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Subsistence under the canopy: Agrobiodiversity's contributions to food and nutrition security amongst coffee communities in Chiapas, Mexico

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ABSTRACT

This paper analyzes the relationship between agrobiodiversity and food security. Results demonstrate that agrobiodiverse landscapes can contribute to food and nutrition security. Maize and bean production, as well as overall agrobiodiversity, were significantly correlated with a reduction in number of months of food insecurity. Due to the volatility of the coffee market, the high prices of food, the inadequate quality of food, and the limited availability and access to food produced inside or outside the communities, strategies that strengthen and diversify local food systems are essential to improving food and nutrition security, as well as livelihoods in general.

KEYWORDS

Food security; agroecology; agrobiodiversity; seasonal hunger; coffee; food sovereignty

Introduction

There is increasing recognition that agroecology and agrobiodiversity[1] can play a central role in a transition towards a more sustainable global agrifood system; one that will both maintain healthy ecosystems and ensure food security for a growing population (IAASTD. International Assessment of Agricultural Knowledge, Science and Technology for Development 2009; de Schutter 2010; Chappel and LaValle 2011; Frison et al. 2006). Agrobiodiversity refers to the variety and variability of living organisms that contribute to food and agriculture in the broadest sense, and the knowledge associated with it (Jackson, Pascual, and Hodgkin 2007). Agroecology is defined as the "ecology of food systems, encompassing ecological, social and economic dimensions", which can be applied as a framework that actively pursues sustainability in agriculture and food systems through a systems-based, transdisciplinary, participatory, and action-oriented approach (Francis et al. 2003, 100; Gliessman 2007; Mendez et al. 2013). Agroecology and agrobiodiversity contribute to social, economic, and ecological

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[1]Agroecology and agrobiodiversity are distinct disciplines with their respective fields of study and literature but can overlap significantly in approach, principles, and values.

benefits around the world, and in particular to food security and food sovereignty, by building resilient food systems (Altieri 2004; Altieri and Toledo 2011; Brookfield 2001; Chappell and LaValle 2011; Frison et al. 2006; Thrupp 2000). Managing for diversity within agroecosystems can both contribute to well-balanced, nutritious diets and provide essential ecosystem services that our food security is dependent upon – such as pollination, pest management, water regulation, and soil fertility, among others (Jackson, Pascual, and Hodgkin 2007; Thrupp 2000). The most studied benefit of agrobiodiversity is the role of crop diversity as a source of genetic material for the breeding of crops that are tolerant and adaptable to an ever-changing environment (Bellon 2004; Jackson, Pascual, and Hodgkin 2007). While genetic diversity is an essential asset of agrobiodiversity, further research is needed that documents the wide variety of other assets provided by agrobiodiverse landscapes (Jackson, Pascual, and Hodgkin 2007). This paper examines the relationship between agrobiodiversity and household food security in coffee landscapes of Chiapas, Mexico, where farmers steward high levels of agrobiodiversity, but also suffer from seasonal hunger.

Achieving food security – defined by the Food and Agriculture Organization (FAO) as "a situation that exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences" (Food and Agriculture Organization 2003, 28) – has been the guiding concept to address the issue of global hunger and poverty, since the 1970s. Earlier definitions emphasized the role of government and public policy in governing macro-level food availability, with less attention to access. After Sen's (1984) groundbreaking work demonstrated that food availability is a limited indicator of food security and that food access – dependent on entitlements, agency and power – is a stronger determinant of hunger, the FAO definition shifted to emphasize the issue of access. Today, the FAO's food security framework encompasses four main principles: availability (sufficient quantities of food available on a consistent basis), access (having sufficient resources to obtain appropriate foods for a nutritious diet), utilization (appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation) and stability (stability of the other three factors over time) (Food and Agriculture Organization 2003; WHO (World Health Organization) 2015). However, policies mainly prioritize the condition of availability, targeting increases in productivity and/or food imports, notwithstanding the fact that availability does not guarantee access and access does not guarantee utilization (Barrett 2010). Where access is addressed, mainstream policies often privilege economic access rather than direct access and control over natural, productive, and socio-political resources. These are the issues that the concept of food sovereignty[2] more directly addresses (Fairbairn 2011; Wittman 2011). Policies

[2]Defined as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems." (Via Campesina, 2007).

that value agrobiodiversity can increase farmer access and control over natural and productive resources, which in turn can lead to improved food security. In order to steer policy in that direction, more empirical evidence linking agrobiodiversity to food security is needed.

