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Household-level drivers of dietary diversity in transitioning agricultural systems: Evidence from the Greater Mekong Subregion

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ABSTRACT

Over the past four decades, agricultural systems in the Greater Mekong Subregion (GMS) have largely evolved from a subsistence orientation toward commercial production, but the multi-faceted changes behind this evolution vary in substance and degree. Despite connoting economic progress, effects of these changes on household welfare indicators such as dietary diversity have been unclear. By taking a comprehensive view of the farm household, this study discerns the drivers of household dietary diversity in this transitional context by linking the Household Dietary Diversity Score (HDDS), as an indicator of dietary diversity, to key household characteristics, livelihood strategies and indicators of farm performance in three study sites in Cambodia, Laos and Vietnam. The Rural Household Multi-Indicator Survey (RHoMIS) tool, a combined survey and analysis platform, was employed to collect data from over 1300 farm households. HDDS is found to increase among the sites in a way that is roughly associated with their state of agricultural transition, though differing combinations of market orientation, specialisation, and intensification traits that describe such a transition suggest that the pathway to commercialisation, and dietary diversity, is not a linear one. Drivers of dietary diversity vary markedly between the sites. In the Laos site, HDDS is most closely correlated to a set of variables closely linked with agricultural transition, while in the Cambodia site it is associated more with other farm and household characteristics. In the Vietnam site, dietary diversity is correlated to the overall value of crop production. Findings point to the need to contextualise site-specific knowledge of linkages between dietary diversity and ongoing agricultural transition in the GMS, as well as policy and interventions seeking to improve dietary diversity in the face of such transition.

Keywords: dietary diversity, agricultural transition, Household Dietary Diversity Score, Greater Mekong Subregion, Cambodia, Laos, Vietnam

1. INTRODUCTION

Throughout the tropics, smallholder livelihoods rely upon mixed agricultural systems that integrate a variety of on-farm crop and livestock enterprises. Increasing population pressures in these areas have been fueling agricultural intensification and transitions to alternative forms of agriculture through processes outlined by Boserup (1965). Though the ability of intensification to meet growing household income and food needs in the tropics remains unclear (Herrero et al., 2014), Boserup's description of agricultural transformation has been useful in describing changes observed throughout the developing world, such as those among smallholder systems supplying agricultural products to rapidly-developing urban centers in sub-Saharan Africa (Herrero et al., 2017).

Perhaps the starkest examples of tropical agricultural transformation can be found within the Greater Mekong Subregion (GMS), a geopolitical area encompassing the Mekong River Basin in Southeast Asia and including the six states of Cambodia, China (specifically Yunnan Province and Guangxi Zhuang Autonomous Region), Laos, Myanmar, Thailand, and Vietnam. Agricultural systems in the GMS have experienced profound and multifaceted transitions over the last four decades, evolving from traditional subsistence agriculture toward commercialised production (Alexander et al., 2017; Ashraf et al., 2017; Johnston et al., 2009; Kenney-Lazar, 2012; Li et al., 2014; Vicol et al., 2018). Changes in the GMS follow pathways differentiated by local and national contexts, but overall are driven by infrastructure development and modernisation, improved market access, and government policy (Diez, 2016; Goto and Douangngeune, 2017; Kyeyune and Turner, 2016). Regional examples include Vietnam's shift from centralised to market-oriented agricultural systems in the 1990's (Cochard et al., 2017; Diez, 2016; Knudsen and Mertz, 2016; Kyeyune and Turner, 2016; Meyfroidt et al., 2013; Nguyen et al., 2015; Truong et al., 2017) and the transition of shifting cultivation into other forms of commercialised agriculture in Laos (Heinimann et al., 2013; Hirota et al., 2014; Ornetsmuller et al., 2016; Southavilay et al., 2013) and Cambodia (Baird and Barney, 2017; McAndrew, 2000; Milne, 2013).

CIAT (2014) specifically focuses on three key characteristics of these transitions in the GMS:

- *Market orientation*. As market linkages strengthen, farmers increasingly produce crop and livestock goods for the market rather than for household consumption.
- Production *specialisation*. In response primarily to market forces, farmers increasingly allocate their production resources to e.g. cash crops, monocropping, specialty crops, and intensive animal production methods, sometimes at the expense of on-farm biodiversity (Rerkasem et al., 2009).
- *Intensification* of production. Farmers introduce nitrogenous fertiliser usage and irrigation for crop production (Johnston et al., 2009), as well as intensive livestock production methods (Stür et al., 2013).

Though evidence of these transitions and their associated influences is ubiquitous across the GMS, the geographic distribution, characteristics, and rates of change of these transitions are not uniform, but rather vary considerably across the region (Johnston et al., 2009). Even at the local level, progressive farmers may seize opportunities to commercialise production while others retain more traditional attitudes and practices (Martin and Lorenzen, 2016), giving rise to a spectrum of households at various stages of agricultural transition. Inter-household variations are then magnified by differences in market access, agricultural systems, and household resource endowments when viewed from a regional perspective. Furthermore, transformations have extended beyond the farm, shifting the balance between on-farm livelihoods and off-farm employment (Martin and Lorenzen, 2016).

In agrarian societies where livelihoods and sustenance are entwined with agriculture, market-driven agricultural transitions would presumably connote economic progress. In reality, the effects of these changes in the GMS on household welfare, and on food security and nutrition specifically, are unclear. Several recent studies in the region, for example, reveal that inadequate nutrition and low dietary diversity remain pervasive (de Sa et al., 2013; McDonald et al., 2015a, b; Nguyen et al., 2013;

Talukder et al., 2013). Linkages between agricultural production and dietary diversity as a critical determinant of nutritional outcomes (Lachat et al., 2018; Ruel, 2003) have been studied elsewhere (Dulal et al., 2017; Koppmair et al., 2017; Mulmi et al., 2017), but with the exception of a few studies, e.g. Michaux et al. (2016), associations between agricultural production and dietary diversity in the GMS are largely unexplored. Furthermore, these studies (in the GMS and elsewhere) typically consider only 1 or 2 aspects of the agricultural system such as production diversity (Jones et al., 2014; M'Kaibi et al., 2017; Saaka et al., 2017; Sibhatu et al., 2015; Sibhatu and Qaim, 2018a; Sibhatu and Qaim, 2018b), while robust analysis of agricultural transitions requires a comprehensive view of the agricultural system and of the farm household.

This study attempts to address this gap by quantifying dietary diversity across a spectrum of households in several GMS study sites and linking it to a comprehensive understanding of farm household and agricultural system characteristics. A host of metrics for dietary diversity are available (Ruel, 2003), but this study centers on the Household Dietary Diversity Score (HDDS), a proxy indicator for dietary diversity that tallies the number of different food groups, on a scale of 1 to 12, consumed by a household over a reference period (FAO, 2011; Swindale and Bilinsky, 2006). The study is based on survey data collected using the Rural Household Multi-Indicator Survey (RHoMIS) tool (Hammond et al., 2017), a digital survey platform designed to rapidly gather comprehensive information on not only household welfare indices like HDDS, but farm and household characteristics as well.

The objective of this study is to discern the key drivers of dietary diversity in sites at various stages of agricultural transition in the GMS by analysing the association of HDDS to key household characteristics, livelihood strategies and indicators of farm performance that include the key factors of agricultural transitions in GMS. The study pays particular attention to (1) a set of farm household 'mutable' variables that will likely change as transitions continue, or conversely, could be targets for proposed interventions, and (2) a subset of these mutable variables that are specifically linked to the

three key aspects of agricultural transition in the GMS. Such a comprehensive analysis across the different sites can improve understanding of the commonalities and differences in drivers of dietary diversity across the region, clarify the interplay between agricultural transition and dietary diversity, and suggest how ongoing transitions may affect dietary diversity in the region into the future.

2. MATERIALS AND METHODS

We collected primary data for analysing the association of HDDS to key household characteristics, livelihood strategies and indicators of farm performance by implementing three household surveys in Cambodia, Laos and Vietnam. Primary data collection supported subsequent household-level statistical analysis.

2.1. Study Site Description

The localities in the three countries where the surveys were implemented (Table 1) were selected based on expert opinion to capture differences in levels of agricultural transition (CIAT, 2014).

Table 1. Study Site Descriptions

Site Name	Location	Site Characteristics	Households
Cambodia	Ratanakiri Province, northeast Cambodia	Agricultural system: Low-input monoculture Topography: Upland Elevation: 200-400 m Population density*: 17 persons/km^2	631
Laos	Xieng Khouang Province, northern Laos	Agricultural system: Mixed crop-livestock Topography: Upland Elevation: 1200 m Population density**: 16 persons/km^2	365
Vietnam	Dak Lak and Dak Nong Provinces, Central Highlands, Vietnam	Agricultural system: Intensive Topography: Upland Elevation: 400-800 m Population density***: 94-143 persons/km^2	310

* National Institute of Statistics (2013)
** Lao Statistics Bureau (2015)
*** Dak Lak Statistical Office (2016), Dak Nong Statistical Office (2016)

2.1.1. Laos Site

Xiangkhouang Province is located in northeastern Laos and is characterised by a plateau surrounded by mountainous terrain. The provincial capital, Phonsavan (19_26’59.30"N, 103_ 13’16.43"E), lies at an elevation of 1095 m.a.s.l. Most farmers are smallholders with mixed crop-livestock systems. Different ethnicities co-exist in the province, with ethnic Lao residing primarily in the lowlands and Hmong in the uplands. Growing seasons for significant crops roughly follow the duration and timing of the wet season, and annual crops are grown from the end of April until the end of October. The main crops are rice (both paddy rice and upland rice), maize for feed, cassava, chili, banana, homegarden vegetables and tea. Animal husbandry focuses on chickens, ducks, cattle, pigs and turkeys. Cut-and-carry forages are collected throughout the year and include *Brachiaria ruziziensis*, *Pennissetum purpureum* and local grass species.

2.1.2. Cambodia Site

153 Ratanakiri Province is remotely situated in northeastern Cambodia and has a population of over
154 150,000, grouped into twelve ethnic groups including Khmer, Lao Tompoen, and Djarai. Ratanakiri has
155 three main landscape types: a basalt plateau in the geographic centre, an upland region bordering Laos
156 with elevations as high as 1624 m.a.s.l, and flatlands along the Tonle River and in the southern portion
157 of the province. Ratanakiri has a monsoonal climate, with a rainy season extending from April to
158 October that accounts for 99% of the total annual precipitation. The average precipitation and
159 temperature between the years 2005 to 2015 were 2318 mm-yr^{-1} and 26 C, respectively. Rice is
160 cultivated for household consumption, and cassava, cashew and rubber are the main cash crops.
161 Some legume crops, such as soybeans and peanuts, are planted in rotations or intercropped with
162 cashew trees or cassava. Animals are mainly reared for meat production. Ruminants serve as living
163 family savings in case of a sudden need of capital. Pigs and poultry are raised for household
164 consumption or are sold in local or regional markets.
165
166 2.1.3. Vietnam Site
167 The Central Highlands of Vietnam have a tropical climate, having an annual average
168 temperature of 24.1 C, with heavy rains during the summer (April to September) and minimal
169 precipitation during the winter months (October to March). The main ethnic groups in the area include
170 Ede, Kinh, Mnong and Jarai. Landscapes are characterised by acidic soils, and farming systems are
171 primarily mixed crop-livestock farms. Livestock include cattle, swine and poultry that are primarily
172 raised for meat production. The main staple crop is rice, and feed crops include maize, cassava and
173 forages. Cash crop production focuses on coffee, pepper and cashew nuts.
174
175 2.2. Survey Implementation

A household survey was implemented in the three sites between December 2015 and March 2016. Respondents were randomly selected from village and commune lists obtained from local authorities by national partners. Cambodian enumerators (the technical staff executing the surveys) conducted the surveys on-farm, while teams of Vietnamese and Lao researchers invited respondents to village meeting halls. Household interviews were conducted in local languages using Android devices. Data automatically uploaded to a cloud server whenever the Android devices successfully connected to the internet and were available for immediate downloading and analysis. The survey instrument used in this exercise was the RHoMIS (Rural Household Multiple Indicator Survey) platform (Hammond et al., 2017).

