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ORIGINAL PAPER

Dietary transitions among three contemporary hunter-gatherers across the tropics

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Abstract

The diets of contemporary hunter-gatherers are diverse and highly nutritious, but are rapidly changing as these societies integrate into the market economy. Here, we analyse empirical data on the dietary patterns and sources of foods of three contemporary hunter-gatherer societies: the Baka of Cameroon ($n = 160$), the Tsimane' of Bolivia ($n = 124$) and the Punan Tubu of Indonesia ($n = 109$). We focus on differences among villages with different levels of integration into the market economy and explore potential pathways through which two key elements of the food environment (food availability and food accessibility) might alter the diets of contemporary hunter-gatherers. Results suggest that people living in isolated villages have more diverse diets than those living in villages closer to markets. Our results also suggest that availability of nutritionally important foods (i.e., fruits, vegetables and animal foods) decreases with increasing market integration, while availability of fats and sweets increases. The differences found seem to relate to changes in the wider food environment (e.g., village level access to wild and/or market foods and seasonality), rather than to individual-level factors (e.g., time allocation or individual income), probably because food sharing reduces the impact of individual level differences in food consumption. These results highlight the need to better understand the impact of changes in the wider food environment on dietary choice, and the role of the food environment in driving dietary transitions.

Keywords Animal source foods · Dietary diversity · Food environment · Fruits and vegetables · Market integration · Nutrition transition

1 Introduction

The quality of diets in traditional hunter-gatherers has been a topic of heated debate, to the point where a "paleo" diet has been promoted as a healthy alternative to industrialized Western diets (Crittenden and Schnorr 2017). From Sahlins (1974) work highlighting the energetic efficiency of hunting and gathering to a recent study showing consistently higher

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rates of food security among societies with a higher reliance on hunting and gathering than in agriculture (Berbesque et al. 2014). A wealth of research has disproved the idea that hunter-gatherer societies live on the brink of starvation. Rather, the diets of contemporary hunter-gatherers are diverse and highly nutritious across different seasons and ecological zones (Crittenden and Schnorr 2017).

However, the diets of contemporary hunter-gatherers, and generally the diets of Indigenous peoples, are rapidly changing (Kuhnlein 2009; Kuhnlein and Receveur 1996). Note that we use the term 'contemporary hunter-gatherers' to refer to societies that, while strictly hunter-gatherers in the recent past, nowadays also engage in other economic activities, such as herding, cultivation, or market transactions to cover and supplement subsistence needs (see Reyes-García and Pyhälä 2017). Indeed, at present, there are no hunting and gathering groups in tropical forests who do not consume some type of cultivated food, whether self-produced or obtained through trade (Crittenden and Schnorr 2017; Bailey and Headland 1991; Bailey et al. 1989). While few studies to date provide quantitative assessments of dietary changes among contemporary hunter-gatherers (Crittenden and Schnorr 2017), the existing studies show that contemporary dietary transitions are associated with market integration and commodification of food systems. Such transitions often include a move away from traditional foods towards more processed foods, higher in fat, added sugar, and salt (Kuhnlein 2009; Kuhnlein and Receveur 1996; Popkin 2004), leading to increasing rates of overweight, obesity and associated chronic diseases such as type II diabetes mellitus and cardiovascular disease (Kuhnlein et al. 2004; Popkin 2004; Rowley et al. 2000). Relative to more sedentary and market-integrated communities, those practising traditional hunting and gathering livelihoods are more fit, have more diverse diets, and consume more meat and wild foods (Parrotta et al. 2015). Given the paucity of research on the topic, two questions remain unanswered. First, how generalizable among contemporary hunter-gatherers is the pattern found in previous research linking integration into the market economy and diet homogenization? And second, what are the pathways through which integration into the market economy alters the diets of contemporary hunter-gatherers?

In this article we address these two questions. In the first part of the article, we analyse empirical data on the dietary patterns and sources of foods of three contemporary hunter-gatherer societies. We specifically focus on differences among communities with diverse levels of integration into the market economy. In the second part of the article, we explore potential pathways through which changes in the food environment associated with integration into the market economy might alter the diets of contemporary hunter-gatherers. The analysis is based on the assumption that nutrition transitions result from changes in elements of the food environment that are likely to impact dietary choice.

Work on the role of food environments in dietary choice has, to date, largely focused on the food environment in markets, with little attention to cultivated and wild food sources (Powell et al. 2015; Ahmed and Herforth 2017). Powell et al. (2015) argue that "In areas where market access is difficult or where markets do not function well, economic factors and market food environments may not be the strongest determinants of food choice: in these settings, we need to understand how the landscape (or natural food environment) affects diets." Herforth and Ahmed (2015) lay out four general aspects of the food environment that are likely to impact dietary choice: availability, affordability, convenience, and desirability. In the case of hunter-gatherer communities these four aspects of the food environment are likely to change as communities become more market integrated and/or sedentary.

Food availability, or what is available for consumption due -for example- to seasonal variation, is likely to change as contemporary hunter-gatherers become more market integrated, largely through changes in their livelihoods. Changing livelihoods may affect the way people use and modify their landscape, which may impact the availability of certain foods (Padoch and Sunderland 2013). For example, communities living in deforested landscapes might have less game animal species available or more sedentary life styles might lead to more intensive land uses and a consequent decrease in the availability of wild foods (Broegaard et al. 2017). Changes in mobility may also impact the seasonal availability of foods.