Agrobiodiverse landscapes are a cornerstone of many peasant livelihoods in the global south and many traditional diets depend on this agrobiodiversity. Not only is agrobiodiversity seen as key to food security, but research is also increasingly linking it to nutrition security (Ickowitz et al. 2013; Jones, Shrinivas, and Bezner-Kerr 2014; Powell et al. 2013; Remans et al. 2011). Nutrition security goes beyond food security by considering the nutritional quality of diet, health care and hygiene. As diets globally are experiencing a nutrition transition, it is paramount that we assess how diversity in our diets – dependent on diverse production systems – can improve overall human health (Khoury et al. 2014). In addition, we need to further explore how diets link environmental health to human health (Tilman and Clark 2014). The nutrition transition phenomenon is characterized by a narrowing food base increasingly composed of high calorie and energy foods (grains, roots) and less micronutrients (fruits, vegetables, leafy greens). The narrowing of the diet produces both undernutrition and obesity, which are both significant health problems today (Johns and Sthapit 2004). Micronutrient deficiencies, also known as hidden hunger, are common in a transition from diverse diets based on whole foods to diets based on highly processed foods, and rich in salt and sugar (Sunderland et al. 2013). Much of the literature analyzing the relationship between agrobiodiversity and food and nutrition security has come out of Africa and Asia, leaving a general gap in Latin America. In particular, very few studies have been conducted in coffee landscapes.

Smallholder coffee farmers represent the largest sector of an approximate total of 14 to 25 million coffee farmers globally (Jha et al. 2014). These growers are embedded in complex and dynamic ecological, social, economic, and political realities that drive management approaches of eco and agroecosystems and livelihood outcomes, such as food security and food sovereignty (Eakin, Tucker, and Castellanos 2006). In Mesoamerica, smallholder coffee farmers tend to participate in what Pimbert et al. (2001) describe as 'plural economies,' whereby farmers manage their agroecosystems for both subsistence production, as well as for local and global markets (Eakin, Tucker, and Castellanos 2006; Isakson 2009; Jaffee 2007; Martinez-Torres 2006). This plural economy is reflected in the diversity of crops and distinct agroecosystems stewarded by these farmers. While there is ample research that shows the contributions made by these diverse coffee systems to biodiversity conservation (Perfecto et al. 1996; Moguel and Toledo 1999; Perfecto et al. 2003; Méndez 2004; Somarriba et al. 2004; Méndez, Gliessman, and Gilbert 2007; Perfecto and Vandermeer 2008; Philpott et al. 2008), there has been less research examining the contributions of these systems to farmer livelihoods, and in particular to food security (Méndez et al. 2010).

Studies in the last decade demonstrate that many smallholder coffee farmers in Mesoamerica suffer annual periods of seasonal hunger (Bacon et al. 2014; Caswell, Méndez, and Bacon 2012; Fujisaka 2007; Méndez et al. 2010; Morris, Méndez, and Olson 2013). These periods can range from 1 to 8 months and are the result of a complexity of factors that include farmer's capacity to produce food crops; coffee price volatility and timing of payments; low yields; high staple food prices; and limited access to support networks, among others (Caswell, Méndez, and Bacon 2012; Morris, Méndez, and Olson 2013). This study assesses and analyzes the impact of agrobiodiversity on reducing the extent of seasonal hunger in coffee growing communities of the Sierra Madre de Chiapas, Mexico.

Study site

The study site is located within the Sierra Madre de Chiapas mountain range, which runs parallel to the Pacific Coast. This mountain range harbors five important biosphere reserves. Our research was conducted with coffee farming households that live within the buffer zone of the El Triunfo biosphere reserve (Figure 1.). El Triunfo reserve covers 120,000 hectares with approximately 25,000 hectares designated as core zone and the rest as buffer zone. About 12,000 inhabitants, who are mostly coffee farmers, live in the buffer zone (INE,

Figure 1. Map of study site.

Institute Nacional de Ecologia 1999). The reserve harbors a diversity of ecosystem types including cloud forests, tropical rainforest and pine-oak forests, which host endangered species of conservation value, such as the jaguar, quetzal, and pavon. Average yearly rainfall is between 1000 mm to 4750 mm, with the latter zones representing the highest rainfall in the country. Altitudes range from 400 to 2750 m above sea level (masl), with coffee grown between 900 and 1800 masl. The main land use systems include shade-grown coffee, maize-bean cultivation, homegardens, and some livestock, with coffee being the sole source of cash for the majority of households. Some households receive assistance from government programs, but in our year of research this was reported to be very low.

Our main partner in the region is the coffee cooperative *Campesinos Ecologicos de la Sierra Madre* (CESMACH) which consists of over 400 farmer members who live in 30 communities nestled in the buffer zone of *El Triunfo* Biosphere Reserve. CESMACH was founded in 1994 by a group of farmers who participated in an organic coffee project implemented by the Reserve. The farmers formed the cooperative to eliminate dependence on *coyotes* (middlemen), provide an alternative to high interest rates from loan sharks, and to organize technical assistance for production and marketing of fair trade and organic coffee. As part of their overall mission, CESMACH seeks to organize farmer families to develop an alternative path to improved farmer livelihoods through agroecological production, social justice, and economic viability. CESMACH is a leading coffee cooperative in both the Sierra Madre and in Chiapas. They are known for defending their autonomy and independence in the face of unequal and top-down approaches (see Campos and Vazquez 2006 for a description of their relationship with Starbucks).

