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# INTERCONNECTIONS OF AGROBIODIVERSITY AND FOOD SECURITY IN RURAL YUCATAN, MEXICO

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by

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# Table of Contents

# List of Figures

# List of Tables

# Abstract

**Interconnections of Agrobiodiversity and Food Security in Rural Yucatan, Mexico**

**Devon D. Sampson**

Biodiversity conservation and food security are often assumed to be separate or conflicting issues. In the municipality of Tzucacab, in a rural corner of Mexico's Yucatan peninsula, I found that crop diversity and food security are deeply intertwined. I measured food security and home garden agrobiodiversity on a randomized selection of sixty smallholder farms in the municipality, conducted ethnographic interviews over a period of four years, and collaborated with six high school students on a participatory photography project documenting local food culture. From the quantitative data, I found that crop diversity is the strongest predictor of household food security during a drought in the rural municipality I surveyed. This finding indicates that maintaining high levels of agrobiodiversity can be an important strategy for subsistence farmers to buffer their food supply against the risk of crop failure. Additionally, I found evidence that diversification of the home garden is one important strategy managing risk among a complex of several approaches to livelihood diversification. The finding helps to explain why some farmers conserve diversity while others do not, and suggests that the goals of agrobiodiversity conservation and rural food security might be better addressed together. These results point to the ability of small-scale, diverse farms run by

*campesino* farmers to feed themselves, challenging the dominant discourse and practice of development that prioritizes increasing yields above all other properties of agroecosystems.

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Figure 1 *La Comida [The Meal]*. Leonor Dzul Uc, 2011.

# 1. Introduction

## *A sense of plenty*

The best way I know to share a sense of a place is to share a meal, so I offer this photograph of a Sunday lunch. It was taken by my collaborator Leonor Dzul Uc at her neighbor's house, in the first moments of a meal with family members who are home from their jobs on the Caribbean coast for a long weekend. The sense of plenty is visible. Tortillas, as always, are the staple, eaten in this case with *alambre*, a Northern Mexican dish, along with a radish relish called *salpicón*. Machine-made tortillas and a plastic pouch of tomato sauce join home cooked meat and fresh garden vegetables on the table; there is no purity of origin in this meal. Rather, it spans cultural identities and draws on the products of several livelihood activities, including the home garden but also tourist industry wages. It is not a traditional meal or typical everyday food, but a special occasion; a moment when sharing good food weaves and reinforces social ties that in turn shape food security. It is a premise of this thesis that even in an indigenous community like Tzucacab we would do better to loosen expectations of local self-sufficiency, and approach both food security and conservation as a contemporary form of adaptation.

I've felt this sense of plenty at many meals in Tzucacab. I remember, especially, a birthday lunch of *po'oc chuuk*, thin slices of pork marinated in bitter orange, garlic and annatto that ten of us ate nearly in silence, it was so good. And, a simple meal of scrambled eggs with *chaya,* (*Cnidoscolus aconitifolius*) a perennial leafy green, spooned onto tortillas and eaten like tacos, served proudly and generously by a friend who will appear later in this manuscript after several visits during which she had very little food to offer us. I vividly remember the gelatinous soup *ko'ol*, thickened with starches extracted from corn masa and flavored by chicken organs, made by two dozen women for a ceremony to bless a new school garden. I even felt that sense of plenty eating tacos made from wild peccary (*Pecari tajacu*), topped with chopped radishes and salt, with a family that in a previous interview had told me that they never hunt. Leonor, after her project of photographing lunch with several families, said that she was surprised that they were eating dishes like the *alambre* that she had never heard of. With rich and varied ingredients and recipes, and equally rich food traditions, there is no shortage in rural Yucatan of that sense of plenty.

This dissertation is about what lies behind that sense of plenty. While for me these homemade meals have always been easy to appreciate, it took learning to look closer, to see the hard work, skill, knowledge, ingenuity, and strategies that make them possible. My research focuses mostly on the strategic ways that households use a diversity of plants and animals to make a living in an environment where rainfall, storms, and food and input prices have always been unpredictable and are becoming more erratic. In poverty, and in uncertainty, piecing together a livelihood takes a strategy. Strategy happens in the kitchen, even though women's work and knowledge is even more invisible in Tzucacab than the work that men do at their *milpas* far off in forest. Leonor Uc photographed 22 steps in the process of turning dried maize into tortillas, making visible her mother's and aunt's exacting skill and knowledge. It happens in small business. Joel Gongora, another young collaborator, photographed his father's fruit tree business, from careful grafting to negotiation and sales. The photographs capture his father's care and close observation, they radiate pride in this work. It happens in migration. It is rumored that 10,000 people from the neighboring municipality of Peto now live in San Rafael, California, and a greater number of people from nearby live in San Francisco. When my collaborator Chelsea Wills, two of the photographers, Leonor and Gilberto Jimenez Chi, and I took the exhibition on a speaking tour in California, we heard countless stories of migration. These were often framed in the form of advice to Leonor and Gilberto, should they want to try working on the other side of the border: keep your goals in mind, know exactly what you want to invest in at home—a house, land, a business. In other words - be strategic.

Learning to see strategy and skill upends many assumptions about rural, poor, and indigenous people. For instance, the idea that migration is a simple matter of fleeing a place with no opportunities is shaken by the realization that often, money earned abroad is invested in homes, farms, and livelihood opportunities in rural places. The idea that traditional farming is unchanging or inherently conservative is undone when one sees the many ways 'traditional' farmers experiment, innovate, and evaluate new technologies. At the same time, some strategies are informed by experiences and experimentation that takes place over multiple generations, encoded into 'traditional knowledge'. In Chapter 4 of this manuscript, we see traditional knowledge and contemporary experimentation at work in one farmers' effort to protect her family against hunger. Looking a little closer at livelihood strategies reveals deep and agile knowledge.

In fact, many agroecological practices that are part of successful strategies for survival have been dismissed by outside observers as inefficient or backwards, only later to be re-described as strategic and adaptive by people who are at once privileged enough to have a voice in the scientific sphere and patient and skilled enough observers to connect the dots. Fire is an effective and, in many ways, efficient tool in cycling between forest and *milpa* fields in Yucatecan shifting cultivation (Hernández Xolocotzi 1995). While growing corn, beans and squash together may look like a haphazard tangle, it can produce not only more food in total but more corn than growing the same crops in neat monocultures (Amador and Gliessman 1990; Gliessman 2007). Growing potatoes in ten or more separate plots may seem inefficient, but it offers lifesaving insurance against crop damage from frost (Goland 1993). Seeing the logic and strategy imbedded in an agroecosystem that looks and functions differently from those that we are used to requires a skill of close observation, often over long periods of time, and a capacity to synthetically understand many moving parts. *Campesino* farmers are, in my estimation, the worlds' masters of these skills; to the extent that I have been able to apply them in this dissertation, I have to credit them as my teachers. I have learned from the best.

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What is the relationship between agrobiodiversity and food security? It is an interdisciplinary question. Both components—agrobiodiversity and food security—are complex and dynamic, difficult to fit into any neat causal relationship. The fact is, there is no truly independent variable for food security, and there is no truly independent variable that explains agrobiodiversity. Both are outcomes of complex, changing processes and multiple causalities. I think this is a large part of what attracts me intellectually to entangled human-nature interactions: it is complex, and it matters. In this dissertation, I do find strong evidence that high levels of agrobiodiversity contribute to greater household food security in Tzucacab, at least at the time of measurement in late 2011. Agrobiodiversity does seem to be causing food
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security.  However, I go on to complicate this finding with another question: what explains the large differences in agrobiodiversity between households?   Finding that the factors that I considered the most likely drivers of agrobiodiversity—income, farm size, the available labor in the household—were weak predictors of agrobiodiversity at best, I started to wonder whether it was possible that food security might also play a role in farmers' decisions that affect agrobiodiversity.  I heard many stories about why some people had stopped growing certain crops, and often, it was to reallocate labor to earning wages or raising cattle, rather than diversified farming, and this was often a decision of desperation.  It seemed possible that diverse farms depend in part on household food security as much as household food security depends on agrobiodiversity.  Rather than a simple, unidirectional causality, there may be a positive feedback loop between agrobiodiversity and food security.  And, the whole complicated context of multiple livelihood activities is implicated in both.

In this messy context, I ask the reader for patience as I try to find signals within noisy data sets.  At the time I began fieldwork, there were no empirical studies that linked agrobiodiversity to a reduced chance of going hungry with quantitative data; that specific question was untested and the appropriate methods for testing it had to be adapted or invented.  I do my best to rigorously test hypotheses in this research, using a randomized household selection and a sample size that provides adequate statistical power to draw robust conclusions, and complimenting the quantitative study with qualitative data.  However, readers looking for conclusive, indisputable evidence that agrobiodiversity drives food security will be disappointed.

My data is too noisy, my measurements too subjective, my time frame too short, my sample size too small. Instead, my hope has been to open room for inquiry into questions about hunger and biodiversity that to me seemed neglected. What is agrobiodiversity for? Under what conditions is it most important? To whom does it matter most?

Since I designed this study and left for Yucatan, publications on the link between agrobiodiversity and human nutrition and food security have accelerated (e.g., Arimond et al. 2010; Frison, Cherfas, and Hodgkin 2011; Scurrah et al. 2012; Fanzo et al. 2013; Boedecker et al. 2014; Jones 2014; Jones, Shrinivas, and Bezner-Kerr 2014). These studies focus mainly on nutritional adequacy, not the risk of hunger; they use many different conceptualizations of food security, operationalized in many different ways, from caloric sufficiency to dietary diversity; and they reach contradicting conclusions, finding positive, negative, and no effect of agrobiodiversity. They are laying the groundwork for future work by experimenting with approaches and methods. At a recent panel on agrobiodiversity and food security at the Association of American Geographers conference, panelists all spoke of the difficulty of unearthing causal ties amid the complexity human-natural systems. Andrew Jones, a panelist who works in public health, said that in his field the expectation is that causal chains are short, one cause making its mark on human bodies. But there are many causal steps and mediating processes between agrobiodiversity and human health, or for that matter, the chance of going hungry. Carl Zimmerer, another panelist, suggested that political ecology and especially the study of how people become more or less vulnerable to disasters could inform our efforts to trace causalities. This area of inquiry is in its experimental stage, and I believe the results and analysis in this dissertation help push it towards more powerful and farther-reaching research. I further discuss future research in the conclusion.

I draw primarily on ecology, economic anthropology, and the already-interdisciplinary discipline of agroecology for this dissertation. Specifically, this work is informed by the literatures on biodiversity and ecosystem functioning/services in ecology, rural livelihoods and vulnerability in political ecology, and risk in economic anthropology. Below, as I introduce the ideas of agrobiodiversity and food security, I also give some background on these areas of scholarship. An inquiry into the relationship between agrobiodiversity and food security asks for action, since conserving agrobiodiversity and strengthening food security are goals. They both address urgent problems that, by their global reach and longstanding history, can seem intractable. Agroecology is, as my thesis advisor often reminds audiences of researchers, a change science. I take a participatory action research (PAR) approach to this research, and I describe by implementation of PAR and theory of change in the conclusion. First, though, I set the scene for this investigation.

## *In the middle of fertile ground*

'Tzucacab' the Mayan name for this mostly Mayan farming town in the south of Yucatan State translates roughly to "in the middle of fertile ground". My understanding of the place comes from many trips to Tzucacab between 2009 and 2014, including an intensive period of research in 2011. In the course of conducting interviews, collaborating with young researchers, and leading a field course for undergraduate students, Tzucacab became a unique place for me, but my impression on my first trip to Tzucacab was that it felt like it could be anywhere poor and rural. It was not remarkably isolated or exotically traditional, nor was it particularly well connected by immigration to the United States like some neighboring towns. It had no tourist attractions. People here have diverse agroecosystems and struggle with food security, as they do in many out-of-the-way places in the world. It is a rural place in what has been called the urban century.

People call themselves Maya here, and Yucatec-Mayan is spoken in about 93% of households in the municipality (Becerril García 2010). Nearly everyone (and all participants in the study) has a home garden, some complex and extensive and others very small. In addition, about 71% of households have a *milpa* (swidden field) where they grow maize in combination with other crops (*ibid.*). Slightly more than one third of the population lives in the main town, also called Tzucacab, that is located near to one of the major highways on the peninsula, and the rest, live in thirteen smaller villages in the municipality. The farthest villages are relatively remote, an hour and a half drive from town on poor roads, along the border of Quintana Roo state.

Agriculture is a mainstay of most livelihoods here, but very few households of the sixty in our quantitative study relied on agriculture alone. Most households were engaged in at least one non-agricultural activity that contributed economically: a member of the household working for a wage locally (41% of households in our study) or in regional cities like Cancun (30%), or making and selling prepared foods or crafts (20%). In addition, 72% of households in the study, (and 78% of households in the municipality (INEGI 2012) receive direct assistance through *Oportunidades,* a conditional cash transfer program aimed at the rural poor, in bimonthly payments that people generally described as important but not enough to ensure that there was always enough for their family to eat.

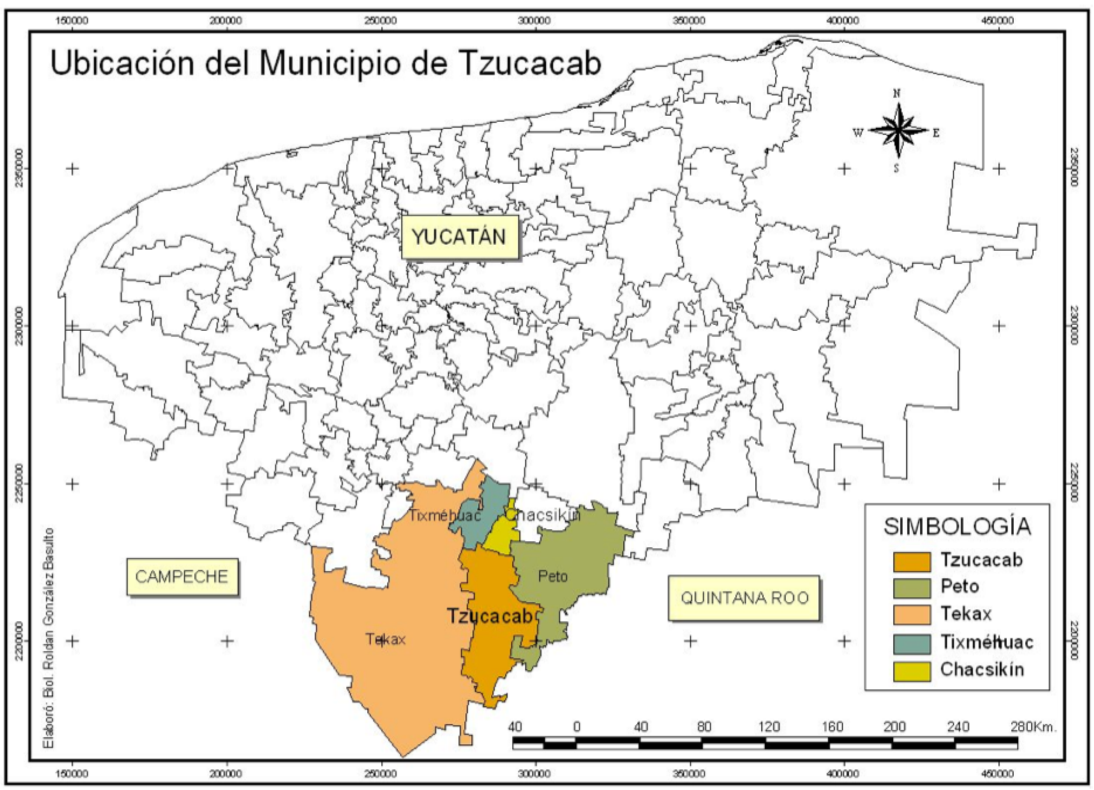


Figure 2. Location of Tzucacab Municipality in Yucatan State (PROTROPICO 2010, 7)

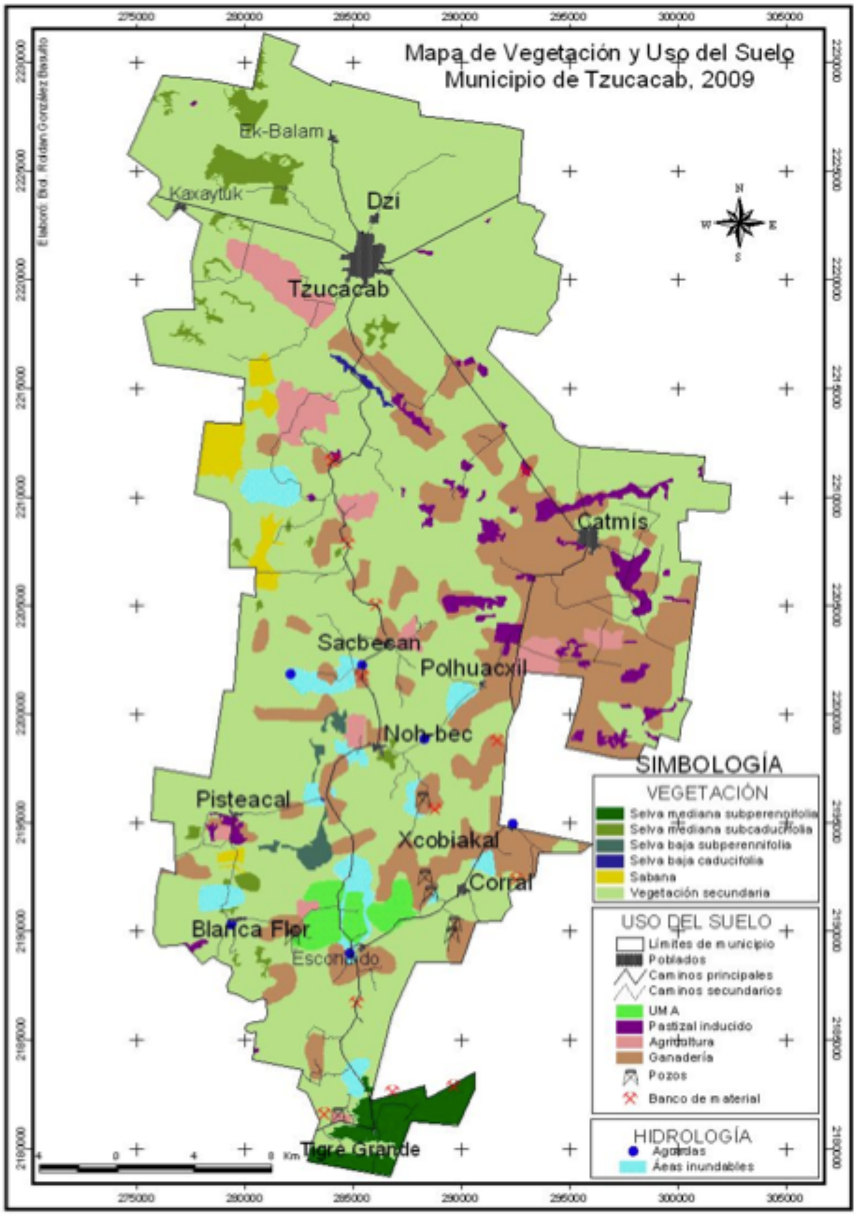


Figure 3. Map of vegetation and land use in Tzucacab municipality, showing the main town of Tzucacab and the 13 villages (PROTROPICO 2010: 26).

### *A brief history of agrobiodiversity and food security in the Yucatan peninsula*

The Yucatan peninsula has a complicated history with agrobiodiversity and food security. The rocky limestone soils and unique hydrology of the peninsula, where rivers run underground and are accessed only where *cinotes* (sinkholes) form, probably has something to do with this history, so much so that Nelson Reed opens his book on the bloody "caste war" rebellion of the mid $19^{th}$ century this way: "The death of billions of Tertiary and Holocene creatures; their deposit at the bottom of a warm, shallow sea; their formation into one great limestone bed; the eventual rising of that mass above water to become the peninsula of Yucatán—these remote events helped to shape the troubles of 1847." Over the estimated 8,000 year history of human-nature interactions on the peninsula, the climate, population, social organization, and kinds of agriculture have all shifted several times (Haug et al. 2003; Allen and Rincon 2003). The introduction of maize from the central Mexican highlands about 5,000 years ago surely affected livelihoods and diets, but it wasn't until traders brought differentiated maize varieties back from the Andes and crossed the two lineages that the resulting larger ears of corn could become a staple. That development, along with the import of tools made from volcanic rocks needed to clear and burn land for shifting cultivation and the technology of using burnt limestone to nixtamalize corn, made tortillas, tamales, and other maize-based foods the staple (Nigh 1976). The shift from mostly hunting and gathering to mostly agriculture may also have been an adaptive response to a period of high climactic variability and frequent droughts starting about 4,000 years ago and lasting about 1,500 years (Ford and Nigh 2009). During this time, populations concentrated on hilltops and other places where water could be gathered and stored (Fedick 1989). The Classic Maya civilization rose during relatively stable climactic conditions (Ford and Nigh 2009). The major cities built during that period were abandoned between 750 and 950 A.D., during which time several severe droughts were recorded in fossil records (Haug et al. 2003). The causes of the abandonment of the Classic Period cities continue to be debated by archeologists.

European contact and colonization changed the composition of home gardens. In our study, the most common taxa that we found in home gardens—citrus, chickens, pigs—were brought from Spain early in Yucatan's colonial history. The structure and function of home gardens, on the other hand, seems to have stayed largely intact (Mariaca-Méndez 2012). Colonialism did bring large-scale industrial monoculture to the peninsula. In the deeper, less rocky soils of the south, where Tzucacab is, sugarcane was the preferred cash crop starting in 1823. In the rockier soils of the north, the native *Henequén* plant (Sisal; *Agave fourcroydes*), long grown in home gardens and used for its fibers, did much better. It was grown on a plantation for the first time in 1833 and the sisal industry became Yucatan's largest employer by 1846 (Reed 2002, 9–10). Both industrial crops required large amounts of labor, which was orchestrated in a system of debt peonage and controlled by *hacienda* owners: debt was paid by labor, and failure to pay was punished by servitude (*ibid*, 12).