2.3. The RHoMIS Platform

The RHoMIS household survey and analysis tool has been described in detail by Hammond et al. (2017) and has now been applied in more than 17 countries in a series of studies (Fraval et al., 2018; Hammond et al., 2017; Hammond et al., 2018; Ritzema et al., 2017b; Stirling et al., 2018), collecting data on more than 13,000 rural households. Briefly, RHoMIS is a set of carefully designed questionnaire modules that are administered digitally using the Open Data Kit (ODK) software platform, along with an associated set of data extraction and analysis tools written in R. The survey is designed to be both flexible enough to suit local contexts and sufficiently standardised to permit rapid deployment, analysis and comparison between multiple sites. The majority of questions in the survey are used for the estimation of a series of pre-defined indicators that include:

- The Household Food Insecurity of Access Scale (Coates et al., 2007) for measuring the frequency and severity of hunger.
- The Household Dietary Diversity Score (Swindale and Bilinsky, 2006), providing an indicator of household nutrition status.

- The Progress out of Poverty Index (Desiere et al., 2015; Grameen Foundation, 2015), an asset-based scoring system to estimate the likelihood that a household is in poverty.
- The Potential Food Availability indicator for quantifying the ability of a household to feed itself through both on-farm and off-farm activities (Frelat et al., 2016; Ritzema et al., 2017b).

These indicators are combined with a comprehensive inventory of agricultural crops and livestock including yields, uses, sale prices and inputs, and an assessment of off-farm incomes. The indicators captured in RHoMIS place the farm household along a continuum of household and farm characteristics, performance indicators and welfare indicators (see Figure 1), not only enabling in-depth analyses of indicators independently, but also integrating analyses of how indicators co-vary and how on-farm and off-farm livelihood strategies correlate to food security, poverty and dietary diversity.

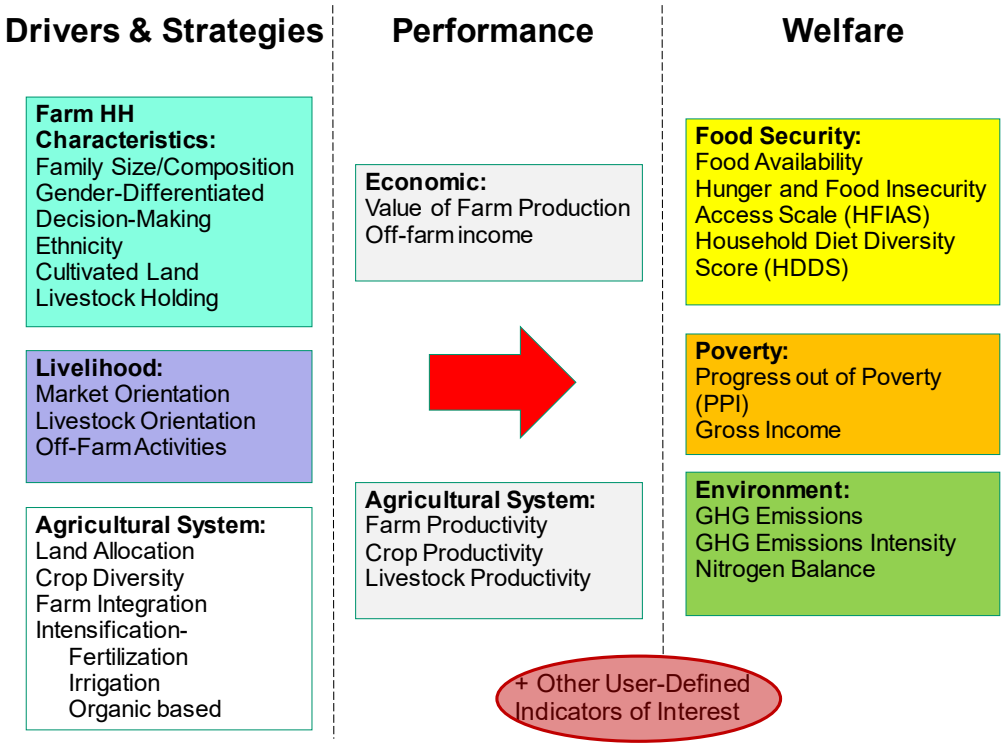


Figure 1. The Structure of the Rural Household Multiple Indicator Survey (RHoMIS): Linking Drivers and Strategies to Household-Level Welfare. Colors denote the different indicator groups.

214

215 2.4. Description of the Key Variables

216

217 2.4.1. Dependent Variable for Food Security: Household Dietary Diversity Score (HDDS)

218 HDDS is calculated by tallying the number of food groups consumed by a household over a given
219 reference period. Typical HDDS studies follow the procedure outlined by Swindale and Bilinsky (2006)
220 by using a standardised list of 12 food groups and a 24-hour recall period. RHoMIS assesses the same
221 set of food groups and localises typical foodstuffs consumed at each study site but uses a 4-week recall
222 period. Respondents indicate consumption of each food group on a 'daily', 'weekly', 'monthly', or
223 'never/less than monthly' basis (Hammond et al., 2017). Each food group consumed on at least a
224 weekly basis is given a score of '1'. Food group representation is summed to provide an overall HDDS
225 score between 1 and 12, representing grains, roots and tubers, vegetables, fruits, legumes, meat, fish,
226 eggs, dairy, fats, sweets, and miscellaneous foods, respectively. This adaptation to the HDDS definition
227 means that values of our HDDS score cannot be interpreted in an absolute way (e.g. that 7-8 food
228 groups suggests a diet of sufficient diversity), as it is not calibrated in any standard way to nutritional
229 requirements. Our results therefore only give insight into the variation of dietary diversity encountered
230 in the populations sampled.

231 We nevertheless chose this approach of measuring dietary diversity to enable comparison of
232 surveys conducted at different points during the agricultural year, as seasonality typically strongly
233 affects dietary diversity scores. With this approach our results are independent of the timing of the
234 single survey application, a factor that in multi-site analyses, as in our case, is otherwise difficult to
235 control. Analyses have shown that our method was highly correlated to 'gold standard' 24-hour recall
236 results when both methods were implemented in the same survey and captured similar ranges in
237 dietary diversity (Martin-Prével et al., 2015). Fraval et al. (submitted) showed a strong association

238 between an adapted dietary diversity score and micronutrient gaps when performing detailed food
239 consumption analyses, further confirming that the indicator conveys key information about food
240 security and also showed that recall length did not affect the HDDs results.
241
242 2.4.2. Independent Variables
243 A simplified and generalized theory of agricultural transition (Figure 2), similar to e.g. Turner and
244 Ali (1996) and alluding to Boserup (1965), forms a backdrop for the identification of independent
245 variables for this study. With increases in regional population density, and accompanying urbanisation
246 and higher demand for labour, both food demand and labour factor prices increase, leading to an
247 agricultural system that garners higher output prices in the context of increasing prices for productive
248 resources. As forwarded in CIAT (2014), the agricultural system transitions away from subsistence-
249 oriented and diverse production activities toward a system that aims to sell farm produce, specialises in
250 profitable production activities and intensifies production (indicated as three aspects of Production
251 System Transition in Figure 2). The sites considered in this study are seen to be at different states of on-
252 going agricultural transition: for example, the Laos sites are still significantly subsistence-oriented, while
253 the sites in Vietnam have largely completed this transition. Furthermore, transition trajectories, as
254 described by differing mixes and degrees of market orientation, production specialisation and
255 intensification, may not be similar across sites. The core of the analysis in this study, therefore, focuses
256 on a selected set of independent variables that represent the three aspects of Production System
257 Transition (Figure 2) in the GMS, rather than the drivers of agricultural transition (i.e. population density,
258 price increases, etc.), to capture the effects of contrasting transition levels and trajectories on dietary
259 diversity.
260

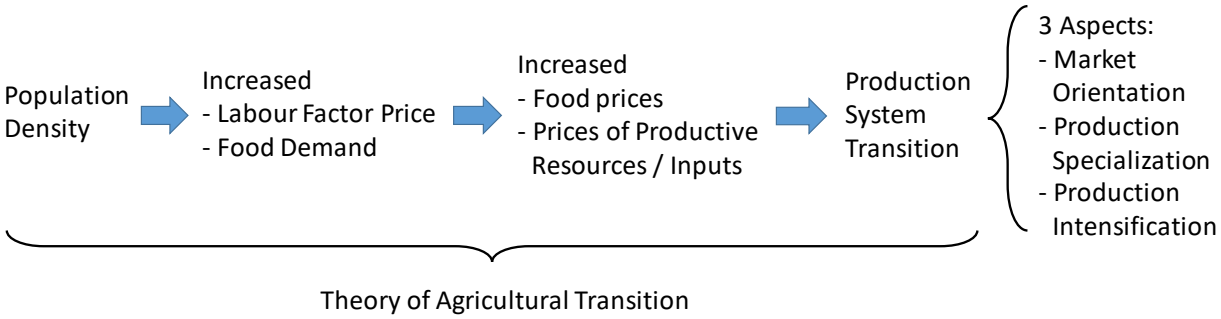


Figure 2. Theory of Agricultural Transition

However, this study does not consider the key transition variables exclusively, but takes a broader view by combining the key transition variables with a set of other 'contextual' variables that describe household characteristics and livelihood strategies, forming a comprehensive set of independent variables with potential association with dietary diversity (Table 2). Some of these variables are essentially 'immutable', i.e. they are fixed and therefore less subject to changes due to agricultural system transitions, or by extension, cannot be readily addressed by interventions. Therefore, variables and indicators distilled from the RHoMIS survey were grouped into two sets of independent variables to compare against HDDS. The Household Characteristics Group (Table 2) contains categorical variables that for the intent of this analysis are considered to be immutable, e.g. ethnicity and household type. Conversely, the Livelihood Strategies and Farm Performance group (Table 2) is a collection of continuous and count variables that are considered to be 'mutable' farm household characteristics and strategies.

278

279 **Table 2. Explanatory Variables for Household Dietary Diversity Score**

Variables	Description	Type*	Units
Household Characteristics			
Ethnicity	Self-identified ethnicity of household.	Cat	n/a
Household Type	Five types of household heads are possible: both parents, single parent, parent working away from home, non-parent, child.	Cat	n/a
Livelihood Strategies and Farm Performance			
Female Decision-Making Control	Female control over potential food energy available, on a scale (0-1): 0 = male-controlled, 0.5 = egalitarian, 1 = female-controlled.	Cont	Dimensionless
Off-Farm Income	Income from off-farm activities.	Cont	$USD.yr^{-1}.person^{-1}$
Market Orientation for Food Availability	Relative importance of crop and livestock sales in generating potential food energy available.	Cont	%, 0-100
Value of Crop Production (per person)	Monetised value of crop production, normalised by household size.	Cont	$USD.yr^{-1}.person^{-1}$
Value of Livestock Production (per person)	Monetised value of livestock production, normalised by household size.	Cont	$USD.yr^{-1}.person^{-1}$
Land Owned (per person)	Household land area, normalised by household size.	Cont	$ha.person^{-1}$
Crop Diversity	Number of crops.	Count	Dimensionless
N Fertiliser Use	Ratio of amount of N fertiliser applied to land cultivated.	Cont	$kg\ N.ha^{-1}$
Land Irrigated	Approximate percentage of land area that is irrigated.	Cont	% (0, 17, 33, 50, 75, 100)
Crop Productivity	Ratio of monetised value of crop production and land area cultivated.	Cont	$USD.ha^{-1}$
Livestock Holdings (per person)	Livestock holdings in Tropical Livestock Units (TLU), normalised by household size.	Cont	$TLU.person^{-1}$
Livestock Diversity	Number of livestock types.	Count	Dimensionless
Livestock Contribution to Food Availability	Percentage of food availability ($kcal.MAE^{-1}.yr^{-1}$) that is traceable to livestock production, either through direct consumption or from proceeds when livestock are sold.	Cont	%, 0-100
Livestock Productivity	Ratio of monetised value of livestock production and livestock holdings.	Cont	$USD.TLU^{-1}$

* 'Cat' = categorical variable, 'Cont' = continuous variable, 'Count' = count variable