Due to the rugged terrain and limited roads, most of the communities are two to three hours from the coffee cooperative office and warehouse in the town of Jaltenango (aka Angel Albino Corzo). During the rainy season (June–October) many communities are periodically inaccessible due to floods and landslides damaging precarious rural roads. The four municipalities where research was conducted are classified as having "very high" levels of marginalization (CONAPO 2011).

Research approach and methodology

Research was guided by a participatory action research (PAR) approach, which facilitated a leadership role for the cooperative in the design, implementation and analysis of the research. PAR has its origins in social psychology (Lewin 1951), alternative pedagogy (Freire 2000), participatory development approaches (Robert 1983; Chambers 1994) and radical sociology (Fals-Borda and Rahman 1991). It emerged as a response to the top-down approach to research and rural development. PAR is a process that involves researchers and other social actors as participants in an integrated process of research, reflection, and action for the purpose of social change or the resolution of an identified problem (Bacon 2005). PAR differs from other research approaches in that it emphasizes the importance and legitimacy of local knowledge and participation in the identification of problems and solutions; is interactive rather than extractive; and the researcher is more a facilitator than a leader. PAR was a particularly relevant approach to our study because food security and agriculture are such complex, context-specific issues. Therefore, in order to begin to understand and analyze the dynamic interactions between diversity of land management and food, the farmer, and his/her cooperative need to be key protagonists in the design, implementation and analysis of the data. Furthermore, their participation ensured their ownership of the process, including the results, and hence an increased propensity to act on those results.

To analyze the relationship between agrobiodiversity managed by coffee farmers and their access, availability, and utilization of food we measured dietary diversity and months of inadequate household food provisioning (MIAFHP) and correlated this with data on species diversity (Ruel 2003; Swindale and Bilinsky 2006). Household surveys, developed in collaboration with CESMACH, consisted of open and closed ended questions and were conducted with 79 member households located in 11 communities of the cooperative, in 2012. These household were selected based on their participation in a recent agroecology and food security and sovereignty project implemented by the cooperative. We stratified the sample by communities, and within each stratum randomly selected from the pool of households in each community that participated in the project. Data were collected on a wide range of livelihoods information regarding social, economic, and natural assets and food security. A second round of household surveys and plant species inventories were conducted in 2013 with 33 households selected from a stratified sample based on level of food insecurity reported in the original survey. Authors returned in June 2014 to share and analyze data through reflection workshops and focus groups with cooperative staff and farmer communities. For this paper, we present data on natural assets, including agrobiodiversity, with an emphasis on food security.

Agrobiodiversity, represented by edible and nonedible plant and animal species richness and abundance as well as management practices, was surveyed within four main systems: coffee, maize and bean plots, homegardens, and livestock. Diversity of edible species in these land use systems was documented based on number of distinct edible plant and animal species, and varieties in the case of maize and beans, reported by farmers via the household surveys. In addition to household surveys, plant species inventories were conducted in coffee plots of 33 households. The plots were sampled by locating the central point of the coffee plots and then delineating a 20 × 50 meter sample plot. Within each of these plots the tree species richness and abundance were documented. The edible plant species richness of the understory was also surveyed, all of which consist of wild foods. All plants found in the coffee plots were identified with the help of the farmer and a plant biologist on the team.

The two food security indicators measured were: (1) Months of Inadequate Household Food Provisioning (MIAHFP); and (2) the Household Dietary Diversity Score (HDDS). The MIAHFP measures the availability of food and the HDDS measures both the access and utilization of food. MIAHFP was developed by the United States Agency for International Development to measure how many months, in a 12-month period, a household lacks enough food to meet their basic needs. It is a subjective metric whereby the interviewee judges how many months of the year their household perceives they do not have enough to feed their families with the foods they want. This measurement is relevant to coffee communities where hunger is experienced seasonally and provides a baseline understanding of the severity of a household's situation (Vaitla, Devereux, and Swan 2009). In the communities we studied, these months are called *los meses* flacos, or the thin months. This indicator is measured by asking the following two questions: *In the past 12 months, were there months in which you did not have enough food to meet your family's needs? If yes, which were the months (in the past 12 months) in which you did not have enough food to meet your family's needs?* These questions were followed by a series of open-ended questions that captured farmers' perceptions of the definition of food insecurity including what foods were in low supply during the thin months and what factors contributed to or mitigated the thin months.

