have negative long-term economic and health effects.

Longitudinal data enriches our understanding of i) LEK and ii) health and nutritional status in two ways. First, it allows us to examine how baseline conditions affect subsequent human growth, thereby helping us understand directionality of the results and better tease apart causality, which cannot be done in cross-sectional analyses. For instance, many studies suggest that children stunted at baseline grow at a different rate than non-stunted children. Since we control for baseline anthropometric measures, we are in an ideal position to separate the contribution of LEK to subsequent growth and thus move beyond contemporaneous association between i) LEK and ii) health and nutritional status. The contribution of baseline anthropometrics, LEK, or socioeconomic status to subsequent growth and development can only be assessed with longitudinal data. Second, longitudinal data allows us to assess whether mediating socioeconomic variables such as LEK attenuate adverse initial conditions. In particular, we do not examine if LEK facilitates convergence of children with poor nutritional status at baseline to the nutritional status of their well-nourished age-sex peers, but the analyses of whether, why, and how convergence exists are fruitful fields of future research in human biology of rural populations in the Global South.

We split LEK into two broad dimensions: Knowledge and skills (Table 1). By knowledge we mean theoretical or passive knowledge of wild plants whereas skills measures dexterity in putting this knowledge to use. Each of the two dimensions contained three parts and was measured in three different ways, as described in Table 1. To probe the dimension of knowledge, we asked if adults knew about objective aspects of 10 plants (*Botany*) or general knowledge of about 19 wild plants (*Tally*) and uses of these 19 plants (*Uses*). To probe the dimension of skills, we asked adults if they knew how to make (*Factual*) or owned (*Goods*) 18 articles made from local wild plants and identified all the purely medicinal plants in the home garden of the household (*Garden*). We shall have more to say about the two umbrella dimensions of LEK and the three parts of LEK in each of these dimensions but for now we stress two points. First, our measures LEK for the most part captures general knowledge of and skills in the use of wild plants that had many uses, such as medicine, food, or construction. Only one measure of LEK (*Garden)* captured competencies in medicinal plants per se and no measure captured specific knowledge and skill in the use edible wild

Table 1
Definition and measurement of LEK variables by two dimensions /a/: Knowledge and skills /b/.

Variable (parts)	Definition and measurement /c/
Dimension – Knowledge (theoretical or passive knowledge):	
Botany	Score is sum of correct answers to ten questions about objective aspects of a wild plant (e.g., "Is the flower of the mahogany tree white?"). For each question we offered three choices, only one of which was correct.
Uses	For each of the 19 wild plants in the variable *Tally* [see next variable] respondents were asked if the plant could be used for food, medicine, firewood, house construction, or other ends. Each of the five uses was scored as 1/0, so one plant could have a theoretical maximum of five uses and a respondent could have a theoretical maximum score of 95 if a respondent believed that each of the 19 plants had five uses.
Tally	Does respondent know 19 plants (e.g., "Do you know the plant called Apaijniquij?"). Each answer scored as 1 (knows) or 0 (does not known); answers to the 19 questions were added.
Dimension – Skills (practical skills in using wild plants):	
Factual	Respondents were read a list of 18 goods made from local wild plants (e.g., dugout canoes) and asked if they knew how to make the goods. Each answer was scored as 1 (yes) or 0 (no) and all answers were added.
Goods	Do you have each of the goods listed in variable *Factual* [see previous variable]? Each answer scored as 1 (have) or 0 (does not have) and all answers were added.
Garden	In 2002, household heads walked with a surveyor around the home garden and identified all medicinal plants (other than fruit trees and newly introduced medicinal plants). The sum of all plants is included as a household-level variable of skills and merged with 2003 data (see discussion in the main body of the article).

/a/ The term LEK is broad and captures knowledge and skills about multiple facets of the local ecology and environment, such as soils, plants, animals, land management, and weather. Unless noted otherwise, in this article we equate LEK with a subset of the corpus: knowledge about wild plants and skills using these wild plants.
/b/ Other than the variable *Garden*, all other variables were measured in 2003. The regressions for children use the mean LEK score of the household. For adults, we use as a predictor the LEK measure of the adult and, as an outcome, their own anthropometric indicator.
/c/ In regressions, LEK variables are logged with an inverse hyperbolic sine transformation to avoid losing observations with values of zero and facilitate the interpretation of results.

plants (though many plants were edible). Second, the focus on general knowledge of wild plants was justified because we did not know then (and still do not know) if what matters for health and nutritional status is specific knowledge of medicinal wild plants, specific knowledge of edible wild plants, or overall knowledge of wild plants. We discuss this limitation more fully in sections [3.3] and [7.3.3].

We explore whether the delayed benefits of LEK are attenuated when societies face large socioeconomic and environmental changes (reviewed in Reyes-García et al., 2016). Large environmental transformation occurs from individual and synergistic processes as diverse as resource extraction, changes in land use, pollution, spread of invasive species, and climate change (Díaz, Settele, Brondízio, & Ngo, 2019). These processes erode the natural resources that rural people need to use LEK. Large socioeconomic changes occur from migration, wage labor, retail, and the spread of health practices from the post-industrialized Global North (hereafter Global North); the latter, whencombined with monetary earnings to pay for health services, gives rural households other options to protect health besides LEK. In all these cases, knowledge and skill will survive in the short run, but their effect will be diminished owing to a shrinking stock of plants, growing reliance on health practices from the Global North, or from both.

Recent years have seen a surge of interest from many behavioral sciences besides anthropology in the study of small-scale societies in the Global South because of the light they throw on findings from the Global North (Broesch et al., 2020), however problematic is the dichotomy between the Global South and the Global North (Khan, Abimbola, Kyobutungi, & Pai, 2022). Before turning to the specific objectives of this study and to what we found we ask how the study of LEK in the Global South contributes to broader interests. LEK speaks to many ongoing worldwide conversations (e.g., conservation, the ownership of knowledge), but one such conversation has to do with human capital theory developed in the Global North (Goldin, 2016). In the Global North and, increasingly, in much of the Global South, schooling contributes to better market (e.g., income) and non-market (e.g., wealth) outcomes for the schooled person. It also produces beneficial spillover effects (externalities) on market and non-market outcomes on the rest of society; for instance, people with more schooling are less likely to commit crimes and more likely to vote (Cohodes & Feigenbaum, 2023; Lochner & Moretti, 2004). When we turn to areas in the Global South without or with fledgling schools in which LEK represents the main form of human capital, we can ask if LEK also produces positive market and non-market outcomes, both for the person with LEK and for neighbors, as schooling does in the Global North? Parallels are appearing. For instance, greater own LEK contributes to hunting success and better health for the individual (Section [1.2]). Besides producing private market and non-market outcomes, LEK has been hypothesized to produce positive economic and other spillover effects on neighbors (Reyes-García et al., 2016). But just as there are overlaps between the two forms of human capital, there are also differences. For instance, academic skills travel more easily across space than local knowledge, which is site specific.

1. What is known about the topics

1.1. LEK definition and measurement

There is no consensus on how to define or measure LEK because LEK is multidimensional. Two common distinctions in the literature are (a) between the dimensions of knowledge and skills and (b) between cultural consensus and objective indicators of knowledge (Kightley et al., 2013; Koster, Bruno, & Burns, 2016; Reyes-García, Paneque-Gálvez, Luz, Gueze, & Orta-Martínez, 2014). The first distinction between the two dimensions of LEK matters because people might know about a plant (knowledge proper) but not know how to use it (skills). To what extent each affects well-being is an open question (Díaz-Reviriego, Fernández-Llamazares, Salpeteur, Howard, & Reyes-García, 2016). The second distinction is important, particularly in the study of LEK's impact on health and nutritional status, because researchers from outside the community do not know the answer about what wild plants are useful or how best to use them, so they need to rely on the agreement of the group to identify wild plants and best practices. In another approach, academic researcher use standard biological or medical knowledge to assess respondents' knowledge (e.g., "Does a rose have thorns?") (Godoy et al., 1998; Zarger & Stepp, 2004).

1.2. The benefits of adult LEK on health

Studies among Tsimane' have generally found positive but small associations between adult LEK and indicators of adult and child objective health and nutritional status, such as adult BMI and child stunting and parasitic infections. A study in 2007 by Tanner et al. (2011) on soil-transmitted helminth infection found that fathers' ethnomedicinal knowledge bore no association with children's infection, but an increase of one point in a mother's test of objective ethnomedical knowledge (range 0–7) lowered the odds a child would be infected by 15%, with the result barely statistically significant ($p = 0.09$). One reason for the finding was the near universal rate of infection; only 16% of the sample did not have parasitic infections. Reyes-García et al. (2008) surveyed 450 adult Tsimane' during 2002–2003 and found that a 100% decline in the score of self-reported knowledge about the use of 19 plants — essentially, if they forgot all their LEK about wild plant uses — correlated with a contemporaneous 4.3% to 6.3% lower BMI – which, in a society with low prevalence of overnutrition, is a negative health outcome. During 2002–2003, McDade et al. (2007) gathered LEK data from 528 adults (age $\geq$ 16y) and health data from ~330 children (2y $\leq$ age $\leq$ 10y). They collected data on five aspects of LEK (three about knowledge, two about skills) and combined them into an index. They estimated the associations between the LEK index and height-for-age (HAZ), age-sex standardized z scores of fats stored in triceps and subscapular skinfolds (ZSF), and C-reactive protein (CRP). Results showed that women and men had similar LEK scores and that more knowledgeable parents (mainly mothers, but also fathers) were less likely to have children with high infectious burden (CRP $\geq$ 1 mg/l), severe growth stunting (HAZ $<$ -3), and marked deficits in body fat (ZSF $<$ -1). The positive links between LEK and health among Tsimane' has been attributed to the fact that LEK improves forest conservation and, thus, the diversity of wild foods and medicinal plants available to Tsimane' (Fernández-Llamazares et al., 2021).

