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MAIN ARTICLE

Evaluating and mitigating locally and nationally variable food security dynamics in Guatemala through participatory causal loop diagram building

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Abstract

Various methods have been proposed to analyze national trends of malnutrition and food insecurity; however, these methods often fail to consider regional specificities that drive national food security dynamics. This case study seeks to close this gap through the novel use of participatory causal loop diagrams (CLDs) to analyze the malnutrition crisis and food security dynamics across diverse regions of Guatemala. Stakeholders from six municipalities with divergent food security outcomes, within territories of similar socioeconomic composition, created CLDs by identifying trends, causes, and consequences of malnutrition and food security. Characterizing and assessing these trends, referred to as the food security dynamic, are the primary goals of this paper. Key results include identification of the complex reinforcing relationship between marginalization, education, and health, which affects food insecurity and malnutrition in Guatemala in a nonlinear way. These results elucidate how similar communities can experience divergent food security outcomes and inform locally appropriate solutions.

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Introduction

Malnutrition, and more specifically undernutrition, occurs when one is not able to access nutritious food in sufficient amounts and is a problem which affects all regions of Guatemala, particularly children in rural homes. It

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manifests itself as stunting, wasting, underweight, or micronutrient deficiencies (World Health Organization, 2016). The absence of food security, defined by the Food and Agriculture Organization (FAO) as "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006), is an important driver of malnutrition, though other factors such as health, marginalization, climate change, and lack of socioeconomic resources also play a major role (FAO, 2013; Singh, 2018). There are evident divisions as to who is most affected and where malnutrition occurs. Across Guatemala, 49% of children under the age of five suffer from chronic malnutrition (stunting), and over 55% of all chronically malnourished (stunted) children in Central America can be found in Guatemala. Most (80%) cases of chronic malnutrition in Guatemala occur in rural areas (Gálvez *et al.*, 2015b). Causes and effects of malnutrition can vary according to where people live and demographic characteristics; for example, rural smallholders may experience malnutrition and food insecurity mainly as a result of changes in climate and agriculture, while urban residents may find that economic policy affects access to nutritious food (Sonnino, 2016). Further characterizing the urban–rural divide, chronic childhood malnutrition affects 34% of urban children, while over 58% of rural children are affected (Gálvez *et al.*, 2015b). Additionally, 65% of Indigenous children suffer from malnutrition compared to 36% of non-Indigenous children (Gálvez *et al.*, 2015b). Chronic food insecurity and malnutrition can lead to severe stunting or low height-for-age. Over 40% of children between three and 60 months are stunted; this number can be up to 50% higher in rural Indigenous regions (Chary *et al.*, 2013).

Commonly used indicators of food security or nutritional status often involve calculation of income, anthropometry, surveys of lived experience, and analysis of dietary intake (Méthot, 2014). While research has found that a variety of factors are involved in food security and malnutrition, the main cause is poverty: the inability to afford food. Over half of the population of Guatemala lives in poverty, with 15% living in extreme poverty (Chary *et al.*, 2013). In many instances, families cannot afford to buy food, especially nutritious food, due to a lack of funds. The incomes of families who depend on smallholder agriculture are more likely to be affected by market and environmental conditions, leading to insecurity in food accessibility (Immink and Alarcon, 1991). When poverty is acute for many of these Guatemalan families, spending income on food may become a lower priority than other spending. Women are disproportionately affected by this, as they are frequently dependent on their husbands for *gastos*, or money to spend on household necessities (Chary *et al.*, 2013). It is clear that money, and the social structures surrounding it, is one of the primary factors affecting malnutrition in children in Guatemala, and that it is, in turn, affected by several socially determined structures. The results of this paper can be applied to