The second food security indicator we measured was the household dietary diversity score (HDDS), which we adapted from Swindale and Bilinsky (2006). The HDDS represents the average number of food groups a household consumes in a week and hence measures relative access to a quality diet. The main food groups are cereals, roots and tubers, vegetables, fruits, meat/poultry, eggs, fish, legumes/pulses/nuts, dairy, eggs, oil/fats, sugar/honey. Upon review with the cooperative, we added two additional food groups: (1) wild leafy greens because they are an important part of the traditional diet; and (2) junk food, or *comida chatarra*, because of its increasing prevalence in communities. Within each food group we also asked what percentage of the food is sourced from subsistence production versus purchased on the market.

JMP Pro 10 for Microsoft Windows was used to produce statistics based on the household survey data and the plant inventory data. In order to examine the relationships between a household's natural assets and food security we conducted Spearman correlations. We used analysis of variance (ANOVA) to compare mean number of thin months across communities. Percentage shade cover in coffee plots was calculated using a densiometer.

Results

Food security

Number of thin months

Sixty-seven percent of households reported being unable to meet their family's food needs in the past year. The average number of months per year (MIAHFP) was 1.6 (with a range of 0 to 8 months) (Figure 2). Most families experienced shortages between the months of June and November. This time of scarcity comes after the maize and bean reserves have been depleted and before the next coffee harvest. It overlaps with an annual increase in staple food prices, as well as the annual rainy season, which causes flooding that limits physical access to food. Other factors contributing to seasonal hunger include low yields, volatile coffee prices, and impacts from climate change. These are all factors typical of seasonal hunger in other parts of the world (Vaitla, Devereux, and Swan 2009).

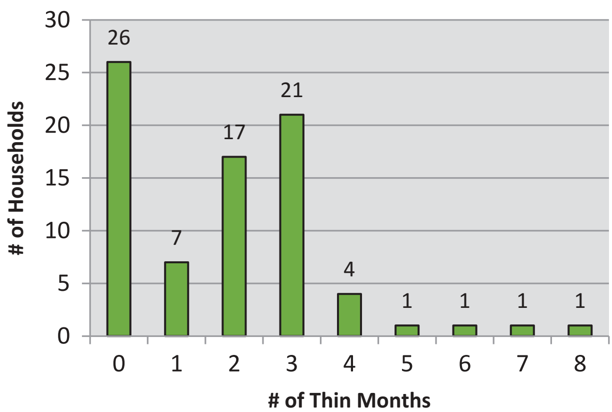

Figure 2. Number of households by number of thin months reported (n = 79).

Dietary diversity

Sugar, cereals (mainly corn tortillas), legumes (mainly black beans), and oil were the food groups with the highest rate of consumption per week, with a range of 5.4–7 days. Food groups eaten on average less than 3 days per week were eggs, wild leafy greens, vegetables, fruits, roots and tubers, meat, and dairy. Although there were families who ate these food groups more than 3 days per week, on average, diets are lacking in these important food groups. The average household is consuming 6.5 food groups in a week, represented by the mean dietary diversity score, with a range of 4–7.7 (Table 1).

On average, households were producing 37% of foods consumed and purchasing 61%. When we exclude those foods that either cannot be produced or are of little nutritional vaue (i.e. oils, sugar, coffee, and junk food)

Table 1. Household dietary diversity and % food produced versus purchased.

	Mean # days/ week	% produced on farm	% purchased
Grains/cereals	7	55	45
Coffee, tea	7	76	9
Sugar, honey	7	6	94
Pulses, legumes, nuts	6.2	57	43
Oils, fats	5.4	0	100
Eggs	2.7	50	50
Wild leafy greens	2.2	79	21
Vegetables	2.2	45	54
Fruits	2	38	59
Roots and tubers	1.3	43	57
Meat, poultry	1	22	78
Junk food	1	Na	Na
Fish	0.8	15	85
Milk and milk products	0.8	1	99
Mean dietary diversity score*	6.5	Na	Na
Mean % produced versus purchased	na	37	61
Mean % excluding oils, sugar, coffee and junk food	na	45	55

*does not include junk food

the averages changed to 45% produced and 55% purchased. Not surprisingly, the highest rate of production is for those foods that are part of the traditional diet: corn, beans, wild leafy greens, coffee, eggs, and to a lesser extent fruits and vegetables. Foods that have the highest rate of purchase are oils and fats, sugar, milk products, fish, and meat. Communities that are closer to the cities produce a lower percentage of foods consumed by their households, whereas communities that are more isolated, nestled in the mountains, produce a higher percentage of their foods. A Spearman's correlation showed an inverse, though somewhat weak, relationship between number of thin months and % of food produced ($r_s = -0.25$, $p = 0.18$, $N = 79$).

Agrobiodiversity

We collected data on agroecological farm management in three main land use systems: coffee, basic grains (bean and maize), livestock, and homegardens (Table 2). All of the farmers interviewed manage their land through the *ejido* land tenure system, a system of communal land management that was central to the agrarian reform of the Mexican revolution. Coffee is the main source of income and livelihood for farmers in our research site. They are all organic and fair trade certified (except for those who are in the process of transition to organic). Mean total landholding was 7.7 hectares. Mean total species richness was 23 and mean total edible species richness was 14 across all land use systems.