Beyond Tsimane', in a study of LEK and health in two subsistence-oriented small-scale societies — the Baka of the Congo Basin and the Punan of Borneo — researchers found that LEK did not bear an association with adult BMI, sum of four skinfolds, mid-arm circumference, or the likelihood of reporting having been sick or having had symptoms of illness, arguably because people with different levels of LEK shared what they foraged and farmed (Reyes-García, Gueze, et al., 2016).

1.3. Empirical studies of changes in LEK

Two approaches have been used to estimate changes in LEK: indirect and direct. Indirect. An indirect approach relies on cohort analysis using cross-sectional data to infer generational changes in LEK. For example, in one study among Tsimane' researchers collected data during 2008–2009 from 651 men (20y $\leq$ age) and found variation in knowledge across domains (Reyes-García et al., 2013). After controlling for age, they found that younger cohorts knew less about medicinal and wild edible plants but knew as much or more than older cohorts about plants for firewood, canoe building, and house construction. Direct. In the direct approach researchers measure LEK with the same methods at different times. Among Tsimane', Reyes-García et al. (2013) drew on two cross-sectional surveys of LEK from different samples a decade apart (2000 and 2009) and found a general loss of knowledge of 1% to 3% per year, with more marked losses among men and people living closer to towns. In one Tzeltal Maya community of Chiapas (Mexico) during 1999, Zarger and Stepp (2004) built on data collected in 1968 by an earlier researcher and tested Tzeltal's children's ability to name the same plants on a trail that had been used in the earlier study. They found no change in knowledge between the two samples. Differential exposure to the Global North, the market economy, and globalization have been implicated for changes in LEK (Cámara-Leret, Fortuna, & Bascompte, 2019).

A new line of research suggests that although historical LEK might be lost, new LEK is continuously being created in response to environmental and socioeconomic changes (Fernández-Llamazares et al., 2021; Gómez-Baggethun & Reyes-García, 2013; Reyes-García, Balbo, et al., 2016). Nevertheless, we know of only one study that has empirically and directly examined changes over time in the content of LEK. In a rural community of Brazil, Pires et al. (2022) did a two-year panel study (2017 and 2019) in which they followed 49 adults (18y < age) and, in addition, compared plant knowledge between 18 children (6y < age < 18y) and 25 adults in 2019. Drawing on evolutionary theory, they hypothesized that knowledge of "core plants" would not change in a short time among adults or between children and adults; the core comprised plants that were known to address effectively the most common illnesses of the population and thus enhance individual and group fitness. They found no confirmation for the hypothesis and concluded that the accumulation of knowledge about core medicinal plants was more "volatile" than they had anticipated.

In sum, studies of the contemporaneous association between i) LEK and ii) health and nutritional status suggest that the effect sizes are small, on average, but LEK protect against very poor health (e.g., severe child stunting), probably from treatments for diarrheal episodes during the first two years of life. We found no diachronic studies on the health and nutritional effects of LEK and only one study about changes in the content of LEK; that study found that LEK changed significantly in only two years.

2. The setting and people

The panel study took place in 13 villages along the river Maniqui (department of Beni) during 2002–2010, but for this article we primarily use yearly data gathered from 2003 until 2010 because 2003 was the first year we gathered comprehensive measures of LEK.

Almost nothing is known about Tsimane' before the twentieth century because they lived in or retreated into the backlands of the Bolivian Amazon beyond the reach of much of the rest of the world (Godoy, 2022). At the beginning of the twentieth century, the Swedish anthropologist Nordenskiöld visited Tsimane' along the river Maniqui and noted they were accomplished horticulturists who doubled as fishers, hunters, and plant foragers (Nordenskiöld, 1999 [orig. 1927], 2001 [orig 1924]). He also noted they enjoyed a healthy diet and had few material possessions (Nordenskiöld, 2001 [orig 1924]). During the mid-1950s, Protestant missionaries from the USA settled permanently along the river Maniqui to proselytize, set up the first rural schools for Tsimane', and offer health services. In the 1980s, missionaries helped Tsimane' form the Tsimane' Council, the official tutelary government for most Tsimane', which has been instrumental in securing land titles from the Bolivian government for Tsimane' dwelling along the river Maniqui (Kempf & Kempf, 2017). In the past two decades, the Tsimane' Council has vetted and specified the conditions that researchers from outside the community must meet when doing research among Tsimane'. The Council increasingly asks these researchers to contribute with in-kind resources to the Council. After the arrival of missionaries and the establishment of rural schools, Tsimane' began to settle more permanently in villages with schools, a shift from their historical semi-nomadic way of life. Notwithstanding the shift toward more permanent residence, Tsimane' at the time of our research were one of the world's most economically self-sufficient, small-scale rural societies. A comparative study of 15 such societies ranked Tsimane' next to last in contact with the marketplace, with an average of 7% of household calories bought in the market (Henrich, Ensminger, McElreath, & Barrat, 2010).

At the time of our research, Tsimane' numbered 17,000 people (INE, 2015) and lived in over 100 villages, mainly in the department of Beni. As in the past, they practiced slash-and-burn horticulture or swidden farming, fishing, hunting, and plant foraging, lived in relatively small villages, and, like other native Amazonian societies, they practiced preferential cross-cousin marriage. Summaries of Tsimane' culture, society, and health have been documented elsewhere (Godoy et al., 2024; Gurven et al., 2017). We next discuss three aspects of Tsimane' society and culture directly germane to this article.

2.1. Local socioeconomic changes during the study relevant to health

During 2002–2010, the study area and Tsimane' in our sample were exposed to many socioeconomic changes. The Bolivian government established national programs to transfer cash for old-age pensions (2002) and promote school attendance (2006) and maternal and child-care (2009). The programs infused cash into Tsimane' households and partly explain the increasing use of cash for health care; during 2004–2010, adult Tsimane' increased real (inflation-adjusted) cash expenditures in medicines and health services by 5% per year (Godoy, 2022). In addition, delivery of public health services increased. Vaccination campaigns in villages became routine, and the government, non-government institutions, and foreign institutions began to supply other health services to Tsimane' besides vaccinations. Tsimane' in our sample could obtain these health services either in their village when health workers from outside the community arrived at villages, or in the town of San Borja, the regional hub of the study area. In San Borja, Tsimane' could attend government clinics or seek private treatment from apothecaries in pharmacies, from private health care providers, or from the non-governmental and foreign research institutions working in the area. Participants in the study lived near health care facilities outside the village. In a village-level survey done with village leaders we found that it took an average of 4.5 h (median 2.5; SD = 7.4) to travel from a village to San Borja, or to a road that reached San Borja. Combined, these changes mean that during the study period Tsimane' had other resources available besides local knowledge of wild plants to protect health.

2.2. Anthropometry

Foster et al. (2005) found considerable growth stunting (HAZ ≤ -2) among Tsimane' children under nine years of age (girls = 43%; boys = 52%). In the sample of children and young adults between 3 and 17 years of age used in this article (2004–2010), 5.06% of all observations of girls ($n = 1837$) and 9.56% of all observations of boys ($n = 1945$) showed severe stunting (HAZ < -3). Stunting has been attributed to parasitic (McDade et al., 2007; S. Tanner et al., 2013) and respiratory infections (Gurven et al., 2017). Stunted children show some catch up growth (Zhang et al., 2016), but complete fewer grades of school and had lower academic skills than non-stunted children (Undurraga et al., 2018). In other anthropometric measures (e.g., muscularity, weight-for-height, fatness) Tsimane' children and adults compare favorably with their age and sex peers in well-nourished populations worldwide (Foster et al., 2005; S. Tanner et al., 2013). Across the nine years of the panel study (2002–2010), most (75%) adult men and non-pregnant women had a healthy BMI (range: 18.5–24.99); only 2% were underweight (BMI < 18.5), 20% were overweight (range: 25–29.99), and 3% had obesity (BMI > 30). Bethancourt, Leonard, Tanner, Schultz, and Rosinger (2019) found small increasing trends in the prevalence of overweight and obesity among women and men.

2.3. LEK

Tsimane' have a rich corpus of local knowledge of plants (reviewed above), animals (Reyes-García & Fernández-Llamazares, 2019), landscape management (Riu-Bosoms et al., 2015), and climate impacts (Fernández-Llamazares et al., 2015). Martínez-Rodríguez (2009) found that parents (mainly mothers) transmitted ethnobotanical knowledge and skills to children as young as six years of age. Local knowledge of wild plants is shared (Reyes-García et al., 2003; 2016) but used mostly for household members. We discovered this from one of the six ways we measured LEK (the six ways are discussed later in Section [3.3]). As part of our interest in health and skills using wild plants, and given time constraints, we decided to take an inventory of medicinal plants in home gardens, aware that Tsimane' also put in medicinal plants in fallow forests (Huanca, 2006) and that home gardens contain plants for other uses besides medicine (Díaz-Reviriego et al., 2016). In 2002, we asked the wife and the husband to identify all medicinal plants (other than fruit trees and newly introduced medicinal plants) as researchers walked with them in their home garden and, for each plant, to indicate who had been treated last with the plant. This information is captured in the variable *Garden* used later. Of the 532 households interviewed, 232 had used medicinal plants; of the 375 plants used, only 6.4% of the plants had been used to treat a person outside the household.