Food accessibility, or the energy, the money, and the time spent to access food (covering both affordability and convenience according to Herforth and Ahmed (2015), is also likely to change as hunter-gatherer communities become more integrated into the market economy. Livelihood transitions often imply that foods that were once obtained from the wild or from subsistence agriculture must be purchased, oftentimes because people no longer have the time to collect, hunt, or grow them. Finally, desirability or food preferences are learnt and highly bound by socio-cultural factors (Serrasolses et al. 2016; Bowles 1998; Fischler 1988) and are also likely to change as hunter-gatherer communities become more market integrated.

In our analysis, we examine differences in importance of different aspects of the food environment in communities with more and less market integration. Because no detailed market survey data were collected with the study, we used seasonal differences to examine the importance of *food availability* and livelihood strategy (assessed by the activity an individual spends most time pursuing) and income to assess the importance of *food accessibility* (including both monetary access and access in terms of time, called *convenience* elsewhere) (Herforth and Ahmed 2015).

2 Case studies

There are few studies of how initial market integration impacts dietary choice and the food environment because most communities that are not yet market integrated are remote, making the collection of dietary surveys resource intensive. For this project, we selected remote, Indigenous communities that still obtained the majority of their food through traditional subsistence systems, including significant amounts of hunting and gathering (i.e. foods from the natural food environment). To increase the ability to draw conclusions across cultural groups and geographic locations (Chrisomalis 2006), we selected societies in three continents: the Baka of Cameroon for Africa, the Punan Tubu of Indonesia for Asia, and the Tsimane' of Bolivia for Latin America. While any other three relatively isolated societies, largely dependent on traditional subsistence systems, might have been suitable for this study, we chose those because we had previous contacts in the areas who facilitated the setting up of the study. Although the involvement in market economies, formal education, and western health systems of these societies is growing, people in the three societies largely continue to depend on hunting, gathering and subsistence farming. Below we provide a general background to each of the studied societies.

The Baka are a hunter-gatherer group of about 35,000 people living in the tropical rain forests of the Congo Basin, and mostly in southeastern Cameroon (Joiris 2003). They traditionally lived in semi-nomadic groups and, despite frequent food exchanges with their sedentary farming neighbors, they depended mainly on wild resources for their livelihood (Bahuchet 1993). Since the 1960s, the Baka have begun to regroup along roads opened by logging companies and to grow their own food, due to defaunation and deforestation and governmental policies and missionary attempts to sedentarize and educate them (Leclerc 2012). The Baka continue to move between villages and forest camps, but their economy is increasingly monetarized (Kitanishi 2006). Previous work suggests that these transitions are often associated with lower meat consumption and with increased malnutrition and disease (Dounias and Froment 2006; Koppert et al. 1993; Froment et al. 1993). Nowadays, the Baka are engaged in both agricultural and forest-related subsistence activities, such as hunting, gathering and fishing. Their daily activities vary over the course of the year, depending on both the agricultural calendar and wild food availability (Table 1).

The second group, the Punan Tubu, live in the mountainous interior of Indonesian Borneo. The Punan number ~10,000 people, and include diverse groups according to the place of origin (Levang et al. 2007). The Punan living in the upper Tubu river (hereafter Punan Tubu) are a group of about 800 people who lived a semi-nomadic lifestyle until the last 15 years, when they settled down in five small, scattered, inaccessible hamlets as a response to strong incentives from the authorities (Sercombe and Sellato 2007). Prior to sedentarization, their main staple food was sago, a starch paste made of forest palm trunks. Starting in the first half of the twentieth century, they progressively adopted upland rice swidden cultivation (Dounias et al. 2007), although the steep slopes, irregular rain patterns, and lack of agricultural inputs still make harvests highly variable. Palm sago has been replaced by easier to prepare, cassava sago, which is an alternative to rice, particularly before rice harvest when the stored rice has been consumed (Table 1). Hunting continues to provide the main source of meat, the Punan preferring bearded pig (*Sus barbatus*), but also hunting several species of deer, pheasants, monitors, snakes, and turtles (Kaskija 2012; Dounias 2007; Sakai et al. 2006). The Punan also fish barbs, carps, and catfish (Puri 2001). As the Punan Tubu also obtain cash from the trade of NTFPs –especially eaglewood (*Aquilaria* spp.)- and from wage labor in government projects (Napitupulu et al. 2016), market products (e.g., rice, noodles, sugar and fats) are increasingly present in their diets (Dounias et al. 2007).

Finally, the Tsimane' are a small-scale Indigenous society of foragers and farmers in the Bolivian Amazon. Numbering ~ 12,000 people, the Tsimane' live in ~100 small villages scattered along rivers and logging roads (Reyes-García et al. 2014). Until the late 1930s, the Tsimane' maintained a traditional semi-nomadic and self-sufficient lifestyle, but their interactions with the Bolivian society have steadily increased since then and they have been mostly settled in permanent villages with school facilities since the 1950s (Reyes-García et al. 2014). Tsimane' livelihoods are predominantly organized around agricultural tasks and game and fish availability throughout the year (Table 1). They rely on slash-and-burn farming of cassava, plantains, maize, rice, and chickens, supplemented by hunting, fishing and gathering wild fruits. Game and fish are generally more abundant in more remote villages (Díaz-Reviriego et al. 2016). Some Tsimane' men, mostly in villages close to town, increasingly engage as wage laborers in logging camps, cattle ranches, and in the homesteads of colonist farmers. The commercialization of forest products (e.g. thatch palm) also provides a primary source of income for many households, often through barter (Vadez et al. 2008). Partly due to these shifts in livelihoods, Tsimane' diets are undergoing rapid change, including the introduction of market foods and beverages, such as dried and salted meat, sugar, noodles, lard, vegetable oil, white flour/ bread, and soda (Zycherman 2013). Such dietary changes, together with other changes in lifestyle, seem to have precipitated a nutritional transition (Zycherman 2015). Although household income level is associated with higher statural growth in children (Godoy et al. 2010), increased household market food expenditures are associated with increased adult body mass index, weight and body fatness (Rosinger et al. 2013).