Table 2. Agroecological land use characteristics.

Coffee (*N* = 79)	
% of farmers with coffee	100
Mean area (ha)	4.9
Mean yield (quintales[4]/ha)	8.2
Total # of tree species	96
Mean # trees/ha	226
Total # edible plant species	20
Maize (*N* = 79)	
% of farmers with maize	43
Mean area (ha)	1.45
Mean yield (T/ha)	1.02
Bean (*N* = 79)	
% of farmers with beans	34
Mean area (ha)	0.8
Mean yield (T/ha)	0.66
Milpa (*N* = 79)	
% of farmers with milpa	22
Mean area (ha)	1.5
Mean yield (kg/ha)	Maize: 942 Bean: 382
Homegardens (*N* = 33)	
% of farmers with homegarden	76
Mean area (m^2)	1690
Mean # edible plant species	6.8
Total # of edible plant species	52
Livestock (*N* = 79)	
% of farmers with livestock	77
Mean (heads)	15

Coffee

Farmers manage a high level of diversity in their coffee plots, including at least 20 edible species of green leafy plants in the understory and fruit trees, which provide shade. Species of green leafy plants include *hierbamora (Solanum nigrum), hierba santa (Piper auritum), quishtan (Solanaceae), chipilin (Crolataria longirostrata), chilillo, tomate de arbol*, and *pacaya* (*Chamaedorea tepejilote*). All interviewed farmers use one or more of these species in their diets. Because most of these plants grow wild in the rainy season, which overlaps with the hunger season, these plants represent an important safety net. Furthermore, many of these species are high in micronutrients, such as iron, folic acid, and vitamin A, which households get very little of from other food sources in their diets (Bye and Linares 2000; Mera Ovando, Castro Lara, and Bye Boettler 2011). Other edible species grown in coffee systems include fruit trees such as avocados, oranges, limes, guava, and peach.

We also found a high diversity of shade tree species, including 96 identified species in the total area surveyed. The most common species were chalum (*Inga oerstediana*), caspirol (*Inga punctata*), trompillo (*Ternstroemia tepezapote*), and huachipilin (*Diphysa robinioides*). The average degree of shade was 53%, with a wide range from 24% to 83% shade on some farms. Coffee systems managed in this region can be classified as a mix of 'rustic' and 'traditional polycultures' according to the Moguel and Toledo (1999) typology. Both of these systems consist of highly diverse and complex wild and cultivated plant species distributed in a multistory system.

We used Spearman's correlation to analyze the relationship between farm diversity in coffee plots and our food security indicators. We found a significant, inverse relationship between total plant abundance in coffee plots, measured by actual number of individual trees, and the number of thin months (Spearman $r_s = -0.4$, $p = 0.02$). This was not a function of landholding size because total plant abundance was calculated based on the same area for each household (50 × 20 meter plots). Similarly, as species richness/farm diversity in coffee increased, measured by number of edible and nonedible plant species in sample coffee plots, the number of thin months significantly decreased (Spearman $r_s = -0.39$, $p = 0.03$). Farmers are also dependent on this biological diversity in their coffee plots for products such as firewood, timber, and medicinals, as well as essential supporting services such as nutrient cycling. An increased asset base of this type may be indirectly contributing to a household's increased food security. No significant correlations were found between farm diversity in coffee plots and dietary diversity.

Basic grains

Maize and bean are the staple foods in these communities. However, 30% of farmers do not produce any maize or beans. Most of these farmers have transitioned their maize and bean plots to coffee. The 70% who do produce these basic grains either have only maize, only beans, both maize and beans cultivated separately, or both maize and beans cultivated in the traditional *milpa* intercropping system. The *milpa* system integrates a diversity of species such as maize, beans and squash. This system has been traditionally managed through shifting cultivation (swidden agriculture), whereby small areas of fallow land or forest are cleared, burned and planted for several years before returning to a long fallow/forest period. In our research sites, this practice is diminishing because of regulations around fire management and a decrease in the amount of land available for an increasing population. Management practices in the basic grain plots incorporate agroecological techniques such as crop rotation, cover crops, intercropping, live fences, and compost. Few farmers reported the use of synthetic inputs, with 15% using fertilizers, 15% using herbicides and 5% using pesticides. Only one farmer used hybrid maize and bean seeds distributed through the government. The rest of the farmers use *criolla* or native seed varieties that are saved, from year to year, and exchanged within the community. Farmers named 18 native varieties of maize and 19 of bean used in the 11 communities we surveyed. In a focus group, farmers identified 17 species of wild and cultivated edible plants harvested from the *milpas*. Thirty-two percent of

Table 3. Spearman correlations for basic grain production and food security indicators.