While the diverse, adaptive home garden agroecosystems require invested, skilled and knowledgeable labor, monoculture plantations require a different labor mobilization strategy, as workers alienated from the outcomes are not likely to work without coercion. Labor can be coerced into the repetitive tasks of tending monocultures, and laborers can be quickly replaced for low-skill jobs, but it would be much more difficult to coerce the careful observation and agility required for diverse agroecosystems. This history of large-scale monoculture begins with colonialism and is entangled with slavery, peonage, and the enabling ideology of racism (Tsing 2005, 167).

Rebellion broke out in Yucatan in 1847, starting a "caste war" along the lines of race and class that would last 54 years, or, according to some Mayan rebels, much longer (Reed 2002). At the beginning of the conflict the Yucatecan military and parts of the Mayan rebel movement negotiated. Coincidentally, talks were held in what was then the small frontier village of Tzucacab. Rebels demanded an end to various taxes, freedom from debt, and a right to farm the land, among other stipulations. The agreement quickly collapsed due to divisions in the Mayan militias (*ibid.* 98). By 1850, the population of Yucatán had been reduced by more than 40 percent, and as much as 75 percent in the southern regions. Some were dead, many of those from starvation. Others had fled into the thicker jungles to the south and east (*ibid.* 141), where the rebellion continued until long after the war officially ended with the conquest of Chan Santa Cruz (now Jóse María Morelos, a 20 minute drive from Tzucacab) in 1901. The demographic change must have scrambled land tenure and disrupted both commercial and 'traditional' agriculture on a massive scale.

The Mexican revolution and the resulting constitution of 1917 guaranteed the right of all peasants to land under the *ejido* system. That clause of the constitution was modified in preparation for the passage of the North American Free Trade Agreement in 1994, allowing *ejido* memberships to vote to parcel off the land to each member, and for the individual plots to be bought and sold on the open market. Of the 60 households I interviewed in 2011, only one was a member of an *ejido* that had not yet been subdivided. With the same neoliberal reforms, price supports for maize were eliminated in favor of payments based on the number of hectares under production, rather than the maize produced (Fox and Haight 2010). Later, subsidies for tortillas were eliminated in favor of *Oportunidades* (Fernald, Gertler, and Neufeld 2009).

It is not entirely clear yet what impact these changes in land tenure and subsidy regimes will have on agriculture in Tzucacab, but one can guess. A *milpero* in Tzucacab now is most often an old man. Younger men and women are more likely to work in the tourist-driven economy on the Caribbean coast, or on one of several large commercial farms in Tzucacab that grow watermelons, cucumbers, tomatoes, and other fresh produce.

## ***Agrobiodiversity***

Biodiversity is the variability among living organisms, including the genetic diversity within species, variability between species, and variability of ecosystems (CBD, 1992). Agrobiodiversity is the subset of biodiversity that farmers use and manage. While agrobiodiversity is sometimes used synonymously with crop diversity, it usually implies a wider range of the taxa involved in agriculture than just those that are intentional planted. Agrobiodiversity also includes the diversity of soil microorganisms and arthropods that affect agroecosystem functions, wildlife that finds habitat in agroecosystems, and the diversity between agroecosystems (Lenne and Wood 2011). Vandermeer and Perfecto (1995) made a useful distinction between 'planned agrobiodiversity', composed of the taxa that farmers actively and intentionally manage, and 'associated biodiversity', which includes everything else that lives in an agroecosystem, or that contributes to its function. Associated biodiversity does affect agroecosystem functioning, for example, the diversity of soil microorganisms (Brussaard, de Ruiter, and Brown 2007), migratory birds that forage in agroecosystems (Segura et al. 2004), and the diversity of habitat surrounding farms (Letourneau et al. 2011) all seem to be important. However, I focus here on planned diversity, which includes crops and livestock that are intentionally planted or raised, and also those that are actively and individually managed and used in the agroecosystem but may not be planted. This latter category includes weedy plants like *epazote* (*Dysphania ambrosioides*) or the *ramón* tree (*Brosium alicastrum*) that sprout by themselves in home gardens but are cared for and used by farmers. As a shorthand, I call this planned diversity simply "agrobiodiversity" through this dissertation.

### *Agrobiodiversity in the Yucatan*

Agrobiodiversity is a defining characteristic of agroecosystems in the Yucatan peninsula. In the milpa, several varieties of maize are planted along with beans and squash, and often other crops like chilies (Hernández Xolocotzi 1995; Tuxill 2005). As these grow they are joined by hundreds of useful wild plants, and the milpa is habitat to wild animals (Toledo et al. 1995). Yucatecan home gardens are perhaps even more spectacular in their diversity of plants and animals for food, medicine, animal forage, firewood, construction materials, the ingredients for ceremonies, and importantly, ornamentals that enhance the aesthetics of a garden (Rico-Gray et al. 1990; Toledo et al. 2008; Mariaca-Méndez 2012). Toledo and colleagues (1995) found 278 useful species in home gardens and *milpas* in the Yucatan peninsula, and an additional 1052 in the forest.

From my first visit to a Yucatecan home garden in 2004, I both found the diversity and complexity enchanting. I wondered, why so diverse? The simplest reason is that many taxa are needed to meet the many needs of a household, both for consumption and sale (Kumar and Nair 2004, Mendez et al. 2001). Even within a species, different varieties (or 'land races') can meet different needs, for instance, by fruiting at different times of the year (Ruenes-Morales et al. 2010). Also, complementary relationships between diverse crops can result in more efficient use of light, space, water, and nutrients (Mead et al. 1986; Amador and Gliessman 1990; Gliessman 2007). Crop diversity is linked to the regulation of pests and diseases, reducing damage and often eliminating the need for pesticides (J. Vandermeer 1989; Andow 1991; Finckh et al. 2000; Zhu et al. 2000; Letourneau et al. 2011). Finally, diversity contributes to more complete nutrition. Essential parts of rural people's diets often come from plants and animals that are not key crops, even though these 'minor' crops are very rarely reported in official figures of production (Penafiel et al. 2011; Halwart 2006).

Not all diversity has these kinds of benefits (Zhang et al. 2007), and managing many kinds of organisms and the interactions between them takes a lot of skilled labor. Kremen and colleagues (2012) use the term 'diversified farming systems' to refer to the kind of farm that intentionally uses functional agrobiodiversity at multiple special and temporal scales to maintain ecosystem functions that provide for food production. They contrast diversified farming systems with industrialized agriculture, which simplify agroecosystems with the goal of maximizing profitability. In industrialized agriculture, highly specialized, technical information that can be universally applied across farms with differing growing conditions and traditions of land management is most valued (*ibid.*). In diversified farming systems, knowledge is more contextual, and more often built out of experience and observation.

It is a misperception, however, that the agrobiodiversity on small farms is hyper-adapted only to the small spaces where it resides. Farmers trade plants and seeds, sometimes across great distances, and much of the risk-buffering advantage of traditional crop varieties comes not from their adaptation to specific conditions but to the plasticity and genetic variations within each variety (Zimmerer 1996; Zimmerer 1998). Also, the agrobiodiversity on smallholder farms is of immense value to large-scale industrial agriculture; it is the primary source of genetic resources that plant breeders use to breed new traits, like pest and disease resistance, into commercial commodity crops. Like biodiversity in general (Vitousek et al. 1997), agrobiodiversity is declining on a global scale (Jarvis et al. 2008; Remans et al. 2014). International institutions now fund a network of seed banks for ex-situ conservation of plant genetic resources, and to a lesser extent, the conservation of those resources on the farms where they developed and continue to evolve (Brush 1986; Altieri and Merrick 1987; Fowler and Mooney 1990).

In-situ conservation is a complex undertaking. It implies preservation of not just the germplasm and genomes of agrobiodiversity, but also the knowledge, agroecosystems, and social-economic conditions under which agrobiodiversity is maintained (Graddy 2014). It is complicated by the fact that these conditions, like crop genomes, are not static. What does conservation mean, after all, in a world that is constantly changing? Ecologists have begun to resolve this question by turning the goals of conservation away from 'naturalness', as if it was an inherent quality of some places, and towards conservation of desired features of ecosystems—for example, their beauty, their biodiversity, or even their feeling of wildness—assisted by an understanding of ecology but identified and prioritized in a political process (Aplet and Cole 2010; Zavaleta and Chapin 2010). Of the many benefits of biodiversity, food security is among the most urgent priorities.

## *Food Security*

Since 1996, the United Nations Food and Agriculture Organization (FAO) has defined food security as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2004b). To reach food security, the existence of sufficient food is not enough. The food must be accessible, reliable, safe, and nutritious; and it must be the kinds of food that people want to eat. Before the term existed, governments measured food security at a national scale, using balance sheets to determine whether a country produced or imported enough food to meet its populations' demands (Jones et al. 2013). This is a poor measure of hunger, given the unequal distribution of resources within countries. By the mid-1970s, working definitions had shifted to focus on access, and to estimate food security at the household scale (Pinstrup-Andersen 2009). Even within a household, though, food security is not always equal. Often, the nutrition of men and boys is prioritized over the nutrition of women and girls (Quisumbing and Maluccio 2000). In the language of international development, the intra-household dynamics of food access is called 'utilization'. Conceptual frameworks for food security at the FAO and World Bank now four include aspects: availability, access, and utilization and stability (Jones et al. 2013).

Measurements of food security vary widely. The world's most prominent indicator is the Prevalence of Undernourishment (PoU) at the center of the FAO's annual *State of Food Insecurity* reports. It is the key statistic used to track progress towards the millennium development goal to halve the proportion of hungry people in the world by 2015, and also the World Food Summit's more ambitious goal of halving the absolute number of hungry people by the same time. As I write this in 2015, data for this year is not yet in, but it appears that the world will meet the first but not the second goal (FAO 2014). PoU is calculated from national food balance sheets, adjusted for the variability and skewness (i.e., degree and pattern of inequality) of food distribution with in each country. It thus accounts for availability and access.

PoU has been critiqued for grossly understating the prevalence and severity of food insecurity in the world. First, for a publication titled *State of Food Insecurity in the World*, the measurement has little to do with the definition of food security. I missed this distinction until recently, as I describe in chapter 4 of this dissertation, even though I had been reading the report in its entirety each year. The estimation reflects a severe definition of hunger: people who are chronically undernourished for at least a year. By undernourished, the FAO means eating less than the estimated number of calories needed for a sedentary lifestyle, which, of course, few farmers have. Nutrient deficiencies beyond a shortage of calories are not considered, nor are intra-household differences (FAO 2014, 47–49). The PoU threshold for hunger is extremely low compared to the way food security and undernutrition is measured in studies focused on the individual or household scale.

There are two common approaches to measuring household food security: one can measure food intake in terms of grams or calories (using 24-hr recalls, food diaries, etc.) and compare that to an *a priori* assumption of an adequate diet, or one can have participants self-identify experiences with food insecurity over a given time frame. For this study, I chose the second approach because: (1) it captures a greater range of the experience of food insecurity, from worrying about food running out to reducing portions to feeling hungry; (2) participants' subjective experience with food insecurity is probably a more direct measure of the success or failure of their livelihood strategy than the quantity of food that they eat. This approach also requires far less time on the part of researchers and participants, allowing for larger sample sizes and more randomly selected samples (fewer households opt out). While this experience-based approach relies on households' own definition of how much food is sufficient, and is therefore more etic than food intake measurements, this methodology is not a simple self-assessment. Asking about specific experiences of food insecurity over a specified time frame is more structured and also more comparable across cultural contexts than asking, for example, for participants to rate their food security on a scale of one to ten. These experiences have been sensitivity-tested and validated with three decades of large-sample data from the United States Department of Agriculture (USDA)'s food security survey (Bickel et al. 2000). After my field work had begun, the Household Hunger Scale, a similar methodology adapted to international situations, was published at the United States Agency for International Domination (USAID) (Ballard et al. 2011), and has since gained popularity. My adaptation was heavily informed by Christopher Bacon's methods in rural Nicaragua (Bacon et al. 2014). I report the methodology I used in detail in chapter 2. In the conclusion of this dissertation, I discuss ways that the methods I used could be improved and combined with other approaches to create a more complete measurement of food security.

***Some notes on food sovereignty***

In the concept of food security, as many farmers movements have pointed out, farmers, fishers, and other food producers play an uncertain role. The consumercentric framework of availability, access, utilization and stability does little to address farmers' struggles for land tenure, water rights, the right to save seeds, market access, and other means of production. In 1996 the Via Campesina, an organization of smallholder farmers' movements, proposed a new term that reflected their demand for not only enough food, but some power within the food system: they demanded *food sovereignty* (Patel 2009). It is difficult to pin down a standard definition of food sovereignty, since one of the central claims is the right of communities to define for themselves the kinds of food systems they want. A widely cited definition emerged at a Via Campesina summit in rural Mali in 2007, which begins, "Food sovereignty is 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. It puts those who produce, distribute and consume food at the heart of food systems and policies rather than the demands of markets and corporations" (La Via Campesina 2007).

Where food security is a technical term, lending itself well to the "anti-politics machine" of the project of a development industry (Ferguson and Lohmann 1994), food sovereignty is a political claim and a concept built for movement building. In Tzucacab there are not obvious, organized movements for food sovereignty, and when I brought it up in focus groups and workshops with the youth researchers, it was usually the first time people from Tzucacab had heard the term (though the same is true of food security). But the concept did make sense to them: a place and a voice for *campesinos* in food systems, a movement of solidarity between people intimately involved in food. It reflected large and small acts of creativity and resistance that many *campesinos* engage in every day.

***Stability and Risk***

So far, I have engaged with the availability, access and utilization aspects of food security, however, most of the analysis in this dissertation centers on the stability of food supplies, and specifically, how people use agrobiodiversity to reduce the chance of a food shortage. Assessing the risk of food shortages differentiates my research from nearly all other empirical studies attempting to link agrobiodiversity to nutrition outcomes (Burlingame, Charrondiere, and Mouille 2009; Penafiel et al. 2011; Termote et al. 2012; Scurrah et al. 2012; Jones et al. 2013; Ali et al. 2013), although the link has been well examined in theory (Altieri 1999; Thrupp 2000; Lin 2011; Frison, Cherfas, and Hodgkin 2011; Sunderland 2011; Tscharntke et al. 2012). Mendez and colleagues (2010) and Bacon and colleagues (2014) have empirically linked agrobiodiversity to livelihood security, and their work has informed my approaches and methods.

One way I address stability of food supplies is by assessing the relationship between biodiversity and ecosystem functioning, as described above. In ecology, biodiversity has been linked to more stable as well as greater or more efficient ecosystem functions (Tilman and Downing 1994; Tilman, Lehman, and Bristow 1998; Ives, Klug, and Gross 2000), and this appears to be true in agroecosystems as well (Mead et al. 1986). I apply this approach in chapter 2.

In chapter 3, I analyze the strategic use of agrobiodiversity to increase or decrease risk in agricultural production, drawing on a model developed in behavioral ecology and economic anthropology. While 'risk' is colloquially used (even in this dissertation) to refer to the chance of something undesirable occurring (e.g., the risk of a hurricane), I use it in chapter 3 to describe the variability of outcomes, desirable or undesirable. In that analysis, risk is "the unpredictable variation in the outcome of a behavior, with consequences for the fitness or utility of an organism" (Cashdan 1990; Winterhalder, Lu, and Tucker 1999). It is the opposite of the concept of 'stability' in the biodiversity-ecosystem functioning literature. Using this framework, I show that farmers may be diversifying or simplifying their agroecosystems and livelihoods to achieve the level of risk that gives them the best chance of meeting basic food needs.

## *Outline*

This thesis is composed of three articles. The first, "Agrobiodiversity Drives Food Security During a Drought in Rural Yucatan, Mexico," tests the hypothesis that those households with more diverse home gardens are also more likely to be food secure. The second, "Food Shortfalls, Labor shortages, Herbicides: A Positive Feedback Between Food Security and Agrobiodiversity in Mayan Agroecosystems " looks at farmer decisions that affect agrobiodiversity, and investigates positive feedbacks between food security and agrobiodiversity. It tests the hypothesis that households that expect to meet their household food needs –that is, not to go hungry—are likely to pursue a high-diversity strategy to decrease the chance of a food shortfall, while households that do not expect to meet their food needs are more likely to pursue a low-diversity strategy.  The third, “Productivism, Agroecology and the Challenge of Feeding the World” contextualizes the findings of the previous two in a broader context of a debate about how to go about alleviating rural hunger.  It challenges the prevailing paradigm that increasing yields per hectare is so important that other properties of agroecosystems, including agrobiodiversity, are expendable. In the conclusion, I discuss opportunities to build on this work with further research and action.

# 2. Crop diversity drives household food security during a drought in rural Yucatan, Mexico

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Target Journal: *Ecology Letters*

**Abstract**: Although it is widely assumed that crop diversity enhances food security of subsistence farmers, this premise has not previously been tested empirically. We found that crop diversity is the strongest predictor of household food security during a drought in a rural municipality of Yucatan, Mexico. Specifically, richness and evenness of plant and animal taxa in home gardens were the best predictors of household food security during the 2011 drought year, outperforming indicators related to household demographics, income and education. Our findings illustrate that maintaining high levels of agrobiodiversity can be an important strategy for subsistence farmers to buffer their food supply against the risk of crop failure. Our study also highlights a need to examine the connection between crop diversity and food security at larger spatial and temporal scales and to further test the assumption that increasing yields at the expense of diversity is a viable pathway to food security.

## *Introduction*

Challenges to rural food security presented by climate change and a growing worldwide demand for food have heightened interest in the ways that crop diversity on small farms might contribute to sustainable, resilient food supplies (FAO 2010; Sunderland 2011). Just as biodiversity has been linked to a wide range of ecosystem functions and services in both managed and natural systems (Loreau et al. 2001; Hooper et al. 2005; Balvanera et al. 2006; Isbell et al. 2011), crop diversity (or agrobiodiversity) is considered important in maintaining agroecosystem functions and services.

Crop diversity has been linked to provisioning services, augmenting yields and making more efficient use of resources (Mead et al. 1986; Gliessman 2007), and to regulating services, including regulation of pests and diseases (Vandermeer 1989; Andow 1991; Zhu et al. 2000; Perfecto et al. 2004). Both kinds of services can be expected to contribute to farming households' food security by increasing yields per unit of land or labor, decreasing costs, and by decreasing the chance of crop failure. Additionally, agrobiodiversity seems to be implicated in the quality of nutrition in some rural communities (Penafiel et al. 2011). Crop diversity may also increase the chance that there will be something to eat when one or more crops fail (Conway 1998), an observation that finds its corollary in the ecology literature as the "insurance hypothesis" – that functionally redundant taxa increase the stability of ecosystem functions so long as they differ in their responses to a given stressor (Yachi and Loreau 1999).

The evidence that agrobiodiversity generally plays a beneficial role of in agroecosystem functioning presents the possibility that subsistence farmers may use agrobiodiversity as a key strategy for achieving household food security. However, there is much less evidence that agrobiodiversity actually lessens the chance that a farming household will go hungry, and little understanding of the relative importance of agrobiodiversity in the complex of strategies and conditions that shape household food security. The idea that agrobiodiversity plays a central role in the food security of subsistence farmers has been championed by several scholars (Altieri 1999; Thrupp 2000; Lin 2011; Tscharntke et al. 2012), and has found a place in some United Nations programs (FAO 1998; FAO 2004a), but to the best of our knowledge, the relationship between agrobiodiversity and food security outcomes has not been tested empirically. Meanwhile, the more common focus of scholarship and programs addressing rural food security is on increasing yields of a few, key commercial crops (Godfray et al. 2010; Foley et al. 2011; Tilman et al. 2011), not on the diversity of crops. Here, we test the hypothesis that crop diversity is an important strategy by which subsistence farmers buffer risks and achieve food security in a risky environment.

To test this hypothesis, we sought to measure whether crop diversity significantly and positively affected household food security, and whether this relationship remained significant when we controlled for other possible drivers of food security. Ecologists assess the effect of diversity on an ecosystem function either by experimentally manipulating diversity (e.g., Tilman and Downing 1994), or by measuring the natural variation in diversity in a landscape and statistically controlling for variation in non-diversity factors that could conceivably affect the ecosystem function of interest (e.g., Rejmánek 1996). We take the latter approach, using the existing variation in agrobiodiversity in 45 home gardens. The household is the unit of study, and food security is the ecosystem service response variable.

## *Methods*

### *Study Site*

Research took place in subsistence agroecosystems— the home gardens of Mayan farmers in the rural municipality of Tzucacab, Yucatan, Mexico (between 19º38' and 20º09'N, 88º59' and 89º14'W). The climate is tropical and seasonally dry, with much of the agriculture dependent on summer rains. Mean annual rainfall was 1272mm between 1981 and 2010 (SMN, n.d.). About 14,000 people live in the municipality in 3,253 households, in the main town of Tzucacab and 13 smaller villages. The majority of residents are Mayan-speaking (INEGI 2012). All 45 study households grow food and other products for subsistence but also engage in a mix of economic activities including commercial agricultural production, wage labor, remittances from family members working outside the area, and collection of government subsidies and conditional cash transfers. We therefore expected crop diversity to be a significant factor among several that influenced household food security.

At the time of measurement in October 2011, many participating households reported that their access to food was more strained than usual. Study participants widely reported that local rainfall during the 2009 and 2010 summer growing seasons had been erratic and low, negatively impacting rain-fed agriculture, especially corn production. Also, participants reported that local prices for corn and other staples were rising rapidly.

