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Dietary transitions among three contemporary hunter-gatherers across the tropics

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30 **Introduction**

31 The quality of diets in traditional hunter-gatherers has been a topic of heated
32 debate, to the point where a “paleo” diet has been promoted as a healthy alternative to
33 industrialized Western diets (Crittenden and Schnorr 2017). From Sahlin’s (1974) work
34 highlighting the energetic efficiency of hunting and gathering to a recent study showing
35 consistently higher rates of food security among societies with a higher reliance in
36 hunting and gathering than in agriculture (Berbesque et al. 2014), a wealth of research
37 has disproven the idea that hunter-gatherer societies live on the brink of starvation.
38 Rather, the diets of contemporary hunter-gatherers have been shown to be diverse and
39 highly nutritious across different seasons and ecological zones (Crittenden and Schnorr
40 2017).

41 However, the diets of contemporary hunter-gatherers, and generally the diets of
42 Indigenous peoples, are rapidly changing (Kuhnlein 2009; Kuhnlein and Receveur
43 1996). Note that we use the term ‘contemporary hunter-gatherers’ to refer to societies
44 that, while strictly hunter-gatherers in a recent past, nowadays also engage in other
45 economic activities, such as herding, cultivation, or market transactions to cover and
46 supplement subsistence needs (see Reyes-García and Pyhälä 2017). Indeed, nowadays,
47 there are no hunting and gathering groups in tropical forests who do not consume some
48 type of cultivated food, whether self-produced or obtained through trade (Crittenden and
49 Schnorr 2017; Bailey and Headland 1991; Bailey et al. 1989). While few studies to date
50 provide quantitative assessments of dietary changes among contemporary hunter-
51 gatherers (Crittenden and Schnorr 2017), the existing studies show that contemporary
52 dietary transitions are associated with market integration and commodification of food
53 systems. Such transitions often include a move away from traditional foods towards
54 more processed foods, higher in fat, added sugar, and salt (Kuhnlein 2009; Kuhnlein

55 and Receveur 1996; Popkin 2004), leading to increasing rates of overweight, obesity
56 and associated chronic diseases such as type II diabetes mellitus and cardiovascular
57 disease (Kunlein et al. 2004, Popkin 2004, Rowley et al. 2000). Relative to more
58 sedentary and market-integrated communities, those practicing traditional hunting and
59 gathering livelihoods are more fit, have more diverse diets, and consume more meat and
60 wild foods (Parrotta et al. 2015). Given the paucity of research on the topic, two
61 questions remain unanswered. First, how generalizable among contemporary hunter-
62 gatherers is the pattern found in previous research linking integration into the market
63 economy and diet homogenization? And second, what are the pathways through which
64 integration into the market economy alters the diets of contemporary hunter-gatherers?

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

74 Work on the role of food environments in dietary choice has, to date, largely
75 focused on the food environment in markets, with little attention to cultivated and wild
76 food sources (Powell et al. 2015, Ahmed and Herforth 2017). Powell et al. (2015) argue
77 that “In areas where market access is difficult or where markets do not function well,
78 economic factors and market food environments may not be the strongest determinants

79 of food choice: in these settings, we need to understand how the landscape (or natural
80 food environment) affects diets.” Herforth and Ahmed (2015) lay out four general
81 aspects of the food environment that are likely to impact dietary choice: availability,
82 affordability, convenience, and desirability. In the case of hunter-gatherer communities
83 these four aspects of the food environment are likely to change as communities become
84 more market integrated and/or sedentary.

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

94 Food accessibility, or the energy, the money, and the time spent to access food
95 (covering both affordability and convenience according to Herforth and Ahmed (2015)),
96 is also likely to change as hunter-gatherer communities become more integrated into the
97 market economy. Livelihood transitions often imply that foods that were once obtained
98 from the wild or from subsistence agriculture must be purchased, oftentimes because
99 people no longer have the time to collect, hunt, or grow them. Finally, desirability or
100 food preferences are learnt and highly bound by socio-cultural factors (Serrasolses et al.
101 2016; Bowles 1998; Fischler 1988) and are also likely to change as hunter-gatherer
102 communities become more market integrated.