280

281 Within the Livelihood Strategies and Farm Performance variable group (Table 2), specific
282 variables were selected to represent the three key aspects of production system transition (Figure 2).
283 Market orientation was represented by the 'Market Orientation for Food Availability' variable, a
284 weighted indicator of the proportion of farm produce that is sold vs. consumed. The weighting uses the
285 'Food Availability' indicator to account for the importance of each farm product to each household's
286 livelihood. The indicator has been tested and applied in a series of recent studies (Frelat et al., 2016;
287 Hammond et al., 2017). 'Food Availability', while not specifically considered as a variable of interest in
288 this study, is a key indicator in RHoMIS and is embedded in the definition of several other variables
289 (Table 2). 'Food Availability' is the food energy, expressed in kilocalories per male adult equivalent per
290 day, potentially available to a household through both on-farm agricultural production and markets
291 (Frelat et al., 2016; Hammond et al., 2017; Ritzema et al., 2017a). Production specialisation is quantified
292 by two indicators: crop diversity (number of different crops grown) and livestock diversity (number of
293 different livestock species kept). Intensification of production is described using several variables as
294 well: N (nitrogen) applied as mineral fertiliser and land under irrigation.
295 Other 'contextual' independent variables (Table 2), considered together with the key transition
296 variables, include key farm and livelihood characteristics that may be associated with dietary diversity
297 such as farm size, livestock holdings and household size. Several key parameters that would typically be
298 included in the Household Characteristics Group, namely Household Size and Gender Decision Type,
299 were incorporated into the Livelihood Strategies category to enhance quality of the results. The Gender
300 Decision Type variable quantifies the relative control of women over the benefits of on-farm and off-
301 farm activities (Van Wijk et al., 2016), and has a continuous value between zero (women have no role in
302 decision-making) and one (women control all decisions related to the benefits of on- and off-farm
303 activities). Tavenner et al. (2019) describes a recent detailed study of this indicator. Though this
304 variable is descriptive of cultural contexts, it is not considered an immutable descriptor and can be

influenced through gender-based interventions. To account for high variability in household size and its effects on household resource endowments and farm productivity, appropriate variables were normalised by the number of household members, including Off-Farm Income, Land Owned, Livestock Holdings, Value of Crop Production, and Value of Livestock Production.

2.5. Analysis Approach

The RHoMIS survey differentiated farmer responses on food groups consumed between food purchased from the market and food produced on-farm. HDDS values are thus partitioned by source, forming three distinct dependent variables for statistical analysis: Total HDDS, HDDS from purchased food ($HDDS_{pur}$), and subsistence HDDS ($HDDS_{sub}$). All data preparation, outlier testing, and statistical analysis were performed in R (R Core Team, 2014).

Aiming to retain the maximum number of households in the dataset, we identified outlier households based on two criteria. First, we manually screened all dependent and independent variables for unreasonable values. Second, we tested the remaining variable values for excessive influence on parameter values by using DFBETA plots in R (Fox and Weisberg, 2011). Households with DFBETA data points having an absolute value greater than $2/\sqrt{(n)}$, where n is the number of households, were labeled as outliers and removed from the dataset. From both outlier criteria, 12, 8, and 3 households were removed from the Cambodia, Laos, and Vietnam datasets, respectively.

Quantitative analysis of HDDS association with categorical and immutable Household Characteristic variables used Kruskal-Wallis testing to identify whether statistically significant differences were apparent between factor levels, and visual inspection of boxplots to discern where differences were most evident. Analysis of HDDS vs. the Livelihood Strategies and Farm Performance Group (Table 2), a collection of mutable continuous and count variables, centered on negative binomial regression, a generalised linear model (Venables and Ripley, 2002). HDDS is an over-dispersed count variable

(Koppmair et al., 2017) and correlation between independent variables is evident due to overlapping variable definitions, e.g. Off-Farm Income and Value of Crop Production are addends in the Food Availability indicator calculation. All models started with a full set of independent variables, and we used the 'step' function in R (Hastie and Pregibon, 1992; Venables and Ripley, 2002) to sequentially remove the most insignificant terms from the regression model using Akaike's Information Criterion. Terms remaining with $p > 0.1$ were then manually removed to leave the most parsimonious model.

Results from the Household Characteristics group analysis did not subsequently inform analysis of the Livelihood Strategies and Farm Performance group. Statistically significant differences in the former would be important to consider if formulating interventions or discerning how cultural differences or resource endowments affect dietary diversity. However, in this study, comparisons within and between the sites are the key area of interest. Thus, we opted to identify Household Characteristics differences as an area for further study and important criteria for in-depth analysis and intervention strategy. Subsequent regression analysis of the Livelihood Strategies and Farm Performance group is thus performed across the entire sample population in each site.

3. RESULTS

3.1. Farm Characteristics

A listing of selected farm and household characteristics provides context for subsequent analysis (Table 3). Median values and interquartile ranges are indicated for continuous and count variables of interest.

Table 3. Selected Farm Household Characteristics

`	Values: Median (Interquartile Range)		
	Cambodia	**Laos**	**Vietnam**
Household Characteristics			
Family size	5 (3)	6 (3)	4 (2)
Ethnicities represented*	6	2	6
Number of household types*	4	5	3
Livelihood Strategies and Farm Characteristics			
Female decision-making control (0-1)	0.50 (0.083)	0.5 (0)	0.5 (0)
Total income (USD.yr^{-1})	1890 (2640)	250 (1270)	3270 (4390)
Off-farm income (USD.yr^{-1}.person^{-1})	14 (98)	0 (11)	79 (318)
Market orientation for food availability (%, 0-100)	80 (49)	9.1 (42)	74 (43)
Value of crop production (USD.yr^{-1}.person^{-1})	340 (420)	194 (195)	558 (966)
Value of livestock production (USD.yr^{-1}.person^{-1})	0.67 (5.2)	4.0 (10)	12 (37)
Land owned (ha)	3.5 (3.6)	1.2 (1.3)	1.2 (1.5)
Land cultivated (ha)	3.5 (3.5)	1.5 (1.7)	1.3 (1.5)
Crop diversity (# of crops produced)	5 (3)	4 (3)	4 (2)
N fertiliser use (kg N.ha^{-1})	0 (0)	0 (0)	34 (38)
Land irrigated (%, 1-100)	0 (17)	0 (50)	75 (83)
Crop productivity (USD.ha^{-1})	500 (420)	890 (740)	1680 (1700)
Livestock holdings (TLU)	0.63 (2.7)	3.7 (5.8)	0.7 (1.9)
Livestock holdings (TLU.person^{-1})	0.13 (0.55)	0.56 (0.91)	0.16 (0.49)
Livestock diversity (# of livestock types produced)	2 (1)	3 (2)	2 (1)
Livestock contribution to food availability (%, 0-100)	0.027 (1.3)	3.7 (8.1)	1.4 (5.8)
Livestock productivity (USD.ha^{-1})	2.5 (32)	5.0 (17)	37 (220)

* A simple count, thus not a median value.

352 Five household types were reported across the 3 sites: (1) two parents, (2) single parent, (3)
353 non-parent household head, (4) household head working away from home, and (5) child household
354 head. Not all household types were reported in each site, and low-frequency household types were
355 consolidated into an 'Other' category in the analysis. The number of distinct ethnicities reported in the
356 Cambodia, Laos, and Vietnam sites were 6, 2, and 6, respectively, though Cambodian survey
357 enumerators used a generic 'Other' ethnic category as a sixth ethnicity during data collection.
358 The Cambodia site exhibits larger farm sizes and cultivation area than either the Laos or Vietnam
359 sites, but similar livestock holdings to the Vietnam site. The Laos site has larger family sizes and a
360 greater diversity of household types, and also places greater emphasis on livestock production (via
361 quantity and diversity) than the other sites.
362 Levels of agricultural intensification, i.e. as reflected by nitrogenous fertiliser input rates and use
363 of irrigation, differ markedly between sites. The Cambodia site is the least intensified of the 3 sites, with
364 negligible N fertiliser use and a median value of the percentage of land irrigated being zero, with an
365 interquartile range of only 17%. The Laos site reflects slightly more irrigation usage, but the overall
366 intensification level remains low. Conversely, intensification levels in the Vietnam site reflect the
367 prevalence of intensified agriculture and high market connectivity.
368
369 3.2. Household Dietary Diversity Score
370 Reported HDDS values cover the entire range of possible values on a scale from 1 to 12. Sample
371 sizes were uneven across the 3 sites, with the Cambodia site having a sample size more than double that
372 of the Vietnam site (Figure 3). The Laos site reports the lowest mean and median HDDS value (Figure 3).

	Camb	Laos	VN
n*	607	334	295
Mean	6.4	5.3	6.8
Median	6	5	7
Minimum	1	1	2
Maximum	12	12	11
Skewness	-1.0	0.58	-1.55
Kurtosis	-3.0	-3.0	-1.23
Shapiro-Wilk	2.07e-8	2.8e-7	3.2e-6

* Number of households after outliers were removed.

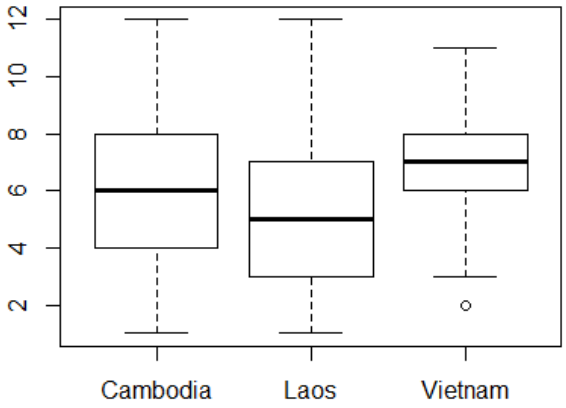


Figure 3. Descriptive Statistics for Household Dietary Diversity Score, Per Site

A Kruskal-Wallis test result of p = 4.9e-13 <0.05 confirms visual inspection (Figure 3) that the central tendency between the 3 sites is not identical. Shapiro-Wilk values and skewness/kurtosis tests (Figure 3), along with visual inspection of HDDS histograms (Figure 4) confirm that, in each site, HDDS values are not normally distributed. A substantial group (~10-15%) of households consumed only 1-2 food groups (normally grains plus either fats or vegetables). This diet information is based on the month of the year when farmers recalled consuming the fewest number of food groups.