### *Household Selection*

Sixty households were chosen at random from a database maintained by researchers at the Autonomous University of Yucatan (UADY) of households participating in a larger study (Becerril García, Casteñeda, and Solís 2014; Becerril García 2010). We were able to obtain high-quality data on agrobiodiversity, food security, and household economics for 45. The selection was stratified to be representative of the populations of the town and each village in the municipality. The households in the UADY database were selected in 2010 by researchers who walked from house to house asking for willing participants in their study until they enlisted 20% of the population of each town or village. They walked systematically from the town and village centers towards the outskirts of town in each direction to control for the tendency of more established and wealthily families to live at the center of towns (Tuxill 2005).

### *Measuring Agrobiodiversity*

We measured home garden richness and evenness by direct observation between June and July of 2011. Teams of local field assistants identified every plant and animal present in the home garden that was actively managed or used by the household, and counted the number of individuals in each taxon. A household member accompanied the team to verify the accuracy of the teams' identifications.

Our diversity metrics reflect the taxonomic level of landrace, cultivar, or variety (in the case of plants) or to the breed level (in the case of animals), since in interviews with key informants, farmers told us that they make most decisions about crops at this sub-species taxonomic level. Here, richness refers to the number of these taxa present, and includes both plants and animals. Evenness is measured by Fisher's J' for the same set of taxa. While previous studies linking agrobiodiversity to smallholder farmers' livelihood outcomes rely on taxonomic richness alone (e.g., Zimmerer 1996; Isakson 2009), we suspected that evenness is another aspect of a farmers' diversity strategies that affects multiple ecosystem functions, and might also affect household food security.

### *Measuring Food Security*

The Food and Agriculture Organization (FAO) of the United Nations defines food security as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2002). There are two common approaches to measuring food security: one can measure food intake in terms of grams or calories (using 24-hr recalls, food diaries, etc.) and then compare that to an *a priori* assumption of an adequate diet, or one can have participants self-identify specific kinds of experiences with food insecurity over a given time frame, and construct an index of food (in)security from those experiences. We chose the second approach because: (1) it captures a greater range of the experience of food insecurity, from worrying about food running out to feeling hungry, in contrast to food-intake approaches that only capture results after any coping strategies have been applied; and (2) participants' subjective experience with food insecurity is probably a more direct measure of the success or failure of their livelihood strategy than the quantity of food that they eat. In addition, this approach requires far less time on the part of research participants and researchers, allowing both a larger sample size and a more randomly selected sample (i.e., fewer households opt out).

We developed interview questions based on the United States Department of Agriculture's (USDA's) methodology (Bickel et al. 2000), adapting it to a place where food is produced by the household as often as it is purchased. Food insecurity was assessed in an in-person interview between September and October 2011. We asked self-identified heads of household if anyone in their household had experienced certain conditions of food insecurity within the last year. The conditions were: (1) worrying that food will run out, (2) eating foods that they do not like or know are less healthy due to a lack of preferred foods, (3) reducing portion sizes or skipping meals due to a lack of food, and (4) feeling the physical sensation of hunger without having access to enough food to satiate it. Each condition was assessed with multiple questions at different points in the interview to try to account for the potential tendency to underreport experiences with food insecurity due to embarrassment. The resulting food security scale ranges from 0 (report all experiences of food insecurity including physical hunger) to 4 (no reported food insecurity). Like the USDA's results, ours were highly nested by severity; food insecurity tended to progress from worry to substitution to rationing to hunger.

### ***Non-diversity Predictors of Food Security***

I measured ten other indicators of household economics with direct relevance to agrobiodiversity in the same in-person interviews: (1) household size, or the number of people that eat daily in the household; (2) age of the head of household; (3) number of years of formal education for the self-identified head of household, who was most often male; (4) consumer-producer ratio, which weighs the production and consumption of each family member by age and sex (Chayanov (1986); (5) off-farm income, calculated from farmers' estimates of their households' income over the previous 12 months from various sources, predominantly wage labor, remittances, income from non-agricultural businesses, and payments from government programs; (6) number of income sources, or the sum of all the distinct income-generating activities reported in the household and is meant as a proxy for the diversity of livelihood activities; (7) number of wage laborers in the household (including members currently working for a wage and members that occasionally work for a wage as needed); (8) home garden size, measured in $m^2$ by walking the perimeter of the home gardens with a Garmin 62s GPS unit; (9) home garden age; and (10) the number of animals in the home garden.

### *Use Groups and Subsets*

In focus groups, farmers identified 9 distinct uses for plants and animals in the home garden, and assigned one or more uses to each taxa. We created a 'food only' subset (the taxa that are used for food), an 'economic products' subset of taxa that contribute tangible economic value to the household (including food, firewood, medicine, spices, construction materials, animal forage, and soil enhancement; but excluding taxa that were only used as ornamentals or to provide shade), and a 'no food' subset (all taxa that are not used for food). We calculated richness and evenness of taxa of each subset for each garden, and used those measurements in the 'diversity+labor' linear regression model to compare the ability of diversity within each subset to predict household food security.

### *Data Analysis*

All data was coded and digitized by the lead author and by field assistants and analyzed using R version 3.1.0. Diversity statistics were calculated using the vegan package for R, version 2.0-10 (Oksanen et al. 2013). All regression results reported were performed using ordinary least squares regression; curvilinear and nonlinear regression models did not increase $R^2$ values compared to OLS. Nested models were compared using F-tests. We used an alpha level of .05 for all tests.

## *Results*

### *Significant Predictors of Food Security*

Most participants (78% of respondents) reported at least some food insecurity during the 12 months preceding the interview, a difficulty many attributed to crop failures stemming from insufficient and poorly-timed rains over the past two growing seasons, and to the rapidly increasing cost of food. Both taxonomic richness ($R^2$=0.12, $F(1,43)$=5.69, $p$=0.02) and evenness ($R^2$=0.086, $F(1,43)$=4.06, $p$=0.05) were positively and independently associated with food security (Figure 4), and both factors together were a stronger predictor of household food security than either factor alone ($p$=0.004, $R^2$=0.226). The Shannon-Wiener diversity (H') index, which incorporates both richness and evenness, even more strongly predicted food security ($R^2$=0.247, $F(1,43)$=2.47, $p$<0.001), though separate richness and evenness measures provide a clearer picture of the differences among gardens and allow more specific recommendations for conserving or increasing home-garden agrobiodiversity.

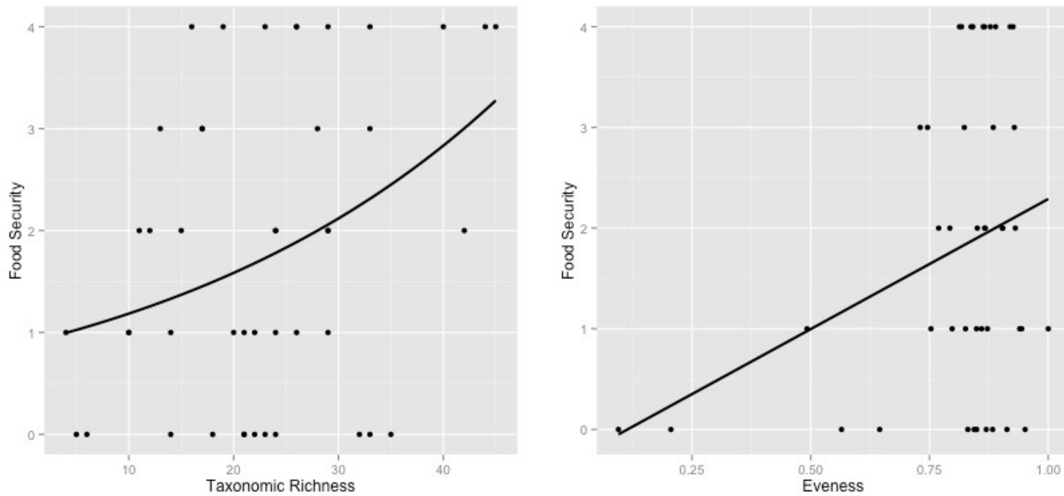


Figure 4. Agrobiodiversity factors predicted household food security. Taxonomic richness (A) and evenness expressed as J' (B) of home gardens are each significant and independent predictors of household food security. Fit lines are the best linear fit of each factor to food security using OLS regression; N=45 households.

Subsistence farmers employ many strategies to buffer the risk of going hungry, and the diversity of their gardens is only one aspect of the diversity of their livelihoods (Netting 1993). Also, more affluent households have been found to have larger and more diverse gardens (Zimmerer 1996), so it is possible that wealth could be driving both home garden diversity and food security, with little or no causal link between our two factors of interest. Crop diversity might play a minor or insignificant role in creating food security when other aspects of household economics are taken into account. We collected household data on demographics, income, and non-diversity characteristics of the agroecosystems (Table 1). Of these ten factors, only the measures of household size ($R^2$=0.063, $p$=0.10) and the head of households' age ($R^2$=0.061, $F(1,43)$=2.78, $p$=0.10) had marginally significant pairwise relationships to food security. In a model combining all factors we measured, taxonomic richness ($\beta$=0.40, $p$=0.02) and evenness ($\beta$=0.40, $p$=0.02) remained significant predictors of household food security, and household size ($\beta$=0.44, p=0.02) became a significant additional predictor; this model was marginally significant ($R^2$=0.42, F(12,32)=1.06, $p$=0.07). A model containing only the ten non-diversity indicators did not predict food security ($p$=0.44; Table 2).

| | *Summary Statistics* | | *One-way regression with Food Security* | |
|---|---|---|---|---|
| **Dependent Variable** | **Mean** | **SD** | **Slope Estimate** | **p** |
| Richness | 22.867 | 9.985 | **0.052** | 0.022 |
| Evenness (J') | 0.811 | 0.172 | **2.585** | 0.050 |
| Shannon-Wiener Index (H') | 2.424 | 0.641 | **1.178** | 0.001 |
| Household size | 4.956 | 2.011 | 0.189 | 0.097 |
| Number of off-farm laborers | 1.111 | 1.027 | 0.323 | 0.149 |
| Consumer:Producer ratio | 8.378 | 7.349 | -0.008 | 0.794 |
| Off-farm income (MXN/year) | 3246 | 2388 | -0.000 | 0.653 |
| Head of household age | 49.20 | 13.07 | 0.029 | 0.103 |
| Head of household education | 3.889 | 4.001 | -0.054 | 0.351 |
| Number of income sources | 4.378 | 2.177 | 0.040 | 0.706 |
| Home garden size (m2) | 1406 | 1558 | 0.000 | 0.544 |
| Home garden age (years) | 24.93 | 16.64 | 0.009 | 0.539 |
| Animal holdings | 20.47 | 23.84 | 0.003 | 0.745 |

Table 1. Summary statistics and one-factor regression of expected drivers of food security.

| | *Dependent variable:* | | | |
|---|---|---|---|---|
| | FS | | | |
| | all variables | diversity | diversity+labor | labor variables |
| | (1) | (2) | (3) | (4) |
| Richness | 0.057** | 0.059*** | 0.055*** | |
| | (0.024) | (0.021) | (0.020) | |
| Evenness | 3.458** | 3.062** | 3.271*** | |
| | (1.425) | (1.199) | (1.137) | |
| Household Size | 0.333** | | 0.266** | 0.268** |
| | (0.137) | | (0.110) | (0.124) |
| Off-Farm Laborers | 0.254 | | 0.270 | 0.329 |
| | (0.236) | | (0.191) | (0.217) |
| Consumer:Producer Ratio | −0.037 | | −0.051 | −0.035 |
| | (0.038) | | (0.031) | (0.034) |
| Off-farm Income | 0.00003 | | | |
| | (0.0001) | | | |
| Head of Household Age | 0.018 | | | |
| | (0.026) | | | |
| Head of Household Education | 0.009 | | | |
| | (0.080) | | | |
| Number of Income Sources | −0.137 | | | |
| | (0.114) | | | |
| Homegarden Size | 0.00004 | | | |
| | (0.0001) | | | |
| Homegarden Age | 0.001 | | | |
| | (0.015) | | | |
| Number of Animals | −0.011 | | | |
| | (0.012) | | | |
| Constant | −4.253* | −2.037* | −3.314*** | 0.406 |
| | (2.176) | (1.156) | (1.198) | (0.651) |
| Observations | 45 | 45 | 45 | 45 |
| $R^2$ | 0.419 | 0.236 | 0.372 | 0.144 |
| Adjusted $R^2$ | 0.201 | 0.199 | 0.292 | 0.082 |
| Residual Std. Error | 1.355 (df = 32) | 1.357 (df = 42) | 1.276 (df = 39) | 1.453 (df = 41) |
| F Statistic | 1.925* (df = 12; 32) | 6.473*** (df = 2; 42) | 4.624*** (df = 5; 39) | 2.307* (df = 3; 41) |
| AIC | 167.71 | 160.08 | 157.23 | 167.16 |
| *Note:* | | | | *p<0.1; **p<0.05; ***p<0.01 |

Table 2. Comparison of models predicting household food security. These include (1) All variables; (2) only the diversity measures, richness and evenness; (3) the diversity measures combined with measures related to household labor availability; and (4) factors related to household labor availability alone. Comparing multivariate models explaining food security. Using an AIC approach to model competition, the "diversity+labor" model is the strongest model.

### *Household Labor Availability*

The significance of household size in the combined model suggests that the labor available in the household is important. In interviews, farmers reported that they struggled with labor availability during food shortages. The urgent need for cash at these times presented a difficult trade-off between investing household labor in the agroecosystem, which could be expected to increase yields (such as weeding), and sending household members to work for a wage, most often on nearby ranches or manual labor in costal tourist areas. Following this logic, we made a model that incorporated the three factors related to household labor (household size, a producer:consumer ratio, and the number of household members working for a wage) along with the agrobiodiversity factors ($R^2$=0.36, F(5,39)=4.40, $p$=0.002; Table 2). This "diversity+labor" model was significantly more predictive of food security than a model with diversity measures alone ($p$=0.05), and the model incorporating all factors was not significantly more predictive than the diversity+labor model ($p$=0.84).

### *Importance of Food-Producing Taxa*

The diversity of taxa used specifically for food could have a stronger effect on household food security than the diversity of all taxa in the home garden. However, it is possible that the diversity of non-food producing taxa played an important indirect role, providing products that benefit the household's economy more broadly, which in turn affects food security. In focus groups with participating farmers, we identified nine distinct uses for home-garden taxa and assigned each taxon to one or more uses, which we used to create two subsets of taxa: those that produce food, and a broader set of economic products including both food-producing taxa and taxa that contribute economically to the household's livelihood in ways that could indirectly affect food security (firewood, medicine, spices, construction materials, animal forage, and soil-enhancing taxa; Figure 5). The diversity+labor model using the 'food only' subset was significant ($R^2$=0.35, $F$(5,39)=4.26, $p$=0.003), as was the model using the "economic products" subset ($R^2$=0.34, $F$(5,39)=3.97, $p$=0.005), but neither model was had a greater $R^2$ or lesser $p$-value than the model using all taxa ($R^2$=0.37, $F$(5,39)=4.62, $p$=0.002). This suggests that all taxa are important to household food security. However, the model based on diversity measures excluding food-producing taxa was not significant ($R^2$=0.20, $F$(5,39)=1.78, $p$=0.141).

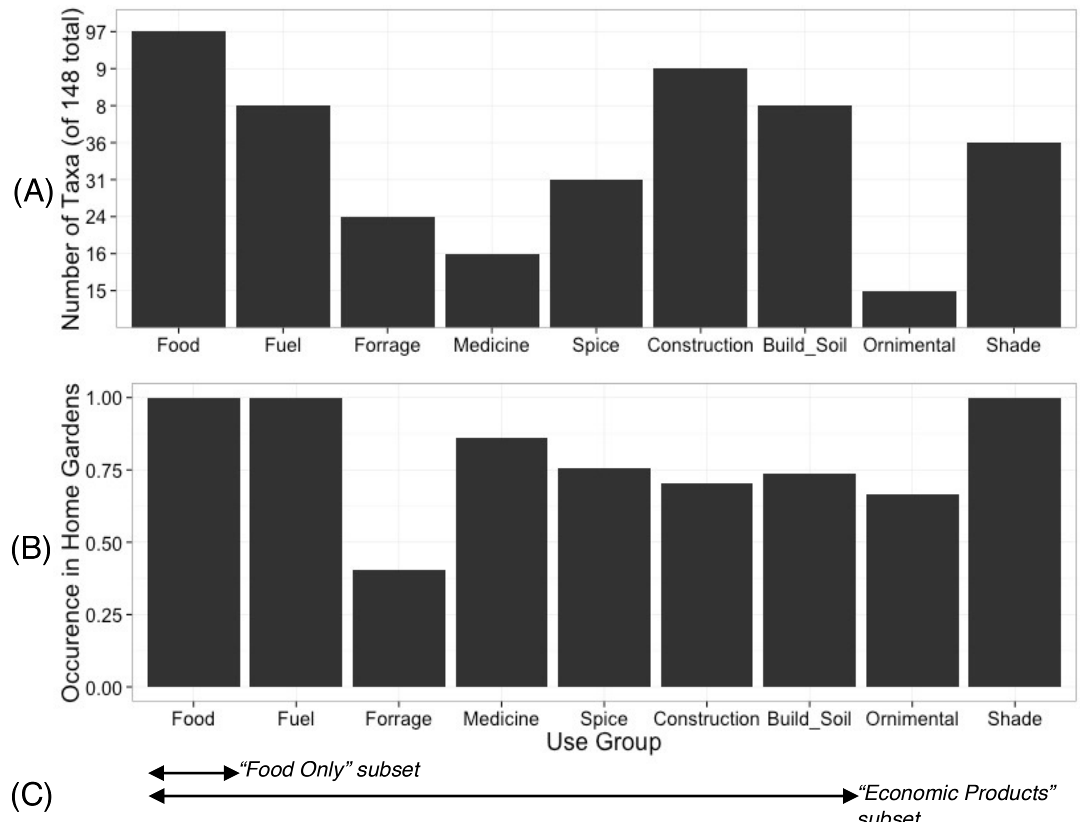


Figure 5. Use groups identified by farmers. (A) The number of taxa (of all 148 identified in the sample) that fall into each use group. Some taxa are assigned to more than one use group. (B) The portion of home gardens where at least one taxa of the use group was found. (C) the use group subsets used in this study.

While there was no clear difference between the overall models, richness of just the food-producing taxa was a slightly more predictive factor within the model ($\beta$ =0.44, $p$=0.003) than richness of the economic products subset ($\beta$ =0.41, $p$=0.005), which in turn was slightly more predictive of food security than all taxa ($\beta$ =0.37, $p$=0.008). There was not a similar pattern for the evenness factor (Table 3; Figure 6). A practical question for both agrobiodiversity conservation and supporting household food security is how many additional taxa, on average, correspond to an increase in one point on the food security scale. By these estimates, and using a 95% confidence interval, between 10 and 64 (mean=18.0) taxa correspond to an additional point on the food security scale; between 6 and 33 (mean=10.5) taxa in the economic products subset or between 5 and 22 (mean=8.0) food-producing taxa correspond to the same difference in food security.

| | Richness | | Evenness | | Model |
|---|---|---|---|---|---|
| Subset | estimate | SE | estimate | SE | $R^2$ |
| All Taxa | .055*** | .020 | 3.27*** | 1.34 | .372** |
| Food Only | .125*** | .039 | 3.01** | 1.41 | .353** |
| Econ. Prod. | .095*** | .032 | 3.33** | 1.42 | .337** |
| No Food | .016 | .066 | 1.54 | .971 | .199 |

Table 3. A comparison the diversity of functional use subsets of taxa and their ability to predict household food security. All regressions use the "diversity+labor" model that incorporates taxonomic richness and evenness and the three indicators related to household labor availability. Significance: *$p$<0.05, **$p$<0.01, ***$p$<0.001.

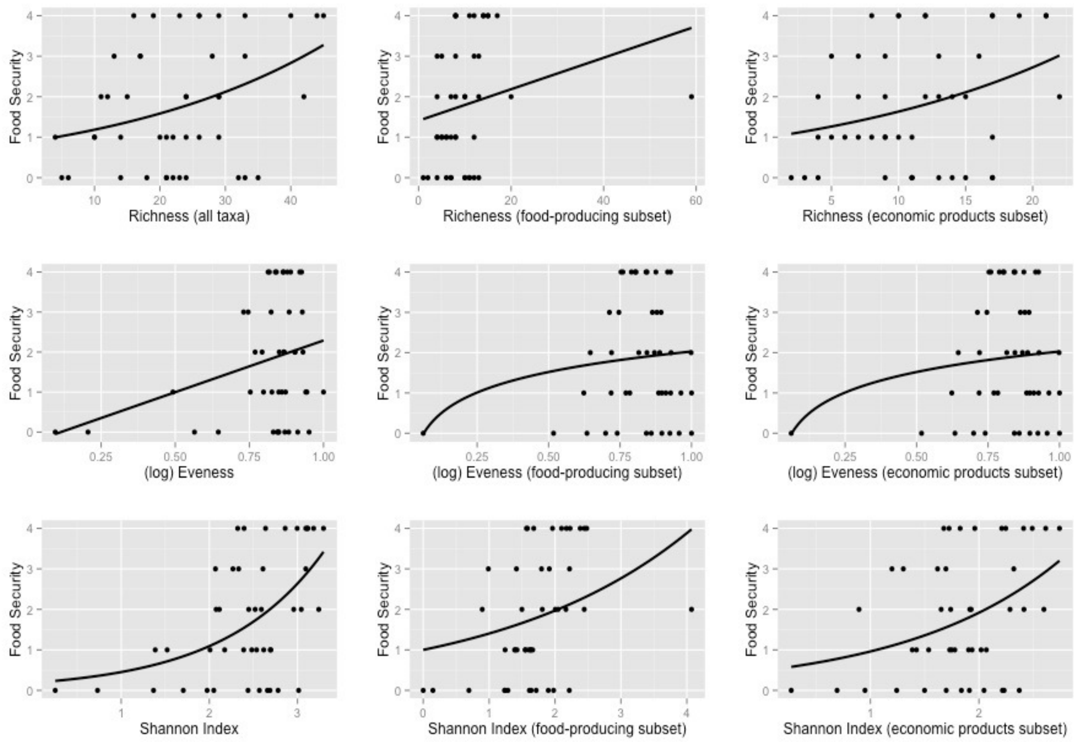


Figure 6. The effect of three home garden diversity measures (richness, evenness, and Shannon index) on food security. These scatterplots compare diversity measures that take into account all taxa in the home gardens, the food-producing subset of taxa, and the "economic products" subset of taxa.