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

110 **Case studies**

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

127 The Baka are a hunter-gatherer group of about 35.000 people living in the
128 tropical rain forests of the Congo Basin, and mostly in southeastern Cameroon (Joiris
129 2003). They traditionally lived in semi-nomadic groups and, despite frequent food
130 exchanges with their sedentary farming neighbors, they depended mainly on wild
131 resources for their livelihood (Bahuchet 1993). Since the 1960s, the Baka have begun
132 to regroup along roads opened by logging companies and to grow their own food, due to
133 defaunation and deforestation and governmental policies and missionary attempts to
134 sedentarize and educate them (Leclerc 2012). The Baka continue to move between
135 villages and forest camps, but their economy is increasingly monetarized (Kitanishi
136 2006). Previous work suggests that these transitions are often associated with lower
137 meat consumption and with increased malnutrition and disease (Dounias and Froment
138 2006; Koppert et al. 1993; Froment et al. 1993). Nowadays, Baka are engaged in both
139 agricultural and forest-related subsistence activities, such as hunting, gathering and
140 fishing. Their daily activities vary over the course of the year, depending on both the
141 agricultural calendar and wild food availability (Table 1).

142 INSERT TABLE 1

143 The second group, the Punan Tubu, live in the mountainous interior Indonesian
144 Borneo. The Punan number ~10,000 people, and include diverse groups according to
145 the place of origin (Levang et al. 2007). The Punan living in the upper Tubu river
146 (hereafter Punan Tubu) are a group of about 800 people who lived a semi-nomadic
147 lifestyle until the last 15 years, when they settled down in five small, scattered,
148 inaccessible hamlets as a response to strong incentives of the authorities (Sercombe and
149 Sellato 2007). Prior to sedentarization, their main staple food was sago, a starch paste
150 made of forest palm trunks. Starting in the first half of the 20th century, they

151 progressively adopted upland rice swidden cultivation (Dounias et al. 2007), although
152 the steep slopes, irregular rain patterns, and lack of agricultural inputs still make
153 harvests highly variable. Palm sago has been replaced by easier to prepare, cassava
154 sago, which is an alternative to rice, particularly before rice harvest when the stored rice
155 has been consumed (Table 1). Hunting continues to provide the main source of meat,
156 the Punan preferring bearded pig (*Sus barbatus*), but also hunting several species of
157 deer, pheasants, monitors, snakes, and turtles (Kaskija 2012; Dounias 2007; Sakai et al.
158 2006). The Punan also fish barbs, carps, and catfish (Puri 2001). As the Punan Tubu
159 also obtain cash from the trade of NTFPs –especially eaglewood (*Aquilaria* spp.)- and
160 from wage labor in government projects (Napitupulu et al. 2016), market products (e.g.,
161 rice, noodles, sugar and fats) are increasingly present in their diets (Dounias et al. 2007).

162 Finally, the Tsimane’ are a small-scale Indigenous society of foragers and
163 farmers in the Bolivian Amazon. Numbering ~ 12,000 people, the Tsimane’ live in
164 ~100 small villages scattered along rivers and logging roads (Reyes-García et al. 2014).
165 Until the late 1930s, the Tsimane’ maintained a traditional semi-nomadic and self-
166 sufficient lifestyle, but their interactions with the Bolivian society have steadily
167 increased since then and they have been mostly settled in permanent villages with
168 school facilities since the 1950’s (Reyes-García et al. 2014). Tsimane’ livelihoods are
169 predominantly organized around agricultural tasks and game and fish availability
170 throughout the year (Table 1). They rely on slash-and-burn farming of cassava,
171 plantains, maize, rice, and chickens, supplemented by hunting, fishing, gathering wild
172 fruits. Game and fish are generally more abundant in more remote villages (Díaz-
173 Reviriego 2016). Some Tsimane’ men, mostly in villages close to town, increasingly
174 engage as wage laborers in logging camps, cattle ranches, and in the homesteads of
175 colonist farmers. The commercialization of forest products (e.g. thatch palm) also