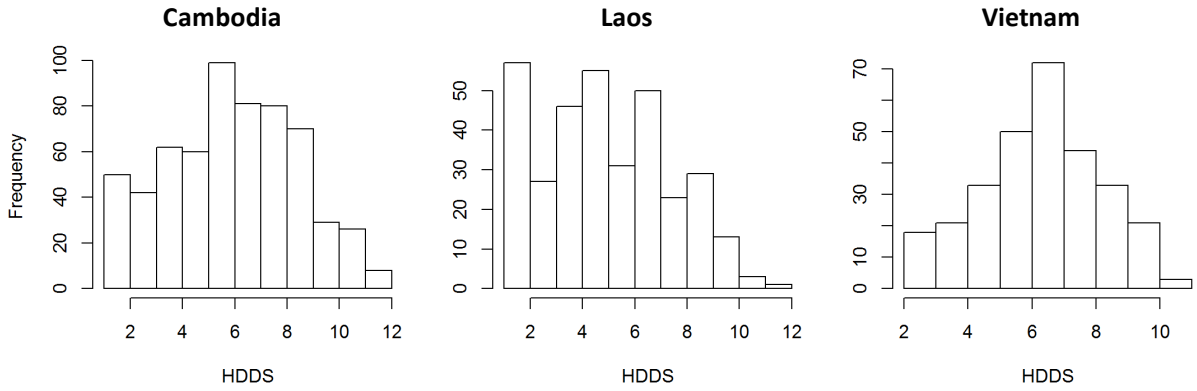
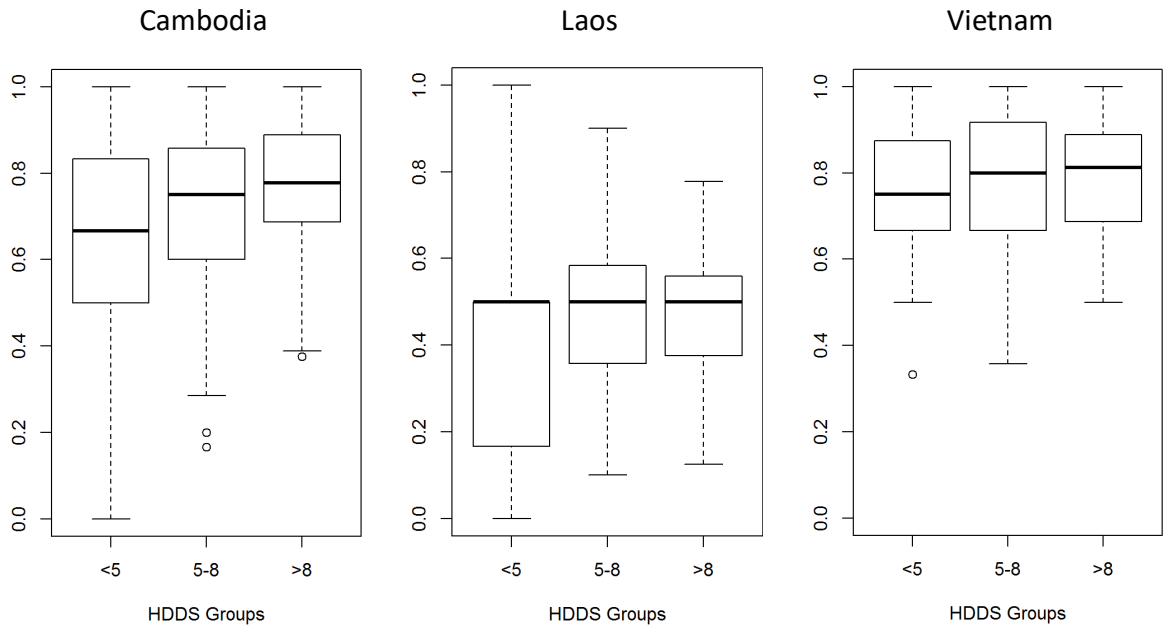


Figure 4. Household Dietary Diversity Score Histograms

386 We considered the fraction of HDDS attributable to purchased food vs. food produced on-farm.
387 Households were grouped into 3 categories at each site: those with HDDS < 5, those with 5 < HDDS < 8,
388 and those with HDDS > 8. These tertiles are subjective, as no guidelines have yet been formulated for
389 the number of food groups considered to be adequate or inadequate (FAO, 2011), and are thus
390 intended to show food purchase trends across an HDDS spectrum. Box plots (Figure 5) show that in
391 Cambodia and Vietnam, purchased food groups are most important for overall HDDS, while in Laos the
392 farm-based groups are most important. In all sites, trends suggest that households with low HDDS
393 (Group 1) showed a lower fraction of HDDS from purchased food.
394



395

396 **Figure 5. Fraction of Household Dietary Diversity Score from Purchased Food, by Groups**

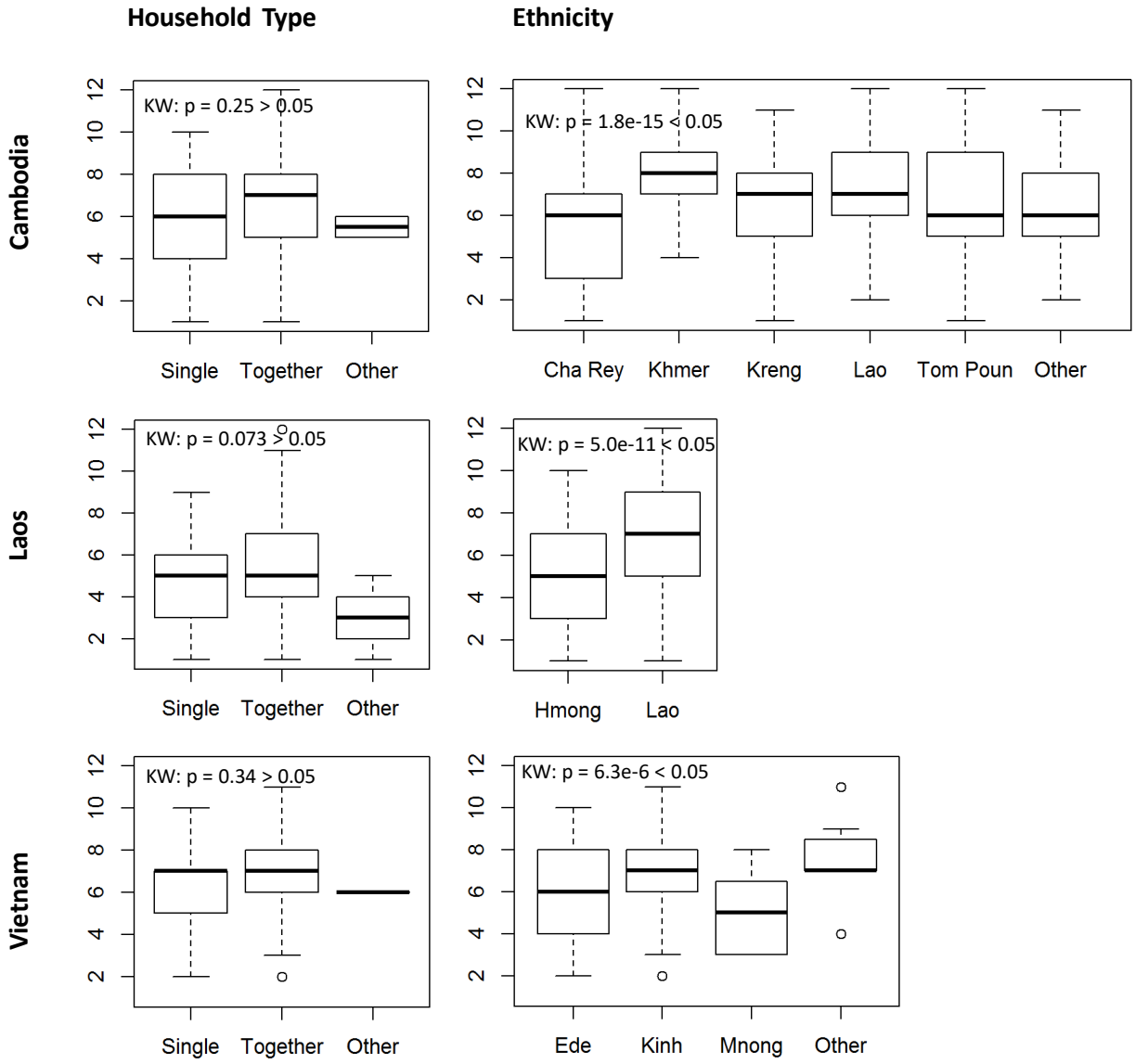
397

398

399 3.3. HDDS vs. Household Characteristics

400 Examination of Household Characteristics centered on 2 variables: Household Type and
401 Ethnicity (Figure 6). Respondents typically self-identified as 'Single [Parent]' or '[Parents] Together'.
402 Frequency of the three other household types was low across all 3 sites, necessitating consolidation into
403 a generic 'Other' household category. Similarly, in the Cambodia and Vietnam sites, ethnicities
404 represented by only a few households were consolidated into an 'Other' ethnicity category.

405



406

407 **Figure 6. Household Dietary Diversity Score by Key Household Characteristics**

408

409 No statistically significant differences in HDDS are evident for the Household Type variable, in
410 any of the 3 sites, as indicated by Kruskal-Wallis p-values greater than the 0.05 significance level.
411 Household Type results contrast sharply with the Ethnicity variable, as differences in HDDS values
412 between ethnicities are statistically significant in all 3 sites.
413 Pairwise Wilcoxon tests reveal more detail on HDDS differences across ethnicities within each
414 site. In the Cambodia site, Khmer HDDS values are significantly greater than the Cha Rey ($p = < 0.001$),
415 Tom Poun ($p < 0.01$), and Other ($p < 0.001$) ethnicities. Aside from the Khmer group, the Cha Rey HDDS
416 values are significantly lower than the Lao ($p < 0.01$) and Tom Poun ($p < 0.01$) ethnic groups. Of the
417 two ethnicities in the Laos dataset, the Hmong HDDS scores are significantly lower than the Lao ethnic
418 majority ($p < 0.01$). In the Vietnam site, the Kinh majority ethnic group shows significantly higher HDDS
419 scores than the Ede ($p < 0.05$) and Mnong ($p < 0.01$) groups, but not the 'Other' ethnic group, a small
420 collection of Nung, Tay, and Thai ethnicities that outperform only the Mnong ethnicity ($p < 0.05$). These
421 results suggest that ethnicity, in all three sites, is an important element to consider when targeting
422 dietary diversity as a key development outcome in agricultural interventions.
423
424 3.4. HDDS vs. Livelihood Strategies and Farm Performance Indicators
425 The second stage of the HDDS analysis focused on assessing the association of a set of 14
426 mutable 'Livelihood Strategies and Farm Performance' indicators (Table 2) with HDDS for each study
427 site. A minimal set of significant regressor variables (with significance levels $p < 0.10$) were assumed to
428 identify key variables associated with HDDS variability. Negative binomial regression coefficients
429 represent log differences in the expected count of HDDS for a unit change in each regressor variable,
430 while holding other regressors constant (Table 4), meaning that an increase in the value of these

variables leads to a negative effect on the expected HDDS score, and therefore a decrease in dietary diversity.

Table 4. Regressor Variables of Significant Livelihood Strategies and Farm Performance for Household Dietary Diversity Score (HDDS)

	Cambodia			Laos			Vietnam		
	HDDS	HDDS pur	HDDS sub	HDDS	HDDS pur	HDDS sub	HDDS	HDDS pur	HDDS sub
Female Decision-Making Control (0-1)	0.22 **	0.28 ***							
Off-Farm Income (USD.yr^{-1}.person^{-1})	5.0e-5 *	6.5e-5 *		1.1e-4 *	2.9e-4 ***				
Market Orientation for FA (%, 0-100)	-2.2e-3 ***	-1.8e-3 *	-4.1e-3 ***	-2.6e-3 *		-3.7e-3 **			
Value of Crop Prod (USD.yr^{-1}.person^{-1})	7.1e-5 *	1.2e-4 ***		2.0e-4 **		4.8e-4 ***	6.9e-5 ***	6.2e-5 **	
Value of Livestock Prod (USD.yr^{-1}.person^{-1})			2.7e-4 *			6.8e-3 **			
Land Owned (ha.person^{-1})	3.2e-2			0.36 **	0.38 **				
Crop Diversity (# of crops)			0.062 ***		-0.053 *				0.091 **
N Fertiliser Use (kg N.ha^{-1})				3.7e-3	5.2e-3				
Land Irrigated (%, 0-100)			4.2e-3 ***	2.5e-3 ***	2.0e-3 *	3.0e-3 ***			
Crop Productivity (USD.ha^{-1})						-4.7e-5			
Livestock Holdings (TLU.person^{-1})		-0.037	0.09 ***						
Livestock Diversity (# of livestock types)				0.049 **	0.086 **		0.068 **		0.33 ***
Livestock Contribution to FA (%, 0-100)	4.5e-3 **	6.1e-3 **							
Livestock Productivity (USD.ha^{-1})				-1.1e-3		-1.8e-3 *			5.1e-4 ***

*** p<0.001, ** p<0.01, * p<0.05, ' ' p<0.1

438 A cross-site comparison reveals several commonalities between sites (Table 4). Value of Crop
439 Production is the only variable that is statistically significant for Total HDDS in all 3 sites, while Crop
440 Diversity, Livestock Holdings, Value of Livestock Production, and Crop Productivity variables are
441 insignificant in all sites for Total HDDS. Accordingly, an increase in crop production may lead to higher
442 dietary diversity in all three sites, while other variables might lead to improved dietary diversity in one
443 or more sites, but not all. A positive association between Off-Farm Income and HDDS in the Laos and
444 Cambodia sites shows the importance of off-farm income in purchasing diverse foods from the market.
445 A strong negative association between Market Orientation for Food Availability vs. HDDS in the Laos and
446 Cambodia sites indicates that increased use of crop and livestock sales to access food energy is matched
447 with a loss of dietary diversity. Otherwise, results differ markedly across the 3 sites (Table 4) in both
448 complexity and content. A minimal set of 2 regressor variables for the Vietnam site contrasts sharply
449 with 8 significant variables for the Laos site.
450 Associations between key indicators and HDDS are further clarified by analysis of marginal
451 effects. The key indicators presented in Figure 7 are limited to the strongest associations with the
452 lowest relative uncertainty as reflected in the p-value (indicated in Table 4). Holding all other regressors
453 at their mean, we see that in the Cambodia site, Female Decision Making Control has a small but highly
454 certain positive association with HDDS (increasing at most by 1 food category across the range of
455 possible values). Conversely, Market Orientation has a small negative association with HDDS. Livestock
456 Contribution to Food Availability has a stronger but more uncertain positive association with HDDS
457 (increasing by a minimum of 1 to a maximum of 6 food categories). In the Laos site, the Value of Crop
458 Production and Land Owned variables are positively associated with HDDS with a high degree of
459 uncertainty. The Land Irrigated variable has a small but highly certain positive association with HDDS. In
460 the Vietnam site, the Value of Crop Production has a less uncertain, positive association with HDDS

when compared to Laos, but the association between Livestock Diversity and HDDS is positive with a high degree of certainty.