	# of thin months (N = 79)		Dietary diversity (N = 79)	
	r_s	p	r_s	p
Maize production (kg)	−0.21	0.07	na	na
Bean production (kg)	−0.29	0.01	+0.2	0.09

farmers who produce maize produce enough to meet their maize consumption needs for the entire year. Twenty-six percent of farmers who produce beans produce enough to meet their bean consumption needs for the year.

We conducted a Spearmen's correlation that showed a significant inverse relationship between number of thin months and maize and bean production as well as a strong positive correlation between bean production and dietary diversity (Table 3).

This suggests that household's who produce high quantities of maize and beans are better able to meet the food needs of their families for the year. Households who do not produce enough are not able to fill this gap by purchasing maize and bean on the market and hence are more likely to suffer from months of scarcity.

Homegardens

Homegardens were present in 75% of the 33 farms we visited in the second phase of research. They contained an average of 6.8 species and we documented a total of 52 different edible species represented by fruit trees, vegetables and herbs. Among the most common species are avocados, onion, chilies, cilantro, banana, lime, orange, rue, and tomato. Most annuals are grown during the dry season from October to May when there is less pest pressure and less rain, which limits growth. However, some households are beginning to experiment with growing annuals during the rainy season, which is also the hunger season, under hoop houses. Our Spearman's correlation did not show any strong correlations between homegarden diversity and food security indicators (MIAHFP and HDDS).

Livestock

The majority of households have chickens in their homegardens or backyards, which are used to produce both eggs and meat (Table 4). As seen in the dietary diversity score, eggs form an important part of the diet, as a source of protein. Less common are turkeys and ducks, which are important meats during festivals and holidays. Some households have horses and donkeys, which are used to carry out the coffee harvest, an essential service that increases efficiency and reduces the burden for the farmers, who would otherwise have to carry these 50 lb bags on their backs. Horses and donkeys

Table 4. Livestock type and quantity.

	Chickens	Turkey	Duck	Cattle	Horse	Donkey	Sheep	Fish pond
Mean	17	3.6	9	6	3	1	12	1
% of farmers	77	13	8	6	3	3	1	1

are often shared in communities. Spearman's correlations did not find any strong correlations between livestock diversity and food security indicators.

Total agrobiodiversity in all land use systems

We analyzed how total agrobiodiversity, measured through species richness, correlated with our food indicators. To do this we used two distinct measures of species richness. The first represented all the distinct species identified through our surveys, whether edible or not, in the following systems: coffee, basic grains, homegardens, and livestock. The Spearman's correlation showed a strong significantly inverse relationship, whereby as species richness increased, number of thin months decreased (Spearman $r_s = -0.5$, $p = 0.0048$). The second measure of species richness represented only the edible species identified in all of the systems. The Spearman's correlation also showed a strong inverse relationship whereby as edible species richness increased, the number of thin months decreased (Spearman $r_s = -0.38$, $p = 0.03$). Although there was no significant correlation between dietary diversity and farm diversity, there was a strong correlation between the percentage of household food produced on farm and farm diversity (Spearman $r_s = 0.3$, $p = 0.04$), which indicates that households who produce most of the food they consume are also managing higher levels of farm diversity.

Discussion

Agrobiodiversity and thin months

Total farm diversity was strongly correlated to a decrease in number of thin months. In coffee plots this correlation was significant for both number of individual trees and number of plant species. As the total plant abundance in coffee plots and species richness in coffee plots increased, the number of thin months decreased. Farmers were dependent on the biological diversity in their coffee plots for other provisioning services, such as firewood, timber, and medicinals, as well as supporting services such as nutrient cycling, and in particular biological nitrogen fixation. Many of the tree species in farmer plots are nitrogen fixers, providing accessible nitrogen in the soil for coffee plants to absorb, potentially contributing to improved health and yields. An increased asset base of this type may indirectly contribute to a household's increased food security. This supports other findings that show the indirect contributions of biodiversity to food security (Rasolofoson et al. 2018; Sunderland et al. 2013), although this relationship has not proved to be consistent everywhere (see, for example, M'Kaibi et al. 2017).