3. Methods to gather data and analysis

The study was conducted with IRB approval from Northwestern University (732–002, 732–007, 732–016, STU000007) and the Tsimane' Council. Since Tsimane' typically set up an independent household by 16 years of age, this age was used to define an adult. We obtained informed consent from all adults in a household at the time of the research, and from people younger than 16 years if they headed a household. We obtained consent from parents to collect data on children.

3.1. Data collection

Every dry season (May–September) during 2002–2010 a team of Bolivian and international researchers and Tsimane' assistants gathered information among all households in 13 Tsimane' villages along the river Maniqui. We trained Tsimane' assistants in the collection of data and collaborated with them to assure they translated the questions accurately when respondents could not understand Spanish. Gathering data during the same time of the year reins in the effect of seasonal variation on health and nutritional status. We selected villages because they varied in proximity to the town of San Borja. Villages in the study were between one hour to one day away by car or outboard motor from San Borja [Section 2.1] and had a median of 19 households (standard deviation [SD] = 6 households).

Stature (cm), body weight (kg) and selected skinfolds (triceps, biceps, subscapular, and suprailiac) were measured following the protocols outlined in Lohman, Roche, and Martorell (1988). A portable Seca stadiometer was used to measure standing height to the nearest 0.1 cm and a Tanita BF-522 W scale was used to measure body weight to the nearest 0.1 kg and to measure percent body fatness in adults. Lange calipers were used to measure skinfold thicknesses to the nearest 0.5 mm. The body mass index (BMI) was calculated as: BMI = body weight (kg) / [stature (m)]^2. We use BMI in the main analysis for children because we want to see how children fare relative to peers in their society and because analyses using raw BMI units are easier to interpret (Berkey & Colditz, 2007), but in the robustness analysis (Section 4.2e) we use BMI-for-age z score to compare Tsimane' children with international peers. Height-for-age z-scores (HAZ) were calculated using the World Health Organization (WHO) growth standards for children 24–60 months of age (de Onis et al., 2004; World Health Organization, 2009) and the WHO references for children >60 months (de Onis et al., 2007). For adults, HAZ was calculated from the NHANES reference values presented in Frisancho (2008). Following the WHO (2009) guidelines, HAZ measures beyond ±6 SDs were flagged as probably contaminated by large measurement errors and excluded from the analyses.

3.2. Sample

Baseline (2002). In 2002 we surveyed the medicinal plants in the home garden of study participants and created the variable *Garden*. A year later we measured (a) LEK about wild plants and (b) anthropometric indicators of short-run nutritional status. (a) For LEK we measured three aspects of the knowledge domain and three aspects of the skills domain among adults (age ≥ 16y) (Table 1). (b) We measured three anthropometric indicators of short-run nutritional status for children (2y ≤ age ≤ 10y) and three anthropometric indicators for adults (Table 2). Recall from the introduction that knowledge and skills are two umbrella dimensions of LEK, each of which contains three parts. To synchronize the datasets, we reformatted the panel so that 2002 data on medicinal plants from home gardens appeared in 2003. We refer to 2003 as the baseline year. Follow-up (2004–2010). After 2002–2003, data collection on anthropometrics and socioeconomic variables occurred once a year in the dry season. Children who were 2y ≤ age ≤ 10y in 2003 were 3y ≤ age ≤ 17y during follow-up; we use the term *children* to cover the entire age range (2y ≤ age ≤ 17y). Table 3 contains summary statistics of the variables used in the analysis for the sample of children and adults measured at baseline.

3.3. Measurement of LEK

We measured LEK along two dimensions: knowledge and skills (Table 1). Knowledge reflects passive or theoretical knowledge about a plant while skills refer to practical skills using the plant. The dimensions of knowledge and skills each contained three parts, and each part was measured in a different way. We treat each of the six parts separately because we want to pinpoint what aspect of LEK impacts health. We acknowledge that LEK captures a holistic body of knowledge that might not be easily disentangled (Reyes-García, 2010). As we shall see later (Section 4), the six parts did not clump neatly, justifying our treating the six parts separately. All but one LEK measure came from self-reports by

Table 2
Definition and measure of outcomes and covariates (besides LEK, for which see Table 1) used in the main analyses (tables 4 A-4B). All variables measured annually during the panel study (2002–2010).

Variable	Definition and measurement /a/
Outcomes /b/:	
Adults/c/ :	
BMI	Body-mass index; body weight [kg]/standing height in meters^2
FAT	Percent body fat measured with bio-electrical impedance analysis (BIA)
Skinfolds	Sum of four skinfolds (triceps, biceps, subscapular, suprailiac)
Children:	
BMI	Body-mass index; body weight [kg]/standing height in meters^2/d/
HAZ	Height-for-age z score
Skinfolds	Sum of four skinfolds (triceps, biceps, subscapular, suprailiac)
Covariates /e/:	
Age	Age of study participant in whole years (children 3y ≤ age ≤ 17y; adults, age ≥ 16y) in 2003
Count	Number of times study participant was measured annually during 2003–2010
Size	Household size; number of people in the household at the time of the yearly survey

/a/ The protocols for collecting data on outcomes are summarized in Godoy et al. (2024).
/b/ In regressions, all outcome variables besides HAZ are transformed into natural logarithms. In Section 3.1 we discuss the procedure to collect anthropometric data.
/c/ Pregnant women excluded.
/d/ In robustness analysis for children (Section 4.2e) we use BMI-for-age z score.
/e/ The regressions also include a full set of binary variables for village and years.

Table 3
Summary statistics of variables at baseline (2003) for adults and children /a/.

	ADULTS					
Individual-level variables:						
		WOMEN			MEN	
	N	Mean	SD	N	Mean	SD
A. Outcomes:						
BMI	180	23.46	3.06	189	23.48	2.21
Fat	160	27.09	6.72	163	17.06	5.44
Skinfolds	176	56.41	19.77	189	34.67	11.79
B. LEK						
Knowledge:						
Botany	211	4.76	1.47	233	4.72	1.34
Uses	223	18.56	7.8	246	20.98	8.89
Tally	223	14.78	3.9	247	15.34	3.51
Skills:						
Factual	227	8.29	2.42	245	7.66	3.77
Goods	227	7.59	3.13	245	6.13	3.52
C. Covariates:						
Age	247	37.68	17.2	281	35.64	15.52
Count	247	5.68	2.33	281	5.95	2.38
Household-level variables:						
	N	Mean	SD			
B. LEK						
Knowledge:						
Botany	210	4.68	1.09			
Uses	214	19.6	7.73			
Tally	214	15.06	3.41			
Skills:						
Factual	218	7.96	2.43			
Goods	218	6.86	2.94			
Garden	203	1.64	1.73			
C. Covariates:						
Size	229	5.98	2.9			

Individual-level variables:						
		GIRLS			BOYS	
	N	Mean	SD	N	Mean	SD
A. Outcomes:						
BMI	256	16.75	1.63	269	17.11	1.65
HAZ	260	−1.77	1.28	270	−1.97	1.39
Skinfolds	223	27.4	7.96	230	22.92	6.81
C. Covariates:						
Age	303	5.19	3.27	322	5.49	3.34
Count	303	6.46	2.09	322	6.39	2.11

/a/ Tables 1–2 contain definition of variables.

all adults (16y ≤ age) living in a household in 2003. The variable *Garden* (a form of skill) was measured at the household level in 2002 by counting only the medicinal plants in the home garden of participants (Section 2.3). For the main analysis of adult anthropometrics, the measures of LEK at baseline refer to the score of the adult respondent. By using this measure of LEK we can assess if own LEK protects an adult's own subsequent health and nutritional status, but for the main analyses of children, the measures of LEK refer to the average LEK of all adults in a household, which is justified because LEK is shared (Reyes-García et al., 2003; 2016) and household pool resources. (In Section 5.2d we evaluate whether average household LEK predicts later anthropometric status among adults).

Other than the variable measuring the inventory of medicinal plants in home gardens (*Gardens*), the other ways of measuring knowledge and skills are blunt instruments because they capture general competencies about wild flora and because their links to wellness is indirect. The five variables do not reflect specific knowledge about health or nutrition, though many of the plants we asked about were used for illnesses. Measures of knowledge and skills about the use of wild plants for illnesses or to improve nutrition would have yielded sharper results. For instance, knowledge about forest wild fruits and skills in finding and preparing these fruits would probably have a larger impact on health and nutritional status than general knowledge about wild plants used to make utensils. The variable *Good*, the number of articles owned made from wild plants known by the respondent, is both a measure of skill and asset wealth. All else constant, we would expect that asset wealth stored in goods made from local wild plants signals greater understanding of the local environment and thus probably contributes to better own and child health and nutritional status. In the discussion (Section [7.3], part 3), we return to this point to assess if a more focused definition of LEK would have produced stronger results.