Table 1 Seasonal availability of products in the three study sites

	Tsimane'		Baka		Punan	
	Rain	Other	Rain	Other	Rain	Other
Month	Nov-March	April-Oct	Aug-Nov	Dec-July	Dec-Feb	March-Nov
Wild foods	Less fish and game; more wild fruits	More fish and game	More game; less fish	Less game; more fish	More game and fruits at the end of season	Some wild fruits; less game
Crops	Rice harvested at end of season	Cassava and plantain available all year	Cassava and plantain available all year	More crops	Cassava available all year	Rice harvested at start of dry season
Income	Minor income from thatch palm all year	Major income from rice sale at the end of season	Limited income from sale of bush meat and NTFPs		Slightly higher income	Limited income

3 Methods

Data were collected during 18 months of fieldwork among each of the three societies (see Reyes-García et al. (2016) and Reyes-García et al. (2018) for a full description of the methodological approach). We used qualitative data collection methods during the 18-months of fieldwork, but mostly during the first six months. Qualitative data collection methods included semi-structured interviews with key informants on local livelihoods, diets, and dietary changes (Davis and Wagner 2003). We also gathered information on food terminology, food preparation practices, ingredients used in local dishes, and meal customs (i.e., number of meals per day, eating habits such as eating out of one pot vs. separate plates, or eating outside the house). We used gendered-specific focus group discussions to collect information on the seasonal calendar.

For this work, we followed the Code of Ethics of the International Society of Ethnobiology. The work received the approval of the ethics committee of the Universitat Autònoma de Barcelona (CEEAH-04102010). Before data collection started, we asked villages and informants to provide Free Prior and Informed Consent (FPIC). We also obtained the agreement from the indigenous groups' relevant political organization.

3.1 Sampling

In each society, we worked in two villages that differed in their distance to the main market town (i.e., *isolated* and *close* villages) (Table 2), as access to market is an important determinant of nutritional transitions. In each village, we requested the participation of all adults (> = 16 years old), and achieved a participation rate above 90%. Our final sample included 393 informants (160 Baka, 109 Punan Tubu, and 124 Tsimane').

3.2 Data collection

Dietary recall Dietary information was collected using a qualitative food recall over a 24 h period adapted from the FAO Guidelines for Assessing Dietary Diversity (Kennedy et al. 2011). Drawing on these guidelines, we classified locally consumed food products according to the 12 following food groups: 1) starch (i.e., cereals, white tubers and roots); 2) dark green leafy vegetables; 3) other vitamin-A rich fruits and

Table 2 Characteristics of communities with greater and lesser market access in the three study sites

Site	Isolated village	Close village
Tsimane'	One of the most remote villages on the river, a three-day (123 km) canoe trip from the market town of Yucumo. Forested area with plentiful wildlife and fish.	A one-day canoe (33 km) trip from Yucumo town. High rates of deforestation and relatively low game availability.
Baka	On a logging road 35 km from the main administrative town of the region and 2 km far from the Bantu village. Degraded secondary forests, higher game availability, but lower diversity.	At the intersection of two logging roads, 12 km from an administrative town of the region and located at the prolongation of the Bantu village. Less degraded secondary forest, but lower game availability.
Punan	Most isolated Punan Tubu village. Located about 86 km from Malinau town at ca.450 m.a.s.l, on the upper Tubu River. Only accessible by a two to three day boat journey and a half-day walk. Mostly surrounded by old-growth forest on steep slopes, managed forests and secondary-growth forest.	Located about 77 km from Malinau town at ca. 350 m.a.s.l on the upper Tubu River. Only accessible by a two to three-day boat journey. Mostly surrounded by old-growth forest on extremely steep slopes, managed forests, and secondary –growth forest.

vegetables; 4) other fruits and vegetables; 5) meat and fish foods (including insects); 6) organ meat; 7) eggs; 8) milk and milk products; 9) legumes and nuts; 10) fats (including oils); 11) sweets; and 12) spices (including condiments and beverages) (Supplementary Material 1). We asked informants to list all the foods and drinks they had consumed during the previous 24-h, inside and outside the house, and each food item was noted in the corresponding food group. Probing was used to help ensure informants did not omit added foods (e.g., sugar) or food items consumed outside the house (e.g., in the forest). The questionnaire was administered in the morning, avoiding holidays, celebrations and/or fasting periods. We also recorded the source of each food item differentiating between items that were cultivated, obtained from the forest, or bought from the market. To capture seasonal variation in food consumption (Table 1), we collected dietary recalls quarterly, aiming at two interviews per person/quarter, but due to high mobility in the sampled populations, we do not have complete data for all informants. For the analysis, we removed informants with only one observation. The average number of observations per informant was 4.9.

Socio-demographic information: At the beginning of the study, we conducted a census in the six studied villages in which we recorded age, sex, and household composition. The census also included information on variables that have been typically used to measure ***exposure to the national society*** (Lara et al. 2005; Zane and Mark 2003). Specifically, we asked about the maximum grade the informant had completed in school and her ability to speak the national language (French for the Baka, Indonesian for the Punan Tubu, and Spanish for the Tsimane'). We differentiated informants who could not maintain a conversation in the national language from those who could.