Maize and bean production were significantly correlated with a decrease in number of thin months. Farmers who produce their own maize and beans fare better in the seasonal hunger months than do farmers who do not produce maize and beans. Indeed, farmers who do not produce their own maize and beans reported having a higher number of thin months. Other studies in coffee communities of Mesoamerica found a similar trend (Eakin, Tucker, and Castellanos 2006; Jaffee 2007). Several sources state that farmers in Mesoamerica believe that subsistence production, specifically maize and beans, is an essential livelihood strategy and a buffer to risks (Bacon 2005; Eakin 2005; Jaffee 2007; Ponette-González 2007). Jaffee (2007) found that farmers increased their area under subsistence production as a response to the coffee crisis. Given that farmers' livelihoods are dependent upon cash from a volatile coffee market as well as a volatile basic grain market (Bacon et al. 2014), cultivating basic grains, even if not enough for the whole year, provides a safety net for household food security. Hence, maize and bean production can serve as a key risk management tool for the inherently tenuous livelihoods of small coffee farmers in Mesoamerica. Furthermore, the continued production of maize and beans, despite its lack of profitability from an economic perspective, has been shown to be linked not only to risk management and maintenance of a safety net, but also to deep cultural significance of the production of maize and *milpas* (Isakson 2009; Perreault 2005; Ponette-González 2007).

Although our paper did not specifically address the role of diversity of landraces of maize and beans on food security, other research has shown the importance of this diversity for farmer's livelihoods (Lerner and Eakin 2011; Olson, Morris, and Méndez 2012; Thrupp 2000). As the center of diversity for maize, Mesoamerican farmers, including coffee farmers, rely on native varieties of maize and beans for their *milpa* plots. Varieties are chosen for a number of reasons including length to maturity, resistance to pests, tolerance to droughts or floods, taste, color and culinary traits. The high levels of native maize and bean diversity in this region reflect the long process of co-evolution between crop varieties and local human populations. Thus, traditional farming systems based on high levels of biodiversity, including crop diversity, are an integral part of socio-cultural systems. Maintaining these traditional seed systems help maintain autonomy from seed companies that promote industrialized production and can provide a wide range of traits that build resilience and adaptation to climate change.

Agrobiodiversity and dietary diversity

One determining factor of nutritional quality is the cultural significance and value placed on certain foods. Mexico has strong and deep cultural ties to food and culinary traditions. At the same time, consumption of highly processed food and associated diet-related diseases such as obesity and diabetes are rising at unprecedented rates (Rivera et al. 2002). In our study site, rates of consumption of "*comida chatarra*" or junk food, were quite low. Respondents were asked how many days a week they consumed junk food. 63% did not eat any, and the average number of days for those who did eat junk food was 1.5 days per week. However, concerns of a nutrition transition are being vocalized in the region given the stark national trends.[3] In fact, CESMACH hosted a series of workshops addressing the health impacts of junk food and has implemented projects that promote the cultivation and use of native wild foods like pacaya.

Our study identified 20 distinct wild food species, most of which are leafy greens, but also palm flowers, snails and mushrooms. These foods may be important for overcoming micronutrient malnutrition and mitigating a nutrition transition because they are believed to contain high micronutrient levels not found in other foods consumed in the typical diet of this region (Bye and Linares 2000; Mera Ovando, Castro Lara, and Bye Boettler 2011). Furthermore, many of these wild foods are nontimber forest products (NTFPs) with preferred growing conditions under the shade of a forest canopy, providing an incentive to conserve forests (Anold and Perez 2001) and/or grow coffee under shade. Consumption of these foods is so prevalent in our research site that in designing the dietary diversity questions for the survey, the cooperative insisted that wild foods be considered as a separate food group. Indeed, throughout Mexico, these foods, known generally as *quelites*, are an important part of the diet, with over 350 species identified across the country (Bye and Linares 2000; Mera Ovando, Castro Lara, and Bye Boettler 2011). In our study site, all households consumed wild foods, regardless of wealth or severity of seasonal hunger, something that suggests their value as part of the traditional diet.

While total agrobiodiversity was correlated with a decrease in number of thin months, where availability and quantity of food is being measured, we did not find a significant correlation between total agrobiodiversity and dietary diversity, which measures quality of the diet. This suggests that households may not be using all of the diversity of foods grown on their farms. It also suggests that other livelihood factors have a stronger influence on dietary diversity. If households are not making full use of their farm diversity, at a potential cost to the diversity of their diets, then nutritional education and a revaluing of the nutritional contributions of this farm diversity could be an important factor to improve food security (Johns et al. 2013). Nutritional education should look to revitalizing and revaluing local traditional cuisines by identifying community members with the knowledge to support this process. Dietary diversity may not have been

[3]Mexico recently surpassed the United States as the number one consumer of soft drinks and has the highest rate of obesity in the world.

strongly correlated to agrobiodiversity because of the timing of collection of this data. We collected dietary diversity data in November and December when most households are able to meet their food needs and therefore diets across the population are more similar than during the thin months. Future research should collect food security data during the seasonal hunger months. Some households in our sample have very little farm diversity but have sufficient access to cash to provide a diverse diet for their families. On the other hand, some households have high levels of farm diversity as well as high dietary diversity. However, there are many confounding factors that lead to these scenarios not always holding true. The relationship between agrobiodiversity and food and nutrition security is complex and other livelihood factors as well as larger structural issues are at play. These nuances raise the important question of how farmers balance subsistence production with market based production and what are the determining factors for a quality diet.