McDade et al. (2007) discuss the selection of wild plants to measure the different parts of knowledge and skills. Here we summarize the main features. First, the selection of plants rested on several studies that took place during 1999–2001, before the start of the yearly panel study, about knowledge and uses of wild plants among Tsimane'. Much of the early work focused on determining agreement between Tsimane' about useful plants. Of the top 92 wild plants for which there was agreement on their usefulness, a subset of 19 wild plants was randomly selected to find out in the general population about the possible uses of the plant. Plants were selected by assigning them a number in a paper and drawing a random sample of the numbered papers from a bag. The 19 wild plants selected were the plants used to measure theoretical knowledge. The 19 plants were not necessarily used chiefly for medicinal or edible purposes, though they could have had those uses. Cultural consensus analysis showed agreement on the chief uses of these plants; the uses for this subset of plants are described under the variable *Uses* in Table 1. The variable *Tally* captures whether the respondent knew the plant. The distinction between *Uses* and *Tally* is important because a person might know about the plant, but not about its uses. In addition, we selected at random 10 plants to judge if people knew the attributes of the plant and used cultural consensus analysis to develop an answer key to score answers. This variable is called *Botany* in Table 1. The choice of 18 goods to assess if respondents knew how to make goods (*Factual*) or owned the article (*Goods*) came from our ethnographic understanding of the ownership of goods commonly made from local plants. The 18 articles were evenly split between goods that women and that men made, and between goods that varied in the difficulty of making them.

3.4. Analyses

Since we followed the baseline sample yearly until 2010 (while keeping track of how often we measured study participants), we can assess (1) how adult LEK at baseline correlated with anthropometric outcomes among adults and children at follow-up and (2) the effects of several types of knowledge and skills on child and adult anthropometrics.

Main analysis. To estimate the association between (a) adult LEK at baseline and (b) anthropometric outcomes of children at follow-up, we use an ordinary-least square (OLS) estimator that estimates anthropometric outcomes as a function of a parsimonious set of well-known predictors (Eq. (1)). We chose an OLS estimator because it is computationally simple and generates easy-to-read coefficients, especially when outcomes and predictors are in logarithms, as in this article. With slight modifications discussed below, we used Eq. (1) for adults. We estimate the parameters of Eq. (1) separately for girls and for boys because children's growth trajectory varies by gender (Frisancho, 2008; Tanner & Davies, 1985). Regressions were done with robust standard errors clustered by household and with village and year fixed effects. We used the Westfall-Young method to correct p values for false discoveries for all the regressions of the main analysis (**Table 4 A** [children], **Table 4B** [adults]) because we had many anthropometric outcomes and measures of LEK; thus, our results are conservative.

$$Y_{ijt\geq 2004} = \alpha + \beta 1 LEK_{kht=2003} + \beta 2 Y_{ijt=2003} + \beta 3 Age_{it} + \beta 4 Size_{ht} + \beta 5 Count_i + \beta 6 Village + \beta 7 Year + \varepsilon \quad (1)$$

Tables 1–2 contain definition of the variables in Eq. 1. The variables

Village and *Year* include a full set of village and year binary variables to control for unchanging traits of villages or years. For example, the study site was affected by severe floods in 2006; year fixed effects removes the effects of this unusual event on anthropometric outcomes, leaving a less biased estimate of LEK. The participant's age (*Age*), household size (*Size*), and number of years measured in the panel (*Count*) are also included. Subscripts stand for the following: i = individual study participant measured in 2003 and followed yearly during 2004–2010, j = type of anthropometric outcome, k = type of LEK, t = time or survey year, and h = household. Stata 17 was used for the statistical analyses.

We use Eq. 1 with three modifications for adults: [1] among outcomes, we use body fat and drop HAZ, [2] LEK measures in the regressions for children capture the average measure of LEK among adults in the household, but in the regressions for adults the LEK measures capture an adult's own LEK score, and [3] we cluster standard errors by individuals rather than by households. The results of the main analysis are included in tables 4 A (children) and 4B (adults); within each **Table 4**, sections 1 and 2 show the results of tests for knowledge (Section 1) and skills (Section 2).

The most important variable in the two versions of equation 1 (one for children, one for adults) is LEK, so the interpretation of the coefficient β1 requires a commentary. β1 captures the average effect of baseline LEK on the outcome for all observations of study participants pooled over 2004–2010. Other than HAZ, the coefficient β1can be interpreted as an elasticity, or the percentage change in the outcome from a one-percent change in LEK at baseline. β1 is not a growth rate, but a summary measure of the delayed impact of LEK on yearly measures of the outcomes observed during 2004–2010; the impact could vary from year to year. The study of year-to-year change in outcomes as a function of baseline LEK is an important topic because it would show if there was catch-up growth (convergence), but the study of year-to-year change or velocity is beyond the scope of this article.

Robustness and extensions. To assess how well the results of the main analysis stood up to further scrutiny (robustness) and to push the main analysis in new directions (extension), in Tables 1–2 of Appendix A we provide guidelines and rationale of the additional analyses for children (Table 1) and adults (Table 2). Appendices B (children) and C (adults) contain the results of the additional analyses. Despite having baseline measures precede the outcomes and repeated measures of participants, we cannot say anything about causal effects because we rely on observational data, but often speak of "effects" or "impacts" for brevity.

Statistical significance, effect size, and realism. *Statistical significance*. The main findings come from tables 4 and correct for false discoveries by conservative assessment of statistical significance (lower *p*-values to indicate significance). Unless noted, the extensions do not use this more conservative evaluation of statistical significance because they are exploratory and ancillary to the main analysis. *Effect size*. After identifying the statistically significant coefficients of tables 4 A or 4B, we comment on their effect size and use terms like "small" or "large". These are subjective terms used to facilitate interpretation and describe the real-world significance of LEK's impact; in particular, we do this by estimating what the impact would be if LEK decreased by 100% (i.e., disappeared) on anthropometric measures (Kirk, 1996). A focus on a decrease in LEK is apt because a diachronic study of two cross-sectional studies cited earlier estimated a yearly loss of LEK of 1% to 3% (Reyes-García et al., 2013). *Realism*. We do not know enough about adult LEK to see how fast an average adult Tsimane' would lose all their LEK. Holding constant other factors and assuming linearity, the 1% to 3% yearly loss implies that it would take 30–100 years to erase completely an adult's LEK. When considering children, a 100% change in average household LEK is more realistic. For example, consider a household with one or two adults, with each adult having a low LEK score. Suppose that one adult with a high LEK score joins the households, then the average LEK score for the household would increase by 100% or more. Or consider a household with two adults, one of whom has a very low LEK score and the other one a very high LEK score; if the latter left the household, the average LEK of the household would drop considerably (though not by 100%). These are realistic possibilities for how average household LEK could affect child anthropometric status but is probably less likely that an average adult who has most likely peaked in how much they know about wild plants could double or lose their entire stock of LEK.

3.5. Broader impacts: Uses of data by Tsimane'

The data we gathered could be useful to Tsimane' in the short and long run. In the short run, we gave Tsimane' a book in Tsimane' about ethnobotanical knowledge (Nate, Ista, & Reyes-García, 2000), posters of what we found about local uses of wild plants, and sponsored workshops on maternal and child health (Fernández-Llamazares, Benyei, Junqueira, & Reyes-García, 2020). In the long run, Tsimane' and the public can use the de-identified coarse and clean datasets, plus documentation, available in several web pages (See Section of "Data availability").

4. Results - children

The six measures of LEK did not correlate highly with each other as reflected in estimates of Cronbach's alphas. Cronbach's alphas for variables about knowledge or skills were low. The alpha values for all adults were 0.6 for the three knowledge variables and 0.5 for the three skill variables. Alpha values for all LEK knowledge + skills variables computed separately for women and men were in the same range, 0.7 for women and 0.6 for men. Most of these results fall below the modest reliability threshold of 0.70 recommended in the literature (e.g., Nunnally & Bernstein, 1994; Peterson, 1994) and, thus, capture the fact that the aspects of LEK we measured do not reflect well a latent variable (Lance, Butts, & Michels, 2006). Results support our treating LEK variables separately.

Women and men did not differ in individual-level scores of botanical knowledges (Table 3**, Section B**), but women had higher score in measures of both types of skills (*Factual, Goods*); a *t*-test comparing mean differences between women and men in these two variables showed results were statistically significant (p's < 0.05). McDade et al. (2007) also found no sex differences in LEK scores between women and men. We can think of at least two reasons for the absence of differences. First, the plants in the knowledge test might have been common and known to most adults. Second, even if some plants were rare, differences in scores between women and men would have converged because Tsimane' share ethnobotanical knowledge (Section 2.3). The only aspect of LEK where meaningful differences appeared was with the variable *Goods,* which captures ownership of articles made from plant material, and here women owned more articles than men. This is consistent with the general findings that most of women's asset wealth is stored in articles made from plant materials whereas men's asset wealth is stored mostly in commercial goods from the marketplace.