Our data collection also included information on three variables that proxy an individual's ***degree of integration into the market economy*** (Lu Holt 2007; Godoy et al. 2005): i) number of times the person visited the main market town during the last 12 months; ii) the monetary value of a set of market items; and iii) cash income obtained from wage labor or from commercializing forest or agricultural products. Information on cash income was collected during quarterly interviews in which informants were requested to provide information regarding the two previous weeks. To obtain a single measure for an individual, we averaged quarterly information. To be able to compare information across countries, we used purchasing power parity (PPP) exchange rates. All monetary values used in this work are expressed in PPP adjusted US$.

Time allocation: To gather data on time allocation, we combined behavioral spot observations with 24-h retrospective recalls. Each week we randomly chose a day when we asked all adults in the sample to recall their main activity during the two previous days (Sackett and Johnson 1998; Reyes-García et al. 2009). Over the 18 months of field work, we obtained an average of 19.2 observations per person (SD 6.9). Unfortunately, we could not always collect data for all individuals in a household. Thus household level metrics could not be computed.

3.3 Data analysis

To analyze dietary patterns and sources of foods we used descriptive and bivariate analysis. We started by coding each food group as 1 ("present"), if the respondent reported consuming at least 1 food item in the group and 0 otherwise, and calculated the percentage of diets that included at least one food item in a food group. We also calculated individuals' 24 h Women's Dietary Diversity Score (WDDS), a proxy for micronutrient adequacy in developing countries (Kennedy et al. 2011). To calculate WDDS we added information on the presence of food items in all the aforementioned food groups, except fats, sweets and spices. We then calculated the mean for each society and differentiating between people living in the *isolated* and the *close* villages. We used a Pearson chi^2 test to assess whether there were statistically significant differences among villages (Table 3).

To analyze sources of foods, we created three new variables for food groups (*crop, wild,* and *market*) which were coded as 1 if at least one of the food items in a group came from that source and 0 otherwise. We then calculated the percentage of diets which included at least one food item of each of the food groups obtained from agricultural fields, the wild, and the market (Table 4). As with dietary patterns, we differentiated between the isolated and the close village in each society and assessed differences using a Pearson chi^2 test.

To analyze if and how changes in food availability and food accessibility might be responsible for the differences in diet associated with market integration of contemporary hunter-gatherers we used bivariate and multivariate analysis. We first looked at potential variations in sources of food according to temporal *availability* (seasonality). We did so by grouping information on food consumption, differentiating between questionnaires that were conducted during the "Rainy" and "Other" seasons and then analyzing sources of food for each season (Table 5). To explore how *accessibility* might alter dietary patterns, we aggregated data on time allocation into four categories: subsistence agriculture, foraging, wage labor, and other (e.g., leisure, cooking, household work). We calculated the share of time an individual was mainly devoted to each activity and classified individuals as predominantly: a) agriculturalists, b) foragers, or c) wage workers if >50% observations were in the corresponding category, and as d) diversifiers, if they did not fit in any of the previous groups. We then explored if there were differences in the food consumed between people in these categories (Table 6).

In the last part of the analysis, we assessed the relative weight of these various factors in modeling WDDS by using

Table 3 Food consumption in three Indigenous societies. Percentage of total diets including a food item in the selected food groups

	Baka		Punan Tubu		Tsimane'	
	Close ($n = 650$)	Isolated ($n = 641$)	Close ($n = 349$)	Isolated ($n = 251$)	Close ($n = 405$)	Isolated ($n = 279$)
Starchy staples	92.6	96.4***	100	99.6	88.9	85.7
Dark green leafy vegetables	70.9	69.2	66.7	69.3	0	0
Other vitamin A rich fruits & vegetables	18.5	17.1	15.5	1.20***	98.5	97.5
Other fruits & vegetables	7.69	6.55	23.2	49.8***	63.7	70.2*
Organ meat	5.85	4.21	2.87	5.18	6.91	31.5***
Meat & fish	28.	47.7***	63.6	49.8***	81.7	97.5***
Eggs	0	0.16	0.29	0	4.44	5.02
Legumes, nuts, and seeds	25.1	36.7***	0.86	0	1.72	5.02**
Milk & milk products	0	0	0.29	0.40	0.24	3.94***
Oils & fats^	43.2	39.6	14.0	39.4***	42.7	56.6***
Sweets^	2.31	0.62**	37.8	35.9	52.8	61.6**
Species, condiments & beverages^	69.4	76.0***	96.8	98.4	90.1	93.1
Women's dietary diversity score (WDDS) (0–9)	2.49	2.78***	2.73	2.75	3.46	3.96***

^ Category not included in the WDDS. **Note:** *, **, and*** Pr < 0.1, <0.05, and < 0.01 in a Pearson chi^2 test

multivariate analysis. Specifically, we analyzed how variation in WDDS relates to food availability, food accessibility, and village and individual level of integration into the market economy using expression (1):

$$\mathrm{WDDS}_{ihvt} = \alpha + \gamma \mathrm{EX}_{ihv} + \beta \mathrm{P}_{ihv} + \lambda N_{ihv} + \Omega \mathrm{S} + \varepsilon_{ihv} \quad (1)$$

where WDDS is the Women's Dietary Diversity Score for subject *i* of household *h* in village *v* at time *t*. EX is a vector that includes our main explanatory variables: *rain*, a variable that captures whether the data were collected in the rainy season or not; and *sh_wage*, a variable that captures the share of time the individual reported working for wage labor; *isolated*, a variable that captures whether the respondent lives in the close or the isolated village; and *trips to town*, *wealth* and *cash income* as measures of individual level integration into the market economy. P_{ihv} is a vector that includes control variables for socio-demographic characteristics of informants (*sex, age, and household size*). N_{ihv} includes the two variables selected to measure exposure to the national society (*speak national language* and *schooling)*. Some invariant characteristics of societies might affect the estimated association. To control for such fixed-effects, we included a set of dummies for the societies of study (S). And ε_{ihv} is the error term, that basically captures the information that the model cannot explain (Table 7). In additional analyses we replaced binary variables for societies by binary variables for villages. To control for the fact that observations may be correlated within individuals, but independent among them, in all regression models we used clusters by individual. The statistical analysis was done using STATA for Windows, version 13. We report *p*-values <0.10 as indicator of statistical significance,