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better understand these structures. Other demographic factors have been found to be linked to malnutrition; many of these are related to resource access, such as literacy of the primary caregiver or availability of potable water (Sereebutra *et al.*, 2006). For example, San Juan Chamelco, one of the territories examined in this research (see the "Study area" section for a comprehensive list of all territories examined), relies mainly on latrines, rather than toilets connected to septic tanks or sewage disposal networks (Gálvez *et al.*, 2015b), and children living in houses without proper sanitation resources were three times more likely to exhibit stunted growth than their counterparts who had access to safe sanitation (Sereebutra *et al.*, 2006). A similar trend was also found regarding the educational level of caregivers: children with illiterate or uneducated parents were five times more likely to exhibit stunting, compared to their counterparts with educated parents (Sereebutra *et al.*, 2006). Access to clean water was also found to be a factor having an impact on the rates of children exhibiting stunted growth and was amplified by the prevalence of parasitic and gastrointestinal diseases due to unsafe water (World Health Organization, n.d.). Considering the consequences of poor nutrition, the most commonly used measurement of malnutrition in children is stunting, defined as a below-average height-for-age. Height stunting can begin in the first year of life (Chary *et al.*, 2013); children who fall behind developmental milestones in their first year of life are those most severely impaired later in life (Chase and Martin, 1970). While the physical effects of stunting can be reversed, brain function, motor development, and mental development may be irreparably affected, and effects are not seen until later in life (Chase and Martin, 1970). As a result, caregivers may not know and understand the effects of malnutrition on their children. Chary *et al.* (2013) found that many mothers or other caregivers did not know that their children were malnourished—rather, they believed that Guatemalans were naturally shorter compared to others.

These nuanced socioeconomic and environmental factors, their internal interactions, and the cumulative interaction this has with the security of food systems at local and regional levels characterize the complex food security and malnutrition dynamic referenced within this paper. Highlighting feedback relationships between these factors and holistically characterizing this dynamic is critical in providing public and private decision-makers with the necessary knowledge to create meaningful change, as is further justified at the end of the introduction. Evaluating indicators or correlations alone, without considering their role in the greater social and ecological system, leads to only a partial understanding of food security. The stagnating levels of malnutrition and food insecurity in Guatemala at the national level suggest that systemic challenges and feedback loops in worsening regions may be counteracting positive external interventions for change. The food security dynamic defined above is made additionally complex because interactions within it are subject to long-term time delays (e.g. the buildup of

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educational levels, demographic changes, the buildup of economic and land capital by families, and the formation of nutritional habits) (Sterman, 2002; Inam *et al.*, 2015). Additionally, potentially counterintuitive feedbacks (e.g. the severity of a health problem and corresponding governmental urgency [or complacency]) can be in effect. Reciprocal interactions between poverty and family sizes and other key variables (education and prevailing political structures) ultimately lead to nonlinear outcomes (Herrera, 2018). In this context, the use of system dynamics or causal loop diagrams (CLDs) can assist researchers and stakeholders in creating solutions that are resilient to the impact of these time delays and feedbacks. This involves making hypotheses regarding the causality of related variables as well as in qualifying and quantifying the role that dynamic relationships between societal, economic, and environmental determinants of food security and malnutrition play in overall system behavior and long-term trends.

The studies presented below have used participatory approaches, in particular CLDs or system dynamics modeling, to analyze food and agricultural systems. Participatory modeling for the analysis of food security and agriculture has particular potential to improve the long-term success of community development projects, as applied by Bakker (2011). It is a useful tool used to resolve complex interactions between the diverse causes of a problem, as highlighted by McGlashan *et al.* (2016). In particular, the co-creation of causal loops with impacted stakeholders, policymakers, and researchers (all of whom are key participants) can help all parties examine problems as holistic systems, rather than isolated incidents (Sarriot *et al.*, 2015). The involvement of these key participants in data collection and the co-creation of causal loops, through unstructured and semi-structured individual and group meetings, is a form of participatory modeling (and is applied in this paper) (Inam *et al.*, 2015). In addition, participatory involvement in system dynamics model conceptualization can often involve group workshops (Eker and Zimmermann, 2016). Resulting solutions can be tailored and adapted over time to the shifting dynamics of a region. In the case of food security analysis, this can be a valuable approach when examining how income, environment, and other factors affect agriculture and food security. Notable examples of participatory system dynamics modeling or CLD building in the agricultural or nutritional fields include a study of smallholder systems and sheep rearing in Yucatán (Parsons *et al.*, 2011a; Parsons *et al.*, 2011b), coastal food systems in Bangladesh (Hossain *et al.*, 2020), small-scale farming in Pakistan (Inam *et al.*, 2017a, 2017b), *Opuntia* ecosystems in the Andes (Marín *et al.*, 2012), public policy and food accessibility in Fiji (Waqa *et al.*, 2017), agricultural exports in Ghana (Banson *et al.*, 2015), and gender roles and food security in Zambia (Kopainsky *et al.*, 2017). While many of these models concentrate more on the socioeconomic or agronomic aspects of food systems, some (Stephens *et al.*, 2012; Malard *et al.*, 2023b) also explicitly attempt to represent food security or other nutritional outcomes.