4.1. Main findings (**Table 4 A**)

The average amount of adult knowledge or skills about wild plants in a household affected different anthropometric indicators at follow-up. Two findings stand out. First, botanical knowledge (*Botany*) correlated with higher BMI (or BMI z scores, as seen later) for girls and boys at follow-up, with similar effect size among girls (β1 = 0.036; SE = 0.017; $p < 0.05$) and boys (β1 = 0.039; SE = 0.014; $p < 0.05$) (Table 4A1). Second, one measure of skills (*Goods*) — a household having an article made from plant material — correlated with higher HAZ for girls (β1 = 0.266; SE = 0.095, $p < 0.01$) and boys (β1 = 0.325; SE = 0.13; $p < 0.05$) (Table 4A2). Although statistically significant after correcting *p*-values for false discovery rates, the effect sizes are small to modest. If the average amount of botanical knowledge (*Botany*) in a household decreased by 100%, a child's BMI would shrink by an average of only ~3% to 4% during 2004–2010. Similarly, if the average amount of skills (*Goods*) in a household shrank by 100%, a child's HAZ would decrease

Table 4A1
Effect of average knowledge of adults in the household (2003) on children's anthropometrics (2004–2010): OLS results.

				GIRLS					
LEK predictor:	BMI	HAZ	Skinfolds	BMI	HAZ	Skinfolds	BMI	HAZ	Skinfolds
Botany	***0.036*****	−0.054	***0.122*****						
	(0.017)	(0.169)	***(0.053)***						
Uses				−0.006	0.216	−0.024			
				(0.015)	(0.131)	(0.049)			
Tally							−0.020	***0.473****	−0.088
							(0.023)	***(0.222)***	(0.089)
Constant	2.103***	−1.507***	2.313***	2.181***	−2.742***	2.682***	2.227***	−3.563***	2.897***
	(0.069)	(0.573)	(0.167)	(0.082)	(0.524)	(0.200)	(0.096)	(0.764)	(0.319)
Observations	1288	1293	1139	1253	1261	1101	1253	1261	1101
R-squared	0.595	0.458	0.500	0.601	0.461	0.498	0.602	0.465	0.499
				BOYS					
Botany	***0.039*****	***−0.425*****	0.063						
	(0.014)	***(0.159)***	(0.048)						
Uses				0.001	0.149	***−0.087*****			
				(0.014)	(0.146)	***(0.041)***			
Tally							0.015	0.240	***−0.133*****
							(0.018)	(0.183)	***(0.051)***
Constant	2.261***	0.495	2.552***	2.335***	−0.834	2.995***	2.288***	−1.109*	3.138***
	(0.063)	(0.426)	(0.119)	(0.088)	(0.513)	(0.166)	(0.089)	(0.620)	(0.185)
Observations	1332	1338	1147	1325	1331	1144	1325	1331	1144
R-squared	0.476	0.607	0.270	0.478	0.600	0.271	0.478	0.600	0.272

Table 4A2
Effect of average skills of adults in the household (2003) on children's anthropometrics: OLS results – continued.

				GIRLS					
LEK Predictor:	BMI	HAZ	Skinfolds	BMI	HAZ	Skinfolds	BMI	HAZ	Skinfolds
Factual	−0.017	0.27	−0.049						
	(0.023)	(0.149)	(0.056)						
Goods				−0.007	***0.266******	−0.011			
				(0.019)	***(0.095)***	(0.051)			
Garden							0.004	0.041	0.017
							(0.006)	(0.051)	(0.018)
Constant	2.203***	−2.329***	2.701***	2.175***	−2.263***	2.597***	2.154***	−1.898***	2.521***
	(0.085)	(0.514)	(0.176)	(0.079)	(0.423)	(0.159)	(0.074)	(0.334)	(0.120)
Observations	1266	1277	1121	1266	1277	1121	1213	1224	1080
R-squared	0.595	0.473	0.494	0.595	0.476	0.494	0.599	0.471	0.511
				BOYS					
Factual	−0.001	0.308	−0.058						
	(0.011)	(0.164)	(0.048)						
Goods				0.002	***0.325*****	−0.025			
				(0.009)	***(0.130)***	(0.036)			
Garden							−0.002	***0.130******	0.026
							(0.004)	***(0.054)***	(0.015)
Constant	2.333***	−1.184**	2.822***	2.324***	−1.156***	2.743***	2.318***	−0.604*	2.654***
	(0.073)	(0.464)	(0.152)	(0.069)	(0.397)	(0.127)	(0.062)	(0.310)	(0.102)
Observations	1268	1274	1101	1268	1274	1101	1261	1267	1086
R-squared	0.460	0.609	0.267	0.460	0.614	0.265	0.473	0.621	0.278

Notes: Regressions are ordinary least squares (OLS) with robust standard errors clustered by households. *, **, and *** significant at ≤10%, ≤5%, and ≤ 1% adjusted for false positives with method developed by Westfall-Young and adapted to Stata by Jones, Molitor, and Reif (2019). Covariates not shown to unclutter the table are identified in Table 2.

by an average of 0.26 to 0.32 HAZ units during 2004–2010.

4.2. Robustness and extensions

The first two analyses that follow (sections [a]-[b]) test if the main results hold up after changing covariates ([a]) or limiting the follow-up period ([b]). In sections [c]-e] we extend the analyses to explore various other aspects of the relationship between LEK and child anthropometrics.

[a] Drop baseline anthropometrics. Since baseline and follow-up anthropometrics among children correlate (e.g., tall children tend to grow slower than short children) and baseline anthropometrics and LEK also correlate positively (McDade et al., 2007), removing baseline anthropometrics will likely change the effect size of LEK depending on the sign and magnitude of the indirect effect between LEK, the outcome, and baseline anthropometrics. After removing baseline anthropometrics, the positive effect of *Botany* on BMI rose from ~0.03 for girls or boys (Table 4A1) to 0.053 (SE = 0.021; $p < 0.05$) for girls and to 0.054 (SE = 0.018; p < 0.05) for boys (**Table 5, Appendix B**) but the former positive effect of the variable *Goods* on HAZ in Table 4A2 (girls = 0.266; boys = 0.325) became smaller and statistically non-significant (girls: $\beta 1 = 0.062$, SE = 0.145, $p = 0.67$; boys: $\beta 1 = 0.266$, SE = 0.208, $p = 0.23$) (**Table 5, Appendix B**).

[b] LEK's effects restricted to end-line (2010) values. We simplify the analysis by focusing on the effects of baseline LEK on end-line (2010) anthropometric values while ignoring the middle years (2004–2009)

(**Table 6, Appendix B**). Results concur with the main analysis; the sign of the coefficients of the two main significant findings from **Table 4 A** remain the same but lose statistical significance. The variables *Botany* and *Goods* correlated with higher children's BMI (*Botany*) or HAZ (*Goods*), as they had in **Table 4 A**, but the effect sizes declined, and results became statistically non-significant. For instance, the impact of *Botany* scores on children's BMI declined from 0.036 (girls) or 0.039 (boys) in Table 4A1 to 0.001 (SE = 0.052; $p = 0.98$) for girls or 0.032 (SE = 0.025; $p = 0.21$) for boys in **Table 6 of Appendix B**. The lack of statistical significance is understandable since the sample size shrank by limiting the analysis to 2010; for example, the sample sizes of children for the regressions with BMI as an outcome in Table 4A1 had ~1300 observations for girls or boys whereas the same regressions in **Table 6 of Appendix B** limited to the year 2010 had only ~120 observations for girls or boys.

[c] Interaction effects of LEK with child's age. We interacted LEK with a child's age to test if LEK effects got smaller as children aged, became more independent of their parents, and started to accumulate their own LEK (Martínez-Rodríguez, 2009). In general, the results of **Table 7 (Appendix B)** show no significant interaction effects between age and *Botany* on BMI or age and *Goods* on HAZ. Only when interacting the variable *Goods* with children's age did we see a decline in the impact of LEK on HAZ, but only for girls; for each additional year of age (holding constant average household LEK), a girl's HAZ declined by −0.041 HAZ units (SE = 0.021; $p = 0.052$). Unfortunately, we did not collect information on LEK for children so we cannot directly test if children's own LEK attenuated the impact of parental LEK on child health, or if a child's LEK protected their health and nutritional status.

[d] Extremely low anthropometric values. We explored whether LEK protects against extreme growth faltering (HAZ < -3) and low values of skinfold deficits (ZSF < -1), as suggested in a prior study using contemporaneous LEK and health outcomes (McDade et al., 2007). Neither *Botany* (knowledge) or *Goods* (skills) — variables that had correlated with better anthropometric outcomes among girls and boys in the main analysis (**Table 4 A**) — had a statistically significant impact on extreme growth faltering among children of either gender (**Table 8, Appendix B**). No form of LEK protected ZSF, and skills had no effect on HAZ or ZSF among girls or boys.

Nevertheless, two types of knowledge — *Uses* and *Tally* — were associated with meaningful and statistically significant reductions in HAZ among girls after adjusting for false positives. The coefficients of **Table 8 (Appendix B)** imply that the complete loss of household knowledge captured in the variable *Uses* would result in an 8 percentage-point increase in the probability a girl would be severely stunted (SE = 0.032; $p < 0.05$) while a complete loss of household LEK captured in the variable *Tally* would result in a 15 percentage-point increase in a girls having ZSF < -1 (SE = 0.052, $p < -0.05$). These are big numbers. We return to the importance of these findings in the discussion section.