4 Results

4.1 Dietary patterns, food sources, and market access

In each society, food consumption differed substantially among villages with more and less market access, diets being generally more diverse in the isolated villages (Table 3). Thus, Baka living in the isolated village had a WDDS of about 0.3 food groups higher than their peers in the close village ($p < 0.001$). The Baka living in the isolated village consumed starchy staple, meat and fish, and legumes and nuts more frequently than the Baka living in the close village. Conversely, the Baka living in the isolated village consumed fewer sweets but more spices, condiments and beverages than their peers. Similarly, the WDDS of the Tsimane' living in the isolated village was about 0.5 food groups higher than the WDDS score of Tsimane' living closer to the market ($p < 0.001$). Food items from the categories of 'other fruits and vegetables', organ meat, meat and fish, legumes and nuts, and milk and milk products were consumed more frequently by Tsimane' living in the isolated village. Unexpectedly, Tsimane' living in the isolated village also consumed fats and sweets more frequently than their peers.

The pattern is somewhat different among the Punan Tubu, as we did not find statistically significant differences in their WDDS score. Thus, although Punan Tubu in the isolated village consumed 'other fruits and vegetables' more often than Punan Tubu in the close village, they consumed meat and fish and other vitamin A rich fruits and vegetables less often. The Punan Tubu in the isolated village also consumed oils and fats more often than people in the close village.

Table 4 Sources of foods in diets, by market access

	Baka N = 1283						PunanTubu N = 600						Tsimane' N = 684					
	Crop		Wild		Market		Crop		Wild		Market		Crop		Wild		Market	
	Cl	Far	Cl	Far	Cl	Far	Cl	Far	Cl	Far	Cl	Far	Cl	Far	Cl	Far	Cl	Far
Starchy staples	38.9***	49.7	5.3***	0.3	60.6	58.4	97.7**	100	.	.	6.6***	.	92.5	94.1	0.6	0.8	15.0	13.4
Dark green leafy vegetables	39.5	43.0	67.1	62.8	15.3***	69.8	96.6**	100	4.3***	100	0.4	.	.	.	.	.	.	.
Other vitamin A rich fruits & vegetables	74.2	65.5	3.3	0.9	22.5*	33.6	94.4	100	3.7	.	.	.	97.7	99.3	1.2***	6.6	2.8***	.
Other fruits & vegetables	90	83.3	.	2.4	14	14.3	44.4***	68	58**	40	1.2	0.8	33.3***	79.1	68.2***	32.1	7.7*	12.8
Organ meat	.	.	97.4	100	2.9	7.4	.	.	100	100	.	.	35.7***	13.6	64.3***	90.9	.	.
Meat & fish	.	.	87.9	88.6	12.1	12.7	0.5	0.8	98.6	99.2	1.3	.	10.0	7.3	77.3***	95.2	18.4***	4.0
Eggs	.	.	.	100	.	.	100	.	.	.	.	.	83.3	78.6	11.1	21.4	5.6	.
Legumes, nuts, and seeds	18.8	19.1	64.8*	55.7	33.1	34	.	.	.	.	100	.	71.4**	100	28.6**	.	.	.
Milk & milk products	.	.	.	.	.	.	100	.	.	.	.	100	.	.	.	.	100	100
Oils & fats^	98.3***	53.5	14.4***	36.6	2.9***	11.4	.	.	36.7***	100	63.3***	100	53.8***	16.5	8.7***	.	37.6***	83.5
Sweets^	.	.	12.5***	100	87.5***	.	1.52***	100	.	.	99.2	100	7.0***	23.3	1.9	2.3	92.1	91.3
Species, condiments & beverages^	82.1***	72.5	4.1***	10.5	97.7	95.9	15.7***	100	0.3	.	99.7	100	0.8	1.1	0.5	.	100***	95.9

*, **, and *** Pr < 0.1, <0.05, and < 0.01 in a Pearson chi^2 test comparing food sources between isolated and close villages

For each food group we calculated the percent of food items obtained as *crops*, from the *wild*, or from the *market*. Since food groups can have items from more than one source, percentages do not necessarily add to 100

We also found variation in food sources associated with market access, although there was less variation between near and far villages in terms of the sources of food than in the frequency of consumption of different food groups (Table 4). Our data show a difference in the source of meat and fish, with more of these food items coming from the wild in the isolated village and more from domestic animals and the market in the close village. Among the Baka, those living in the close village obtained less of their staples from cultivated crops but more from the wild and less of their dark green leafy vegetables from markets than Baka living in the isolated village. Among the Punan Tubu, those living in the close village obtained less starch from cultivated crops but more from the market, than people from the more isolated one. They also obtained less of their fruits and vegetables from cultivated sources and more from the wild than those living more isolated.