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One research project (Herrera, 2018) applied participatory modeling to engage stakeholders in two maize-farming communities in Guatemala (Jutiapa and Huehuetenango) to address food system resilience (Herrera, 2018); this work demonstrates a "system dynamics based approach to planning for resilience in food systems to climate change" to inform effective public sector planning that can bolster community food system resilience (Herrera, 2018, p. i). Notably, work by Herrera (2018) "makes the methodological decision" to position its research approach in intentional alignment with the work of other modeling and systems thinking studies that address issues such as food security and system/policy resilience (Herrera, 2018, p. 20). However, there remains a lack of studies which have used participatory construction of CLDs to highlight how communities can experience divergent outcomes in the state of their food security, even when communities are within a common socioeconomic territory of relatively homogenous geographical and socioeconomic composition.

This study seeks to fill the gap in the literature regarding divergent local outcomes in food security through the novel application of systems thinking (participatory modeling) to allow for a holistic understanding of regional food security dynamics. This understanding can be used to inform the creation of solutions (e.g. more effective food security programs or policies) that can be successful at a local level, even if they are imposed on a large scale. These are essential steps in mitigating the malnutrition crisis in Guatemala. Without this level of local nuanced understanding, solutions proposed to address the issue are more likely to be unsuccessful, as explained by the phenomenon of "policy resistance" (Sterman, 2002). As the participatory creation of CLDs is actively recognized as a method of determining a holistic understanding of a system (e.g. the food security dynamic) and its nonlinear interactions and complex parts, these methods are emphasized throughout this result-focused paper (Parsons *et al.*, 2011a; Parsons *et al.*, 2011b). Lack of application of systems thinking in previous works begins to explain why many of the previously implemented policies and solutions addressing food security issues in Guatemala have been widely unsuccessful. This paper seeks to illuminate this dynamic and contextualize how adjacent municipalities can experience divergent outcomes in the state of their food security, even when municipalities are within a common, seemingly largely geographically and socioeconomically homogenous territory. The study aims to show how divergent local outcomes in food security are driven by the impacts of nuanced socioeconomic and environmental factors, which differ between municipalities based on their unique system characteristics. By presenting and analyzing CLDs constructed with stakeholders within these oppositely trending municipalities (e.g. municipalities experiencing improvements in food security vs. stagnation or deterioration of food security in each territory of interest), a more holistic understanding of system structures leading to food insecurity can be achieved (as compared to non-systems thinking

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"linear" or indicator-based approaches). Through analysis of CLDs, key feedback loops will be identified that exist uniquely in various adjacent municipalities. These key feedback loops illustrate which key system differences explain such divergent outcomes. It is intended that these key system differences can also be extrapolated by policy makers and other key actors (e.g. government officials and other academics) to understand divergent outcomes in food security across all of Guatemala.

Methodology

Stakeholder identification

To include relevant and diverse stakeholder groups during the stakeholder identification stage, a Stakeholder Salience Model approach (Mitchell *et al.*, 1997) was employed to identify the roles of possible stakeholders in the region's socioeconomic structure (Table 1). Under this methodology, three categories of stakeholder were identified by framing their activities in the region around three attributes—power, legitimacy, and urgency. The first category, called latent stakeholders, had only one of the three attributes; the second category, expectant stakeholders, referred to stakeholders who had two out of three of the attributes mentioned above; while the third category referred to definitive stakeholders who had all three attributes and included government organizations that had the power to create relevant programs, budgets, and policies to affect change. Stakeholders were then prioritized according to the relevance of their experience to the problem variable.