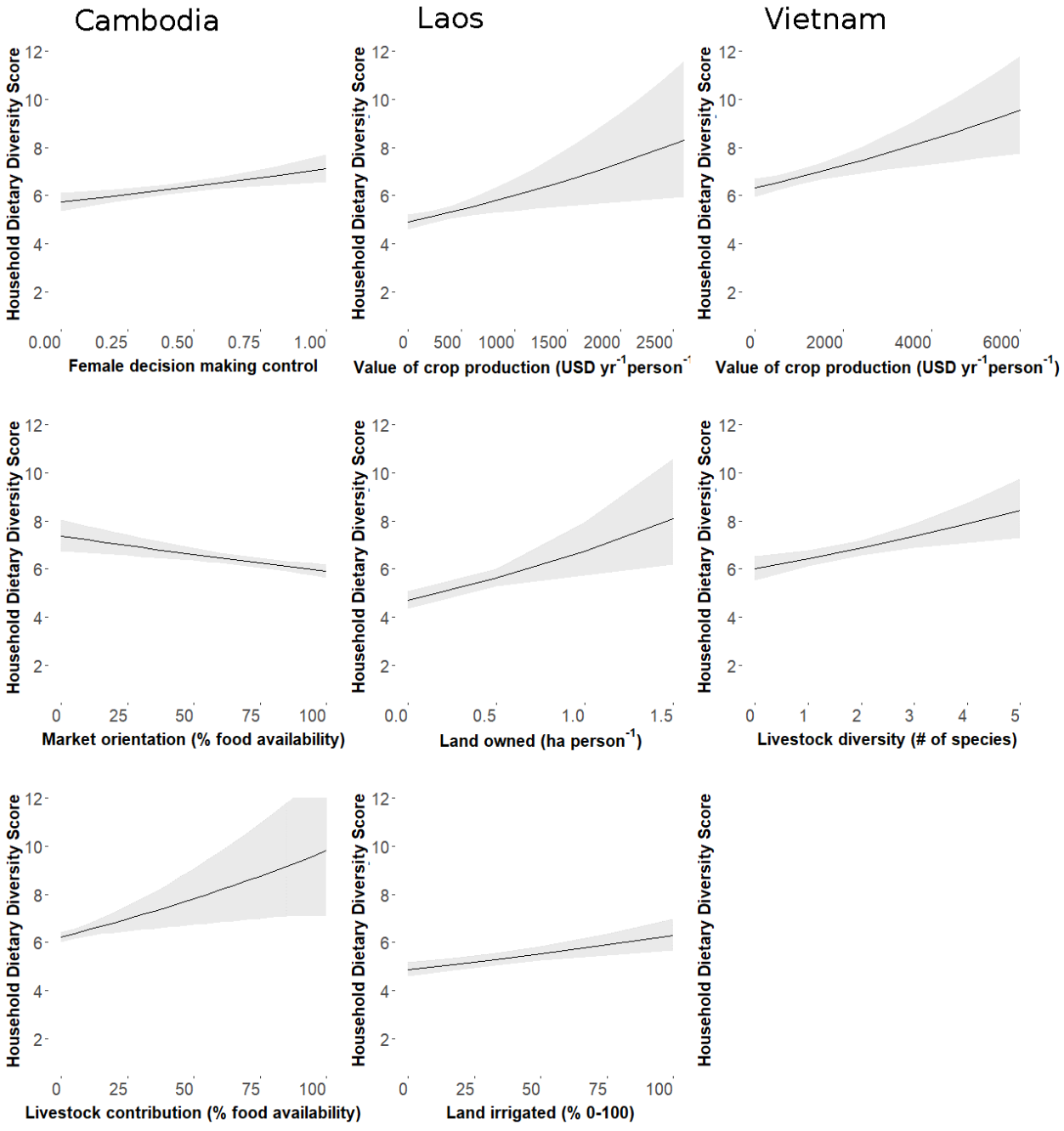


Figure 7. Marginal Effects Plots of Key Indicators

467

468 3.4.1. Cambodia Site

469 Reliance on markets for dietary diversity (Figure 5) is further reflected in synchrony between
470 $HDDS_{pur}$ and Total HDDS regressor variable sets, and dissimilarity between $HDDS_{sub}$ and Total HDDS.
471 Variables associated with increased dietary diversity coming from on-farm produce are thus different
472 from those that positively affect purchased dietary diversity. Though $HDDS_{sub}$ plays a minor role in the
473 Cambodian household, Value of Livestock Production, Crop Diversity, Land Irrigated and Livestock
474 Holdings are linked to $HDDS_{sub}$, and increases in these variables lead to increased dietary diversity. Only
475 the Cambodia site indicates linkages between Female Decision-Making Control and Total HDDS:
476 increased decision power of women leads to increased diversity in the food purchased, and thereby to
477 increased overall dietary diversity.

478

479 3.4.2. Laos Site

480 Households in the Laos site rely on both markets and consumption of farm products for dietary
481 diversity (Figure 5), differing from the predominant market orientation of the other 2 sites, and further
482 evidenced by the strong synchrony in regressor variables between purchased and subsistence HDDS and
483 Total HDDS. Whereas in Cambodia total dietary diversity is in most cases only affected positively if a
484 positive relationship between the independent variable and purchased HDDS is evident, in Laos total
485 HDDS can be affected positively (and negatively) by both the farm-based and purchased HDDS routes.
486 Of the 3 sites, the Laos site shows the strongest linkage between HDDS and agricultural intensification
487 strategies, i.e. N Fertiliser Use and Land Irrigated. N Fertiliser Use is positively related to purchased
488 HDDS (more mineral fertiliser use means more production, more sales and thereby more cash available
489 to buy diverse food), whereas irrigation leads to positive effects on dietary diversity based on both
490 purchases and consumption of farm-based production.

491

492 3.4.3. Vietnam Site

493 Regression results forward only 2 significant variables for Total HDDS, and as such, the Vietnam
494 site has the simplest statistical model of the 3 sites. The most significant regressor variable for Total
495 HDDS is the Value of Crop Production, matched by a similar value for the same variable for $HDDS_{pur}$, with
496 higher value of crop production leading to higher purchased dietary diversity, and thereby also to higher
497 total dietary diversity. The relatively small proportion of HDDS from on-farm sources is correlated to
498 Crop and Livestock Diversity as well as Livestock Productivity. All of these variables have a positive
499 effect on farm-based dietary diversity, with Livestock Diversity (the number of different livestock species
500 raised on-farm) not only leading to an increase in farm-based dietary diversity, but also to an increase in
501 total dietary diversity.

502 To frame subsequent discussion, Table 5 summarises the statistical results by regrouping the
503 set of 14 Livelihood Strategies and Farm Performance variables (Tables 2-3). The three transition
504 aspects of market orientation, production specialisation, and intensification are defined in simple terms
505 using 5 of the 14 regressor variables. The market orientation indicator is the Market Orientation for
506 Food Availability variable. The specialisation aspect is comprised of the 'inverse' of the Crop Diversity
507 (e.g. low crop diversity indicates high specialisation) and Livestock Diversity variables. Intensification is
508 reflected by N Fertiliser Input and Irrigation variables. The remaining nine regressor variables place
509 results within the wider farm household context, i.e. Farm Characteristics, Farm Performance, and Other
510 Household Characteristics categories. Variable medians and interquartile range results (Table 3) are
511 subjectively interpreted as Low, Med[ium], or High, and regression results against Total HDDS (Table 4)
512 are indicated by sign and significance. Results therefore summarise whether a variable has a high or low
513 value and whether it has a large effect on HDDS. For example, nitrogenous fertiliser use is typically an
514 important determinant of production and an entry point for production intensification. However, it is

not identified as a significant variable in any of the sites. In Cambodia and Laos, the use of mineral fertiliser is low while in Vietnam it is high, but results show little variation in intra-site mineral fertiliser use. So though mineral fertiliser would be expected to affect production positively, it does not have large within-site variation and therefore in analyses at the integration level does not arise as a key variable.

Table 5. Levels of Independent Variables and Interpreted Correlated Variation to Household Dietary Diversity Score

		Cambodia		Laos		Vietnam	
Household Dietary Diversity Score (median):		**6**		**5**		**7**	
Agricultural Transition		Level	CV*	Level	CV*	Level	CV*
Market Orientation	Market Orientation for FA	High	(-)***	Low	(-)*	High	
Specialisation	Crops	Low		Med		Med	
	Livestock	High		Med	(-)**	High	(-)**
Intensification	N Fertiliser	Low		Low	(+)	High	
	Irrigation	Low		Low	(+)***	High	
Farm Characteristics	Land Owned	High	(+)	Low	(+)**	Low	
	Livestock Holdings	Low		High		Low	
Farm Performance	Value Crop Production	Med	(+)*	Low	(+)**	High	(+)***
	Crop Productivity	Low		Med		High	
	Value Livestock Production	Low		Med		High	
	Livestock Productivity	Low		Med	(-)	High	
	Livestock Contribution to FA	Low	(+)**	Low		Low	
Other HH Char's	Female Decision Control	Med	(+)**	Med		Med	
	Off-farm Income	Med	(+)*	Low	(+)*	High	

*CV = Correlated Variation

3.5. Food Group Differentiation with HDDS

Figure 8 displays food group composition for each HDDS value across the full HDDS range within each site. Charts reveal the distinctions between sites and shifts in food groups as HDDS scores

increase, for Total HDDS as well as its purchased and subsistence components. The differences between the sites in the dietary diversity represented in the purchased and subsistence components of HDDS reflect results displayed in Figure 5: the diversity of the purchased portion of HDDS dominates in the Cambodia and Vietnam sites, while the food group diversity originating from on-farm production and purchasing are roughly equal in the Laos site.

Examination of one food category illustrates the utility of food group disaggregation. The 'fruits' category becomes prevalent in each of the sites when HDDS values reach a value of approximately '7', as shown in the Total HDDS charts in Figure 8. Further information can then be gained through close examination of the 'HDDS purchased' and 'HDDS subsistence' charts. In the Laos site, for example, the 'fruit' category is insignificant below 'HDDS purchased' scores of 6. As the maximum allowable HDDS score for a farm household is 12, an 'HDDS purchased' score of 6 corresponds to an 'HDDS subsistence' score of 6 or less. These results therefore suggest that Lao site households consume what little fruit they produce on-farm. Households with a Total HDDS score of roughly 6 or above then increasingly turn to market sources.

Households in the Laos site clearly produce rice for consumption and purchase little grain from the market, while the inverse is true for the Vietnam site. As in the case of fruit, consumption of dairy and legumes is negligible in all sites below Total HDDS = 7, but above this threshold, dairy products are typically purchased and legumes are produced on-farm. Fats and sweets are consumed by almost all households and are already present in diets of low diversity. In the Vietnam site, eggs and vegetables, and to a smaller extent meat and fruits, originate on-farm, while in the Cambodia site, grains, roots and tubers, eggs, fruits and fish originate from on-farm production. In the Laos site, virtually all crop-based food groups originate from on-farm production.