## *Discussion*

The significant and positive relationship between crop diversity and food security support our hypothesis that agrobiodiversity is a key strategy by which smallholder farmers buffer the risk of going hungry in the municipality of Tzucacab in late 2011, while food supplies and access were strained by drought and rising prices. The fact that crop diversity measures outperformed all other predictors of food security in this case suggests that diversity deserves more attention in research on rural hunger and the resilience of rural livelihoods. These results cannot establish that differences in home garden diversity cause differences in food security, but they do point to the intriguing possibility that diversity can play a larger role than previously assumed. The immediate causes of food insecurity that most farmers identified in Tzucacab—crop failure resulting from drought and unstable prices of food and agricultural inputs—are faced by smallholder farmers worldwide, and can reasonably be expected to continue or intensify for many subsistence farming households as economies and rainfall patterns change. If high levels of crop diversity do help to buffer the effects of these pressures, this finding could lead to more effective programs to strengthen rural food security and to preserve agrobiodiversity *in situ*.

Our results implicate both taxonomic richness and evenness in household food security. Studies linking biodiversity to ecosystem functions and services tend to include evenness, but previous studies in the social sciences linking agrobiodiversity to household economics or nutrition have relied on richness alone (Zimmerer 1996; Isakson 2009). Evenness, like richness, reflects a dimension of a household's strategy for allocating scarce resources in the garden: higher evenness indicates an allocation of households' time and space to growing many different taxa, while lower evenness indicates a concentration of resources on one or a few taxa. The positive relationship we observed between both richness and evenness and food security suggests that a generalist strategy in the home garden was more likely to help a household achieve food security than a specialist strategy. We would have observed much smaller effects if we limited our definition of agrobiodiversity to taxonomic richness. Further research might find more value in agrobiodiversity if it includes evenness measures. Additionally, using more of the aspects of biodiversity that we don't analyze here (e.g., functional diversity, response diversity) may help to illuminate mechanisms that link crop diversity to food security.

A key point of contention in the study of biodiversity and ecosystem functioning has been whether it is the number of taxa that affects functions, or which specific taxa are present is more important; the accumulation of many studies in the area suggest that both matter (Cardinale et al. 2012). We find a corollary in the way farmers talked about making decisions about crop diversity. Participants did not speak about diversity *causing* food security in a mechanistic way (e.g., if they could increase the number of crops they grew that they would be more protected from the risk of drought), rather they spoke about adding specific crops known to produce food under pressure (e.g., adding certain drought-resistant root crops, or adding livestock to hedge their households' food supply against a rapidly increasing cost of meat). From their point of view, it was not the diversity of crops *per se* that achieves food security, but the accumulation of many decisions about what to grow that affected their ability to feed their households under conditions beyond their control; diversity played a role in building resilience to several kinds of unpredictable stressors.

One implication is that finding effective interventions is likely to be more complicated than finding ways to convince smallholder farmers to add taxa to their home gardens, since not just any additional taxa will do. To be effective, additional taxa must fit into farmers' strategies for mitigating risk, so efforts at diversification must leverage farmers' knowledge and experience. Another implication is that efforts to increase rural food security by increasing yields on small farms might actually make rural livelihoods more vulnerable to disturbances, if diversity is lost in the process of boosting yields of key crops.

Clearly, more research into the mechanisms linking crop diversity to food security is necessary, and research at greater special and temporal scales are needed to identify the contexts in which crop diversity effectively buffers the risk of hunger. If crop diversity drives food security in many contexts and provides resilience to many kinds of disturbances, the implications are far-reaching. Initiatives to strengthen rural food security could find common ground with those seeking to preserve crop diversity *in situ* and develop integrated ways to support farmers in implementing high-diversity strategies that contribute to robust and resilient livelihoods. Finally, agricultural development initiatives that aim to reduce rural food insecurity by helping small-scale farmers invest in low-diversity strategies, like commercial monoculture, must find ways to avoid or mitigate the effects of lost crop diversity on food security that these projects might cause.

# 3. Food Shortfalls, Labor Shortages, and Herbicides: A Positive Feedback Between Food Security and Agrobiodiversity in Mayan Agroecosystems

Devon D. Sampson

Target Journals: *Human Organization* or *Human Ecology*

**Abstract.** I investigate the complex relationship between risk, agrobiodiversity, and household food security in a rural Mayan community in Yucatan, Mexico, where agrobiodiversity varies greatly between home gardens. Drawing on in-depth interviews with farmers there, I find that agrobiodiversity is nearly universally valued in Tzucacab, but there are differing opinions about the ability of diversified agriculture to provide for a household's needs. I raise the possibility that these differences in opinion could be shaped by long-term experiences with food (in)security, and result in different levels of investment in diverse agroecosystems. Additionally, I identify a pathway by which food insecurity results in temporary labor shortages, which in turn result in agrobiodiversity declines. These findings help to explain why some farmers conserve diversity while others do not, and suggest that the goals of agrobiodiversity conservation and rural food security might be better addressed together

### *Introduction*

Farmers around the world face the challenge of adapting to changing climates, taxed natural resources and shifting economies, all while increasing yields to meet the needs of a growing population and increasing per capita food demand. Since the 1950s, improved varieties of key food crops, along with packages of agricultural technologies designed for large-scale monocultures, have resulted in impressive yield increases on many farms around the world. At the same time, the diversity of crops on which the world's food supply depends has narrowed dramatically (Gepts 2006; FAO 2010; Khoury et al. 2014), an effect, at least in part, of the industrialization of agriculture and the promotion of 'green revolution' technologies around the world (Zimmerer 1991; S. Brush 1991). This presents a contradiction between agrobiodiversity conservation and current plant breeding efforts to increase yields while responding to changing growing conditions and emerging pests. Plant breeding depends on agrobiodiversity, but the largest plant breeding efforts, and the industrial model of agriculture in which it they are embedded, threaten agrobiodiversity.

This contradiction can be only partially alleviated by *ex situ* conservation of crops and wild relatives in seed banks. Seed banks can help to preserve a subset of the most economically important germplasm, but in doing so freeze its adaptation to a changing world and divorce it from the dynamic social and environmental contexts in which it evolved. Preserving dynamic agrobiodiversity requires conservation *in situ*, in the context of small, diverse farms (Altieri and Merrick 1987; Oldfield and Alcorn 1987).

Successful conservation of agrobiodiversity *in situ* likely depends on the continued value of agrobiodiversity to smallholder farmers more than anything else. If a particular cultivar does not contribute to a smallholder's livelihood, she is not likely to continue to cultivate it for very long. Likewise, if diversified farming in general does not support a viable livelihood, farmers are likely to devote less and less labor to diverse farms as they re-allocate labor to other activities. This may seem obvious, but it is less obvious what aspects of agrobiodiversity are most valuable to smallholders, in what situations agrobiodiversity contributes most to smallholder livelihoods, and what aspects of smallholder livelihoods are most affected by agrobiodiversity enhancement or loss. A better understanding of the more specific ways in which agrobiodiversity supports smallholder livelihoods, and smallholder livelihoods support agrobiodiversity, could inform better programs and policies that support both.

Despite very real concerns about declining agrobiodiversity at the global scale (FAO 2010; Khoury et al. 2014), and despite apocalyptic predictions that 'improved' varieties coming out of institutional crop breeding programs would quickly displace traditional varieties (Harlan 1972; Harlan 1975; Frankel 1974), researchers have found that many smallholder farmers have retained high levels of diversity on their farms, even as they incorporate 'improved' crop varieties into their diverse agroecosystems (Brush 1986; Zimmerer 1996; Isakson 2009). Based on farmers' explanations of their choices, these researchers concluded that diversity helped to reduce the chance of hunger due to crop failure. Both the diversity of varieties and species on the farm and the heterogeneity within traditional varieties are implicated in reduced livelihood risk (Zimmerer 1998). In light of these studies, agrobiodiversity seems more like a valuable risk-reducing tactic, not just a relic of 'traditional' agriculture.

Smallholder farmers use several tactics to reduce risk to their livelihoods and to cope with environmental variability; how exactly agrobiodiversity fits into the broader set of tactics, and its relative importance among them, are not self-evident. Halstead and O'Shea (*Bad Year Economics: Cultural Responses to Risk and Uncertainty* 2004)describe four categories of cultural responses that buffer livelihoods against environmental variability: mobility, diversification, physical storage, and exchange. Agrobiodiversity is a subset of the broader category of diversification, which for smallholder farmers also includes diversification of livelihood activities across sectors (Netting 1993; Ellis 2000) and the spatial scattering of fields across microclimates (Goland 1993; Forbes 2004). There is no straightforward relationship between agrobiodiversity and other forms of livelihood diversification. On one hand, diverting household labor to nonagricultural activities can have a negative impact on agrobiodiversity (Zimmerer 1991), but on the other, the proceeds from higher-value cash crops and wages of household members abroad can support diverse agroecosystems (Zimmerer 2013).

Likewise, food security is only one aspect of a sustainable livelihood, albeit a central one. Under stress, households can be expected to employ coping methods to avoid hunger, some of which may cut into assets critical to livelihoods (Wisner et al.

2004). Eating or selling livestock to an extent that the breeding stock is reduced, taking out loans against land, or selling parcels outright to cover emergency costs are examples of coping strategies that can damage future productivity. In this analysis, I will focus especially on the coping strategy of diverting labor from managing diverse agroecosystems to working temporary jobs to generate cash. Such coping strategies would leave households more vulnerable to hunger in the future, but may not show up in current assessments of food insecurity.

In a previous study (Chapter 2 of this dissertation), I measured agrobiodiversity in 45 home gardens in the rural municipality of Tzucacab, Yucatan, in Southeastern Mexico. There was a wide range in home garden diversity in this sample—taxonomic richness ranged from 4 to 45—suggesting that the value and role of agrobiodiversity differed between households. I did find that higher levels of agrobiodiversity were associated with higher levels of food security, even when I controlled for differences in income, farm size, household labor, and multiple indicators of socioeconomic status. Several farmers told me that they planted a wide diversity of crops in order to protect themselves against the possible failure of any one crop; in the words of one farmer, "so that there will be something to eat if the corn gets flattened." In several farm visits during the particularly hard times precipitated by two years of drought and the rapidly rising cost of food and agricultural inputs in late 2011, I observed households subsisting on secondary crops like cassava (*Manihot esculenta*) and lima beans *(Phaseolus lunatus)* that normally complement staples like corn and beans (see Chapter 4 for an ethnographic account of secondary crops providing protection from hunger). From this combination of quantitative and qualitative data, I concluded that agrobiodiversity was functioning as an effective risk-minimizing strategy. At least at that moment in late 2011, agrobiodiversity was ensuring food security in peasant households much the way that the "insurance hypothesis" in ecology predicts that functionally redundant species support ecosystem functions and services during a disturbance (Yachi and Loreau 1999).

While I found evidence that agrobiodiversity was driving food security, another question remained: what accounts for the large difference I observed in agrobiodiversity between households? One possibility is that those differences can be explained by a household's ability to implement agrobiodiversity, rather than on differences in strategy. If a household has a very small piece of land, for example, or available labor is severely limited, they will not be able to care for a high-diversity garden regardless of intention. This is certainly possible, as indicators of household wealth and socioeconomic status positively associated with home garden agrobiodiversity in several studies (Zimmerer 1996; Zimmerer 2007; Coomes and Ban 2004), and farm size was a strong predictor of diversity in other studies (Millate-E-Mustafa, Hall, and Teklehaimanot 1996; Bernholt et al. 2009).

Another possibility, however, is that something about being more food secure puts households in a better position to grow a high-diversity garden. This would complicate my previous finding that agrobiodiversity was causing food security, indicating that there may be a positive feedback between agrobiodiversity and food security. It may seem contradictory to suggest that agrobiodiversity 'causes' food security and that some aspect of food security also 'causes' agrobiodiversity. However, it is easy to imagine many mechanisms by which food security could result in greater agrobiodiversity that do not contradict the original finding. Less hungry household members may be better able to do the skilled work of managing diverse agroecosystems. For the household with a very precarious food supply, there would likely be less time and energy for growing fresh vegetables, herbs, medicinal plants, ornamentals, and other plants and animals that enhance quality of life, since seeking calories or the cash to buy them would take precedence (see Figure 7).

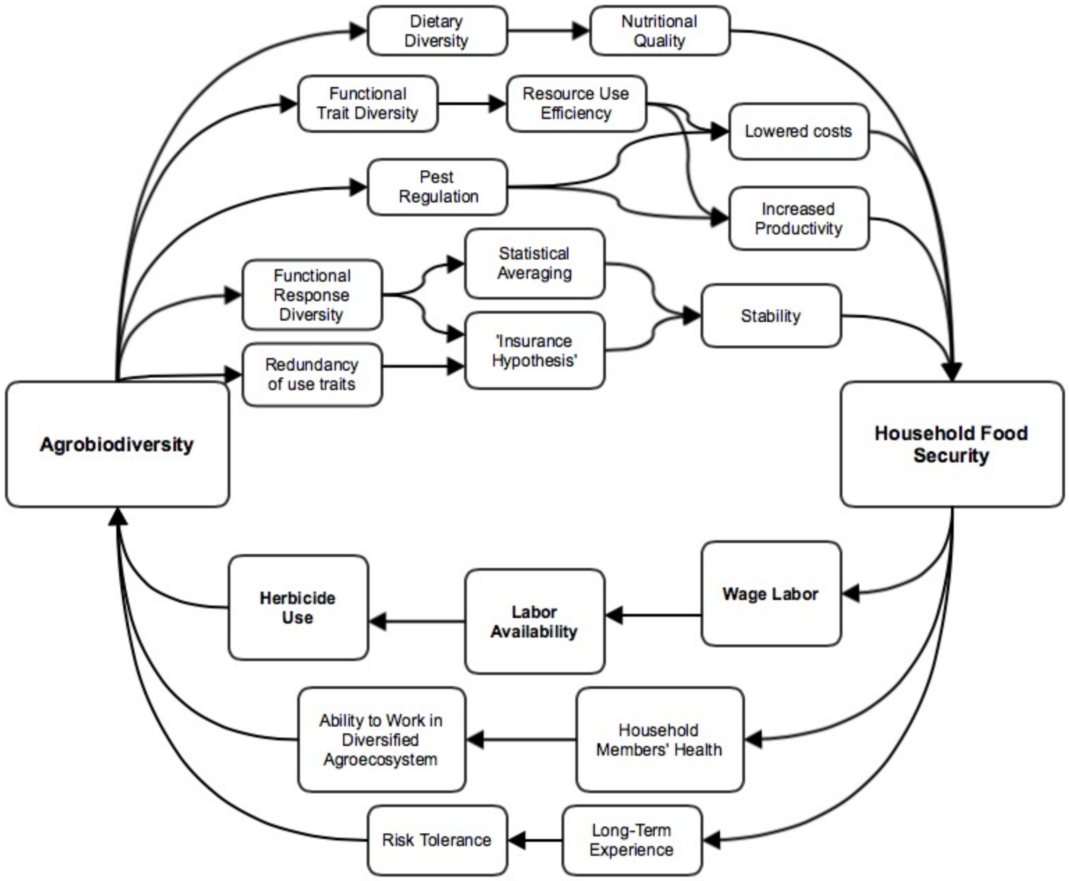


Figure 7. Some hypothesized causal pathways linking agrobiodiversity and household food security.

In this paper, I turn to the experiences of contemporary smallholder farmers in the Yucatan peninsula of Mexico to explore mechanisms by which agrobiodiversity and food security are mutually reinforcing, and conversely, that a decline in one can precipitate a decline in the other. I present evidence that there is a positive feedback loop between agrobiodiversity and food security, refuting unidirectional causality. The relationship between agrobiodiversity and food security takes place in a complex context of rural livelihoods; many socioeconomic and environmental factors shape food security, and many factors shape and constrain smallholders' choices that affect agrobiodiversity. I address this complexity in two ways: first, I present quantitative data on agrobiodiversity, food security, and ten other indicators related to household economics intended to represent a wide array of that possible drivers of food security and/or agrobiodiversity. This data allows me to examine correlations between these factors, food security, and agrobiodiversity, revealing a rough snapshot of the relative importance of these factors at the time of measurement. Second, I present qualitative data from interviews with smallholder farmers in which they explain their choices that affect agrobiodiversity and food security. This analysis—emic and etic, deductive and inductive—reveals differing approaches to achieving food security between households, in which agrobiodiversity plays markedly different roles. Farmers' motivations and experiences illuminate mechanisms by which food security affects agrobiodiversity and agrobiodiversity affects food security.

### *Methods and Study Site*

Research took place in the municipality of Tzucacab, in the South of the Mexican state of Yucatán, during 2010 and 2011. About 14,000 people live in the municipality in 3,253 households, in the main town of Tzucacab and in 13 smaller villages. The majority of residents are Mayan-speaking (INEGI 2012). The climate is tropical and seasonally dry, with much of the agriculture dependent on summer rains. I selected 60 households at random from a database maintained by researchers at the Autonomous University of Yucatan of households participating in a larger study (Becerril García, Casteñeda, and Solís 2014; Becerril García 2010). The households in the database, in turn, were selected using a semi-random methodology in 2010 by researchers who walked systematically from house to house asking for willing participants in their study until they enlisted 20% of the population of each town or village. My selection was stratified to be representative of the population of the main town and each village in the municipality of Tzucacab. I was able to obtain high-quality data on agrobiodiversity, food security, and household economics for 45 households, and quantitative analyses are based on this sample.

***Measuring Agrobiodiversity***

Home garden agrobiodiversity was measured by direct observation. Teams of local field assistants counted every plant and animal present in the home garden that was actively managed or used by the household. I measured diversity at the taxonomic level of landrace or variety (in the case of plants) or to the breed level (in the case of animals), since interviews with key informants revealed that this is the taxonomic level at which farmers make decisions that affect diversity. A household member accompanied the field assistants to verify the accuracy of the teams' identifications. Most studies that link agrobiodiversity to food and nutrition outcomes rely on taxonomic richness (the number of taxa present) as the sole measure of diversity (Zimmerer 1996; Perreault 2005; Isakson 2009), while studies of biodiversity in the field of ecology consider evenness (the distribution of individuals among taxa) to be another important dimension of agrobiodiversity (Magurran 2004). I see evenness as a potentially important aspect of a households' agrobiodiversity strategy: in addition to high richness, high evenness reflects a high-diversity strategy, while low evenness reflects a specialization strategy. Counting every plant and animal allowed me to calculate evenness (as Fishers' J') and the Shannon-Wiener diversity index (H') that incorporates both richness and evenness.

***Measuring Food Security***

There are two common approaches to measuring household food security: one can measure food intake in terms of grams of calories (using 24-hr recalls, food diaries, etc.) and compare that to an *a priori* assumption of an adequate diet, or one can have participants self-identify experiences with food insecurity over a given time frame. I chose the second approach because: (1) it captures a greater range of the experience of food insecurity, from worrying about food running out to feeling hungry, in contrast to food-intake approaches that only capture results after any coping strategies have been applied; and (2) participants' subjective experience with food insecurity is probably a more direct measure of the success or failure of their livelihood strategy than the quantity of food that they eat. In addition, this approach requires far less time on the part of research participants and researchers, allowing both a larger sample size and a more randomly selected sample (fewer households opt out).

Interview questions were adapted from the United States Department of Agriculture's (USDA's) methodology (Bickel et al. 2000) for a place where food is produced by the household as often as it is purchased. Our method is similar in approach to the USAID's Household Hunger Scale, published after fieldwork had begun (Ballard et al. 2011). Food insecurity was assessed by an in-person interview with heads of household to ascertain if anyone in their household had experienced certain aspects of food insecurity within the last year, namely: (1) worrying that food will run out; (2) eating less preferred, unfamiliar, or less healthy foods; (3) reducing portion sizes or skipping meals due to a lack of food; and (4) feeling the physical sensation of hunger without having access to enough food to satiate it. Each condition was assessed with multiple questions at different points in the interview to try to account for the potential tendency to underreport experiences with food insecurity due to embarrassment. The resulting scale ranges from 0 (severe food insecurity including physical hunger) to 4 (no reported food insecurity). Like the USDA's results, ours were highly nested by severity; food insecurity tended to progress from worry to substitution to rationing to hunger.

***Measuring Household Economics***

I measured ten other indicators of household economics with direct relevance to agrobiodiversity in the same in-person interviews: (1) household size, or the number of people that eat daily in the household; (2) consumer-producer ratio, which weighs the production and consumption of each family member by age and sex (Chayanov (1986); (3) number of wage laborers in the household (including members currently working for a wage and members that occasionally work for a wage as needed); (4) off-farm income, calculated from farmers' estimates of their households' income over the previous 12 months from various sources, predominantly wage labor, remittances, income from non-agricultural businesses, and payments from government programs; (5) number of income sources, or the sum of all the distinct income-generating activities reported in the household and is meant as a proxy for the diversity of livelihood activities; (6) age of the head of household; (7) number of years of formal education for the self-identified head of household, who was most often male; (8) home garden size, measured in $m^2$ by walking the perimeter of the home gardens with a Garmin 62s GPS unit; (9) home garden age; and (10) the number of animals in the home garden.