176 provides a primary source of income for many households, often through barter (Vadez
177 et al. 2008). Partly due to these shifts in livelihoods, Tsimane' diets are undergoing
178 rapid change including the introduction of market foods and beverages, such as dried
179 and salted meat, sugar, noodles, lard, vegetable oil, white flour/ bread, and soda
180 (Zycherman 2013). Such dietary changes, together with other changes in lifestyle, seem
181 to have precipitated a nutritional transition (Zycherman 2015). Although household
182 income level is associated with higher statural growth in children (Godoy et al. 2010),
183 increased household market food expenditures are associated with increased adult body
184 mass index, weight and body fatness (Rosinger et al. 2013).

185 **Methods**

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

196 For this work, we followed the Code of Ethics of the International Society of
197 Ethnobiology. The work received the approval of the ethics committee of the
198 Universitat Autònoma de Barcelona (CEEAH-04102010). Before data collection
199 started, we asked villages and informants to provide Free Prior and Informed Consent

200 (FPIC). We also obtained the agreement from the indigenous groups' relevant political
201 organization.

202 **Sampling**

203 In each society, we worked in two villages that differed in their distance to the
204 main market town (i.e., *isolated* and *close* villages) (Table 2), as access to market is an
205 important determinant of nutritional transitions. In each village, we requested the
206 participation of all adults (≥ 16 years old), and achieved a participation rate above
207 90%. Our final sample included 393 informants (160 Baka, 109 Punan Tubu, and 124
208 Tsimane').

209 **Data collection**

210 ***Dietary recall:*** Dietary information was collected using a qualitative food recall
211 over a 24 hour period adapted from the FAO Guidelines for Assessing Dietary Diversity
212 (Kennedy et al. 2011). Drawing on these guidelines, we classified locally consumed
213 foods products according to the 12 following food groups: 1) starch (i.e., cereals, white
214 tubers and roots); 2) dark green leafy vegetables; 3) other vitamin-A rich fruits and
215 vegetables; 4) other fruits and vegetables; 5) meat and fish foods (including insects); 6)
216 organ meat; 7) eggs; 8) milk and milk products; 9) legumes and nuts; 10) fats (including
217 oils); 11) sweets; and 12) spices (including condiments and beverages) (Supplementary
218 Material 1). We asked informants to list all the foods and drinks they had consumed
219 during the previous 24-hours, inside and outside the house, and each food item was
220 noted in the corresponding food group. Probing was used to help ensure informants did
221 not omit added foods (e.g., sugar) or food items consumed outside the house (e.g., in the
222 forest). The questionnaire was administered in the morning, avoiding holidays,
223 celebrations and/or fasting periods. We also recorded the source of each food item
224 differentiating between items that were cultivated, obtained from the forest, or bought

225 from the market. To capture seasonal variation in food consumption (Table 1), we
226 collected dietary recalls quarterly, aiming at two interviews per person/quarter, but due
227 to high mobility in the sampled populations, we do not have complete data for all
228 informants. For the analysis, we removed informants with only one observation. The
229 average number of observations per informant is of 4.9.

230 ***Socio-demographic information:*** At the beginning of the study, we conducted a
231 census in the six studied villages in which we recorded age, sex, and household
232 composition. The census also included information on variables that have been typically
233 used to measure *exposure to the national society* (Lara et al. 2005; Zane and Mark
234 2003). Specifically, we asked about the maximum grade the informant had completed in
235 school and her ability to speak the national language (French for the Baka, Indonesian
236 for the Punan Tubu, and Spanish for the Tsimane’). We differentiated informants who
237 could not maintain a conversation on the national language from those who could.