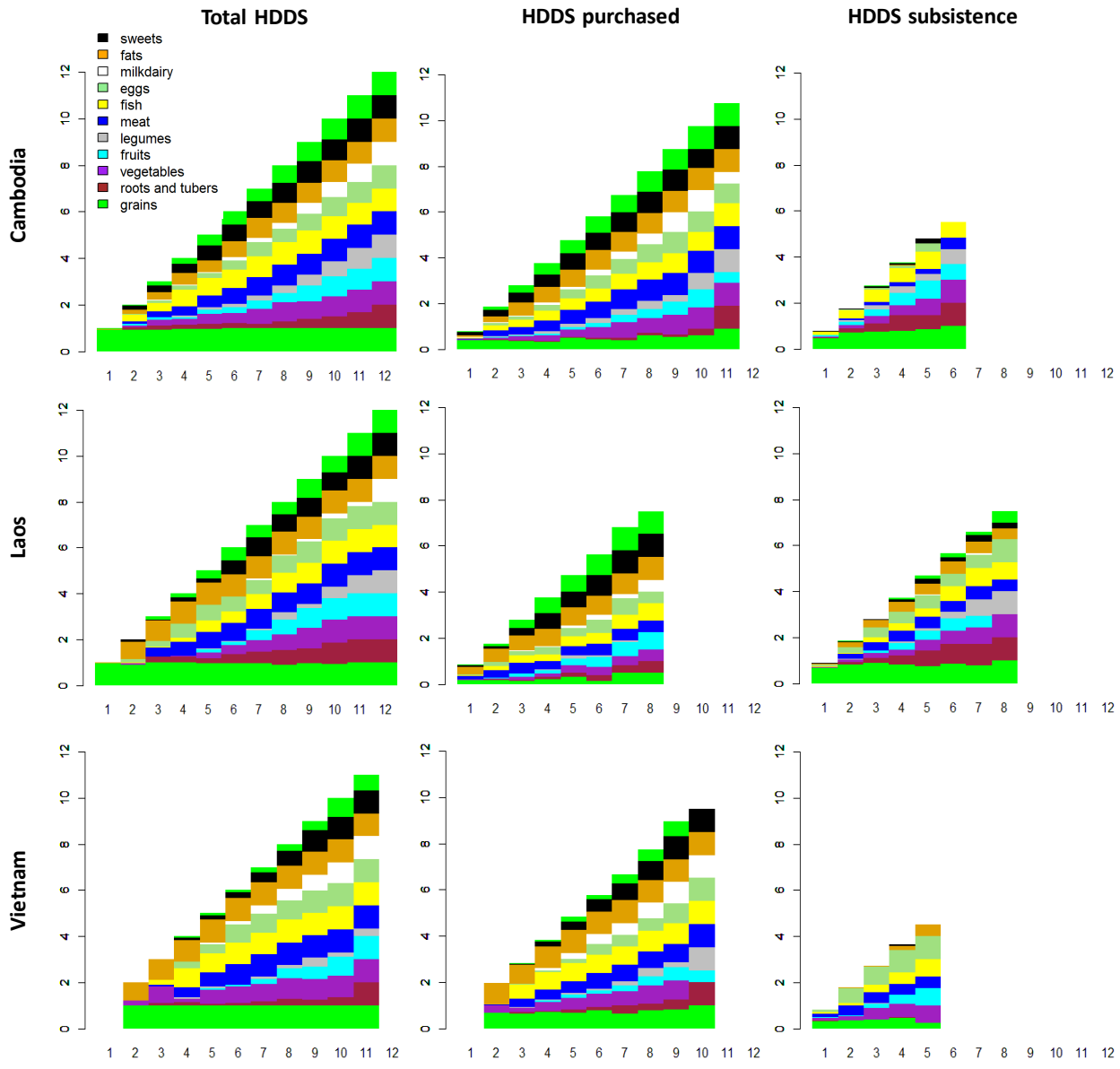


Figure 8. Dietary diversity: proportion of households consuming specific food categories by farm type and period. Both the horizontal and vertical axes show the total dietary diversity scores. On the vertical axis, the composition of household diets are shown using colour-coded food categories. The vertical axis thereby shows the proportion of households consuming each category at specific dietary diversity levels.

4. DISCUSSION

Results establish that dietary diversity, as measured using HDDS, varies between three GMS study sites that are perceived to be in various phases of agricultural transition (Table 5). A key component of the analysis is associating HDDS to a simple but comprehensive set of mutable farm, livelihood, and household characteristics, as mutable characteristics are likely to change as agricultural systems undergo further change. Forging these links requires an understanding of 2 factors for effective interpretation of results within and across sites: (1) the levels of each variable, at each site, representing those characteristics, and (2) the variation of those variables within each site and the significance of the association of that variation with HDDS. For example, the Value of Crop Production variable in the Vietnam site has high variation that is significantly correlated to HDDS, around a high median production value relative to the other sites. Both data provide meaningful information. On the other hand, a lack of correlated variation in N fertiliser use rates to HDDS in the Vietnam site does not reflect its unimportance as a 'driver': high crop production levels in the Vietnam site in fact depend upon fertiliser inputs. Rather, there is little variation in N fertiliser input rates correlating to HDDS because fertiliser use is high across the spectrum of farm households in the Vietnam site. Interpretation of the data within its site context is therefore a key component of the analysis.

4.1. Laos Site

Relative to the other two sites, the Laos site is positioned at the lower end of the spectrum in terms of income (Table 3) and dietary diversity (HDDS, Figure 3). Following Boserup's theory of agricultural intensification via induced innovation (Boserup, 1965) and as outlined in Herrero et al. (2014), the Laos site appears to be in only the initial phases of agricultural transition (Table 5). Livelihood strategies have a strong subsistence orientation, particularly in production of grains, roots

582 and tubers, and some vegetables (Figure 8). Households are more dependent on on-farm production in
583 terms of HDDS than the Vietnam or Cambodia sites, as reflected in the fraction of HDDS that is
584 purchased (Figure 5), and significant synchrony between $HDDS_{sub}$ and Total HDDS regression terms
585 (Table 4).

586 Agricultural transition variables (i.e. those representing market orientation, intensification, and
587 specialisation shown in Table 5) are key drivers of dietary diversity, though not all in the same direction.
588 Intensification influences HDDS positively, but intensification is currently evident only through limited
589 irrigation (Table 3), primarily for subsistence paddy rice production (Figure 7). Furthermore, irrigation
590 expansion is the most significant driver of HDDS, through both market and subsistence pathways (Table
591 4). Fertiliser use is limited, though regression results indicate that as application of fertiliser increases,
592 HDDS improves through marketing of produce (Figure 5).

593 However, HDDS also trends negatively against other transition aspects. The significant negative
594 correlation with livestock specialisation (Table 5) reflects a subsistence orientation toward livestock
595 production (also reflected through high livestock holdings), thus enhancement of livestock diversity
596 would presumably lead to higher dietary diversity. However, increased livestock diversity is associated
597 with higher HDDS through market connectivity (Table 4), so a fuller understanding of market
598 interactions is needed to more fully interpret this dynamic.

599 Agricultural transition is not the only driver of dietary diversity in the Laos site, though it is
600 arguably the dominant influence. Though off-farm income is negligible, regression results show a
601 dramatic effect on dietary diversity through market purchases when off-farm income becomes available.
602 Overall, with increased crop production, through either more land or through intensification,
603 households first diversify diets via on-farm production, with some shift in orientation towards markets
604 (Figure 5).

These findings may suggest that the linkage between ongoing agricultural transition, or perhaps interventions, to improved dietary diversity may be somewhat predictable, but would depend on the balance between what are currently positive intensification influence vs. negative specialisation and market orientation influences. Production intensification shows a clear positive HDDS trend but coupling intensification with market connectivity that is conducive to HDDS enhancement, within a context that is still strongly subsistence-oriented, would be critical. Improvement in off-farm income and maximising the value of crop production are important 'non-transition' farm household characteristics to consider.

4.2. Cambodia Site

The Cambodia site is positioned between the Laos site and the Vietnam site in terms of HDDS (Figure 3) and all forms of income (Table 3). The site presents a mixture of agricultural transition traits that differ from those of Laos, i.e. along the trajectory of increased market orientation, intensification, and specialisation. Agricultural systems appear to be focused on specialized and non-irrigated cash crop production, with relatively low crop production levels that are nonetheless primarily intended for the market, especially across the border with Vietnam. HDDS is primarily associated with food purchases (Figure 5), a finding supported by the lack of synchrony between the significant factors for $HDDS_{sub}$ and Total HDDS (Table 4). High market connectivity is a prerequisite condition for this to be true. At the same time, the intensification strategies of fertiliser use and irrigation are nearly absent. Livestock production is de-emphasised, with the Cambodia site having the lowest livestock holdings of any site. Despite being a market-oriented site, crop diversification, irrigation, and increased livestock production, when present, produce foodstuffs that are primarily consumed by the household (Table 4) including rice, roots and tubers, and vegetables (Figure 8). Some food groups, i.e. dairy, fats, sweets, and eggs are obtained only from the market (Figure 8).

629 Unlike the Laos site, agricultural transition characteristics appear to have little bearing on
630 dietary diversity, which is instead associated with non-transition farm and household aspects. However,
631 keeping in mind that levels of associated variables are important to consider along with the variables'
632 correlated variability, the lack of significance for e.g. fertiliser or irrigation, may be explained by the lack
633 of any variation to correlate against HDDS. There may simply be too little fertilisation or irrigation
634 utilised among the surveyed households to be measurable against HDDS, but introduction of
635 intensification strategies may well have a positive (albeit unknown) effect on dietary diversity.
636 Strikingly, the variable with the most significant correlation to HDDS, Market Orientation for
637 Food Availability, is negatively correlated, as in the case of the Laos site. This variable indicates the
638 degree that crop and livestock production sales are used to obtain potential food energy (Table 2). This
639 result appears counter-intuitive, as increasing market orientation in an agricultural context having
640 strong market connectivity would seem to give farm households the opportunity to purchase a diverse
641 basket of food groups, as is in fact reflected in Cambodia's purchase food group distribution (Figure 8).
642 However, this result may reflect a changing attitude toward dietary diversity as farm revenues increase,
643 or may indicate that farm proceeds may be used for other non-food purposes such as school fees.
644 Furthermore, some farm households in remote areas may be far from markets, but are still highly
645 market-oriented through traders. For these households, market access to a diversity of purchased
646 foodstuffs may be limited, and income from farm sales thus may not necessarily translate to higher
647 dietary diversity.
648 Association of dietary diversity with non-transition variables (e.g. productive resources such as
649 land and livestock holdings, and productivity and household characteristics such as female decision
650 control and off-farm income) is more prominent for the Cambodia site than the Laos site (Table 5).
651 Livestock holdings are low, yet production is relatively market-oriented (Figure 7). Conversely, farms are
652 larger relative to the other sites, but increased farm size remains positively correlated to HDDS.

Cambodia is the only site where Female Decision-Making Control has non-trivial variation and is significantly associated with HDDS. As in the Laos site, off-farm income is low, but is associated with increasing HDDS when it is accessible.

The Cambodia site presents a different picture of early-stage agricultural transition (market orientation, intensification and specialisation as shown in Table 5) than the Laos site, where market orientation is less prominent. Specialisation and intensification traits reflect pre-transition conditions, while livelihoods are dependent on cash crop production on larger farms. It is therefore uncertain how further agricultural transition will affect dietary diversity. However, based on results from Laos and Vietnam, introduction of even small intensification measures will likely correlate to improved dietary diversity. The importance of non-transition aspects must not be ignored in the transition process, and improved female decision-making over food purchases along with greater off-farm income could produce large HDDS gains.

4.3. Vietnam Site

Vietnam presents the lowest poverty (as expressed by income, Table 3) and highest HDDS of any of the 3 sites (Figure 5). Farms have seemingly undergone the transition to commercialisation and specialisation (Table 5), and are small but highly intensified (Table 3 and Table 5). A high percentage (75%-80%) of HDDS is purchased, rather than produced on farm (Figure 5). Food groups are well-represented, with the exception of roots and tubers, which are consumed typically only by high-HDDS households (Figure 8).