### ***Quantitative Analysis***

Data was coded by field assistants in Yucatan and processed by the author using the statistical computing software R, version 3.1.2. Diversity statistics were calculated using the vegan package for R, version 2.2-1. Correlations are 2-tail Pearson's product-moment correlations.

### ***Ethnographic Data***

Interviews reported here were collected from three different populations. Some ethnographic data was collected during the food security interviews described above. Most of the farmer perspectives reported here were informal interviews and participant observation with eight key informants between April 2010 and December 2013. Of these key informants, six were also participants in the food security survey. Many of these interviews were digitally recorded while others were documented in field notes. A third group of interviews was conducted and video-recorded by field assistants Gilberto Jiménez Chi and Leonor Dzul Uc. All interviewees' names have been changed in accordance with confidentiality agreements and human subjects protocol, except for Doña Rosi, who was not a participant in the food security interviews and asked that her real name be used.

### ***Results***

At the time of the food security interviews in late 2011, a majority (78%) of households reported at least some experience with food insecurity over the proceeding year, but a minority (27%) had suffered physical hunger because of a lack of food, the most severe experience of food insecurity that I measured (Figure 8, Table 4). Food security is correlated with agrobiodiversity $r(43)=0.34$, $p=0.02$), but more a mathematical certainty than an indication of a positive feedback, as I have already found using regression analysis that agrobiodiversity was driving food security (Chapter 2). Of the household economic data, only household size was marginally significant in its correlation with food security ($r(43)=0.25$, $p=0.1$).

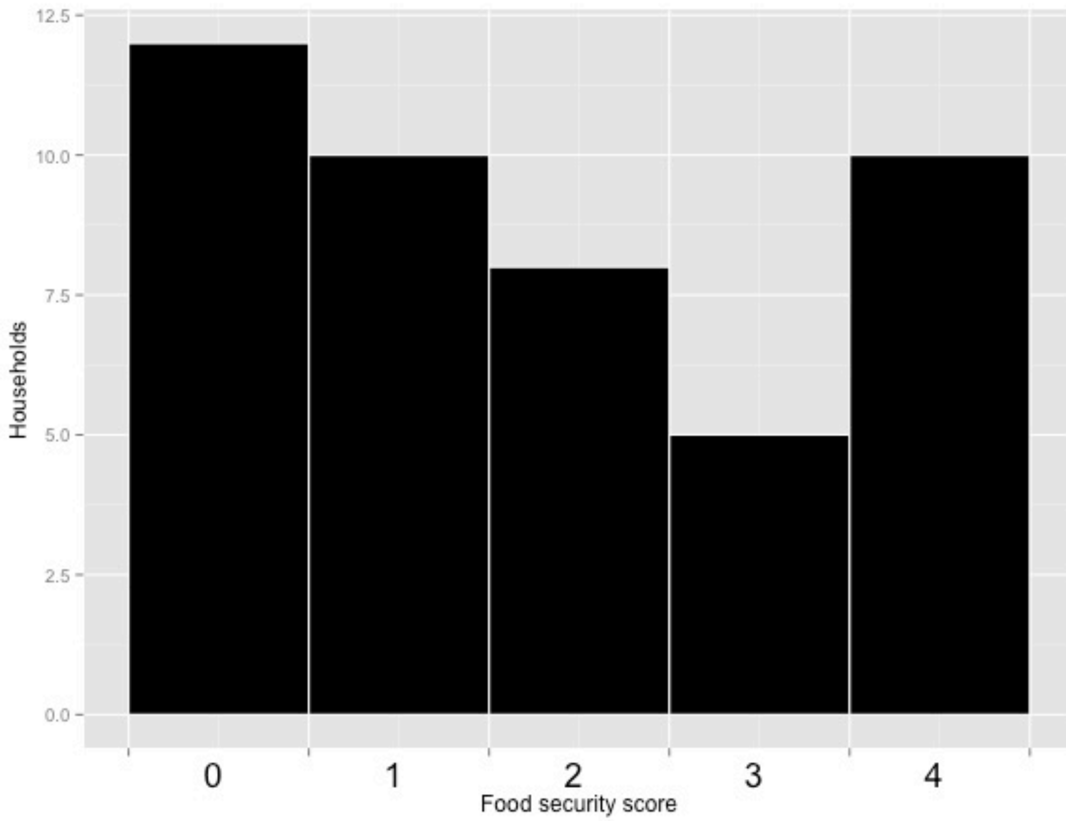

Figure 8. Frequency of food security scores among households. A food security score of 0 means that a household reported all experiences with food insecurity over the preceding 12 months; a food security score of 4 indicates that a household reported no experiences of food insecurity in that time frame.

| *Indicator* | *Mean* | *SD* | *Min.* | *Max.* | *Median* |
|---|---|---|---|---|---|
| Food Security Score | 1.80 | 1.52 | 0 | 4 | 2 |
| Taxonomic richness | 22.87 | 9.99 | 4 | 45 | 23 |
| Pileu's evenness (J') | 0.81 | 0.17 | 0.10 | 0.85 | 1.00 |
| Shannon Index (H') | 2.42 | 0.64 | 0.25 | 3.30 | 2.54 |
| Household members | 4.96 | 2.01 | 1 | 10 | 5 |
| Consumer:Producer ratio | 1.04 | 0.05 | 0.98 | 1.18 | 1.02 |
| Household members working off-farm | 1.11 | 1.03 | 0 | 5 | 1 |
| Off-farm income (pesos/year) | 3,246 | 2,388 | 0 | 9,233 | 2,920 |
| Number of income sources | 4.38 | 2.18 | 1 | 8 | 4 |
| Head of household's age | 49.20 | 13.07 | 25 | 81 | 48 |
| Head of household's formal education | 3.89 | 4.00 | 0 | 17 | 3 |
| Home garden size ($m^2$) | 1,406 | 1,558 | 118 | 7,303 | 841 |
| Home garden age (years) | 24.93 | 16.64 | 1 | 60 | 20 |
| Livestock holdings | 20.47 | 23.84 | 0 | 96 | 15 |

Table 4. Descriptive statistics of food security, agrobiodiversity, and household economics.

Households' home gardens differed greatly in both size and diversity (Table 4). The large difference in diversity between home gardens begs for an explanation. One possibility is that home garden agrobiodiversity is shaped by socioeconomic constraints that differ between households that have little to do with food security. I used Pearson's correlation tests to measure the relationship between agrobiodiversity metrics and several possible constraints on agrobiodiversity (Table 5). There were marginally significant ($p < 0.1$) relationships between agrobiodiversity (quantified as H') and off-farm income, head of household's age, and the number of livestock that a household owns. A few of these results warrant clarification. The negative relationship between H' and off-farm income ($r(43) = -0.02$, $p < 0.10$) does seem to contradict positive relationships between agrobiodiversity and income observed in other locations (Zimmerer 1996), but those studies used richness as the sole measure of diversity, which in our case has no relationship with income. The two other characteristics with marginally significant correlations with agrobiodiversity, head of household's age (for H', $r(43) = 0.26$, $p < 0.10$) and livestock holdings (for H', $r(43) = 0.25$, $p < 0.10$), could be proxy measures for household wealth: older households have successfully survived many farming seasons and may have accumulated savings, and livestock both requires wealth and is a common way to store wealth. The correlation of H' with livestock holdings is driven by richness ($r(43) = 0.40$, $p < 0.01$), not evenness ($p > 0.10$), and is perhaps partially explained by the fact that animal species in the home garden are reflected in the diversity measures. It does however seem likely that animal holdings are also a form of stored wealth and thus a proxy for household wealth. If these findings indicate a correlation between household wealth and agrobiodiversity, they are consistent with similar studies in Andean home gardens (Zimmerer 1996; Zimmerer 2007; Coomes and Ban 2004). In our study, the size of the home garden has no relation to agrobiodiversity, in contrast to home garden studies in Bangladesh (Millate-E-Mustafa, Hall, and Teklehaimanot 1996) and Niger (Bernholt et al. 2009).

| | *Agrobiodiversity* | | | |
|---|---|---|---|---|
| *Indicator* | *Richness* | *Evenness (J')* | *Shannon Index (H')* | *Food Security* |
| Household members | .14 | -.06 | .10 | .25† |
| Consumer:Producer ratio | .15 | .06 | .21 | .00 |
| Household members working off-farm | .03 | .04 | .03 | .22 |
| Off-farm income (pesos/year) | -.05 | -.26† | -.25† | -.07 |
| Number of income sources | .01 | .20 | .17 | .06 |
| Head of household age | .18 | .17 | .26† | .25 |
| Head of household formal education | -.05 | -.23 | -.17 | -.14 |
| Home garden size ($m^2$) | .09 | .06 | .16 | .09 |
| Home garden age (years) | .06 | -.17 | -.09 | .09 |
| Livestock holdings | .40** | -.06 | .25† | .05 |

Table 5. Pearson's product-moment correlations (2-tail) between agrobiodiversity and characteristics of the household and home garden. n=45, df=43, significance: †p<0.1, * p<0.05, **p<0.01.

While it does seem possible that several of these factors in combination could partially explain the differences in agrobiodiversity between home gardens, there is no clear evidence here that any of these factors are determining home garden agrobiodiversity. This leaves open the possibility that some significant part of the difference between home gardens can be explained by a positive effect of food security—that is, a positive feedback between food security and agrobiodiversity. For evidence of a positive feedback, I turn to qualitative data. Specifically, I look for evidence of a difference in opinions about the value of agrobiodiversity for achieving food security that could be explained as households success or failure in meeting their basic food needs over the long term, and for instances in which farmers described making decisions that made their gardens more or less diverse because of their experience of food security or insecurity.

***The importance of agrobiodiversity***

If the difference in diversity between gardens can be explained by differences in households' livelihood strategies, rather than differences in constraining factors, I would expect to see a difference in opinion about the value of agrobiodiversity. The majority of people I interviewed in Tzucacab believed that it is preferable to grow a wide diversity of plants and animals in the home garden. People's explanations reflected a wide range of benefits of a diverse home garden. Some of these imply a direct connection to food security; while others imply a less direct connection to food security, that agrobiodiversity benefits their livelihood in a broader sense, especially when compared to nonagricultural or commercial agriculture livelihood activities:

> [agrobiodiversity] is important so you don't have to always be going to the market to buy the things you need.
>
> It used to be when I lived in Playa [Playa del Carmen, a coastal city with a booming tourist economy], if I wanted a lime for my food, I would have to go buy one. One peso here, two pesos there. Now I just go out and pick it.
>
> [growing a diversity of crops] is important to support yourself and to show that you have learned something from what your parents have taught you, about your culture.
>
> There are so many things that you need, and so many of them are in your garden, more than people know. There is medicine; there is a leaf that you can use to scrub your dishes.
>
> So that when your corn gets flattened [by a hurricane], you still have something to eat…a little eggs, a little *chaya*.

Other gardeners emphasized that diversified farming was an accessible way for them to make a living, even if they did not have access to potentially more lucrative labor markets or more industrialized forms of agriculture:

> I'm old now so there are not so many things I can do [to make a living] but I do what I can here… I used to go to work, I made my *milpa* and I would get paid to work clearing forest… Here I have to plant everything I need.
>
> It's because of the rocky soil here. It's not like in other places, where the land goes on and on and you can pass through it with tractors. We can only do that in our little *cancabeles* [rock-less patches of red oxisols] where people can plant habanero chilies [for commercial markets]. Here, in-between the rocks, we can plant other things. That little spot [gesturing] is good for a papaya, water it every once in a while and it will grow.

In these explanations, a diverse home garden is a strategy by which marginal land and marginalized laborers can be very productive. It can provide a wide range of products conveniently in the yard, it is a practice of cultural identity, and it can provide a stable source of food, especially when other livelihood activities do not. Part of its value may be that it does not compete directly for labor or land with other, more commercially oriented agroecosystems and nonagricultural sources of income. Seen this way, a diverse home garden is a valuable, even essential part of a diversified livelihood.

Not everyone considered agrobiodiversity important. A field assistant recorded a video interview with a friend their age, about 18, who worked in agriculture:

> You should do one thing, but do it very well. For example, if you plant corn, plant nothing but corn, if you plant something else, plant only that, and really do that well. Otherwise, if you get involved in too many crops, you have to deal with too many different problems.

This dissenting opinion was rare, however. That I found few people arguing for less diversity may have to do with the fact that I spent more time with the most passionate advocates for diversified farms, and the fact that, even in my randomized sample, I could not hide the fact that I admired the complexity and diversity of people's home gardens. Over several years of research by the Autonomous University of Yucatan (UADY) in Tzucacab, it is possible that valuing agrobiodiversity has entered the 'public script' (Scott 1999) of values that peasants know researchers want to hear. Still, it seems that there is a broad agreement that high-diversity home gardens are valuable, and a range of characteristics make them valuable.

Even households that participated in capitalized, large-scale agriculture valued agrobiodiversity in the home garden. A member of a farming collective that grows corn and a few other crops, called a *mechanizado* for the central role of tractors in that agroecosystems, said that he also grows corn in his home garden, along with a mix of beans, lima beans, and various squashes. The herbicides and mechanization that they use in the *mechanizado*, he says, make it impossible to plant a diversity of crops together with the maize. He explained the logic of participating in both kinds of agriculture: "In the *mechanizado*, you have to use a lot of poison to kill the bugs and the weeds, and the fertilizer is expensive, but its worth it to have the security of having an irrigated crop." Another household in the study had recently received a large government-backed loan for a deep well and irrigation system that came with requirements to use certain corn seeds and a regimen of pesticide applications. They had stopped cultivating a traditional *milpa* to concentrate their labor on commercial crops of hybrid corn and watermelons, but had moved many of the crops formerly grown in the *milpa*—squashes, beans, cucumbers and chilies—to the home garden, increasing its diversity.

The near consensus I encountered in Tzucacab that agrobiodiversity was valuable and desirable did not help to explain the differences in diversity between home gardens. Where I did find differences in opinion, however, was in attitudes about the viability of agriculture in general to provide a viable livelihood.

***"The land doesn't provide anymore"***

During the food security interviews, I often heard that a household had stopped planting a certain crop or set of crops, most commonly the *milpa* crops corn, beans, and squash, after several consecutive seasons of crop failures or meager harvests.  In one of my first interviews on food security, a young couple who had recently had their first child described their choice to put less time into home garden agriculture, and to stop growing a *milpa* altogether.  The husband was working on a commercial papaya farm for a low wage of 570 pesos per week (approximately US$42 at October 2011 exchange rates).  He and his wife used these words to describe this decision: "The land doesn't provide anymore" ("*El campo ya no da*"). In subsequent interviews, I heard the same words from at least 14 more interviewees of many ages (I started counting only after I began to recognize the pattern).  It is no surprise that when high-diversity agriculture was not working for a household, and especially, not providing a reliable food supply, they might make choices that result in lower diversity on their farms.

In the highlands of Guatemala, Isakson (2009) heard a similar, but more specific explanation for reallocating household labor to activities that are more lucrative than subsistence agriculture: "there is no profit in planting a *milpa*" ("*no hay ganancia en sembrar la milpa"*). When he added the market value of crops produced in the milpa and subtracted expenses, he found that they were quite right—the milpa was seldom profitable, especially in comparison to other kinds of labor.  However, he argues, people continue to plant *milpas* to meet a variety of needs that alternative ways of making a living do not provide, including the pleasure of working outside for oneself, a foundation of shared cultural identity, and importantly for our hypothesis, a source of food that is independent of the fluctuations in food prices and demand for labor.  99% of farmers Isakson (*ibid*.) interviewed considered the *milpa* important to household food security, and two-thirds considered it very important. Although Tzucacab has a very different climate and a different Mayan culture, and the *milpa* is a different agroecosystem from the home garden, people articulated similar reasons for its importance: a fall-back source of food, a place they enjoy working and living, a place where Maya cultural identity is reproduced.

I became curious about what exactly people meant when they said "the land doesn't provide anymore." What change had transformed the land from something that provides to something that does not? Many farmers who used those words, including the couple described above, talked about climate change and a noticeable shift in rainfall patterns that left crops (and especially corn) vulnerable to drying out. Others spoke more broadly that pollution had eroded the land's productive capacity, or that the soil had simply become tired.

For a differing opinion, I asked several key informants whom I had gotten to know over visits to their very diverse farms what they thought people had meant when they told me that the land doesn't provide anymore. José, a farmer who grows subsistence crops and also a variety of fruit for export markets in a remarkably diverse 20-hectare orchard, was incredulous. "The ones who say that are the ones who don't want to plant," he told me, "Of course the land doesn't provide if you don't plant anything." He emphasized that the landrace of corn that he grows had reliably produced a crop for the last thirty years since his father had started planting it, "some years very little, but always enough to save the seed", while in the same time period nearly all of his neighbors had experienced at least a few years of total loss. I can verify that his success is rare, of the 60 households surveyed, not one had continually grown the same corn seed for 30 years. José attributed his success to a variety of factors: the 'strong' seed, his careful conservation of mature patches of forest that he said brought the rain, careful planting with the moon cycle, and a refusal to use herbicides or fertilizers. In explaining his success in the fruit growing business, he had told me that rather than planting in straight lines or grouping kinds of fruit together he carefully placed each kind of fruit tree in its optimum place, at the top or bottom of small variations in elevation, in very rocky or less rocky patches, and in the shade of other trees or exposed to full sun. This strategy, along with grafting only during the new moon, allowed him to achieve reliable harvests without irrigation, he told me. It seemed to me that the common thread of the factors to which he attributed his success all indicated a practice of close observation and a rejection of cutting corners on methods he knew to work. To be fair, I would add that his established family business gave him much more access to capital than his neighbors, and his two large trucks gave him advantageous access to regional fruit markets.

José was not the only successful farmer to dismiss the statement that "the land doesn't provide anymore" as a complaint of those who did not put in the work to do it right. The difference in opinion highlights a difference in livelihood strategy that did seem linked in part to success. For some households, diversified farming works and is a worthy investment of labor and other resources. For others, diversified farming, or perhaps farming in general, is a losing proposition. In the long run, households can be expected to make decisions that affect agrobiodiversity based on this outlook, allocating resources to diverse agroecosystems or diverting them towards other livelihood activities.

It seems reasonable to assume that this outlook is shaped in part by the successes or failures that a household had experienced with agriculture over the long-term. For a household that depends mostly on agriculture, the experience of running out of food due to crop failures would assumedly erode confidence in the land's ability to provide for their basic needs. This divergence of opinions suggests a context for a positive feedback between the experience of food and livelihood security and agrobiodiversity, but it is unsatisfying in that it does not identify a specific mechanism by which a lessened confidence in agriculture, or a reallocation of labor away from the home garden, would result in reduced agrobiodiversity.

### ***Labor Shortages, Herbicides, and Agrobiodiversity Loss***

Doña Rosi, a passionate advocate of agrobiodiversity conservation who became a key informant in my study, had a diverse home garden on a small plot of land in the main town of Tzucacab and was active in a school garden project that advocated agrobiodiversity conservation, suggested such a mechanism. She surprised me when she agreed that "the land doesn't provide like it used to." She described it this way:

> In my fathers' time, everything that he planted would produce. He would plant watermelons and he would get big watermelons, more than he could carry home, so many that he was giving watermelons away. He would give you a watermelon if you were walking down the street and he was on his way back from the *milpa*… in those times, you would see a *campesino* coming back from his *milpa* with buckets full [of produce].

What had changed, she argued, was the introduction of agrochemicals, especially herbicides:

> *Campesinos* today only know how to grow corn. When you plant, you mix the seeds of lima beans, beans, jicama—lots of seeds in with your [corn] seed. But what happens? When it comes time to weed [*deshierbar*], they fill up their bottle of herbicide, and with that they fumigate, they 'cut down' the weeds [*chopear*]. And all these things they planted, they kill them, and only the corn is left. All the other seeds that they put in the soil, they die, because they kill them with the herbicide. This makes me sad, because before, there were no *campesinos* who carried around a backpack of herbicides to go kill everything that they had planted.

The biochemistry of Rosi's hypothesis checks out: the herbicides that *campesinos* use in Tzucacab most often contain 2,4-D as their active ingredient, sold under brand names like *Esterón* and *Machete*. These herbicides kill dicotyledonous plants like beans and squash but do not affect monocotyledons like corn. Rosi attributed the use of herbicides to cutting corners, with more than a hint of contempt for farmers who did not want to do the hard work of removing weeds using a machete. Edelmira, who also has a very diverse garden (she is profiled in detail in chapter 4), independently described the same effect, but attributed the use of herbicides to labor shortages, positioning it more as an act of desperation. As we walked through the garden, she told me that she was behind on removing weeds. When I asked if she considered using herbicides, she said:

> No. No. I'm waiting for there to be a day little less sun so that I can clean up here… I will cut them down like this [cutting at the roots of a plant with a machete]… People who use herbicides are left with only corn. Nothing else grows because it is killed by the herbicide… But to clear out weeds like this with the machete, it is work. My son says, "if you like, we can do it with herbicides" but you would have to be so careful to avoid the plants.

A few months later, she told me that she had used herbicides to clean up the patch out of desperation, with all her responsibilities, all the tasks of her large garden, and with her husband working six days a week on a nearby ranch and her son working on a commercial watermelon harvest crew, she didn't have time to weed the corn by hand:

> Right now we are buying corn and the price of corn is high. When you have to work to buy corn there is no time to weed by hand.

Her beans and lima beans died, of course. Herbicides are a labor saving technology, but they do seem to come at the cost of agrobiodiversity. Edelmira used them on only a small portion of her home garden in a moment when labor was in particularly short supply, but, as she said, many people use them much more commonly. Removing weeds is one of the most time-consuming tasks in Yucatecan milpas (Hernández Xolocotzi 1995). Wage labor simultaneously reduces a household's supply of labor available for diverse agroecosystems and makes cash available for chemical replacements for labor. Beyond herbicides, chemical fertilizers replace the labor of clearing new land in the forest or making compost. Tractors, in the few places in Tzucacab accessible to them, and for the few people with access to enough capital, replace the labor of many farm tasks. Herbicides are probably not the only mechanism by which food insecurity, contributing to a need for wage labor and a local labor shortage, ends up reducing agrobiodiversity.