Latent, expectant, and definitive stakeholders were identified for each territory surveyed. Among the latent stakeholders were medical centers, a university, and organizations focused on Indigenous and women's education and literacy. Most expectant stakeholders were municipal organizations, households, individuals, or communities in the studied regions. Within these, dependent stakeholders such as community organizations or churches had no decision-making power. Finally, the definitive stakeholders were representatives of the different government bodies. Because they were governmental or associated with national or multinational actors, these organizations had legitimacy and recognition and the ability to create far-reaching programs. These actors often had to comply with the goals of other institutions, lending them a sense of urgency. These three categories gave researchers a better sense of how certain stakeholders interacted with the problem variable; for example, certain marginalized stakeholders were more likely to experience the problem of malnutrition than make political decisions regarding mitigation of the problem. The categorization of stakeholders allowed for a better range of experiences to be represented in the creation of CLDs (Inam *et al.*, 2015).

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Table 1. Stakeholder categorization chart

Category of stakeholder	Type of stakeholder	Attributes	Examples of stakeholders
Latent	Inactive	Power	None were encountered.
	Discretionary	Legitimacy	• Universities • Consultants • Nongovernmental organizations
	Plaintiffs	Urgency	None were encountered.
Expectant	Dominant	Power, legitimacy	• Corporations • Municipalities
	Dependent	Urgency, legitimacy	• Community organizations • Households • Churches
	Dangerous	Power, urgency	None were encountered.
Definitive	Definitive	Power, urgency, and legitimacy	• Governments • National or multinational institutions

Stakeholders were chosen for this study according to the Stakeholder Salience Model (Mitchell *et al.*, 1997).

Participatory causal loop diagrams (CLDs)

Participatory CLD-building interviews were conducted with stakeholders in each study municipality. Each in-person interview lasted for 1 to 2 hours and proceeded through four main stages (Vennix, 1996): (a) problem definition; (b) identification of causes of the problem (direct and indirect); (c) identification of consequences of the problem (direct and indirect); and (d) identification of feedback loops from consequences back to causes and proposition of policies. Each stakeholder was given a large sheet of paper and a set of "sticky notes" on which to write the variables (problem, cause, or consequence); these notes were placed on the main sheet and connected with arrows indicating causality and polarity (positive or negative) of the relationship. According to the preference of the stakeholder, malnutrition or food (in)security was chosen as the problem variable. Ensuring that the problem was present in the stakeholders' lives was of key importance, as it secured their motivation and ability to speak about causes and effects of the problem. As causes were identified, stakeholders were asked to identify the immediate (first-order) causes of the problem, then to identify secondary causes of these immediate causes, and so on to tertiary and further-removed causes until the conversation reached an end. A similar approach was then used with regards to consequences. Stakeholders were also asked about the obstacles they saw in the mitigation of the problem and its causes, particularly with regards to political and economic change (Inam *et al.*, 2015).

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Beginning with the CLD of one stakeholder, variables and links from other stakeholders of the same municipality were progressively added (by the facilitator from the research group). Conflicts between different CLDs of the same municipality were treated according to Inam *et al*. (2015). After stakeholders from each region finished their interviews, several group CLDs were created for each municipality. These loops each focused on major themes found in the region (health, economy, social structure, agriculture and food, and family and well-being). These CLDs were then used to identify potential driving factors of change (represented and best summarized in identified feedback loops), where processes that were especially emphasized by multiple stakeholders or appeared in the CLDs of multiple municipalities were captured.

Models presented in the text below are the translated, optimized versions of the thematic CLDs of each municipality. The original Spanish models were translated into English. While many loops were identified, the variables that were not mentioned in the discussion and that did not directly influence the main CLD feedback loops were reduced to avoid cluttering. The models displayed below were standardized such that synonymous variables and paths were combined to make figures more readable, and comparable. Furthermore, where reduced thematic CLDs of a municipality did not add significant amounts of new information by themselves, they were re-combined, preserving only key parts of each. The models presented here are those identified to be most relevant and critical to the stakeholders and discussion. The original Spanish, unreduced CLDs are available upon request from the authors.