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

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

255 **Data analysis**

256 To analyze dietary patterns and sources of foods we used descriptive and
257 bivariate analysis. We started by coding each food group as 1 (“present”), if the
258 respondent reported consuming at least 1 food item in the group and 0 otherwise, and
259 calculated the percentage of diets that included at least one food item in a food group.
260 We also calculated individuals’ 24hour Women’s Dietary Diversity Score (WDDS), a
261 proxy for micronutrient adequacy in developing countries (Kennedy et al. 2011). To
262 calculate WDDS we added information on the presence of food items in all the
263 aforementioned food groups, except fats, sweets and spices. We then calculated the
264 mean for each society and differentiating between people living in the *isolated* and the
265 *close* village. We used a Pearson chi² test to assess whether there were statistically
266 significant differences between villages (Table 3).

267 To analyze sources of foods, we created three new variables for food groups
268 (*crop*, *wild*, and *market*) which were coded as 1 if at least one of the food items in a
269 group came from that source and 0 otherwise. We then calculated the percentage of
270 diets which included at least one food item of each of the food groups obtained from
271 agricultural fields, the wild, and the market (Table 4). As with dietary patterns, we

272 differentiate between the isolated and the close village in each society and assessed
 273 differences using a Pearson chi2 test.

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

289 In the last part of the analysis, we assess the relative weight of these various
 290 factors in modeling WDDS by using multivariate analysis. Specifically, we analyze
 291 how variation in WDDS relates to food availability, food accessibility, and village and
 292 individual level of integration into the market economy using expression [1]:

$$293 \quad [1]WDDS_{ihvt} = \alpha + \gamma EX_{ihv} + \beta P_{ihv} + \lambda N_{ihv} + \Omega S + \varepsilon_{ihv}$$

294 where WDDS is the Women’s Dietary Diversity Score for subject i of household
 295 h in village v at time t . EX is a vector that includes our main explanatory variables: *rain*,

296 a variable that captures whether the data were collected in the rainy season or not; and
 297 *sh_wage*, a variable that captures the share of time the individual reported working for
 298 wage labor; *isolated*, a variable that captures whether the respondent lives in the close
 299 or the isolated village; and *trips to town*, *wealth* and *cash income* as measures of
 300 individual level integration into the market economy. P_{iiv} is a vector that includes
 301 control variables for socio-demographic characteristics of informants (*sex*, *age*, and
 302 *household size*). N_{iiv} includes the two variables selected to measure exposure to the
 303 national society (*speak national language* and *schooling*). Some invariant
 304 characteristics of societies might affect the estimated association. To control for such
 305 fixed-effects, we included a set of dummies for the societies of study (S). And ε_{iiv} is the
 306 error term, that basically captures the information that the model cannot explain (Table
 307 7). In additional analyses we replaced binary variables for societies by binary variables
 308 for villages. To control for the fact that observations may be correlated within
 309 individuals, but independent between them, in all regression models we used clusters by
 310 individual. The statistical analysis was done using STATA for Windows, version 13.
 311 We report p-values < 0.10 as indicator of statistical significance,

312 **Results**

313 *Dietary patterns, food sources, and market access*

314 In each society, food consumption differed substantially between villages with
 315 more and less market access, diets being generally more diverse in the isolated villages
 316 (Table 3). Thus, Baka living in the isolated village had a WDDS about 0.3 food groups
 317 higher than their peers in the close village ($p < 0.001$). The Baka living in the isolated
 318 village consumed starchy staple, meat and fish, and legumes and nuts more frequently
 319 than the Baka living in the close village. Conversely, the Baka living in the isolated
 320 village consumed less sweets but more spices, condiments and beverages than their

321 peers. Similarly, the WDDS of the Tsimane' living in the isolated village was about 0.5
322 food groups higher than the WDDS score of Tsimane' living closer to the market
323 ($p < 0.001$). Food items from the categories of 'other fruits and vegetables', organ meat,
324 meat and fish, legumes and nuts, and milk and milk products were consumed more
325 frequently by Tsimane' living in the isolated village. Unexpectedly, Tsimane' living in
326 the isolated village also consumed fats and sweets more frequently than their peers.