[e] Other. ***i]*** To expand the analysis beyond objective health indicators, we tested whether LEK affected the number of days children had been bedridden (as reported by parents) in the past two weeks and found no significant results for knowledge variables and none for girls, but found the counter-intuitive result that greater scores in the variables *Factual* and *Goods* were associated with about a 20% increase in the likelihood the child would have been bed-ridden the previous week (SE ~0.08, p's < 0.05;**Table 9; Appendix B**). ***ii]*** In the analysis thus far we used raw BMI for reasons discussed earlier (Section [3.1]), but in **Table 10 (Appendix B)** we used BMI-for-age z score to compare Tsimane' children against their age and sex peers in well-nourished international populations (de Onis et al., 2004, 2007). We found the same main finding as in **Table 4 A**; the loss of *Botany* knowledge would result in a reduction of 0.28 BMI z-score units among girls (SE = 0.014; $p = 0.04$) and 0.40 BMI z-score units among boys (SE = 0.40; $p = 0.003$). **Tables 4 A** and **Table 10 (Appendix B)** complement each other; while **Table 4 A** shows that the loss of all *Botany* knowledge in a household would reduce a child's BMI compared with children in the rest of the sample of Tsimane' children, **Table 10** suggests that the gap separating Tsimane' children from international age-sex peers would widen as well from the loss of all *Botany* knowledge in the household. ***iii]*** In Eq. 1 we assumed a linear relation between anthropometric outcomes and LEK. In **Table 11 (Appendix B)** we relax the assumption and add a quadratic term for LEK variables to assess if the relation was non-linear. The results suggest that most relationships were linear, with one exception. Among boys, the relation between each of the three knowledge variables and BMI resembled an inverted U. This result suggest that the average positive effect of the three knowledge variables on BMI among boys is lower than if we assume a linear relationship as done in **Table 4 A**; for example, the complete loss of *Botany* knowledge in the household (**Table 11**) would result not in a 33.2% reduction in BMI (as implied in the coefficient of the variable *Botany*) but in a 26.5% reduction after acknowledging the role of the quadratic term (−0.067): 0.265 = 0.332–0.067.

5. Results – adults

5.1. Main findings (*Table 4B*)

Findings from adults and children showed similarities and differences.

Similarities. [a] The effect sizes of knowledge among adults were small (Table 4B1) as they had been for children. Among women, skinfolds would decrease by 11% if they lost all their knowledge captured in the variables *Botany* (SE = 0.05; $p < 0.05$) or *Tally* (SE = 0.059; $p < 0.10$) and their BMI would shrink by 4% if they lost all their knowledge embodied in the variable *Tally* (SE = 0.017; p < 0.05), or 2% if they lost all their knowledge contained in the variable *Uses* (SE = 0.013, $p < -0.10$). If men lost all their knowledge captured in the variable *Uses*, their skinfold would decrease by 17.9% (SE = 0.059, p < 0.05) and their BMI by 2.6% (SE = 0.013, p < 0.10). Other than the effect of *Uses* on men's skinfold, the effect sizes were small. [b] Different aspects of knowledge affected the same anthropometric outcome, but only among women. A woman's BMI was affected by the variables *Uses* and *Tally* and her skinfold was affected by the variables *Tally* and *Botany*. These results are broadly reminiscent of the finding among girls that HAZ was affected by the variable *Goods* (Table 4A1*)* and *Tally* (Table 4A2). Sex differences in the impact of the variables *Botany* and *Tally* on BMI or skinfold between women and men cannot be attributed to gender differences in the score of these two knowledge variables since there were no statistically significant gender difference in scores of any knowledge variable (see introduction to Section 4).

Differences. [a] Among adults, skills bore no association with anthropometric outcomes (Table 4B2) whereas among children, one skill (*Goods*) correlated with better HAZ (Table 4A2). [b] Among both girls and boys, the variable *Botany* improved BMI while the variable *Goods* improved HAZ. With adults, only the variable *Uses* correlated with a better anthropometric outcome for both sexes (BMI).

5.2. Robustness and extensions

[a] Drop baseline anthropometrics. All the statistically significant coefficients of Table 4B1 discussed in the main analysis (Section 5.1) increased in size after dropping baseline anthropometric values (**Table 5, Appendix C**), and most of them doubled or tripled in size, suggesting strong positive indirect effects between (i) baseline anthropometric values and (ii) end-line anthropometric values and LEK. For example, in the main analysis a woman who lost all her knowledge captured in the variable *Tally* would experience a 11.2% lower skinfold (Table 4B1); after removing baseline skinfold, her skinfold would be 21.8% lower (SE = 0.115, $p = 0.06$).

[b] LEK's effects restricted to end-line (2010) values. None of the main findings of **Table 4B** reappear when limiting the analysis to end-

Table 4B1
Effect of adults' own knowledge in 2003 on their own anthropometrics (2004–2010): OLS results.

				WOMEN					
LEK predictors:	BMI	FAT	Skinfolds	BMI	FAT	Skinfolds	BMI	FAT	Skinfolds
Botany	0.019	0.096	0.110**						
	(0.013)	(0.063)	(0.050)						
Uses				0.020	0.004	0.058			
				(0.013)	(0.058)	(0.048)			
Tally							0.040**	0.055	0.112*
							(0.017)	(0.100)	(0.059)
Constant	2.223***	2.125***	3.174***	2.225***	2.358***	3.316***	2.173***	2.216***	3.163***
	(0.045)	(0.209)	(0.132)	(0.058)	(0.194)	(0.169)	(0.065)	(0.305)	(0.194)
Observations	870	765	850	834	722	818	834	722	818
R-squared	0.783	0.468	0.599	0.777	0.452	0.582	0.779	0.453	0.584
				MEN					
Botany	−0.006	−0.008	0.012						
	(0.012)	(0.042)	(0.053)						
Uses				0.026**	0.082	0.179**			
				(0.013)	(0.054)	(0.059)			
Tally							−0.003	−0.018	0.097
							(0.021)	(0.080)	(0.082)
Constant	2.307***	2.137***	2.661***	2.223***	1.970***	2.214***	2.305***	2.269***	2.467***
	(0.057)	(0.133)	(0.139)	(0.063)	(0.184)	(0.214)	(0.078)	(0.252)	(0.259)
Observations	958	818	957	900	761	899	900	761	899
R-squared	0.653	0.398	0.525	0.675	0.426	0.526	0.672	0.422	0.512

Table 4B2
Effect of adults' own skills in 2003 on their own anthropometrics (2004–2010): OLS results.

				WOMEN					
LEK Predictor:	BMI	FAT	Skinfolds	BMI	FAT	Skinfolds	BMI	FAT	Skinfolds
Factual	0.011	0.084	0.035						
	(0.014)	(0.067)	(0.055)						
Goods				0.009	−0.001	−0.005			
				(0.013)	(0.052)	(0.039)			
Garden							−0.000	0.002	0.010
							(0.005)	(0.018)	(0.021)
Constant	2.229***	2.142***	3.370***	2.230***	2.320***	3.454***	2.262***	2.334***	3.408***
	(0.045)	(0.179)	(0.147)	(0.044)	(0.160)	(0.122)	(0.038)	(0.131)	(0.094)
Observations	840	729	820	840	729	820	810	698	794
R-squared	0.788	0.465	0.585	0.788	0.460	0.584	0.776	0.472	0.589
				MEN					
Factual	−0.005	0.016	−0.003						
	(0.008)	(0.025)	(0.031)						
Goods				−0.001	0.036	0.007			
				(0.006)	(0.022)	(0.026)			
Garden							−0.003	−0.019	0.012
							(0.005)	(0.022)	(0.018)
Constant	2.290***	1.972***	2.703***	2.286***	1.969***	2.696***	2.315***	2.257***	2.767***
	(0.055)	(0.102)	(0.124)	(0.055)	(0.100)	(0.118)	(0.055)	(0.107)	(0.111)
Observations	897	766	896	897	766	896	893	759	892
R-squared	0.649	0.433	0.527	0.648	0.437	0.527	0.656	0.404	0.517

Notes: Same as Table 4A1, except that in this table robust standard errors are clustered by individuals.

line values (**Table 6; Appendix C**), probably from the loss of statistical power mentioned earlier in the analysis of children.

[c] Extremely low anthropometric values. In **Table 7 (Appendix C)**, we test whether adult LEK protects adults against extremely low anthropometric values. The outcome variables in **Table 7** are binary and set to 1 if the value was <-1SD (and zero otherwise) of the measure in this sample because we wanted to capture a locally relevant low measurement; the values for the outcome variables are not defined relative to an international standard. We find that LEK protects only women and only one type of LEK (*Botany*) affords protection for two outcomes: BMI and skinfolds. A 100% loss of botanical knowledge (*Botany*) would result in a 12.3 percentage-points lower likelihood of having BMI < -1 SD (SE = 0.058, $p = 0.03$) and a 20.9 percentage points lower probability of having skinfolds<−1 SD (SE = 0.060, $p = 0.01$).