Oils and sweets were the food groups with more differences in source among the close and the isolated villages (Table 4). The Baka in the isolated village obtained all their sweets from the wild (i.e., honey), whereas those in the close village obtained them from the market. For both the Baka and the Tsimane', isolated villages obtained more of their fat and oils from the market, while those in the close communities obtained them on farm (e.g., from cultivated oil palm or domestic animals).

4.2 Food availability, food accessibility, and market access

Overall, there is a strong seasonal variation in diets, reflected in a lower WDDS during the rainy season than during the rest of the year (Baka and Tsimane' $p < 0.001$, Punan Tubu $p = 0.06$; Table 5). During the rainy season, the Baka consumed starchy staples, dark green leafy vegetables, other fruits and vegetables, and meat and fish less frequently, and obtained a lower percentage of these from the market and a greater percentage from the wild. In the rainy season, the Baka also consumed oils and fats, sweets, and spices and condiments less often and obtained a lower percentage of these from the market. Similarly, during the rainy season the Tsimane' consumed foods in the categories of staples, organ meat, and meat and fish less frequently, but other fruits and vegetables more frequently (with a greater percentage of these obtained from the wild). The lower consumption of meat and fish in the rainy season is concurrent with a greater percentage of fish and meat obtained from the market at that time. They also consumed oils and fats, sweets and spices and condiments less frequently in the rainy season, obtaining less of them from the market (Table 5).

The diets of the Punan Tubu showed less seasonal variation. The most important patterns of seasonal variation for the Punan Tubu refers to a greater dependence on purchased

Table 5 Seasonal differences in frequency of food group consumption and sources of food

	Rainy				Other			
	%	C	W	M	%	C	W	M
Baka (n = 1283)								
Starchy staples	89.6	59.5***	7.2***	42.4	97.2***	36.5	0.5	68.3***
Dark green leafy vegetables	59.6	56.7***	66.0	3.7	76.0***	35.6	64.5	12.9***
Other vitamin A rich fruits & vegetables	19.9	85.9***	2.2	12.0	16.7	59.4	2.2	38.4***
Other fruits & vegetables	2.8	76.9	7.7**	15.4	9.5***	88.6	.	13.9
Organ meat	5.2	0	100	9.5	4.9	.	97.6	2.4
Meat & fish	32.0	0	91.2	10.1	41.1***	.	87.1	13.5
Eggs	0				0.1	.	100	.
Legumes, nuts, and seeds	32.4	16.0	81.8***	15.9	30.0	20.3	45.9	41.5***
Milk & milk products	0				0	.	.	.
Oils & fats^	33.0	40.9	69.3***	4.42	46.1***	85.1***	7.6	8.1
Sweets^	0				2.3***	.	30.0	70.0
Species, condiments & beverages^	42.3	56.4	11.7**	95.3	89.6***	81.5***	6.6	97.2
WDDS	2.41***				2.71			
PunanTubu(n = 600)								
Starchy staples	100	93.0	0	11.3***	99.8	100***	.	2.1
Dark green leafy vegetables	67.0	98.7	2.4	2.4**	68.0	97.8	9.5	.
Other vitamin A rich fruits & vegetables	7.8	77.8	22.2***	0	9.9	97.9**	.	.
Other fruits & vegetables	58.3***	67.2*	49.3	0	28.7	54.7	46.0	1.4
Organ meat	0				4.7**	.	100	.
Meat & fish	28.7	0	100	0	64.7***	0.6	98.7	1.0
Eggs	0				0.2	100	.	.
Legumes, nuts, and seeds	0.9	0	0	100	0.4	.	.	100
Milk & milk products	0.9	100	0	0	0.2	.	.	100
Oils & fats^	20.0	0	40.	100***	25.8	.	76.9**	70.0
Sweets^	26.1	14.3	0	96.7	39.6***	4.1	.	100**
Species, condiments & beverages^	96.5	22.2	0	100	97.7	20.0	0.4	99.8
WDDS	*2.63**				*2.85*			
Tsimane' (n = 684)								
Starchy staples	84.8	92.9	0	10.3	90.8**	93.4	1.4**	18.8***
Dark green leafy vegetables	0			0	0			
Other vitamin A rich fruits & vegetables	98.1	99.2*	1.4***	0.8	98.1	97.4	5.8	2.6*
Other fruits & vegetables	72.6***	41.9	64.4***	9.4	59.2	69.0***	35.8	10.7
Organ meat	10.3	13.2	86.8	0	24.7***	21.8	83.3	0
Meat & fish	82.9	8.2	83.3	14.1*	94.3***	9.4	87.6	9.7
Eggs	0.3	100	0	0	9.8***	80.6	16.1	3.2
Legumes, nuts, and seeds	2.5	100	0	0	3.8	83.3	16.7	0
Milk & milk products	2.7*	0	0	100	0.6	0	0	100
Oils & fats^	38.0	29.3	5.71	65.0*	60.4***	40.8**	3.7	55.5
Sweets^	53.3	12.8	2.0	89.3	60.1*	15.8	2.1	94.2*
Species, condiments & beverages^	87.8	0.9	0	96.7	95.6***	1.0	0.7	100***
WDDS	*3.54****				*3.97*			

%: Overall proportions of diets including food items in the selected category, C: Crop, W: wild, M: market

*, **, and *** Pr < 0.1, <0.05, and < 0.01 in a Pearson chi^2 test comparing reliance of food sources in different seasons