327 INSERT TABLE 3

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

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

344 and vegetables from cultivated sources and more from the wild than those living more
345 isolated.

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

352 INSERT TABLE 4

353 *Food availability, food accessibility, and market access*

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

368 INSERT TABLE 5

369 The diets of the Punan Tubu showed less seasonal variation. The most important
370 patterns of seasonal variation for the Punan Tubu refers to a greater dependence on
371 purchased staples in the rainy season, and a less frequent consumption of meat and fish
372 and organ meat during the rainy season (Table 5). While oil and fat consumption did
373 exhibit seasonal variation, a larger share of the fat and oil consumed in the rainy season
374 came from the market. Consumption of sweets was less frequent in the rainy season and
375 a lower share of them came from the market (Table 5).

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

384 INSERT TABLE 6

385 *The correlates of WDDS*

386 When considering the three societies together (Table 7, Model 4), the distance of
387 the village to the market and season were associated in a statistically significant way
388 with WDSS. Overall, people living in the isolated villages had a higher WDSS than
389 their peers living in the close villages. Additionally, the WDDS was generally lower
390 during the rainy season than during the rest of the year. We find the same pattern when
391 analysing data for the Baka (Model 1) and the Tsimane' (Model 3) samples, but not

392 among the Punan Tubu (Model 2). When looking at the pooled sample, we also found a
393 weak and negative association between people who allocate more time to foraging and
394 WDDS. However, the association is not found in any of the regressions with separate
395 samples. None of the variables that proxy for individual level of integration into the
396 market economy are consistently associated to WDDS across the three case studies.

397 INSERT TABLE 7

398 **Discussion**

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

404 In the three studied societies, we found variations in diets and food sources
405 associated with integration into the market economy. Although the diets of the three
406 societies were different from one another, we found a similar pattern in that there was
407 higher dietary diversity in isolated villages, a trend that was corroborated through
408 multivariate analyses. Moreover, the difference found was relatively large when
409 compared with results from previous studies (see Jones (2017) for a review of the
410 literature). Importantly, the higher dietary diversity in the isolated villages was due to
411 the more frequent consumption of nutritionally important food groups (e.g., fruits,
412 vegetables, meat, fish). Our results, however, also point at some counterintuitive
413 findings, such as that people living in the isolated villages also consumed more
414 frequently fats and oils (Tsimane' and Punan Tubu) and sweets (Tsimane') than people
415 in the close village. Specificities of the study sites (i.e., sugar cane cultivation and the

416 presence of a school lunch program in isolated Tsimane' villages and higher
417 consumption of oil from wild pigs in Punan villages) help explain these findings, but the
418 finding in itself warms against overgeneralizations in the analysis of dietary diversity
419 data.

420 Our second finding relates to the role of different elements of the food
421 environment, i.e., food availability and food accessibility, in explaining dietary
422 diversity. One potential explanation for the changes is the relative importance of
423 different aspects of the market and the natural food environments. Except for the Baka,
424 who have a long history of barter with agriculturalist neighbors (Bailey et al. 1989;
425 Yasuoka 2013, 2009), our data show that staple foods are rarely purchased in study
426 communities. Similarly, very little of the fruits, vegetables, or animal source foods
427 consumed across the three sites were obtained from the market. It should be noted that,
428 to a certain extent, markets in the three sites offer a variety of food items, including
429 meat, fruits, vegetables, oils, and sweets, but participants in our sample seem to rely on
430 markets mostly to increase the consumption of oils and fats, sweets and sugars, and
431 spices. The pattern, often seen in the early stages of the nutrition transition (Popkin
432 2004). Our results show greater reliance on wild foods. especially wild animal source
433 foods, in more remote villages supports Powell et al. (2015)'s assertion that in more
434 remote areas wild and cultivated aspects of the food environment are more important
435 relative to market aspects of the food environment.