[d] Household-level measures of LEK. If households pool resources and knowledge (Lavi & Friesem, 2019; Reyes-García, Gueze, et al., 2016), then it might be the average LEK of the household that produces health and nutritional effects on adults, not the LEK of the individual adult. To examine this possibility, **Table 8 (Appendix C)** replicates **Table 4B**, but with household-level measures of LEK and clustering by household rather than by individuals (as in **Table 4B**) since all adults in a household would share the same LEK values. Results produce larger impacts, and at least one effect was quite large. Among women, the effect of *Botany* on skinfold increased from 0.11 (Table 4B1) to 0.20 (SE = 0.073, $p < 0.05$; **Table 8, Appendix C**), implying that a loss of all *Botany* knowledge in a household would reduce women's skinfolds by 20%. The effects of *Tally* on BMI rose marginally from 0.04 (Table 4B1) to 0.057 (SE = 0.02; $p < 0.01$; **Table 8, Appendix C**) for women and the

effect of *Uses* on BMI among men also rose slightly from 0.026 (Table 4B1) to 0.031 (SE = 0.014, p < 0.05; **Table 8, Appendix C**). Thus, although coefficients got larger when using a household average measure of LEK, effect sizes remained small other than with women's skinfold.

[e] Other. *i]* We tested whether LEK correlated with the number of self-reported bedridden days and found almost no effect among men but found a counter-intuitive result that a 100% increase in skills embodied in the variables *Factual* and *Goods* correlated with a 28.3% (SE = 0.113, *p* = 0.013) and a 15.8% (SE = 0.085, *p* = 0.065) greater probability of being bed ridden (**Table 9, Appendix C**). Since the average woman in the sample had been bed-ridden 2.73 days during the fortnight before the interview in 2003 (SD = 4.7 days), a 15.8%–28.3% increase in the number of bedridden days would bring the total up to 3.3 days bedridden for a two-week period. The finding that LEK correlates with worse perceived morbidity is reminiscent of what we found with children (Section 4.2e). *ii]* We tested whether own LEK bore a non-linear relation with anthropometric outcomes by re-estimating **Table 4B** with a quadratic term and found faint, barely discernable significant hints of an inverse U-shaped relation for men and none for women, so we can tentatively conclude that a linear relationship captures relatively well the links between anthropometric outcomes and LEK variables among men (**Table 10, Appendix C**).

6. Limitations

[a] There is one robustness analysis we did not undertake but which could explain the modest effects of knowledge and skills of wild plants on adult or child outcomes (Section 7.3). This analysis has to do with interaction effects between knowledge of wild plants and other variables. It is possible that it is not only the direct effect of various aspects of knowledge and skills or their aggregate that correlates with anthropometric markers, but the triple interaction between knowledge (*Botany, Uses, Tally*), skills proper (*Factual*), and resources (*Goods*, *Garden*). For wild plants to have health effects, people must know about the plants, how to use the plants, and have access to the plants. We did not analyze triple interaction effects because of the danger of running an overfitted model with excessive multicollinearity owing to our limited sample. *[b]* Leaving aside endogeneity biases embodied in the variable LEK (Section 7.4), we have estimated the average protective effect of LEK on anthropometric indicators of short-run nutritional status. We cannot directly assess whether the protective role of LEK wanes with environmental and socioeconomic changes because such a test would require interacting LEK with an exogenous variable that proxies for such a change. Using variables like town-to-village distance or travel time to town would not help because they are endogenous since Tsimane' decide how far to live from town. The ideal control group would be one composed of study participants dwelling in a place with limited environmental and socioeconomic perturbations. *[c]* The study's duration of nine years limits our ability to examine very long-term impacts on health outcomes like mortality but is novel in its ability to track changes in nutritional status and morbidity among children and adults over nine years. For children, the nine-year span might not cover very long-term effects, but captures a major life-cycle transition from childhood to adolescence.

7. Discussion

In this section we summarize the results for children and adults, discuss reasons for the small effect sizes, and posed unsolved puzzles for future research.

7.1. Summary of results for children

Positive findings. One form of knowledge (*Botany*) and one form of skill (*Goods*) correlated with better child BMI (and BMI z score) and HAZ. These results were sensitive to the exclusion of baseline anthropometric values (**Table 5; Appendix B**) and the years included in the analysis (**Table 6; Appendix B**). Effect sizes were small, amounting to a 3% loss of BMI or about a 0.3 HAZ units for a child if the average stock of *Botany* or *Goods* in a household disappeared.

Nevertheless, two forms of knowledge (*Uses, Tally*) were associated with large reductions in the likelihood a girl would be severely growth stunted (HAZ < -3) (**Table 8; Appendix B**). The finding that LEK protects HAZ at follow-up complements from a different angle a previous analysis showing that general LEK protected against concurrent severe stunting among girls and boys (McDade et al., 2007); here we show that this protection extends over time only for girls. **Table 8 (Appendix B)** shows that a 100% reduction in the average amount of the LEK variables *Uses* or *Tally* in a household would increase the probability a girl would be severely growth stunted by 7 and 15 percentage points, respectively. Leaving aside the probability that a household would lose all knowledge embodied in these variables, the magnitude and real-world implications at the population level are large and meaningful. Recall from Section 2.2 that 5.06% of girls between 3 and 17 years of age during 2004–2010 were severely growth stunted (HAZ < -3). Our estimates imply that a complete loss of these two forms of adult knowledge would increase the share of girls who were severely stunted from 5.06% to 13%–20%. These are big and important numbers, especially when one considers that childhood growth stunting among Tsimane', and elsewhere in the rural Global South, correlates with many adverse schooling, health, and socioeconomic outcomes during childhood and adulthood, and possibly across generations (Undurraga et al., 2018).

Thus, depending on the level of HAZ examined — average HAZ (**Table 4 A**) or severe growth stunting (**Table 8, Appendix B**) — three types of LEK (*Goods*, *Uses*, *Tally*) correlated with improved HAZ, principally of girls.

Null findings. We found almost no evidence that the effects of LEK waned as the child aged (**Table 7, Appendix B**) or that LEK affected perceived morbidity (**Table 9, Appendix B**). The use of BMI-z score (**Table 10, Appendix B**) instead of BMI or the use of a non-linear estimator (**Table 11, Appendix B**) for LEK did not alter the main results of **Table 4B**.

7.2. Summary of results for adults

Positive findings. [a] *Women*. Three measures of LEK —*Botany, Tally, Uses* — protected women's anthropometric status. These variables bore a positive association with women's skinfolds and BMI. The positive associations appeared in the main analysis (**Table 4B**), after dropping baseline anthropometric values (**Table 5, Appendix C**), and when using the average LEK score of the household (**Table 8, Appendix C**). [b] *Men*. Whereas three LEK variables protected health among women in a consistent way, only one LEK variable (*Uses*) protected health among men consistently across the various analyses, but only with BMI and skinfolds. *Uses* correlated positively with these two anthropometric outcomes in the main analysis (**Table 4B**), after excluding baseline values (**Table 5, Appendix C**), and when using a household average of LEK (**Table 8, Appendix C**). With one exception (household-level measure of *Botany* on women's skinfold; **Table 8, Appendix C**), effect sizes were small.

Null findings. Skills bore no correlation with adult anthropometrics and no type of LEK correlated with body fat measured with bioelectrical impedance analysis. We found weak evidence that the effects of LEK were non-linear.

The two chief overall findings of this study dovetail with the results of previous analyses among Tsimane' and other societies. First, small effect sizes are found in other societies. Recall from Section 1.2 that LEK did not protect health in a comparative study of two subsistence-oriented societies, one in Borneo and one in the Congo Basin. Though not dealing directly with health, but with a closely related construct (food consumption), a study with 109 adults in rural northeastern Brazil, found that local knowledge of medicinal plants did not predict food consumption (Sousa, Albuquerque, & Araújo, 2022). Second, the role of LEK in protecting against growth stunting found in previous cross-sectional analyses among Tsimane' (Section 1.2) persist over seven years but only for girls. In the next two sections we explain these two principal findings.

7.3. Explaining the small effect sizes of LEK

[1] Change. We noted that the study of the effects of LEK over time is a gateway into assessing the stability of the socioeconomic and environmental landscape and suggested that the shelf life of LEK is short with external changes. In Section 2.1 we noted the many socioeconomic changes affecting the sample and study area. Major changes could explain the small effect sizes observed; we say "could" because we did not have a control group exposed to less socioeconomic and environmental perturbations. Our findings nevertheless provide indirect support for previous studies suggesting that LEK is less likely to help when there are deep and rapid environmental and socioeconomic changes (Reyes-García, Balbo, et al., 2016) and concurs with the results of the short panel study by Pires et al. (2022) showing that LEK can change in a short time for reasons discussed in the introduction. [2] Random measurement errors. Random measurement errors of LEK could also contribute to small effect sizes. It is possible that respondents did not understand well the questions and guessed when answering, thereby producing an attenuation bias. [3] LEK mismeasurement. Our measure of LEK covered general knowledge of wild plants (some medicinal) whereas a more comprehensive measure of medicinal wildplants and edible wild themselves could have produced clearer results. Nevertheless, Tanner et al. (2011) used a pointed test of ethnomedical knowledge that asked adults whether wild plants could be used to cure intestinal parasites and found almost no association between test scores and helminth infection of children (Section [1.2]). However, the small effect size in the study by Tanner et al. could have arisen not from mismeasurement, but from the ubiquity of parasitic infections, which left slight variation to be explained. On a related point, the variable *Garden* measured the number of medicinal plants observed in the home garden of study participants and that variable also produced no salient results. [4] Negative interactions between local plants and industrial medicines. The modest impact could have arisen if the active ingredients of wild plants and allopathic medicines interact negatively, as Liwa et al. (2017) found in a study of herbal medicines and allopathic treatments among adults with hypertension in Tanzania. [5] Threshold. It is possible that LEK correlates clearly with anthropometric indicators only along certain ranges of LEK scores, such as scoring above a critical threshold level of LEK. We partially addressed this concern by testing for non-linearities. In addition, and on a simpler level, to examine this possibility, we compare household LEK scores between stunted (HAZ $\leq$ -2) and non-stunted children, the intuition being that stunted children would come from households with lower LEK scores. We found no support for the intuition with one exception. Stunted children were more likely to come from households with 23% fewer plants in the home garden. Among all households ($n = 532$) with and without medicinal plants, the statistics for the number of plants per household were as follows: average = 2.8, median = 3, min = 0, max = 11, standard deviation = 2.1. [6] Limited variation in anthropometric measures. We also explored whether possible modest variation in outcome variables could explain the results. To explore this topic, we computed the coefficient of variation for each anthropometric outcome for girls, boys, women, and men. We found that the coefficient of variation was higher for fat than for BMI or skinfolds among adults and was higher for skinfolds than for BMI or HAZ among children and yet neither fat nor skinfolds showed any consistent association with LEK.