Table 6 Food accessibility, by time allocation

	Baka				Punan				Tsimane'			
	F	A	W	D	F	A	W	D	F	A	W	D
Starchy staples	94.7	93.1	100	94.8	100	100	100	99.2	88.5	84.4	87.5	91.1
Dark green leafy vegetables	70.9	66.3	80.	69.7	70.3	64.8	64.7	67.2	0	0	0	0
Other vitamin A fruits & vegetables	16.2	18.8	13.3	21.9	8.51	13.2	5.88	6.87	98.8	98.6	100	96.3
Other fruits & vegetables	7.05	5.45	0	8.71	35.2	34.1	41.2	32.1	67.1	69.2	37.5	61.7
Organ meat	5.05	4.56	0	5.16**	2.59	6.59	11.8	1.53	15.5	23.7	25.***	9.56
Meat & fish	37.6	37.6	40.	37.4	50.7	69.8***	47.1	57.3	85.4	90.5	87.5	90.4
Eggs	0	0	0	0.322	0.37	0	0	0	5.28	5.69	0	2.21
Legumes, nuts & seeds	30.1	29.2	33.3	34.2	03.7	0.549	5.88**	0	3.42	4.74*	0	0
Milk & milk products	0	0	0	0	0	0.549	0	0.76	1.55	2.37	0	1.47
Oils & fats^	43.75*	34.7	26.7	41.0	24.1	24.2	47.5	23.7	48.8	48.8	62.5	44.9
Sweets^	1.20	2.0	0	1.93	35.6	42.3	47.5	31.3	55.0	54.0	75.	63.2
Species, condiments & beverages^	72.9	68.3	73.3	74.8	97.4	97.8	100	96.9	90.4	92.4	100	91.9
WDDS (0–9)	3.43	2.54	2.67	2.72	2.75	2.68	2.90	2.76	3.66	3.79	3.36	3.53

F: Foragers, A: Agriculturalist, W: Wage labour, D: Diversifiers

staples in the rainy season, and a less frequent consumption of meat and fish and organ meat during the rainy season (Table 5). While oil and fat consumption did exhibit seasonal variation, a larger share of the fat and oil consumed in the rainy season came from the market. Consumption of sweets was less frequent in the rainy season and a lower share of them came from the market (Table 5).

Time allocation did not seem to relate to diet (and presumably food accessibility), as the individual consumption of different food groups varied little according to individual time allocation, and did not seem to have an overall impact in dietary diversity (Table 6). Thus, despite some specific differences in the three societies (e.g., Baka foragers consume more oils and fats, Punan Tubu agriculturalists consume more fish and meat, and Tsimane' wage workers consume more organ meat than people in other groups), there are no statistically significant differences in the WDDS across time allocation groups.

4.3 The correlates of WDDS

When considering the three societies together (Table 7, Model 4), the distance of the village to the market and season were associated in a statistically significant way with WDSS. Overall, people living in the isolated villages had a higher WDSS than their peers living in the close villages. Additionally, the WDDS was generally lower during the rainy season than during the rest of the year. We find the same pattern when analysing data for the Baka (Model 1) and the Tsimane' (Model 3) samples, but not among the Punan Tubu (Model 2). When looking at the pooled sample, we also found a weak and negative association between people who allocate more time to foraging and WDDS. However, the association was not found in any of the regressions with separate samples. None of the variables that proxy for individual level of integration into the market economy are consistently associated with WDDS across the three case studies.

5 Discussion

In this work we used data from three contemporary hunter-gatherer societies 1) to assess variation in dietary patterns and food sources associated with market integration, and 2) to explore the role of two key elements of the food environment, food availability and food accessibility in explaining such variability. We organize the discussion around the main findings for these two goals.

In the three studied societies, we found variation in diets and food sources associated with integration into the market economy. Although the diets of the three societies were different from one another, we found a similar pattern in that there was higher dietary diversity in isolated villages, a trend that was corroborated through multivariate analyses. Moreover, the difference found was relatively large when compared with results from previous studies (see Jones (2017) for a review of the literature). Importantly, the higher dietary diversity in the isolated villages was due to the more frequent consumption of nutritionally important food groups (e.g., fruits, vegetables, meat, fish). Our results, however, also point at some counterintuitive findings, such as that people living in the isolated villages also consumed more frequently

Table 7 Ordinary least square regressions (dependent variable WDDS)

	(1) Baka	(2) PunanTubu	(3) Tsimane'	(4) Pooled
Isolated village	0.3033***	0.0111	0.5191***	0.2892***
	(0.0794)	(0.0834)	(0.1113)	(0.0509)
Rainy season	−0.3281***	−0.1085	−0.2959***	−0.2665***
	(0.0663)	(0.0837)	(0.0717)	(0.0426)
Share forage	0.0521	−0.2994	−0.3455	−0.2862*
	(0.3337)	(0.3189)	(0.3185)	(0.1670)
Trips to town	0.0126	−0.0031	0.0030	0.0044
	(0.0179)	(0.0170)	(0.0065)	(0.0058)
Wealth	0.0008	0.0000	−0.0000	−0.0000
	(0.0012)	(0.0000)	(0.0000)	(0.0000)
Cash income	−0.0024	0.0015**	0.0001	0.0001
	(0.0054)	(0.0006)	(0.0001)	(0.0001)
Male	0.1122	−0.0340	−0.0262	0.0860
	(0.0938)	(0.1255)	(0.1315)	(0.0652)
Age	−0.0076**	−0.0001	−0.0011	−0.0045***
	(0.0029)	(0.0029)	(0.0026)	(0.0016)
Household size	0.0026	0.0078	0.0218	0.0128
	(0.0150)	(0.0174)	(0.0177)	(0.0096)
Natl language	0.1292*	0.1115	0.1175	0.1324***
	(0.0752)	(0.0969)	(0.0956)	(0.0505)
Schooling	0.0079	−0.0096	0.0041	−0.0136
	(0.0430)	(0.0195)	(0.0290)	(0.0146)
Baka				−1.0909***
				(0.0715)
Punan				−1.0980***
				(0.0764)
_cons	2.6529***	2.5681***	3.4370***	3.6631***
	(0.1836)	(0.2365)	(0.2004)	(0.1157)
N	851	572	643	2066

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

fats and oils (Tsimane' and Punan Tubu) and sweets (Tsimane') than people in the close village. Specificities of the study sites (i.e., sugar cane cultivation and the presence of a school lunch program in isolated Tsimane' villages and higher consumption of oil from wild pigs in Punan villages) help explain these findings, but the finding in itself warns against overgeneralizations in the analysis of dietary diversity data.