436 Our results on seasonal variation suggest that food *availability* is an aspect of
437 food environments impacting dietary change in these settings. Overall, in the three sites
438 (although less so among the Punan Tubu), there was lower dietary diversity and less
439 frequent consumption of most food groups during the rainy season. Lower dietary

440 diversity during the rainy season likely relates to challenges associated to hunting and
441 fishing during the rainy season (as all the groups reported lower consumption of meat
442 and fish during the rainy season), as well as to challenges associated to transportation in
443 general (as all the groups also reported lower consumption of foods from markets
444 during the rainy season). In other words, the rainy season seems to be the most food
445 insecure period in the studied societies. Conversely, we found little dietary differences
446 in relation to factors associated with food *access*. Income was not a significant predictor
447 in two of the groups and people's time allocation. Spending more time foraging was not
448 associated with greater consumption of those food groups primarily obtained from the
449 wild, nor spending more time engaged in wage labour was associated with greater
450 consumption of those food groups primarily obtained from the market. A potential
451 explanation for a lack of relationships among diet and time allocation, livelihood and
452 income is the prevalence of food sharing in the studied communities. Food sharing is
453 reported as ubiquitous in many small-scale societies (e.g., Isaac 1978; Enloe 2004;
454 Bliege-Bird & Bird 1997; Woodburn 1998; Gurven 2005), and was certainly the case in
455 the three studied societies (Reyes-García et al. 2016). The finding, however, should be
456 read with caution as individual time allocation might indeed depend on household
457 decisions. Further research should explore the issue using household level metrics.

458 It is possible that other elements in the food environment not explored here
459 might help understand diet. For example, Herforth and Ahmed (2015) consider that
460 food desirability, or the psycho-cultural aspects that shape food preferences and
461 avoidances, may also change as contemporary hunter-gatherer communities become
462 more market integrated. While food aversions are largely innate and evolutionarily
463 protective, food preferences are learnt and highly bound by socio-cultural factors
464 (Serrasolses et al. 2016; Bowles 1998; Fischler 1988). Food preferences, and the use of

465 food to mark social status and cultural identity, could act either to hasten dietary
466 transitions associated with market integration or to preserve the use of traditional foods
467 (Reyes-García et al. 2015). For example, bushmeat consumption may be higher where
468 bushmeat is a marker of socio-economic success and lower where processed or
469 imported animal source foods are a sign of social prestige (Nasi et al. 2011; van Vliet et
470 al. 2015). Similarly, wild vegetables might be socially rejected if they are considered
471 food for the poor or uncivilized (Chweya and Eyzaguirre 1999; Powell et al. 2014), but
472 the same foods might become *delicatessen* once they enter specialized markets (Reyes-
473 García et al. 2015). Therefore, a higher social status associated to foods that are not
474 typically available in local diets (i.e., fats, oils, sugar) might drive the choice of foods in
475 the market context.

476 **7. Conclusion**

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

489 findings and past research showing a strong positive association between market
490 integration and dietary diversity (Jones 2017; Sibhatu et al. 2015).

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

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509 **Conflict of Interests**

510 The authors declare they have no conflict of interests.

511

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703

704 **Table 1:** Seasonal availability of products in the three study sites

	Tsimane'		Baka		Punan	
	Rain	Other	Rain	Other	Rain	Other
Dates	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

705

706

707

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

Site	Isolated village	Close village
Tsimane'	One of the most remote villages on the river, a three-day (123km) canoe trip from the market town of Yucumo. Forested area with plentiful wildlife and fish.	A one-day canoe (33km) 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 2km 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 86km from Malinau town at ca.450m.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 77km from Malinau town at ca. 350m.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.

710

711 **Table 3:** Food consumption in three Indigenous societies. Percentage of total diets
 712 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 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***

713 Note:[^]Category not included in the WDDS. **Note:** *, **, and *** Pr<0.1, <0.05, and <0.01
 714 in a Pearson chi2 test.

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 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 chi2 test comparing food sources between isolated and close villages.

Note: 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.

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 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 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 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 chi2 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

Table 7. Ordinary Least Square regressions (dependent variable WDDS)

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

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$