Diverse farms require large amounts of labor, and a shortage of labor could undo them in many ways. In Peruvian highland towns, seasonal labor shortages due to a combination of reduced local economic opportunities and increased demand for workers to harvest rice in the lowlands caused many households to abandon the short-season corn and potato varieties that required labor during the rice harvest. There, diversity was not lost by slow erosion as values changed or displacement by 'improved' varieties, rather, whole types of crops were lost suddenly (Zimmerer 1991). In the Yucatan peninsula, the attraction of wage labor in construction and tourism on the coast has attracted so many young workers that the coast is sometimes called, tongue-in-cheek, the *milpa*; it is somewhere men go to make a living (Cruz 1996, 78). In Tzucacab, the institution of the actual *milpa* agroecosystems is widely thought to be in decline, and 73% of households in my study had at least one household member working for a wage at the time of the interview. The loss of crops that are vulnerable to herbicides may be only the first step in agrobiodiversity loss from the abandonment of the entire *milpa* agroecosystems. To the extent that labor shortages are driven by household members seeking employment as an emergency response to food insecurity, this constitutes one positive feedback between agrobiodiversity and food security.

I did not quantify the reason for off-farm labor in the food security interviews, but some respondents did volunteer the reasons why household members worked off-farm. While many interviewees reported that household members worked for a wage only when there was no work to do on the farm, others reported working wage jobs as a stop-gap measure to meet food needs:

> [My husband] is working for a rancher. He earns very little, but we need the money now because corn is expensive.

> My little brother is working right now, because he couldn't afford the cost of studying and the cost of food. He works whatever jobs he can get here in Tzucacab, maybe 5 days a week… It is a help for the family right now.
>
> For the last month and a half, my husband José has been working at *Valle del Sur* [a commercial farm specializing in cucumbers for export] because we are out of money.
>
> My sons are working some weeks, when there is work here in the community. [They do it] to buy our food each week.

For these and several other households, low food security was forcing a decision to allocate labor to cash generation in the short-term, away from their agroecosystems. These interviews were conducted at a time of especially low food security in Tzucacab, so presumably, the need to divert labor was temporary. However, if the temporary labor shortage reduces agrobiodiversity, and that reduction in agrobiodiversity results in a livelihood more vulnerable to whatever stressors come next, the positive feedback between agrobiodiversity loss and food insecurity could make them more likely to need to divert labor away from their agroecosystems again.

### ***Conclusion***

There does seem to be at least one causal pathway by which food insecurity results in reduced agrobiodiversity, in which some food-insecure households devote labor to wage earning as an emergency measure to meet food needs, then use herbicides to lessen the labor demands of growing food, reducing diversity as a side-effect. This reduction in agrobiodiversity could contribute to a more fragile agroecosystem, as lessened agrobiodiversity may increase a household's chance of going hungry (Chapter 2). Together, these findings suggest a positive feedback between food insecurity and agrobiodiversity loss.

Of course, the opposite would be true too: policies and interventions that support food security may help households avoid the need to choose between investing labor in diverse agroecosystems and working wage jobs to avoid food shortfalls. Strengthened safety nets seem especially promising in this regard. Of course, such policies would have to not also encourage reductions in agrobiodiversity. Interventions intending to assist farmer livelihoods by boosting yields at the expense of agrobiodiversity, for example, the common practice in Yucatan of subsidizing agrochemicals, may have negative impacts on agrobiodiversity.

Designing effective interventions will require more research into the multiple causalities linking agrobiodiversity and food security. Some significant questions remain, due to the fact that parsing agrobiodiversity from other risk management strategies is difficult. First, the interaction between diversifying crops and diversifying economic activities is complex. On one hand, there are apparent trade-offs in labor allocation between economic diversity and agrobiodiversity in a household. On the other, income from wages and remittances are often invested in diverse agroecosystems, and growing specialty crops for market has been found to increase agrobiodiversity in several places (Zimmerer 1996; Isakson 2009). Second, the lag between a decision about agrobiodiversity (planting an additional crop variety, for example) and the resulting change in household food supplies may in many cases be too long to make crop diversification or specialization a viable place for implementing short-term strategies for managing risk. Cropping decisions for annual plants and many livestock species are made one or more times a year, meaning that farmers can make changes in these components of agrobiodiversity in response to food shortages that last only a year or two, and later, re-invest in diversity. However, decisions about the many perennial plants happen much less frequently. These, presumably, change with long-term assessments of the value of agrobiodiversity, including assessments passed from generation to generation and encoded in traditional knowledge. Households have many options for increasing or decreasing the variability in their food supply, and some—such as diversifying economic activities—presumably have more immediate results than changing the diversity of the home garden.

Disentangling causes and effects will require measurements of food security and agrobiodiversity with the same households over multiple growing seasons. Longitudinal data could help determine when and under what conditions experiences with food insecurity lead to reductions in agrobiodiversity, and under what conditions changes in agrobiodiversity affect household food security. Causal connections could be evaluated more directly by observing changes from one year to the next; seeing, for example, if a shortfall in food security one year is likely to result in a change in agrobiodiversity in the following years. Additionally, incorporating etic measurements of food intake to complement our experience-based measurements of food security, and measuring household risk orientations independent of food security through methods like participatory risk mapping (Smith, Barrett, and Box 2000), would provide finer-grained tools to assess the trends that I observed and move towards a more complete causal understanding of the relationship between food security and agrobiodiversity. Such an understanding could illuminate opportunities for policies and development interventions to support households in both agrobiodiversity conservation and rural food security.

# 4. Productivism, Agroecology and Feeding the World

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Target Journal: *Gastronomica*

***Abstract***. One strategy for alleviating hunger has long dominated both academic discourse and the interventions of the worlds' largest governmental and philanthropic institutions: grow more food per hectare of land. This 'productivist' ideology gains a sense of moral urgency from the calculation that agriculture will need to feed 9 billion people by 2050, but hunger is caused by poverty and complex social and environmental relationships, not the simple ratio of population to production. What's more, diverse farms provide for tangible and intangible needs that are never recorded as yields. While small-scale diverse farms may seem simple and backward in comparison to genomic plant breeding and precision agriculture, this perception is in the eye of the beholder—it is shaped by productivism. Through the lens of one farmer in rural Yucatan, Mexico, this paper explores the value of what may be lost in a renewed effort to boost yields on small farms. Via a trip to the Food and Agriculture Organization's headquarters in Rome, it explores the difficulty of bringing alternative worldviews and ways of farming, especially agroecology, into a large development institution. Small-scale, diverse farming systems may be uniquely well adapted to the challenge of feeding a changing world.

### *Doña Edelmira*

The road to Doña Edelmira's house is narrow, thick brush has quickly closed in from both sides during the hot, rainy summer. Chelsea and I bumped around the potholes in a rental car for about an hour on our way south from the University of Yucatan's research station in the town of Tzucacab, towards the south of the Tzucacab municipality where we had several interviews about household food security scheduled with farmers. It was September, and we past fields cut into the forest where ears of corn were ripening on stalks that famers had recently doubled over to help it dry, harvest was coming soon. It would, we heard, be the first good harvest after two years of drought. I'm not sure what we expected to hear in our interviews, but that drive through the lush landscape, and the meals we had been enjoying with friends we had made in Tzucacab over the past few years, gave me a sense of plenty that was about to shift uncomfortably. I met Edelmira a couple of months before, when a computer program randomly assigned her to our research sample of 60 households in the municipality, and, with a team of research assistants, we identified and counted every plant and animal in her home garden. Her garden was spectacularly diverse, even for rural Yucatan, and took hours to survey. Our study was designed to test the hypothesis that households with more diverse gardens where also more food secure, that is, that agrobiodiversity helped to buffer the risk of going hungry. Now, I had designed and piloted a battery of questions designed to measure food security, and Edelmira was one of our first interviews. We pulled the car to the side of the road in front of our house.

We interviewed Doña Edelmira in her garden, sitting in the shade of her tamarind tree. It was a long interview, covering many aspects of how she and her family made a living, how the many things that she grows in this garden feed them, and when they are not enough. Meanwhile, she was interrupted often by her kids and grandkids; the work of running her household did not stop. She got up twice to shoo small groups of turkeys away from her flowers, once to scare off a debt collector looking for an outstanding balance on a water tank, and once again to turn down a tortilla salesmen on a motorbike. To my battery of questions on her experiences with food insecurity over the last year ("In the last year, have you worried that your family would run out of food before you could get more? Have you had to eat food that you didn't like or know was unhealthy because there wasn't enough good food? Have you reduced portion sizes or skipped meals in your family because there wasn't enough food? Has anyone in your family felt hungry and not been able to satisfy it because there wasn't enough food?), she answered that her family was currently experiencing all but the most severe. Then she invited us to stay for lunch.

She wasn't the only one we interviewed to report that she was currently rationing food and skipping meals, or for that matter, to invite us for lunch afterwards. That fall was a series of intense interviews and long drives to places where food reserves had long since run out, and the new crop was not quite ready yet to take its place. I'm not sure why I didn't foresee that we would be asking about hunger at the precise moment when people were struggling the most. People talked about the immediate causes of hunger, mostly the drought of the past few years and rising food prices, but also about injuries that prevented a member of the family from working, and sometimes the demands on household income of sending children to school. After years of disappointing yields, some households had decided not to plant corn this year, and instead to pursue other ways of making a living that in some cases panned out and in others did not. Nearly half of the households we interviewed reported rationing or skipping meals, and a quarter reported feeling physical hunger.

But then there was the question of lunch. In some cases, we found a way to politely decline. When one woman told us in the interview that each member of her household was eating two and a half tortillas each day and later asked us to stay for tacos, apologizing that the tacos would be filled only with *ibes (Phaseolus lunatus)*, a kind of lima bean, we made the excuse that we had to get to the next interview. But when Edelmira asked us to stay for lunch she did it with such obvious pride that we accepted. Her daughter brought us each a steaming plate of *yuca*, the starchy cassava root (*Manihot esculenta*) boiled in sugar syrup, which we ate under the tamarind tree.

## Productivism

Poverty and marginalization, prevalent in rural places, conspire with unpredictable growing conditions and erratic food prices to make many hundreds of millions of people vulnerable to running out of food. It is unsurprising then that people involved in food production— farmers, pastoralists, fishers— make up the large majority of the hungry people in the world (FAO 2004b, 25). What is surprising to me is that one approach has dominated has dominated large-scale efforts to alleviate rural hunger in the world: produce more food per hectare of land.

Norman Borlaug, the plant scientist who won the Nobel Peace prize for his role in kickstarting the green revolution by breeding new high-yielding grain varieties and mobilizing massive philanthropic investments in industrial agriculture in Mexico and India, believed wholeheartedly that eliminating hunger from the world was a matter of increasing production while controlling population growth. The green revolution did not end hunger, though, and the package of new crop varieties, fertilizers, pesticides, tractors, irrigation and credit that he prescribed had devastating side-effects. He dismissed those questioning the net effect of the green revolution as elitists, saying, “If they lived just one month amid the misery of the developing world, as I have for 50 years, they'd be crying out for tractors and fertilizer and irrigation canals, and be outraged that fashionable elitists were trying to deny them these things” (Reed 2009). Earl Butz, United States Secretary of Agriculture under Nixon, put production above all else in U.S. farm policy, advising farmers to “plant fencerow to fencerow” and, to achieve the efficiencies that come with economies of scale, to “get big or get out”. When asked about growing concerns over pesticide use, he reiterated his commitment to production, saying “Before we go back to organic agriculture, somebody is going to have to decide what 50 million people we are going to let starve” (Goldstein 2008).

But hunger is not necessarily caused by a lack of food. Hunger happens even where food is plentiful; much of the agricultural policy in the United States, for example, is intended to deal with a persistent problem of overproduction, while, at last count, 17.5 million American households were food insecure (Coleman-Jensen, Gregory, and Singh 2014). The economist Amartya Sen, another Nobel winner, opens his book *Poverty and Famines* with this observation: "Starvation is the characteristic of some people not *having* enough food to eat. It is not the characteristic of there *being* not enough food to eat. While the latter can be a cause of the former, it is but one of many *possible* causes" (Sen 1981, 1; emphasis his). He argued that hunger was mostly a problem of poverty, and a failure of democracy, not production. Sen recognized that there is an appealing straightforwardness to the idea that boosting agricultural productivity can cure hunger, especially in comparison to the complex social relationships that he argues actually shape peoples' access to food. "The mesmerizing simplicity of focusing on the ratio of food to population," he wrote, "has persistently played an obscuring role over centuries, and continues to plague policy discussions today much as it has deranged anti-famine policies in the past" (*ibid*, 8). *Poverty and Famines* informed interdisciplinary research that dives into the complex, situated social relations that make rural people more or less vulnerable to hunger (e.g., Watts and Bohle 1993; Wisner et al. 2004), but in the mainstream of efforts to alleviate hunger, the focus on production persists.

A new wave of scholarship in top academic journals once again calls for investments in development and extension of agricultural technologies in order to boost yields on small farms as *the* key strategy for addressing hunger (Godfray et al. 2010; Foley et al. 2011; Tilman et al. 2011). These arguments draw a Malthusian urgency from the calculation that 9 billion people will need feeding by 2050, while per capita demand for food is also increasing, that the planet's resources are already overtaxed, and that climate change poses massive new challenges to agriculture. The proposed solution turns on "closing the yield gap" between relatively low-yielding small farms and the theoretically possible yields measured on nearby high-yielding farms and agricultural research stations (Neumann, et al., 2010; Licker, et al., 2010). Greater yields on small farms will bring greater incomes for smallholder households, the argument goes, stimulating rural economies and resulting in further gains in food security. Some caveats are made for sustainability. Reducing the amount of fossil fuels and water required, reducing postharvest waste, and slowing the development of pesticide resistance join crop productivity on the to-do list of technical challenges requiring research and development and eventually extension to farmers around the world (Beddington 2010). But the focus of these works is still squarely on production and population—on "feeding 9 billion by 2050" (Godfray et al. 2010)— precisely the deceptively simple calculation that Sen criticized. I have started to call this narrow focus "productivism," as at this point, 35 years after *Poverty and Famines*, the myopic focus on production as the means to ending hunger seems to me more like an ideology than an analysis or a plan; the approach deserves to be an *–ism*.

Closing the yield gap implies transforming "low-yielding" small farms to function like "high yielding" farms and research plots, which brings us to another critique of the focus on productivity at all costs. Farming the green revolution way, where managing production is a calculus of inputs and outputs, and crops are planted in large-scale monocultures designed for mechanization and economies of scale, may not actually be the most productive approach—depending on how production is conceptualized and measured. For example, farmers in Southern Mexico often grow maize, beans and squash together in an arrangement that produces more food per square meter of land than separate monocultures of each crop. Complementary relationships between the crops resulted in more efficient use of light, space, water, and nutrients (Mead et al. 1986; Amador and Gliessman 1990; Gliessman 2007). Around the world, crop diversity is linked to the regulation of pests and diseases, reducing damage and often eliminating the need for pesticides (J. Vandermeer 1989; Andow 1991; Finckh et al. 2000; Zhu et al. 2000). Essential parts of rural peoples' diets often come from plants and animals that are not key crops, and thus are completely invisible in official figures of yields and productivity (Penafiel et al. 2011; Halwart 2006). The "minor" crops that go uncounted are probably among the most important in the fight against micronutrient deficiencies that affect an estimated 2 billion people (Burlingame, Charrondiere, and Mouille 2009; FAO 2014). In the gaze of productivism, much of what happens on small, diverse farms is invisible.

## *Diversity and food security*

Doña Edelmira is among the poorest of farmers that we interviewed and her garden is among the most diverse. The day of the interview, root crops seemed to be separating her household from acute hunger. We accepted Edelmira's invitation to lunch that day, partly because we were hungry and exhausted after two hours of talking, and partly because she was so palpably eager to share something with us. Theirs is the only household of the sixty in the study growing *yuca* in their home garden, though I had eaten it in soups occasionally and, around Easter, boiled in palm sugar until it became candy. She grows many different kinds of things as a strategy for dealing with the risk of farming, some of which are grown especially for times of scarcity like these. To make the point, she recounted something that her neighbor used to tell her. “There are many people who say, ‘plant *camote,* plant *yuca*, *mo’tz’iim*, *makal*, so that when famine comes again, like it did before, you have something.’ Old people say this. An old man who died, that’s what he told me. Because famine will come again.” The boiled cassava was not a meal, but it was filling. It functioned that day as a backup food, insuring Edelmira’s family against the most extreme end of our scale of food insecurity. After lunch, she dug up some of the lumpy roots to show us, and put them in the Chelsea’s hands, urging her to take them home and plant them.

In focus groups we ran with farmers of several ages, *yuca* and *makal* (*Xantosoma yucatanense*) came up as examples of foods that were once common and are now scarce. Along with many other fruits and vegetables, they were spoken of with concern for the loss of traditional crops and healthy foods. Home gardens, like diets, are not static, so it is not surprising that some varieties disappear from gardens as tastes and needs change. Some of the species most iconic to home gardens, like this tamarind tree, and most integral to Yucatec cuisine, like bitter orange, are not native to the Americas. They have integrated themselves over the past half millennium. Their concern was for the rate of change, and where it was going. Focus group participants talked about meals they remembered their parents or grandparents making that would be hard to make now, for lack of key ingredients, and of strange sounding plants that they missed, like the *papa voladora*- the flying potato (*Dioscorea bulbífera*). They were also concerned with shift towards foods you have to buy. "It used to be," one participant said, "that when you were hungry for a snack, there was something you could pick." On a global scale, agrobiodiversity has dwindled in ways that researchers fear could reduce the stability and adaptability of global food systems (Khoury et al. 2014).

Agrobiodiversity is a defining characteristic of home gardens in the Yucatan peninsula (Rico-Gray et al. 1990; Toledo et al. 2008; Mariaca-Méndez 2012), and Edelmira's garden is a prime example. Much like a mature tropical forest, fruit trees of different heights form multiple canopies that take full advantage of the available light. The tamarind tree, where our interview takes place, arches over her home and a garden, along with an avocado and a mango, below that, *ramon* and *cayomito* trees, and closer to the ground, shrubby lime trees and *achiote* that cast a dark shade where chickens and turkeys hide in the middle of the day. Squash vines seek out sunny spots, roses and herbs surround the kitchen, edible roots live underground. Here you have to watch your step for tomatoes and chilies, which Edelmira positions in favorable pockets of soil between limestone rocks. Like tropical gardens around the world, hers is both ecologically and economically complex, providing dozens of products throughout the year for domestic use and for sale (Kumar and Nair 2004, Mendez et al. 2001).

Diverse agroecosystems require skilled labor to care for the many different kinds of plants and to manage the interactions between them; the farmer must know, for example, which kinds of annual crops will thrive underneath bananas and which will not.  So why plant so many different plants, why raise so many different animals? Ask Edelmira and she will emphasize that she loves working in her garden, growing and experimenting with new plants, and that practically, it makes sense to grow as many of her households necessities as possible in this village where there is not much food for sale, and not much money to buy it with anyway.  She might also mention that diversity allows her to have something left to eat if disastrous conditions destroy many, but not all, of her crops.  She could point to hurricane Isodore that landed just as corn was ripening in September of 2002, flattening crops and displacing several villages to the south where the soils are less permeable and flooding is rare but possible; or to a locust invasion that pushed families to the edge of starvation sometime in the 1950s, a second-hand story from before her birth that I heard from many people here, told as a parable for the importance knowing the edible plants of the forest. In this interview, she talked about drought and food prices.  Rains were delayed and sporadic during the 2009 and 2010 growing seasons, and reduced corn harvests had long since run out by our interview in late 2011 while the current year's corn had not yet been harvested.  After several years of bad harvests, many households decided not to plant corn at all, a decision that for many may have been forced by the rapidly rising costs of fertilizer and herbicides on which some corn farmers depend (Edelmira does not depend on these inputs).  Low production of the staple grain was compounded by food prices that seemed to creep up every time they went to the store; interviewees reported that the local price for corn more than doubled in the month of September.

### *A hegemonic logic*

I've been asking friends why they think the productivist paradigm has lasted so long. My friend Joey Smith, who owns a small organic farm in Northern California, reflected on the attractive scale of the approach: "When people say, 'I don't want to feed the world, I want to feed my community', it sounds funny to society." Zoe Vangelder said, "it's become hegemonic," using the term Antonio Gramsci used, writing from a prison cell in Italy, for a worldview that has been made so ubiquitous and so ingrained in institutions, social relations, and culture that it is difficult to think anything else (Gramsci 1992 [1975]). It feels like common sense. Teaching a class on the politics of reproduction at Cornell University, Sara Keene ran into Gramscian hegemony. "It never ceased to amaze me how resistant students were to challenging capitalist logic or values," she wrote me, "People have a difficult time imagining any other way to produce food."

"50 years of propaganda for the green revolution." Eric Holt-Gimenez, the director of the food policy think tank Food First, told me. Industrial agriculture presents many more opportunities for extracting surplus labor value—that is, for profit—than small-scale diversified systems. As my friend Annie Shattuck put it, "It's for the expansion of a profitable model." If you set out to find an example of productivism in action today, you would soon run into AGRA, the Alliance for a

Green Revolution in Africa, funded principally by the Bill and Melinda Gates Foundation and the Rockefeller Foundation. Eric has been a vocal critic of their approach, which focuses on training genomic plant breeders in Africa to develop new varieties and extend those, along with fertilizers and credit, to small-scale farmers, as well as investing in infrastructure and advocating for policy reforms. "The green revolution narrative supports the commercialization of both upstream and downstream agribusiness," he told me, "so it will always be heroically celebrated over all other approaches." Corporations that sell seeds, fertilizers, pesticides and farm machinery, and those that and buy agricultural commodities, stand to make billions in a large-scale conversion to industrial agriculture in Africa. If the many African-lead agroecology efforts got even a fraction of that kind of investment, he says, there could be a real chance of alleviating hunger (Holt-Giménez 2008). Annie added, "It's complicated, because it is partially true that raising yields can raise income and lower the cost of food temporarily. It's attractive because it is a technical fix, not a political fix. No resource redistribution is required."