Low correlated variation of post-transition market orientation, specialisation, and intensification variables to HDDS (Table 5) is likely due to uniformity across the sample population: most households are already highly connected to markets, with highly specialised and intensified agricultural systems. Despite high market orientation, livestock diversity still plays a role in increasing dietary diversity

677 through on-farm consumption of livestock products, highlighting the potential role of livestock to
678 support dietary diversity in post-transition households. Otherwise, variations in the value of crop
679 production are the predominant driver of HDDS, as crop production equates to cash resources for
680 purchasing diverse foodstuffs (Figure 8).
681
682 4.4. Cross-Site Trends
683 Though limited in farm size, the Vietnam site has transitioned to highly market-oriented,
684 specialised, and intensified agricultural systems, unsurprisingly matched with high farm performance
685 indicators (Table 5). The Cambodia and Laos sites are at different positions in the transition space but
686 have markedly different transition pathways in terms of market orientation, specialisation, and
687 intensification. The Cambodia site, with low fertiliser and irrigation usage, is nonetheless highly market
688 oriented. The Laos site shows a different trend, with some crop specialisation and irrigation (primarily
689 for rice production), but with low market orientation and emphasis on subsistence production. These
690 results illustrate transition processes in the GMS may be multi-dimensional rather than linear.
691 HDDS appears to be more related to cropping system transitions than to livestock systems,
692 whether crops are consumed on-farm or sold in the market. Interestingly, crop diversification shows
693 little effect on Total HDDS: gains in $HDDS_{sub}$ are matched with losses in $HDDS_{pur}$ (Table 4). These
694 contrasting effects might be one explanation why the literature on the link between crop diversity and
695 dietary diversity shows confusing results, with limited effects of crop diversity on dietary diversity at
696 best (Cook, 2018; Waha et al., 2018). Livestock diversification may be associated with higher HDDS, but
697 pathways differ between sites. Our results on the contrasting effects of diversification on $HDDS_{sub}$ and
698 $HDDS_{pur}$ show that crop and farming diversification need to be understood as part of overall livelihood
699 diversification strategies (Mortimore and Adams, 2001; Newsham and Thomas, 2011).

Analysis of household characteristics reveals that though significant differences in dietary diversity are not apparent between household types, ethnicity was a major driver of HDDS scores in each site (Figure 6), and therefore should be considered in further studies, farming systems analysis or intervention design. This study focused on variability within each site to give indications of drivers of dietary diversity, and thus the site populations were not disaggregated by ethnicity. Further research is needed, however, to understand the nature of dietary diversity differences between ethnic groups, and to understand how agricultural transition trajectories and potential interventions could be shaped by ethnicity.

The disaggregation of the food groups by origin (Figure 8) gives key information on how continuing agricultural transition may result in transitions within specific food groups, or potentially for projects that try to improve dietary diversity through on-farm interventions. This information can also give insights into possible policy recommendations. In the Vietnam site, only eggs and vegetables originate on-farm, and to a smaller extent meat and fruits, while in the Cambodia site grains, roots and tubers, eggs, fruits and fish originate from on-farm production. These food groups and their corresponding products could be targeted to directly improve dietary diversity through home consumption of production. Other production interventions that would potentially increase production would indirectly improve dietary diversity if farmers use the extra income to buy diverse foods. The fact that appreciable amounts of fats and sugars are consumed by households with low dietary diversity scores suggests that this is unlikely to be a viable pathway to diverse diets unless these undesirable consequences are countered. Policies that support further production intensification should therefore be paired with nutrition education; otherwise, improved incomes will likely not result in improved diets. In the Laos site, essentially all crop-based food groups originate from on-farm production, thereby suggesting that production intensification options could directly result in more diverse diets.

5. CONCLUSIONS

The objective of this study was to discern key drivers of dietary diversity, as measured by an adapted implementation of the Household Dietary Diversity Score, in three study sites in the Greater Mekong Subregion that represent different stages of agricultural transition from subsistence to commercialised production. Characteristics differ between the sites as indicated by levels and trends in indicators representing 3 primary transition descriptors: market orientation, specialisation, and intensification. Agriculture in the Vietnam site has essentially transitioned, while the Laos and Cambodia sites display divergent combinations of transition traits. These results suggest that agricultural transformation in the context of the GMS is best described in terms of multiple pathways rather than a linear progression.

Dietary diversity, as measured using HDDS, varies in a statistically significant manner between three GMS study sites that roughly follows that commercialisation transition. However, drivers of dietary diversity differ markedly between the sites. In the Laos site, HDDS is most closely correlated to a set of variables closely linked with agricultural transition, while in the Cambodia site it follows other farm and household characteristics. In the Vietnam site, dietary diversity is closely correlated to the overall value of crop production. These findings show that continuing agricultural transitions will exhibit differing trajectories between the sites, with concomitant impacts on dietary diversity.

Agricultural transition pathways are site-specific, and therefore contextualised policies and approaches are needed to ensure that agricultural transitions do not occur at the expense of dietary diversity. Though findings cannot be translated directly to intervention recommendations in this study, they do provide indications of where interventions might be needed to support or potentially offset the effects on dietary diversity from ongoing agricultural transition processes. Cambodia and Laos show much potential for input-driven intensification, while in Vietnam diversification is a key policy entry point, as well as further diversification of livestock production. This will lead to increased market

orientation, but it must be accompanied by nutrition education to stimulate diversification strategies. Future research can focus on discerning the linkages between dietary diversity and key drivers in greater detail, perhaps in conjunction with household analysis and modeling to formulate specific interventions. These efforts should carefully consider the differentiating role of ethnicity as a driver of dietary diversity.

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7. REFERENCES

Alexander, K., Case, P., Jones, M., Connell, J., 2017. Commercialising smallholder agricultural production in Lao People's Democratic Republic. Dev. Pract. 27, 965-980.

Ashraf, J., Pandey, R., de Jong, W., 2017. Assessment of bio-physical, social and economic drivers for forest transition in Asia-Pacific region. Forest Policy Econ. 76, 35-44.

Baird, I.G., Barney, K., 2017. The political ecology of cross-sectoral cumulative impacts: modern landscapes, large hydropower dams and industrial tree plantations in Laos and Cambodia. Journal of Peasant Studies 44, 884-910.

Boserup, E., 1965. The Condition of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure. Aldine Publishing Company, London.

CIAT, 2014. Hands and Minds Connected to Boost Eco-efficiency on Smallholder Livestock-Crop Systems. International Center for Tropical Agriculture, Cali, Colombia.

Coates, J., Swindale, A., Bilinsky, P., 2007. Household Food Insecurity Access Scale (HFIAS) for measurement of food access: indicator guide. USAID, Washington, D.C.

Cochard, R., Ngo, D.T., Waeber, P.O., Kull, C.A., 2017. Extent and causes of forest cover changes in Vietnam's provinces 1993-2013: a review and analysis of official data. Environ. Rev. 25, 199-217.

Cook, S., 2018. The spice of life: The fundamental role of diversity on the farm and on the plate. IIED and Hivos, London and The Hague.

Dak Lak Statistical Office, 2016. Statistical Yearbook of Dak Lak. General Statistics Office, Ministry of Planning & Investment of Vietnam.

Dak Nong Statistical Office, 2016. Statistical Yearbook of Dak Nong. General Statistics Office, Ministry of Planning & Investment of Vietnam.

783 de Sa, J., Bouttasing, N., Sampson, L., Perks, C., Osrin, D., Prost, A., 2013. Identifying priorities to improve
784 maternal and child nutrition among the Khmu ethnic group, Laos: a formative study. Matern. Child Nutr.
785 9, 452-466.
786 Desiere, S., Vellema, W., D'Haese, M., 2015. A validity assessment of the Progress out of Poverty
787 Index(PPI)(TM). Eval. Program Plan. 49, 10-18.
788 Diez, J.R., 2016. Vietnam 30 years after Doi Moi: achievements and challenges. Z. Wirtsch. 60, 121-133.
789 Dulal, B., Mundy, G., Sawal, R., Rana, P.P., Cunningham, K., 2017. Homestead Food Production and
790 Maternal and Child Dietary Diversity in Nepal: Variations in Association by Season and Agroecological
791 Zone. Food Nutr. Bull. 38, 338-353.
792 FAO, 2011. Guidelines for Measuring Household and Individual Dietary Diversity. FAO, Rome.
793 Fox, J., Weisberg, S., 2011. An {R} Companion to Applied Regression, Second Edition ed. Sage, Thousand
794 Oaks CA.
795 Fraval, S., Hammond, J., Lannerstad, M., Oosting, S.J., Sayula, G., Teufel, N., Silvestri, S., Poole, E.J.,
796 Herrero, M., van Wijk, M.T., 2018. Livelihoods and food security in an urban linked, high potential region
797 of Tanzania: Changes over a three year period. Agric. Syst. 160, 87-95.
798 Fraval, S., Yameogo, V., Ayantunde, A., Hammond, J., Imke, J.M.d.B., Oosting, S.J., van Wijk, M.T.,
799 submitted. Pathways to food security in rural Burkina Faso: the importance of consumption of home-
800 produced food versus purchased food. Food Secur.
801 Frelat, R., Lopez-Ridaura, S., Giller, K.E., Herrero, M., Douxchamps, S., Djurfeldt, A.A., Erenstein, O.,
802 Henderson, B., Kassie, M., Paul, B.K., Rigolot, C., Ritzema, R.S., Rodriguez, D., van Asten, P.J.A., van Wijk,
803 M.T., 2016. Drivers of household food availability in sub-Saharan Africa based on big data from small
804 farms. Proc. Natl. Acad. Sci. U. S. A. 113, 458-463.
805 Goto, K., Douangngeune, B., 2017. Agricultural modernisation and rural livelihood strategies: the case of
806 rice farming in Laos. Can. J. Dev. Stud. 38, 467-486.

807 Grameen Foundation, 2015. 2015 Progress out of Poverty Index.
808 Hammond, J., Fraval, S., van Etten, J., Suchini, J.G., Mercado, L., Pagella, T., Frelat, R., Lannerstad, M.,
809 Douxchamps, S., Teufel, N., Valbuena, D., van Wijk, M.T., 2017. The Rural Household Multi-Indicator
810 Survey (RHoMIS) for rapid characterisation of households to inform climate smart agriculture
811 interventions: Description and applications in East Africa and Central America. Agric. Syst. 151, 225-233.
812 Hammond, J., van Wijk, M.T., Pagella, T., Carpena, P., Skirrow, T., Dauncey, V., 2018. Shea butter: a pro-
813 poor, pro-female route to increased income, in: Todd Rosenstock, A.N.E.G. (Ed.), The Climate-Smart
814 Agriculture Papers: Investigating the Business of a Productive, Resilient and Low Emission Future.
815 Springer International Publishing.
816 Hastie, T.J., Pregibon, D., 1992. Generalized linear models, in: Chambers, J.M., Hastie, T.J. (Eds.),
817 Statistical Models in S. Wadsworth & Brooks/Cole.
818 Heinimann, A., Hett, C., Hurni, K., Messerli, P., Epprecht, M., Jorgensen, L., Breu, T., 2013. Socio-
819 Economic Perspectives on Shifting Cultivation Landscapes in Northern Laos. Hum. Ecol. 41, 51-62.
820 Herrero, M., Thornton, P.K., Bernues, A., Baltenweck, I., Vervoort, J., de Steeg, J.V., Makokha, S., van
821 Wijk, M.T., Karanja, S., Rufino, M.C., Staal, S.J., 2014. Exploring future changes in smallholder farming
822 systems by linking socio-economic scenarios with regional and household models. Glob. Environ.
823 Change-Human Policy Dimens. 24, 165-182.
824 Herrero, M., Thornton, P.K., Power, B., Bogard, J.R., Remans, R., Fritz, S., Gerber, J.S., Nelson, G., See, L.,
825 Waha, K.B., Watson, R.A., C., W.P., Samberg, L.H., van de Steeg, J., Stephenson, E., van Wijk, M.T.,
826 Havlik, P., 2017. Farming and the geography of nutrient production for human use: a transdisciplinary
827 analysis. The Lancet Planetary Health 1, e33-e42.
828 Hirota, I., Koyama, T., Ingxay, P., 2014. Mountainous Livelihood in Northern Laos: Historical Transition
829 and Current Situation of a Swidden Village, in: Yokoyama, S., Okamoto, K., Takenaka, C., Hirota, I. (Eds.),
830 Integrated Studies of Social and Natural Environmental Transition in Laos. Springer, New York, pp. 39-59.