Our second finding relates to the role of different elements of the food environment, i.e., food availability and food accessibility, in explaining dietary diversity. One potential explanation for the changes is the relative importance of different aspects of the market and the natural food environments. Except for the Baka, who have a long history of barter with agriculturalist neighbors (Bailey et al. 1989; Yasuoka 2009, 2013), our data show that staple foods are rarely purchased in the studied communities. Similarly, very little of the fruits, vegetables, or animal source foods consumed across the three sites were obtained from the market. It should be noted that, to a certain extent, markets in the three sites offer a variety of food items, including meat, fruits, vegetables, oils, and sweets, but participants in our sample seem to rely on markets mostly to increase the consumption of oils and fats, sweets and sugars, and spices, the pattern often seen in the early stages of the nutrition transition (Popkin 2004). Our results show greater reliance on wild foods, especially wild animal source foods, in more remote villages. This supports the assertion of Powell et al. (2015) that, in more remote areas, wild and cultivated aspects of the food environment are more important relative to market aspects.

Our results on seasonal variation suggest that food *availability* is an aspect of food environments impacting dietary change in these settings. Overall, in the three sites (although less so among the Punan Tubu), there was lower dietary diversity and less frequent consumption of most food groups during the rainy season. Lower dietary diversity during the rainy season likely relates to challenges associated with hunting and fishing during the rainy season (as all the groups reported lower consumption of meat and fish during the rainy season), as well as to challenges associated with transportation in general (as all the groups also reported lower consumption of foods from markets during the rainy season). In other words, the rainy season seems to be the most food insecure period in the studied societies. Conversely, we found few dietary differences in relation to factors associated with food *access*. Income was not a significant predictor in two of the groups and in two of the groups and there was no clear pattern of relationships between diet and people's time allocation people's time allocation. Spending more time foraging was not associated with greater consumption of those food groups primarily obtained from the wild, nor was spending more time engaged in wage labour associated with greater consumption of those food groups primarily obtained from the market. A potential explanation for a lack of relationships among diet and time allocation, livelihood and income is the prevalence of food sharing in the studied communities. Food sharing is reported as ubiquitous in many small-scale societies (e.g., Enloe 2004; Bliege Bird and Bird 1997; Woodburn 1998; Gurven 2005), and was certainly the case in the three studied societies (Reyes-García et al. 2016). The finding, however, should be treated with caution as individual time allocation might indeed depend on household decisions. Further research should explore the issue using household level metrics.

It is possible that other elements in the food environment not explored here might help understand diet. For example, Herforth and Ahmed (2015) consider that food desirability, or the psycho-cultural aspects that shape food preferences and avoidances, may also change as contemporary hunter-gatherer communities become more market integrated. While food aversions are largely innate and evolutionarily protective, food preferences are learnt and highly bound by socio-cultural factors (Serrasolses et al. 2016; Bowles 1998; Fischler 1988). Food preferences, and the use of food to mark social status and cultural identity, could act either to hasten dietary transitions associated with market integration or to preserve the use of traditional foods (Reyes-García et al. 2015). For example, bushmeat consumption may be higher where bushmeat is a marker of socio-economic success and lower where processed or imported animal source foods are a sign of social prestige (Nasi et al. 2011; van Vliet et al. 2015). Similarly, wild vegetables might be socially rejected if they are considered food for the poor or uncivilized (Chweya and Eyzaguirre 1999; Powell et al. 2014), but the same foods might become *delicatessen* once they enter specialized markets (Reyes-García et al. 2015). Therefore, a higher social status associated with foods that are not typically available in local diets (i.e., fats, oils, sugar) might drive the choice of foods in the market context.

6 Conclusion

Results from this study suggest that people living in villages that are far from market towns had more diverse diets than those living in closer villages. We also found that the consumption of nutritionally important foods (fruits, vegetables and animal foods) decreases with increasing market integration, while the consumption of foods such as fats and sweets increases. Our findings dovetail with previous literature on nutrition transitions (Kuhnlein 2009; Kuhnlein and Receveur 1996; Popkin 2004; Parrotta et al. 2015), suggesting that greater market access does not necessarily translate into more diverse or healthier diets. Differences found, however, seem to relate to contextual changes in the food environment (i.e., village access to wild and/or market foods) and seasonality, rather than to individual level factors (i.e., time allocation or individual income), probably because food sharing levels up differences in food consumption. More research is clearly needed to sort out the differences between these findings and past research, which showed a strong positive association between market integration and dietary diversity (Jones 2017; Sibhatu et al. 2015).

As remote subsistence-oriented communities become more market integrated, they face changes in their food environments, including reduced access to nutritionally important foods from traditional wild and cultivated sources and increased access to purchased foods including fats and sweets. These changes in the food environment will make it immensely challenging for communities to continue traditional dietary patterns and avoid dietary and nutrition transitions that may adversely impact their health and overall wellbeing.

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