### *The complex relationship of diversity to food security*

When I told a friend who runs a diverse, sloping garden on the UC Santa Cruz campus that I was running a study designed to test the hypothesis that households with more diverse gardens were more likely to be food secure, he stared at me for a minute. "How much time and money did you spend on that?" he asked. Farmer friends in California and Yucatan often responded the same way, either slightly confused or incredulous that such an obvious question needed investigation. He finally conceded, "Well I guess sometimes you have to prove things scientifically." His response, I think, was equal parts a recognition of the need to confront the overwhelming dominance of productivism in agricultural policy with all the legitimacy attached to empirical research, and a jab at the whole academic profession from a farmer surrounded by a university.

As obvious as it may seem to diversified farmers, however, it has been surprisingly difficult to find empirical evidence that agrobiodiversity is associated with greater food security or nutrition. Diverse diets are associated with greater food security (Hoddinott and Yohannes 2002) and improved nutrition (Arimond and Ruel 2004; Savy et al. 2005). Minor and native crops, as well as wild plants and animals in and around farms, make up important portions of the calories and micronutrients in many peoples' diets (Ogle et al. 2001; Roos, Islam, and Thilsted 2003; Singh and Garg 2006; Roche et al. 2008). Given this evidence, it would seem easy to link agrobiodiversity to food security and nutrition. Nations that produce more diverse arrays of crops and livestock do seem to have lower incidences of malnutrition, and that the difference cannot be attributed to differences in wealth alone (Remans et al. 2014). But when researchers try to detect a similar pattern at the household or individual level, they often find either weak associations (Scurrah et al. 2012) or no effect (Termote et al. 2012; Ali et al. 2013).

There are several reasons why this might be. First, food security and nutrition are the results of many complex processes and conditions, and distinguishing the causal impact of agrobiodiversity among all the other conditions that shape food access to food, and all the other strategies households employ to ensure their food supply, is difficult. Second, agrobiodiversity is also the result of a complex set of conditions and strategies, including the availability of land and seeds to a household, and the ways a household allocates labor between on-farm and off-farm livelihood activities. Third, while studies usually take measurements once or at most a handful of times over a year or two, hunger happens at punctuated intervals, so researchers are likely to miss food insecurity during short periods of field work.

Then, besides the question of whether or not agrobiodiversity affects food security, there are the pressing practical questions of when and how. How important is agrobiodiversity among the many strategies rural households use to achieve food security? What kinds of diversity matter most, in what situations, and for what kinds of households? And, what do households stand to loose if diversity is lost from these agroecosystems?

Edelmira's insistence on the importance of agrobiodiversity was a majority view among households in our study, but some farmers had a different take on the role of diverse gardens, and put more stock in different strategies for buffering the risk of hunger. One younger farmer told us that one should "focus on one or two crops, and do them well", rather than spread one's efforts among many crops. Several people told us that agriculture in general was a loosing strategy. We often heard the phrase "*el campo ya no da*"— *the fields don't provide anymore.* This sometimes seemed to mean that good yields are now harder to come by than they once were, and other times implied that agriculture can no longer provide what a modern family needs. Several farmers told us that they hoped their children would pursue non-agricultural livelihoods, gaining access to wage jobs either through education or by relocating to the tourist towns on the coast, while the majority hoped that their children would continue farming, at least a little, even if they also work for a wage.

### *Strategic diversity*

Farming is, in a word, risky. Unpredictable rainfall, unpredictable summer storms that may flatten the corn crop, unstable (but so often rising) prices for food and for agricultural inputs as well as unstable (but often falling) prices received for crops, unpredicted illness in the family when labor is needed most— these are possibilities that loom over smallholder farmer livelihoods, that put them at risk. Farmers use many strategies buffer risk. They diversify livelihood activities, with some household members working on the farm and others in non-agricultural sectors, and often, some family members migrate to work in tourist centers on the coast or to the United States. They jump through bureaucratic hoops to qualify for government safety-net programs and subsidies. They invest in livestock that can be eaten or sold in emergencies. They form and strengthen social ties when times are good, and when needed, call on this 'social capital' for assistance. And of course, they diversify their gardens.

Diversity helps reduce risk the same way that a diversified portfolio of assets protects an investor: since different investments are differently exposed to any given unpredictable stressor, the averaged gains or losses in a diversified portfolio are likely to be smaller. At an international field course on Agroecology that I attended, one farmer declared, “the only ones who are diversified are us *campesinos* and Carlos Slim”, referring to the Mexican business magnate with holdings in telecommunications, retail, construction, mining and more.

Diversity seems part of *campesino* identity— both the diversity of organisms in gardens and the diversity of ways of making a living. *Campesino* doesn’t quite translate to farmer, the way we understand it as a profession, since people in Tzucacab who call themselves *campesinos* use it to refer to someone who makes their living from the land but not entirely, who grows for their households’ consumption but not exclusively, who's livelihoods are characterized by multiple strategies that are constantly adapted to shifting conditions at the margins of formal economies. The word implies poverty but also, for many, a pride in the independence that comes from working for oneself, and in the ingenuity and skilled labor of bringing food into the world for a living.

Diverse gardens are not a purely defensive strategy. They can allow farmers the flexibility to capture minor windfalls. When lime crops in Northern Mexico and the Southern United States froze on the trees in early 2012, fruit buyers drove from town to town offering as much as twenty times the regular price for a box of limes. Edelmira and several of her neighbors cashed in on the opportunity while simply not eating limes for the few weeks while prices were high. There were plenty of sweet and bitter oranges, sweet limes, and grapefruits to take their place in meals. The diversity of their farms lend themselves to the opportunity to sell commodities only for peak prices. A similar effect has allowed Indonesian peasants to grow rubber in diverse agroecosystems much more profitably than on nearby plantations: trees can be tapped when prices are high, and simply allowed to grow while prices are low, while surviving on the many other crops in their gardens (Dove 1993).

Ecology brings into focus a different way that diverse agroecosystems reduce risk. Over the last two decades, through hundreds of studies and analyses, ecologists have argued about the role of biodiversity in ecosystem functioning and ecosystem services. Ecosystem services are those ecosystem functions that benefit human life, for example, carbon fixation or drinking water filtration. The underlying question is whether the high levels of diversity that we observe in so many ecosystems are necessary, or if a small subset of those species would be able to provide the services on which we depend. In short, how diverse is diverse enough? This area of research is made urgent by the precipitous loss of biodiversity from the planet and concern for how this will affect ecosystem services that we depend on, especially given the pressure on ecosystems to adapt to a changing climate (Cardinale et al. 2012). Diverse ecosystems often contain several taxa that perform each essential function, or that could perform that function, in case something happens to the primary species performing that function (Yachi and Loreau 1999).

In the context of subsistence farms, food security can be thought of as a service of diverse agroecosystems. Of course, many factors besides crop diversity affect a households' food security— wealth, income, land holdings— just as many non-diversity factors affect any ecosystem service. Ecologists tease out the affect of biodiversity on ecosystem services by either experimentally manipulating diversity while keeping other factors the same, or by measuring the natural variations in diversity in randomly selected plots, and controlling for all other factors that they suspect could affect the ecosystem service of interest and control for those in a statistical model. We took this second approach in our study.

In our study, we did see a statistically significant effect of agrobiodiversity on food security. Using regression models to control for income, household demographics, garden size and other factors that we thought might also affect food security, we found that home garden diversity explained about 40% of the difference between households in food security (Chapter 1). It was not a clean regression line— statistically, there was a lot of noise-- but it was statistically significant. I think that we probably found a moment, by accident, when pressures on food security were at their highest and therefore crop diversity having the strongest affect in the mitigation of hunger. It was one of the moments that Edelmira's elderly neighbor had warned her about.

### *805 million hungry*

When my friend Zoe calls to tell me that the United Nation's Food and Agriculture Organization (FAO) will be holding its first-ever symposium on agroecology, and it was just three weeks away, I know I want to go. We had been talking about attending another FAO meeting, the annual Committee on Food Security summit, where diplomats and scientists from around the world meet to assess the state of food insecurity in the world and strategize programs for ending hunger. This is the meeting where figures for the number of hungry people in the world are worked out from dozens of indicators lent by member countries: 870 million people in 2011, 842 million in 2012, 805 million in 2013 (FAO 2012a; 2013; 2014). Most of the recommendations in these reports are in the productivist tradition, increasing yields through top-down interventions-- but not all. The FAO also leads the way among large inter-governmental agencies on analyses and programs geared towards addressing gender inequality in food systems (FAO 2011), disparities in land tenure and access to forests and fisheries (FAO 2012b)—just the kinds of complex social relationships that Sen found to shape access to food. Some FAO programs even promote agrobiodiversity as a strategy for food security. Some of the most compelling calls for conserving agrobiodiversity in the interest of food security come from the FAO (2002; 2005). The FAO has also been at the center of the green revolution, especially since it began a collaborative effort with Borlaug to train plant breeders from around the world at the research station he ran in Mexico. It has the contradictions of a large organization.

This meeting on agroecology looked much more interesting than the committee on food security, though. Diplomats and researchers would be joined by farmers and representatives of farmers' movements from around the world. I called my thesis advisor, Steve Gliessman, to ask what he knows about it, and he says he has been booked to give the keynote address. I emailed the organizers with a last-minute appeal for an invitation. I started to hear rumors that even hosting a symposium on agroecology at the FAO was controversial within the organization, and that certain member states, including the U.S., had asked for assurances that sensitive topics like land reform and genetically modified organisms not be discussed. I bought a plane ticket and a couple of weeks later was in Rome.

The FAO is in a monolithic white building from the Mussolini era, near the Roman Coliseum. Zoe and I, along with a cardboard tube containing a poster on my work in Yucatan, went through security screening to cross the "border" onto diplomatic land. In a large conference room inside, flags from the 194 member countries hung above a long table for presenters, and our seats contained headphones, wired for simultaneous translation. I clicked from Spanish to English to French as Steve welcomed the attendees and introduced agroecology as a collaborative science that starts with a recognition that farmers are the experts of their own agroecosystems, a discipline where farmers and researchers work together to make more sustainable food systems.

That first evening, there was a reception in the eighth-floor rooftop cafeteria with a view of the Roman Coliseum. I was making small talk about how nice it was to be with other people who worked closely with the 805 million food-insecure people, in the place that made that statistic. A colleague who knows my work corrected me: even though that figure is published in an annual FAO report called "The State of Food Insecurity in the World," it has little to do with food insecurity as I measured it. It is based on a calculation called the "prevalence of undernourishment". People who suffer periodic hunger do not qualify, nor do those that constantly worry about food supplies but are able to avoid hunger at great expense in other areas of their lives. It quantifies chronic hunger that lasts at least one year (FAO 2014, 44). What's more, the calculation probably underestimates the number of people who are chronically hungry, since it assumes that a "sufficient" diet is defined as enough calories for a sedentary lifestyle—something that few farmers or laborers have (Lappé et al. 2013). It reflects a grinding, physiologically devastating degree of hunger.

I flushed with embarrassment, and with sadness. I felt incredibly naïve that I had so grossly underestimated the severity of hunger in the world. By that standard, no one in my study – not Edelmira, and probably not any of the families who were going hungry when I interviewed them—were part of the 870 million *chronically* hungry people in the FAO's figure for that year. Nearly one in eight people in the world were much more severely hungry than them. How many billions suffer periodic hunger like that that I observed in Yucatan?

There are two possible interpretations of this news. In one, I realize people I work with are relatively well-off, that their strategies for food security, including their diverse gardens, have little to do with the realities of hundreds of millions suffering chronic hunger. Perhaps Borlaug was right, that for that kind of devastating hunger, another top-down green revolution is needed to increase food supplies, and worth the drawbacks. Maybe my objection to the loss of agrobiodiversity that is implied in "closing the yield gap" was petty in comparison to the severity of hunger.

There is, however, another possible interpretation: That the world has important lessons to learn from farmers who are able to make food security even in situations of poverty. Farmers are indeed relatively well-off in Yucatan, where government is relatively functional and stable, where land tenure has been guaranteed by the Mexican constitution until relatively recently, where the rocky soils that cover most of the peninsula have repelled tractors and green revolution packages, where there are rich seed systems and traditional knowledge that provide necessary ingredients for diversified agriculture. In contrast to the green revolution package of seeds, chemicals, and credit, maybe these conditions make up an entirely different kind of package for food security that we should be trying to disseminate to farmers around the world. In this interpretation, the appropriate response of an institution like the FAO is to learn from those farmers, encourage and magnify their ingenuity, and to advocate for the basic rights and political power that makes diversified farming possible.

The contradictions and tensions of the FAO permeated the conference. Some presenters laid out plans for combining agroecological techniques along with technologies like fertilizers and transgenic crops to use the best of both approaches, while others argued that agroecology is not just another tool for fine-tuning industrial agriculture, it is a proven alternative and challenge to it. Predictably, my favorite presentations at the conference were from farmers engaged in agroecology: the Vietnamese farmer whose rice paddies produce three crops each year, plus ducks and fish, using techniques developed with a grassroots Farmer Field School; the community organizing effort in Colombia that restored both forest cover and food security to a small mountain valley, after a disastrous series of government programs promoting market crops with high prices that inevitably crashed leaving the valley deforested and without water. Steve was invited to give some closing remarks, which he used for a call to action. Agroecology, he told the symposium, is a set of practices, not a set of products: We must lean from nature. We must move from simple to complex. We must link the producer and the eater. We must link science and practice. We must begin the process of transformation with participatory processes (Gliessman 2014).

It was, of course, a challenge to the FAO. In the question and answer session, a woman representing a farmers' organization from India asked, "Though I understood all the analyses of my method of farming, I am left with one question that I could not understand: when we the women's self-help groups, we the farmers' organization, are spreading this agroecology method in my country, why can't the FAO?" The audience applauded. The question and answer session became a forum of comments from agroecology practitioners discussing the details of a revolution: it will take action but also strength and vision; remember that gender equality is at the heart of questions about hunger. As the comments continued, an influx of people I hadn't seen during the previous two days filed into the auditorium, mostly men in dark suits and noticeably attractive young women. Zoe elbowed me, and said, "this always happens when the diplomats arrive. They all have beautiful twenty-somethings for aids."

The conference closed with remarks from José Graziano da Silva, Director General of the FAO. His reflection was loaded with every tension of the symposium. "Today we opened… a window in this building… that for more than half a century has been considered the cathedral of the green revolution. We are conscious of this special moment, just as we, the FAO, were conscious when, in the 1970s, we brought a young scientist who was teaching at Chapingo [University in Mexico] to teach in India how to achieve high yields of maize—Dr. Norman Borlaug, consultant to the FAO. The FAO knew that this new paradigm, the green revolution, could alleviate the hunger that we confronted in Asia and Africa. Like every scientific and technological revolution has its time, we know that the paradigm of the green revolution is starting to show its weaknesses. That is why we are looking for new alternatives. I think that today what we have heard is a clear indicator that we have a promising paradigm in agroecology, as one possibility among many… that include various possibilities, like genetically modified organism, and reducing chemical inputs" (da Silva 2014).

### *The "Crazy Farmers"*

When we return for another interview with Edelmira in February, crops have been harvested and there is more food to go around. Also, she has finally received a payment from *Oportunidades,* the federal poverty alleviation program focused on rural women, a feat that took hitchhiking into the main town several times with various copies of official documents and attending countless workshops at the community health clinic, mostly about healthy eating and exercise. She immediately shows Chelsea and me the pigs that she bought with the government payment. I ask her to wear a lapel microphone and digital recorder while she takes us on a tour of her garden. Edelmira has become a friend and a key informant in the study, and she has a way of talking about gardens and food that I don't want to forget. The microphone is an awkward presence at first, but she quickly forgets that it is there. She picks up her one-year-old granddaughter before we head out on the tour, so the recording is full of baby sounds and discussions in Mayan between them.

Edelmira's garden is now full of sprawling squash plants, running between dried corn stalks and under banana plants. This squash, called *x'top,* is grown for its seeds, which are roasted and ground and become a key ingredient in Yucatecan cooking. She's made a good bet on this small market crop, right now they are selling for a relatively high price. She has seeds spread out on plastic sheets to dry, and the pigs are happily eating the skins and pulp of the squash. Like gardeners everywhere, she's apologetic about work not done—cleaning out dried corn stalks, squash vines and weeds. "I've got to clean it out in here, because you know what I want to plant this year? I'm going to plant Jicama. You know, jicamas, for salad? Because now that these bananas have grown up, I won't be able to plant corn under them. I have to see what seeds will grow underneath the bananas." For Edelmira, there's never enough time for the garden, juggling all the work of running her household mean the garden never quite matches her ambitions, it's the product of both vision and pragmatism.

We follow the narrow strip of land that she owns back through a field of corn stalks and the dried vines of two kinds of beans and three kinds of squash-- her *milpa*, the part of farming that is traditionally men's work. Edelmira is one of several women *milperas* that we interviewed, even though doing men's work makes them eccentric in the eyes of some neighbors. Her husband used to keep a milpa, but now works long days six days a week on a nearby ranch, and I've never actually met him. Her oldest son helps in the garden, but now is working long hours picking watermelons and loading them on to semi-trucks that haul them directly to the central produce market in Mexico City, and one of her daughters, who has a love of caring for the animals, has a newborn baby. She informs us that we're headed to another daughter's plot of land, just past her own, to show us her crops as well.

In the middle of pointing out medicinal plants growing in the milpa, Edelmira stops and tells us, "Some people say I'm crazy for doing this. My husband sometimes says, 'why do you work so hard in the garden?' and I say, I don't know, maybe I'm crazy, I just like it. I don't know why, but I love it." Edelmira is not crazy, of course, she's a skilled gardener and an agile innovator. She is not the only one who has told us something like this. A gardener and activist who has spent countless hours creating a biodiversity conservation garden on a piece of land at the middle school in Tzucacab said, “My kids say, ‘mom, you must be crazy, working so hard on land that isn’t even yours.’” A woman who recently moved back to her tiny village after fifteen years in Playa del Carmen, a tourist destination on the coast, said people did say she must be crazy, but she says she is just happy to be somewhere where she can plant fruit trees and make a milpa. A commercial fruit grower told me that when he explains to buyers that he doesn’t use any irrigation at all in his orchard, rather, he simply places his dozens of kinds of fruit trees in precisely the kind of soil where they will get the right amount of moisture, they often accuse him of lying and call him crazy.

Chelsea and I started referring to these farmers as the crazy ones. Virginia Nazarea, writing about the farmers in the Philippines who love the many local aromatic varieties of rice and grow a staggering array of sweet potatoes, said that there is at least one in every village there, too. She called them *Pilosopong Tacio* after a fictional character whose name was a play on the Filipino word *pilosopo,* which means both “philosopher” and someone socially strange and irritating (Nazarea 1998, xi). Craziness is, of course, a matter of context. Their love of farming, and of the flavorful, traditional varieties that just require the skills of an attentive farmer, seems crazy in a world where “old” varieties are cast as “low-yielding” and farming itself is seen as an occupation with a questionable future.

Their crazy approach to farming, and their crazy varieties, may be particularly well adapted to future farming conditions. One late night following a conference, a prominent scientist gave me a dark prediction. He thinks agrobiodiversity will slowly be lost from the vast majority of the worlds' farmland, but kept in a few, isolated places that resist, until the industrial food system finally collapses under its unsustainable appetites for chemicals and resources, at which point the knowledge and seeds held by agrobiodiversity resistors will be in overwhelming demand. I would like to make a movie based on this apocalyptic version of events. But even now, there are examples on smaller scales. After a hurricane caused an estuary to overflow and flood farmland in West Bangal with salt water, farmers collaborated with an exceptionally farmer-oriented seed bank to resurrect traditional varieties of rice that tolerate saline soils. Those varieties had disappeared from local farms (Deb 2009). In Yucatan, when animal feed prices increased dramatically with the price of other global commodities in 2007, interest surged in the locally adapted breeds of pigs and chickens that don't require nearly as much grain. By one estimate, the population of the *cerdo pelón* variety of pigs had fallen to 238 individuals in 2005 (Sierra et al. 2005).

I sometimes call these varieties *traditional*, and the kind of farming that Edelmira and the other "crazy" farmers do *traditional farming*, but to see it as only traditional is to miss the more dynamic part of what they do. Certainly, tradition is one strong part of it. When Edelmira heeds the advice of her elderly neighbor and plants root crops to prepare for times of need, there is continuity of knowledge between generations. Experiences from long time frames, longer than a human lifespan, can inform current decisions. Sometimes when I'm in Edelmira's garden, having driven out of cell phone range and past several pyramids abandoned in the jungle, it is easy to feel like we are apart from the rest of the world, time-shifted into a place where people have been growing and eating food much the way their ancestors did, that the seeds and techniques have been passed from generation to generation for the estimated 8,000 years of agriculture on the peninsula. In a world where genetic splices and precision agriculture dominate discussions about the future of agriculture, Edelmira's garden can seem like a relic of a different time. But this is an illusion of privileged outsiders. Connections to the broader world run deep here, with family ties to migrants. Global trade has brought more than half the plants and animals to people's home gardens over the last 500 years. The pressures of climate change and shifting economic policies are felt here.