7.4. Explaining why LEK protects against stunting

We can speculate about the reasons for the strong negative associations between the variables *Uses* or *Tally* and severe stunting among girls (HAZ < -3) (**Table 8, Appendix B**). [1] Plant use. More knowledgeable adults might have used wild plants to diversify the diet and treat ill children. We did not ask about uses of wild plants, so we cannot assess if the reduction in stunting came from parents intentionally using wild plants to redress severe stunting. Importantly, note from the descriptive statistics of the previous paragraph that stunted children were more likely to come from households with fewer medicinal plants in the home garden, hinting at the idea that easily access to plants + specific forms of LEK helped to redress stunting. [2] Adult ability. We borrow the term ability from economics to cover hard-to-measure, often unseen traits such as drive, intelligence, and, in our case, intrinsic interest in health and wild plants. We did not measure ability and since ability would correlate positively with both good health and LEK, the failure to measure ability would introduce omitted-variable bias. Ability would not only mediate the relation between LEK and health but could also explain the links between LEK and HAZ. It might not be LEK that produces health benefits, as we have assumed throughout. Instead, having sick people in the household could galvanize solicitous adults to learn more about wild flora. In fact, having sick or undernourished children at home might prompt parents to use any resource — LEK, income, assets, credit, social relations — to redress stunting. There is some evidence for this intuition. In a two-year randomized controlled trial in 40 Tsimane' village outside the panel study used in this article we selected at random between the female or the male head of the household to receive large amounts of edible rice, and found that child stunting declined in households when mothers received the transfer (Bauchet et al., 2021).

7.5. Remaining puzzles

In this section we pose glaring puzzles raised by the article. Although we could speculate about answers, we thought it prudent to pose them as challenges for future researchers.

[a] Tsimane' health not fully protected by LEK despite knowledge sharing. If skills (*Goods*) and knowledge (*Uses, Tally*) each correlate in their own way with higher child HAZ and if Tsimane' share LEK, why is there so much child growth stunting? [b] One outcome, two bodies of knowledge. Why are skills (*Goods*) associated with better average child HAZ, but why is knowledge (*Uses*, *Tally*) associated with a lower likelihood of extremely low HAZ? Are we witnessing specialization in LEK, where one aspect of LEK (*Goods*) provides general protection but plays a small role among children with extremely poor growth, for whom other forms of LEK (*Uses, Tally*) redress growth stunting? This might be akin to emergency medical knowledge in advanced economies; general health knowledge improves daily wellness for the average individual, but emergency medical knowledge helps with unforeseen crises. [c] Skills. Why did skills have such negligible effects on adult anthropometrics? In the introduction we raised the possibility that the general principles behind LEK could be more useful than practical skills over time. [d] Gender differences. Why does LEK reduce severe stunting only among girls and why does LEK increase self-reported poor health only among women?

8. Conclusions

This study contributes to the nascent field of studies about the fate of local ecological knowledge (Fernández-Llamazares et al., 2021; Salali et al., 2020; Turvey, Bryant, & McCune, 2018). Some argue that these knowledge systems might not be able to change fast enough to keep up with rapid global environmental and socioeconomic change and continue helping humans cope with their environment, particularly as connections between people and the environment are increasingly being broken (Fernández-Llamazares et al., 2021). The results of this study point to three future steps.

[1] A better identification strategy is needed to increase confidence in causal effects. All studies linking LEK with health have been correlational. Until researchers use a more convincing identification strategy to establish causality, assertions about the value of LEK for human well-being or the environment remain questionable. We realize other approaches (e.g., natural experiments) have shortcomings (Keele & Small, 2019; Leatherdale, 2019), but the field is ready for alternative approaches that lessen the noise from correlational studies. [2] The field is also ready to expand the sample of societies studied. All but two multivariate studies about LEK's effect on health come from one society, Tsimane' (Section 1.2). [3] If LEK can be shown to causally improve health, the stage would be set to examine how LEK changes in response to large socioeconomic and environmental changes.

Credit authorship contribution statement

Ricardo Godoy: Conceptualization, Writing – review & editing. **Tomás Huanca:** Project administration, Supervision. **William R. Leonard:** Conceptualization, Data curation, Funding acquisition, Writing – review & editing. **Thomas McDade:** Conceptualization, Formal analysis, Methodology. **Victoria Reyes-García:** Conceptualization, Data curation, Formal analysis, Writing – review & editing. **Asher Y. Rosinger:** Formal analysis, Methodology, Writing – review & editing. **Susan Tanner:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare they have no conflicts of interest.

Data availability

The data associated with this research are available at Ricardo Godoy - Brandeis University Researcher Profiles - Output - All assets.

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Appendix A. A guide to the robustness and additional analyses [major changes shown in bold in the two tables below]

Table 1
Children.

Excel Table	Outcomes	Ages	Follow-up	Covariates	Rationale
Main analysis					
4	Eq. 1	$3 \leq$ age ≤ 17	2004–10	Eq. 1	Eq. 1
Robustness					
5	Eq. 1	$3 \leq$ age ≤ 17	2004–10	**No baseline anthropometric**	Since baseline and later anthropometrics correlate and baseline anthropometrics and LEK also correlate dropping baseline anthropometrics should change the effects of LEK.
6	Eq. 1	**$9 \leq$ age ≤ 17**	**2010**	**Age, household size**	Table 6 used to see if LEK at baseline produces effects by end-line (2010) independent of what happened in middle years (2004–2009)
Additional					
7	Eq. 1	$3 \leq$ age ≤ 17	2004–10	Eq. 1 + **interaction Age*X's**	Age interacted with all predictors of Eq. 1 (other than set of year and village dummies) to assess if LEK effects vary by the age of children at baseline
8	**HAZ < -3 ZSF < -1**	$3 \leq$ age ≤ 17	2004–10	Eq. 1	Does LEK affect extreme health values? ZSF = 2 skinfolds.
9	Eq. 1 **& bed-ridden days**	$3 \leq$ age ≤ 17	2004–10	Eq. 1.	Outcome is number of bed-ridden days in past 14 days to examine how LEK affects perceived morbidity
10	**BMI-age z score**	$3 \leq$ age ≤ 17	2004–10	Eq. 1.	BMI-for-age z score following international guidelines to assess if results change by how BMI is expressed
11	Eq. 1	$3 \leq$ age ≤ 17	2004–10	Eq. 1. + **quadratic terms for LEK**	To detect non-linearities

Table 2
Adults.

Excel Table	Outcomes	Follow-up	Covariates	Rationale
Main analysis				
4	Eq. 1	2004–10	Eq. 1	Eq. 1 for children with modifications indicated in Section 3.4
Robustness				
5	Eq. 1	2004–10	**No baseline anthropometric**	Since baseline and later anthropometrics correlate and baseline anthropometrics and LEK also correlate dropping baseline anthropometrics should change the effects of LEK.

(continued on next page)

Table 2 (*continued*)

Excel Table	Outcomes	Follow-up	Covariates		Rationale
6	Eq. 1	**2010**	**Age, household size**		This table is here to see if LEK at baseline produces effects by end-line (2010) independent of what happened in middle years (2004–2009)
Additional					
7	**Y binary < -1SD/ a/**	2004–10	Eq. 1		Does LEK affect extreme values. Outcomes is binary var. = 1 if outcome <1SD of raw outcome, 0 otherwise
8	Eq. 1	2004–10	**HH-level LEK**		Household-level LEK measures clustered by household
9	Eq. 1 **& bed-ridden days**	3 ≤ age ≤ 17	2004–10	Eq. 1.	Outcome is number of bed-ridden days in past 14 days to examine the effects of LEK on perceived morbidity
10	Eq. 1	3 ≤ age ≤ 17	2004–10	Eq. 1. **+ quadratic terms for LEK**	To detect non-linearities

/a/ The binary variable for the outcome (1 if <-1SD, 0 otherwise) was constructed separately for adult women and men in the sample (not relative to an international reference population).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.evolhumbehav.2024.106594.

The computer codes, processed data, and some of the coarse data have been archived in Mendeley at the following link: Adult local ecological knowledge and health among Tsimane', a native Amazonian society in Bolivia - Mendeley Data [data.mendeley.com].

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