831 Humidtropics, 2012. Humidtropics: Integrated Systems of the Humid Tropics Program. International
832 Institute for Tropical Agriculture (IITA), Ibadan, Nigeria.
833 Johnston, R.M., Hoanh, C.T., Lacombe, G., Noble, A.N., Smakhtin, V., Suhardiman, D., Kam, S.P., Choo,
834 P.S., 2009. Rethinking agriculture in the Greater Mekong Subregion: how to sustainably meet food
835 needs, enhance ecosystem services and cope with climate change, in: Institute, I.W.M. (Ed.).
836 International Water Management Institute, Colombo, Sri Lanka, p. 26.
837 Jones, A.D., Shrinivas, A., Bezner-Kerr, R., 2014. Farm production diversity is associated with greater
838 household dietary diversity in Malawi: Findings from nationally representative data. Food Policy 46, 1-
839 12.
840 Kenney-Lazar, M., 2012. Shifting Cultivation in Laos: Transitions in Policy and Perspective, in: (SWG-
841 ARD), R.C.b.t.S.o.t.S.W.G.f.A.a.R.D. (Ed.), Vientiane, Lao PDR.
842 Knudsen, C.M.S., Mertz, O., 2016. Improved land tenure not the driver of economic development in a
843 Vietnamese community. Geogr. Tidsskr. 116, 82-84.
844 Koppmair, S., Kassie, M., Qaim, M., 2017. Farm production, market access and dietary diversity in
845 Malawi. Public Health Nutr. 20, 325-335.
846 Kyeyune, V., Turner, S., 2016. Yielding to high yields? Critiquing food security definitions and policy
847 implications for ethnic minority livelihoods in upland Vietnam. Geoforum 71, 33-43.
848 Lachat, C., Raneri, J.E., Smith, K.W., Kolsteren, P., Van Damme, P., Verzelen, K., Penafiel, D., Vanhove,
849 W., Kennedy, G., Hunter, D., Odhiambo, F.O., Ntandou-Bouzitou, G., De Baets, B., Ratnasekera, D., Ky,
850 H.T., Remans, R., Termote, C., 2018. Dietary species richness as a measure of food biodiversity and
851 nutritional quality of diets. Proc. Natl. Acad. Sci. U. S. A. 115, 127-132.
852 Lao Statistics Bureau, 2015. Provisional Report: Lao Population and Housing Census. Lao Statistics
853 Bureau, Vientiane, p. 58.

Li, P., Feng, Z.M., Jiang, L.G., Liao, C.H., Zhang, J.H., 2014. A Review of Swidden Agriculture in Southeast Asia. Remote Sens. 6, 1654-1683.

M'Kaibi, F.K., Steyn, N.P., Ochola, S.A., Du Plessis, L., 2017. The relationship between agricultural biodiversity, dietary diversity, household food security, and stunting of children in rural Kenya. Food Science & Nutrition 5, 243-254.

Martin-Prével, Y., Allemand, P., Wiesmann, D., Arimond, M., Ballard, T., Deitchler, M., Dop, M.-C., Kennedy, G., Lee, W.T.K., Moursi, M., 2015. Moving forward on choosing a standard operational indicator of women's dietary diversity. Food and Agricultural Organization of the United Nations (FAO), Rome, Italy.

Martin, S.M., Lorenzen, K., 2016. Livelihood Diversification in Rural Laos. World Dev. 83, 231-243.

McAndrew, J.P., 2000. Indigenous adaptation to a rapidly changing economy: The experience of two Tampuan villages in northeast Cambodia. Bulletin of Concerned Asian Scholars 32, 39-51.

McDonald, C.M., McLean, J., Kroeun, H., Talukder, A., Lynd, L.D., Green, T.J., 2015a. Correlates of household food insecurity and low dietary diversity in rural Cambodia. Asia Pac. J. Clin. Nutr. 24, 720-730.

McDonald, C.M., McLean, J., Kroeun, H., Talukder, A., Lynd, L.D., Green, T.J., 2015b. Household food insecurity and dietary diversity as correlates of maternal and child undernutrition in rural Cambodia. Eur. J. Clin. Nutr. 69, 242-246.

Meyfroidt, P., Phuong, V.T., Anh, H.V., 2013. Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central Highlands of Vietnam. Glob. Environ. Change-Human Policy Dimens. 23, 1187-1198.

Michaux, K.D., McLean, J., Li, H.Q., Lynd, L., Hou, K., Talukder, A., Green, T.D., 2016. Homestead Food Production (HFP) with or without Aquaculture Improves Women's Dietary Diversity Scores, Household Food Security and Income in Prey Veng Province, Cambodia. Faseb J. 30, 2.

878 Milne, S., 2013. Under the leopard's skin: Land commodification and the dilemmas of Indigenous
879 communal title in upland Cambodia. Asia Pacific Viewpoint 54, 323-339.
880 Mortimore, M.J., Adams, W.M., 2001. Farmer adaptation, change and 'crisis' in the Sahel. Glob. Environ.
881 Change-Human Policy Dimens. 11, 49-57.
882 Mulmi, P., Masters, W.A., Ghosh, S., Namirembe, G., Rajbhandary, R., Manohar, S., Shrestha, B., West,
883 K.P., Webb, P., 2017. Household food production is positively associated with dietary diversity and
884 intake of nutrient-dense foods for older preschool children in poorer families: Results from a nationally-
885 representative survey in Nepal. Plos One 12.
886 National Institute of Statistics, 2013. Cambodia Inter-Censal Population Survey. National Institute of
887 Statistics, Ministry of Planning, Phnom Penh.
888 Newsham, A.J., Thomas, D.S.G., 2011. Knowing, farming and climate change adaptation in North-Central
889 Namibia. Glob. Environ. Change-Human Policy Dimens. 21, 761-770.
890 Nguyen, H.N., van de Fliert, E., Nicetic, O., 2015. Towards a holistic framework for impact assessment of
891 agricultural research for development - understanding complexity in remote, culturally diverse regions
892 of Vietnam. Australas. Agribus. Rev. 23, 12-25.
893 Nguyen, P.H., Strizich, G., Lowe, A., Nguyen, H., Pham, H., Truong, T.V., Nguyen, S., Martorell, R.,
894 Ramakrishnan, U., 2013. Food consumption patterns and associated factors among Vietnamese women
895 of reproductive age. Nutr. J. 12, 11.
896 Ornetsmuller, C., Verburg, P.H., Heinimann, A., 2016. Scenarios of land system change in the Lao PDR:
897 Transitions in response to alternative demands on goods and services provided by the land. Appl. Geogr.
898 75, 1-11.
899 R Core Team, 2014. R: A language and environment for statistical computing, in: Computing, R.F.f.S.
900 (Ed.), Vienna, Austria.

Rerkasem, K., Lawrence, D., Padoch, C., Schmidt-Vogt, D., Ziegler, A.D., Bruun, T.B., 2009. Consequences of Swidden Transitions for Crop and Fallow Biodiversity in Southeast Asia. Hum. Ecol. 37, 347-360.

Ritzema, R.S., Frelat, R., Douxchamps, S., Silvestri, S., Rufino, M.C., Herrero, M., Giller, K.E., Lopez-Ridaura, S., Teufel, N., Paul, B., van Wijk, M.T., 2017a. Is production intensification likely to make farm households food-adequate? A simple food availability analysis across smallholder farming systems from East and West Africa. Food Secur. 9, 115-131.

Ritzema, R.S., Frelat, R., Hammond, J., van Wijk, M.T., 2017b. What works where for which farm household: rapid approaches to food availability analysis, in: Öborn, I., Vanlauwe, B., Phillips, M., Thomas, R., Atta-Krah, K. (Eds.), Integrated Systems Research for Sustainable Intensification of Smallholder Agriculture. Earthscan.

Ruel, M.T., 2003. Operationalizing Dietary Diversity: A Review of Measurement Issues and Research Priorities. The Journal of Nutrition 133, 3911S-3926S.

Saaka, M., Osman, S.M., Hoeschle-Zeledon, I., 2017. Relationship between agricultural biodiversity and dietary diversity of children aged 6-36 months in rural areas of Northern Ghana. Food & Nutrition Research 61.

Sibhatu, K.T., Krishna, V.V., Qaim, M., 2015. Production diversity and dietary diversity in smallholder farm households. Proc. Natl. Acad. Sci. U. S. A. 112, 10657-10662.

Sibhatu, K.T., Qaim, M., 2018a. Farm production diversity and dietary quality: linkages and measurement issues. Food Secur. 10, 47-59.

Sibhatu, K.T., Qaim, M., 2018b. Review: Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. Food Policy 77, 1-18.

Southavilay, B., Nanseki, T., Takeuchi, S., 2013. Analysis on Policies and Agricultural Transition: Challenges in Promoting Sustainable Agriculture in Northern Laos. J. Fac. Agric. Kyushu Univ. 58, 219-223.

Stirling, C.M., Farnworth, C.R., Hammond, J., Chinyophiro, A., van Wijk, M.T., 2018. Household Methodologies to Reduce Gender Inequality and Increase Household Resilience to Climate and Other Shocks: A Case Study from Malawi. Climatic Change (submitted).

Stür, W., Khanh, T.T., Duncan, A., 2013. Transformation of smallholder beef cattle production in Vietnam. International Journal of Agricultural Sustainability 11, 363-381.

Swindale, A., Bilinsky, P., 2006. Household Dietary Diversity Score (HDDS) for measurement of household food access: Indicator guide, Washington, D.C.

Talukder, Z., McLean, J., Lynd, L., Kroeun, H., Green, T.J., 2013. HOUSEHOLD FOOD SECURITY, DIETARY DIVERSITY, ANEMIA, AND ANTHROPOMETRIC STATUS OF POOR WOMEN FARMERS IN PREY VENG, CAMBODIA: A CROSS-SECTIONAL STUDY. Ann. Nutr. Metab. 63, 932-932.

Tavenner, K., van Wijk, M., Fraval, S., Hammond, J., Baltenweck, I., Teufel, N., Kihoro, E., de Haan, N., van Etten, J., Steinke, J., Baines, D., Carpena, P., Skirrow, T., Rosenstock, T., Lamanna, C., Ng'endo, M., Chesterman, S., Namoi, N., Manda, L., 2019. Intensifying Inequality? Gendered Trends in Commercializing and Diversifying Smallholder Farming Systems in East Africa. Frontiers in Sustainable Food Systems 3.

Truong, D.M., Yanagisawa, M., Kono, Y., 2017. Forest transition in Vietnam: A case study of Northern mountain region. Forest Policy Econ. 76, 72-80.

Turner, B.L., Ali, A.M.S., 1996. Induced intensification: Agricultural change in Bangladesh with implications for Malthus and Boserup. Proceedings of the National Academy of Sciences 93, 14984.

Van Wijk, M.T., Hammond, J., Fraval, S., Ritzema, R.S., Bolliger, A.M., Long, C.T.M., 2016. Including gender equity in a survey tool for rural households, in: Pyburn, R., van Eerdewijk, A. (Eds.), A different kettle of fish? Gender integration in livestock and fish research. KIT, Amsterdam.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, Fourth Edition ed, Springer, New York.

949 Vicol, M., Pritchard, B., Htay, Y.Y., 2018. Rethinking the role of agriculture as a driver of social and
950 economic transformation in Southeast Asia's upland regions: The view from Chin State, Myanmar. Land
951 Use Pol. 72, 451-460.
952 Waha, K., van Wijk, M.T., Fritz, S., See, L., Thornton, P.K., Wichern, J., Herrero, M., 2018. Agricultural
953 diversification as an important strategy for achieving food security in Africa. Global Change Biology 24,
954 3390-3400.

955