Good famers like Edelmira constantly innovate, they try new techniques, and they share stories of success and failure with other farmers. They have to, because needs and conditions never stand still. Droughts and storms have periodically devastated crops in the Yucatan since long before rising carbon dioxide levels began increasing their frequency and severity; both the accumulation of knowledge over generations and the constant experimentation of farmers contribute to the ability to adapt. Backwardness is in they eye of the beholder. To an outside observer, what Edelmira does can seem deceptively simple, but, given the challenges that the world faces, it may be at the cutting edge of agriculture. Small-scale, diverse farming systems may be uniquely well adapted to the challenge of feeding a changing world.

### ***Food Sovereignty***

Productivist arguments use the fear of surging population and widespread food shortages to reduce everything but productivity to unnecessary niceties. Agrobiodiversity, independence from the need to purchase pesticides and fertilizers, uniquely flavorful varieties, and most of all, a central role for farmers creativity and ingenuity in the food system—in the productivist paradigm, these may be desirable, but they can be sacrificed for increases in productivity. Resistance to productivism involves making the valuable non-production aspects of agriculture visible. In 1996, perhaps in that same auditorium at the FAO, an umbrella group of farmers organizations called the Via Campesina introduced the World Food Summit to the term “food sovereignty” (Patel 2009). Food sovereignty counters the paradigm of food security by insisting that power in the food system matters as much as sufficient food. Many definitions exist (e.g., Via Campesina 2007), but my favorite is from a photograph of a hand-painted banner at a Via Campesina conference in Mali. It begins, “For an agriculture with peasants, for fishing with fisherfolk, for livestock with pastors” (A. Lappé 2007).

In my criticism of productivism, I don’t mean to suggest that “we”, the world, won’t need to grow more food to meet the demands of a growing population, or that big changes in agricultural practices won’t be needed to maintain productivity in a world where resources are scarce and growing conditions uncertain.  The need for change is undeniable, even if there is no evidence that growing more food alone can ever alleviate hunger.  I just put my faith in a different set of agricultural innovators. If the heroes of the green revolution are plant breeders and philanthropists, the heroes of food sovereignty are the crazy farmers.

# 5. Conclusion

Probably the most pressing questions about agriculture in Tzucacab, and indeed in many places in the world with long histories of indigenous culture and farming, is whether or not it will continue, and if so, in what form. At a panel discussion during an agroecology course in Chiapas, Francisco Rosado May, Rector of the Intercultural University of Quintana Roo and himself Yucatec-Maya, described the several millennia of resilience of his people, through various empires, conquest and the caste war. The collapse of the Maya civilization, he said, was a fantasy of anthropologists and tourists; his people and culture continued to thrive. But then, he turned his attention to the rapidly growing cities on the coast, fueled by tourism, that are attracting young Mayans by the thousands. He compared this movement to the exodus from the Classic Period cities and the displacement of the population during the Caste War, saying it was once again creating "a Mayan diaspora within the peninsula." Unless we find new forms of struggle that support the innovations that have always been necessary for food sovereignty, he said, "we realize that the collapse of our culture will finally be a reality, perhaps in the 21st century" (Rosado May 2010).

I can't answer the survival question. My results in this dissertation get at some aspects of it. In the first paper, I show that agrobiodiversity does seem to matter for survival. At the time of the interviews, during a drought and increasing food prices, agrobiodiversity did seem to be buffering households against hunger. In the second paper I examine the opposite direction of causality. A household's food security position—whether they expect to go hungry or not—may help explain why some gardens are very diverse and others are not. If so, the goals of food security and agrobiodiversity conservation are more tightly interdependent than was previously thought. In the last paper, I make an argument for survival of small-scale, diverse farms run by *campesino* farmers, challenging the dominant discourse and practice of development that prioritizes increasing crop yields above all other properties of agroecosystems. It seems clear to me that survival involves resisting "productivism" and re-imagining the path towards a world without hunger.

These results, however, fall short of a satisfying answer to the survival question. It is a question that came up all the time during this research, even in Yucatan. Chelsea and I often talked to older farmers who would tell us that young people are just not interested in agriculture anymore, that they would rather work in tourism, and that the future of food and Mayan culture was uncertain. As one farmer put it, "What are we going to eat in the future, rocks?" We realized, though, that we had not heard from any young people. We were missing the voices of the vary people who were in the process of making the decisions that would shape the future of Tzucacab.

With the help of the Autonomous University of Yucatan (UADY) and a grant from the Mexican government's Institutional Fund for Regional Scientific and Technological Development (FORDECyT, for its initials in Spanish), we hired six young researchers during their final semester at the technical high school in

Tzucacab. We put them to work identifying and counting plants and animals in home gardens, a task at which they excelled, resulting in the agrobiodiversity data used here. This group, we realized, would be our window into a young person's perspective on Maya-ness, change and survival.

We adapted a methodology called PhotoVoice (Wang and Burris 1994; Wang and Burris 1997), in which participants whose voices are underrepresented in mainstream discourse use photography to examine issues from their perspectives, and often, to speak truth to power. It is a participatory action research (PAR) methodology. It produces information, in the form of photographs and captions, but it also produces tools for change. As part of the work, for example, we assembled an advisory board of decision makers, academics, farmer-activists and artists to help us make the work relevant to those who have the power to make changes. We coached photographers in engaging the media, and they reached a large audience through newspaper coverage and appearances on the radio. We viewed the training in digital photography-- and even more so the training in community organizing—as not just a means towards the exhibition, but an investment in change-makers. After all, the survival question is not just a question to be answered with data; it's a question to be addressed with action.

The photographers picked up the technical skills quickly, but visual literacy and finding confident voices came more slowly. This is where Chelsea's expertise in popular education and visual arts were indispensable. We workshopped the photography two days a week for eight weeks over the summer of 2011. It was part artist critique and part Freirean literacy workshop (Freire 1970), only the literacy was visual. Chelsea used books by Annie Leibovitz and Graciela Iturbide, and copies of Rolling Stone magazine, to teach what an effective image could be, and the stories that images could tell. Photographers took thousands of photographs, selected the twenty best each week, wrote captions for them, and critiqued each other's work. They worked on assignments, visually investigating questions that mattered to them, taking photographs and then critiquing them. Slowly, the photographs got more intimate, capturing moments closer to the photographers' hearts.

At Chelsea's insistence, we never treated the photographs as documentation of what was happening in Tzucacab. Rather, we treated them as cultural objects made to communicate and travel. In those workshops, we discussed what the photographers wanted to communicate about themselves to their community and about their community to a larger audience. There were no clean answers, of course. Some weeks, students would be disillusioned with life in Tzucacab and counting the days until they could leave, other weeks they would be determined to stay. This tension comes through in the photographs, though in the photographs that they selected for the exhibitions, they mostly told the story of pride in their town and livelihoods.

The work culminated in an exhibition in Tzucacab in October of 2011. We printed the photographs on vinyl banners and hung them in front of the municipal government building. Students invited friends and families, local *campesino* leaders and decision makers from the local, state, and federal governments. In a happy accident, our exhibition weekend coincided with the publication of the eligibility list for the *Oportunidades* program, so thousands of people who came to the municipal building to see if they were eligible for the conditional cash transfer stayed to see our photographs.

The week before that exhibition, I felt how important the photographs would be. First, while we were meeting to plan the event at the university field station, we brought out the first large prints - of Leonor's series on tortillas. Kitchen employees gathered around to see them, discussing the finer points of tortilla making, and how women's labor and skill in the kitchen goes unrecognized. Next, we gave an interview on Xepet, the Mayan-language radio station. The photographers had been practicing their talks for the exhibition opening for weeks, but so far they had come off as timid and overly literal; the enthusiasm and curiosity that came through one-on-one disappeared when they stood up to practice a speech. In front of the radio microphone, though, they spoke passionately about food traditions and food sovereignty, biodiversity and the importance of their town. This articulate charisma continued in the exhibition in Tzucacab, exhibits in Mérida, and on a speaking tour in California.

Figure 9. Exhibiton of participatory photography in Tzucacab, October 1, 2011.

A standard definition of PAR is elusive, since by its nature enacted in particular contexts and in response to particular needs. PAR doesn't lend itself to a standard set of practices or methodologies, but like agroecology or food sovereignty, people recognize it by a set of principles. Some of my favorites come from Fals-Borda, whose 'ingredients' of PAR include: (1) The ontological possibility of a popular science; (2) a transformation of the relationship between the researcher and the researched from a "subject/object" relationship to a "subject/subject" relationship of mutual learning and respect; (3) building the power of the poor, autonomous from their richer collaborators, in their struggle for social change (Fals-Borda and Rahman 1991; cited in C. Bacon 2005). I like these principles because they re-position "action" and "participation" as a shared work between researchers and communities, rather than outcomes of a project. Action in PAR is as personal as it is professional, and is as much a process as an outcome.

In that sense, my PAR work was successful. I don't get to decide how the youth researcher/photographers apply their skills but I am confident that they, especially Leonor and Gilberto who came on the speaking tour, will make profound changes in their community and beyond. But there is still a lot to be done. For one, hunger in Tzucacab does not seem to be going anywhere. PAR practitioners engage in a cycle of action and reflection, a praxis of engaged scholarship and activism. Writing this dissertation has been a long reflection.

There are many shortcomings to this dissertation. First, the data I collected is limited to one time and place, and to a relatively small sample size. This in turn limits my ability to generalize the results and the kinds of claims about biodiversity and food security that I can make. Second, my methodology on food security is nonstandard. While I believe in the results, they are hard to compare with other studies. In the words of a rejection letter for the first paper of this dissertation from the Proceedings of the National Academy of Sciences, "The sample size (n = 45) and the method of 'self-reporting' without some backup verification are not convincing." While I disagree that experience-based measures of food insecurity are simply 'self-reporting', I do agree that larger sample sizes, more comparable measurements, and more extensive triangulation of the experience of food insecurity are needed to make a strong case for the role of agrobiodiversity in food security.

The next steps for research seem straightforward. The food security assessment can be streamlined from a grueling two hours to a 20-minute interview, and standardized to calculate Household Hunger Scores that are comparable with other studies (Ballard et al. 2011). Well-trained field assistants can help to administer this survey a much larger sample sizes, and the measure can be repeated to capture variation in food security in an between years. 24-hour recalls could compliment this survey, as could new indicators for food security and wellbeing developed in collaboration with community members. Participatory risk mapping (Smith, Barrett, and Box 2000) and tenable mapping (Lu et al. 2014) could help locate food insecurity in the broader context of risks that households face, and assess the importance of agrobiodiversity among the many strategies households use to build food security. We could build on the success of measuring agrobiodiversity by direct observation, extending it into *milpas* and commercial fields as well as home gardens. We could work collaboratively with other rural communities to collect comparable data and share results and lessons learned across cultural and geographical differences. We could use repeated measures, even long-term monitoring of agrobiodiversity and food security in the same households, to start to tease out cause and effect. We could get closer to discovering when, under what conditions, and for whom agrobiodiversity matters most.

As for the 'action' from PAR, the next steps are movement building. I have no doubt that farmers, especially the best farmers, the "crazy farmers" I talk about in chapter 3, have everything they need to grow food in a changing world. However, they run into political limits to their influence. I believe that the most fruitful collaborations will involve both the knowledge and experience of farmers and also the reach and privileged discursive power of researchers to bring farmers' struggles to wider and more powerful audiences. They will involve local actions —for instance, organizing to re-appreciate agrobiodiversity, to create community food reserves, to leverage more favorable market access—and also national and global campaigns. There is no recipe for building food sovereignty, it will be an adaptive path requiring ingenuity and creativity. Luckily, many farmers that I met in Tzucacab have both in abundance.

# Appendix 1. Plant and Animal Taxa found in Tzucacab Home Gardens

| Common Name | Genus | Species | Family |
|---|---|---|---|
| remolacha | *Beta* | *vulgaris* | Amaranthaceae |
| epazote | *Dysphania* | *ambrosioides* | Amaranthaceae |
| cebolla | *Allium* | *cepa* | Amarillydaceae |
| cebollina | *Allium* | *tuberosum* | Amarillydaceae |
| lirio | *Crinum* | *augustum* | Amarillydaceae |
| mango | *Mangifera* | *indica* | Anacardiaceae |
| ciruela tuspana | *Spondias* | *purpurea* | Anacardiaceae |
| ganzo | *Anser* | *anser* | Anatidae |
| guanabana | *Annona* | *muricata* | Annonaceae |
| saramuyo | *Annona* | *squamosa* | Annonaceae |
| anona | *Anonna* | *sp* | Annonaceae |
| apio | *Apium* | *graveolens* | Apiaceae |
| cilantro | *Coriandrum* | *sativum* | Apiaceae |
| zanahoria | *Daucus* | *carota* | Apiaceae |
| margaritas | *Rhabdadenia* | *biflora* | Apocynaceae |
| coco | *Cocos* | *nucifera* | Arecaceae |
| huano | *Sabal* | *mexicana* | Arecaceae |
| henequen | *Agave* | *fourcroydes* | Asparagaceae |
| maguey | *Agave* | *sp.* | Asparagaceae |
| girasol | *Helianthus* | *annuus* | Asteraceae |
| lechuga | *Latuca* | *sativa* | Asteraceae |
| acelga | *Beta* | *vulgaris* | Betoideae |
| jícara | *Crescentia* | *cujete* | Bignoniaceae |
| achiote | *Bixa* | *orellana* | Bixaceae |
| ciricote | *Cordia* | *dodecandra* | Boraginaceae |
| roble | *Ehretia* | *tinifolia* | Boraginaceae |
| ganado bovino | *Bos* | *taurus* | Bovidae |

| | | | |
|---|---|---|---|
| borrego | *Ovis* | *aries* | Bovidae |
| colinabo | *Brassica* | *napus* | Brassicaceae |
| repollo | *Brassica* | *oleracea* | Brassicaceae |
| rabano | *Raphanus* | *sativus* | Brassicaceae |
| pitahaya americano | *Hylocereus* | *undatus* | Cactaceae |
| pitahaya indio | *Hylocereus* | *undatus* | Cactaceae |
| nopal | *Opuntia* | *sp.* | Cactaceae |
| mamey | *Mammea* | *americana* | Calophyllaceae |
| perro | *Canus* | *lupis* | Candidae |
| papaya | *Carica* | *papaya* | Caricaceae |
| pez tilapia | *Oreochromis* | *sp.* | Chichlidae |
| paloma | *Leptotila* | *verrauxi* | Columbidae |
| almendron | *Terminalia* | *catappa* | Combretaceae |
| camote blanco | *Ipomoea* | *batatas* | Convolvulaceae |
| camote morado | *Ipomoea* | *batatas* | Convolvulaceae |
| sandia | *Citrullus* | *lanatus* | Cucurbitaceae |
| melon chino | *Cucumis* | *melo* | Cucurbitaceae |
| melon criollo | *Cucumis* | *melo* | Cucurbitaceae |
| pepino blanco | *Cucumis* | *sativus* | Cucurbitaceae |
| pepino verde | *Cucumis* | *sativus* | Cucurbitaceae |
| calabaza kaita/x-top | *Cucurbita* | *argyrosperma* | Cucurbitaceae |
| calabacito | *Cucurbita* | *pepo* | Cucurbitaceae |
| calabazo | *Laganaria* | *sicararia* | Cucurbitaceae |
| lec | *Laganaria* | *siceraria* | Cucurbitaceae |
| chayote | *Sechium* | *edule* | Cucurbitaceae |
| papa voladora | *Dioscorea* | *bulbifera* | Dioscoreaceae |
| chaya | *Cnidoscolus* | *aconitifolius* | Euphorbiaceae |
| yuca | *Manihot* | *esculenta* | Euphorbiaceae |
| yuca cubana | *Manihot* | *esculenta* | Euphorbiaceae |
| cholul | *Apoplanesia* | *paniculata* | Fabaceae |
| flamboyan | *Delonix* | *regia* | Fabaceae |
| pich | *Enterolobium* | *cyclocarpum* | Fabaceae |
| huaxin | *Leucaena* | *leucocephala* | Fabaceae |
| tzalam | *Lysiloma* | *latisiliquum* | Fabaceae |
| jicama blanca | *Pachyrrizus* | *erosus* | Fabaceae |
| ibes blanco | *Phaseolus* | *lunatus* | Fabaceae |

| | | | |
|---|---|---|---|
| ibes negro | *Phaseolus* | *lunatus* | Fabaceae |
| frijol | *Phaseolus* | *vulgaris* | Fabaceae |
| frijol x-col de milpa | *Phaseolus* | *vulgaris* | Fabaceae |
| jabin | *Piscidia* | *piscipula* | Fabaceae |
| tamarindo | *Tamarindus* | *indica* | Fabaceae |
| gato | *Felus* | *catis* | Felidae |
| belladona | *Kalanchoe* | *blossfeldiana* | Kalanchoe |
| toronjil | *Melissa* | *officinalis* | Lamiaceae |
| hierba buena | *Menta* | *citrata* | Lamiaceae |
| menta | *Metha* | *x piperita* | Lamiaceae |
| albahaca | *Ocimum* | *basilicum* | Lamiaceae |
| oregano | *Oreganum* | *vulgare* | Lamiaceae |
| aguacate | *Persea* | *americana* | Lauraceae |
| saac paa | *Byrsonima* | *bucidaefolia* | Malpighiaceae |
| nance | *Byrsonima* | *crassifolia* | Malpighiaceae |
| grocella | *Malpighia* | *galbra* | Malpighiaceae |
| ceiba | *Ceiba* | *pentandra* | Malvaceae |
| tulipan | *Hibiscus* | *rosa-sinensis* | Malvaceae |
| jamaica | *Hibiscus* | *sabdariffa* | Malvaceae |
| cedro | *Cedrela* | *odorata* | Meliaceae |
| caoba | *Swietenia* | *macrophylla* | Meliaceae |
| ramon | *Brosimum* | *alicastrum* | Moraceae |
| platano huatano | *Musa* | *acuminata* | Musaceae |
| platano enano | *Musa* | *sapientum* | Musaceae |
| platano manzano | *Musa* | *sapientum* | Musaceae |
| guayaba | *Psidium* | *guajava* | Myrtaceae |
| jasmin | *Jasminum* | *gracile* | Oleaceae |
| maracuya | *Passiflora* | *edulis* | Passifloraceae |
| gallina de cuello desnudo | *Gallus* | *gallus* | Phasianidae |
| gallina de engorda | *Gallus* | *gallus* | Phasianidae |
| gallina negra | *Gallus* | *gallus* | Phasianidae |
| pavo | *Melleagris* | *gallopavo* | Phasianidae |
| pavo de monte | *Melleagris* | *ocellata* | Phasianidae |
| zacate limon | *Cymbopogon* | *citratus* | Poaceae |
| zacate taiwan | *Digitaria* | *insulari* | Poaceae |

| | | | |
|---|---|---|---|
| maiz amarillo | *Zea* | *mayz* | Poaceae |
| maiz blanco | *Zea* | *mayz* | Poaceae |
| maiz x-mejen amarillo | *Zea* | *mayz* | Poaceae |
| bo’ | *Coccoloba* | *spicata* | Polygonaceae |
| verdolaga | *Portulaca* | *oleracea* | Portulacaceae |
| loro | *Amazona* | *xantholora* | Psittacidae |
| rosa palida blanca | *Rosa* | *alba* | Rosaceae |
| rosa | *Rosa* | *chinensis* | Rosaceae |
| rosa princesa | *Rosa* | *chinensis* | Rosaceae |
| café | *Coffea* | *arabica* | Rubiaceae |
| naranja agria | *Citrus* | *aurantium* | Rutaceae |
| cajera | *Citrus* | *ducarama* | Rutaceae |
| grey | *Citrus* | *grandis* | Rutaceae |
| chinalima | *Citrus* | *limetta* | Rutaceae |
| limon | *Citrus* | *limonia* | Rutaceae |
| china | *Citrus* | *sinensis* | Rutaceae |
| mandarina | *Citrus* | *sp.* | Rutaceae |
| limonaria | *Murraya* | *paniculata* | Rutaceae |
| ruda | *Ruta* | *graveolens* | Rutaceae |
| mamuncillo amarillo | *Melicocus* | *bijugatus* | Sapindaceae |
| mamuncillo blanco | *Melicocus* | *bijugatus* | Sapindaceae |
| cayumito verde y morado | *Chrysophyllum* | *cainito* | Sapotaceae |
| zapote negro | *Diospyros* | *digyna* | Sapotaceae |
| kaniste | *Lucuma* | *campechiana* | Sapotaceae |
| choch | *Pouteria* | *glomerata* | Sapotaceae |
| chile costeño | *Capsicum* | *annuum* | Solanaceae |
| chile dulce | *Capsicum* | *annuum* | Solanaceae |
| chile jamaiquino | *Capsicum* | *annuum* | Solanaceae |
| chile parado | *Capsicum* | *annuum* | Solanaceae |
| chile piquin | *Capsicum* | *annuum* | Solanaceae |
| chile rojo | *Capsicum* | *annuum* | Solanaceae |
| chile verde | *Capsicum* | *annuum* | Solanaceae |
| chile x-catic' | *Capsicum* | *annuum* | Solanaceae |
| pimiento morron | *Capsicum* | *annuum* | Solanaceae |
| chile habanero | *Capsicum* | *chinense* | Solanaceae |

| | | | |
|---|---|---|---|
| galan de noche | *Cestrum* | *nocturnum* | Solanaceae |
| tomate pais | *Lycopersicon* | *lycopersicum* | Solanaceae |
| tomate salet | *Lycopersicon* | *lycopersicum* | Solanaceae |
| toronja blanca | *Lycopersicon* | *lycopersicum* | Solanaceae |
| tabaco | *Nicotiana* | *tabacum* | Solanaceae |
| ave de paraiso | *Strelitzia* | *sp.* | Stretziliaceae |
| cerdo americano | *Sus* | *domesticus* | Suidae |
| cerdo pelon | *Sus* | *domesticus* | Suidae |
| mariposa blanca | *Hedychium* | *coronarium* | Zingiberaceae |
| catzin | ? | ? | |
| tes | ? | ? | |
| ramo de señorita | ? | ? | |

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