Balancing plural economies and food security for improved food policies

Farmers' livelihoods in our research site balance subsistence and market oriented agriculture (semi-subsistent agriculture). Our research shows that, on average, 37% of food consumed by households is produced on-farm. When we omitted sugar, oils, and coffee, in order to gauge what percentage of the food that has the potential to be grown in the region is actually grown and consumed, the percentage increased to 45%. Although there was no strong correlation between the percentage of food produced and food security, it is an important question to continue raising in the many communities around the world that directly rely on natural resources for their food security.

Mainstream development policy often promotes increased cash crop production as a measure to improve food security in subsistent or semisubsistent rural households in the global south, but this strategy has had mixed results on food security (Anderman et al. 2014; Maxwell and Fernando 1989; VonBraun 1995). Some studies show that a transition from this mixed livelihood to one that is more dependent on a cash crop without the subsistence safety net, can increase vulnerability of households to food insecurity (Anderman et al. 2014; Jones, Shrinivas, and Bezner-Kerr 2014). There are several key factors that determine whether or not this transition can improve food security, including: (1) women's control over income; (2) ability of local food markets to provide nutritional and affordable foods; and (3) price stability of cash crops sold and of staple crops sought for purchase. Hoddinott and Haddad (1995) found that when women administer household income, child nutritional indicators improved. Gender inequality, domestic violence, and alcoholism are pervasive problems in our study site

[4] 1 quintal = 57.5 kg.

and directly impact the amount of money made from coffee sales that goes towards food for the household. When cash is available to purchase food, physical access can be a challenge due to the isolation of communities and lack of local markets. When local markets are available, the quality of the food can be poor, with most products consisting of sodas and snack foods, and no or very little fresh fruits and vegetables or grains/legumes. The safety net of subsistence agriculture needs to be valued as an important part of rural farmers' livelihood portfolio directly contributing to food security.

Two important studies in Mesoamerica that look at agrobiodiversity and food security conducted by Perreault (2005) and Isakson (2009) ask why high levels of agrobiodiversity exist even when households have been integrated into local, regional and global markets for decades. Two important reasons reported were that: (1) on-farm agrobiodiversity provides a buffer against market volatility and (2) higher diversity can contribute to for food security in areas with varied ecological conditions. These reasons are supported by the widely accepted theories from agroecology and livelihoods fields that more diversified production systems and a more diversified livelihood result in decreased vulnerability and increased resilience (Altieri and Toledo 2011; Amekawa 2011; Ellis 2000; Scoones 1998).

Conclusion

Results from this research contribute to a growing body of evidence that agrobiodiverse landscapes can contribute to food and nutrition security. The challenge is to identify context-dependent strategies and policies that support and promote practices that link agrobiodiversity conservation and rural livelihoods. Our research identified three important themes that merit further research and development attention as follows:

(1) The relationship between agrobiodiversity and food security is complex, but our research and that of others shows it to be an important relationship with potential to support food security efforts in smallholder farming communities.
(2) Food production for consumption by farmers producing commodity/cash crops is important for food security, and should be better supported by development and food policy in combination with support for cash crop production.
(3) Certain types of agrobiodiversity, like *quelites*, which have been largely ignored by food and development policy have great potential to support food and nutrition security, and may offer nutritional resilience in the face of global environmental change (Powell et al. 2013; Termote et al. 2014).

Due to the volatility of the coffee market, the high prices of food, the inadequate quality of food, and the limited availability and access (economic and physical) to food produced inside or outside the communities, strategies that strengthen local food systems are essential to improving livelihoods. These strategies may include improved access to productive resources, in particular native seed varieties, and improving overall agroecological management of the different land use systems, including basic grains, wild foods, and homegarden production. Since low dietary diversity can contribute to macro and micro nutrient deficiencies, diversity of food production and participatory nutritional education are also key. The potential for high levels of agrobiodiversity and food security to coexist will also be affected by the existence of supportive policies and development interventions that enable farmers to maintain the socio-cultural processes that support the production of agrobiodiversity. In the context of coffee farmers in Mesoamerica, there is reason to be optimistic. Despite market integration, which often leads to decreases in farm diversity, many farmers in this region continue to manage agrobiodiverse farms as a part of their socio-cultural structures and values. Farmer movements in the region, such as Via Campesina and their member organizations, as part of their platform for food *sovereignty*, are advocating for a system that integrates nature's rights and human rights for a more ecologically resilient, socially just and economically fair agrifood system. Academics and policy makers need to move beyond the single, silver bullet solutions toward holistic systems-based approaches that also value the multiple benefits of agrobiodiversity. Strategic alliances between different actors – farmers, government, academics, nongovernment organizations – can help produce evidence-based and context-specific approaches that influence policies in order to promote agroecology and food sovereignty for sustainable livelihoods and food and nutrition security.

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