Study area

Six municipalities surveyed in this research represent four of the 10 total socioeconomic territories across Guatemala, as previously identified (Gálvez *et al*., 2015a). See Appendix A1 for a visual representation of territories (IARNA, 2014) and Appendix B1 for municipalities. The territories represented are: Noroccidente (territory 1), Franja Transversal (territory 2), Costa Sur (territory 4), and Oriente (territory 5). Where possible, within each territory, two municipalities were surveyed—one which exhibited a trend toward improvement of food security using childhood malnutrition rates as an indicator (positive, denoted: +), and one which showed a trend toward deterioration of food security (negative, denoted: −). However, in Costa Sur (territory 4) and Oriente (territory 5) it was only feasible to identify one negatively trending municipality (denoted M4−) and positively trending municipality (denoted M5+), respectively. To qualify as a positive municipality, rates of chronic childhood malnutrition in the area had to decline between 2001 and 2008, and subsequently continue to trend downward or maintain the same

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rate until 2014 (Gálvez *et al.*, 2015b). To qualify as a negative municipality, rates of chronic childhood malnutrition had to significantly increase during the same period or had to follow an unpredictable pattern of improvement and deterioration. The six municipalities selected for discussion in this paper from the nine studied municipalities are: San Martín Jilotepeque (M1+) and San Juan Chamelco (M1−) in territory 1, Chisec (M2−) and Cubulco (M2+) in territory 2, San Juan Ermita (M4−) in territory 4, and Santa Catarina Mita (M5+) in territory 5. Noroccidente (territory 1), also known as the *altiplano noroccidental* or northern highlands territory, is a region characterized by a mountainous ecosystem and an agricultural economy. Almost 92% of the population in the territory is Indigenous, and 74% of the population is characterized as living in rural conditions (Gálvez *et al.*, 2015a). In San Martín Jilotepeque (M1+), there were high levels of illiteracy, poverty, and unemployment (Gálvez *et al.*, 2015b). About half of residents reported feelings of marginalization. While San Juan Chamelco (M1−) had similar levels of unemployment, the region had lower levels of extreme poverty, marginalization, and illiteracy. In this study, M1− was noted as a region with negative tendencies, while San Martín Jilotepeque (M1+) showed positive trends (Figure A1 and B1).

Cubulco (M2+) and Chisec (M2−) are found in Franja Transversal (territory 2), also called the *franja transversal del norte* or the northern transverse strip. This territory is composed of 24 municipalities, with a predominantly Indigenous population (83%). The territory has the highest illiteracy rate and largest rural population in the country, at 37% and 83%, respectively. Agriculture provides the main source of income, and cultivation is mainly focused on corn, cardamom, and coffee. Territory 2 has a warm and humid ecosystem (Gálvez *et al.*, 2015a). Stakeholders in Chisec (M2−), located in the region of Alta Verapaz, noted low rates of illiteracy, marginalization, and extreme poverty. Urbanization is high in this region. M2+, in Baja Verapaz, has similar results to M2− for urbanization, illiteracy, and marginalization, but higher rates of extreme poverty (Gálvez *et al.*, 2015b). Unemployment in both regions is very high. In this study, Cubulco (M2+) was noted as trending toward positive conditions, while Chisec (M2−) trended negatively.

San Juan Ermita (M4−) is in Costa Sur (territory 4), which is concentrated in the south along with some municipalities in the *altiplano*. This territory is also mainly dependent on agriculture as a source of income. However, it has a lower proportion of Indigenous population than territories 1 and 2, at 12% of the population. Moreover, 24% of the population is illiterate and 68% live in a rural portion of the territory (Gálvez *et al.*, 2015a). San Juan Ermita (M4−) showed high rates of unemployment and extreme poverty in stakeholder interviews, but relatively low rates of marginalization and illiteracy (Gálvez *et al.*, 2015b). There were high rates of urbanization in San Juan Ermita (M4−), which is noted as trending negatively in this study.

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Santa Catarina Mita (M5+) is a municipality in territory 5, called *oriente* or east. This territory is composed of 59 municipalities and is characterized by low water availability, leading to only 55% of income being tied to agriculture. Less than 13% of the population of territory *5* belongs to an Indigenous group, and 21% of the population is illiterate. About 50% of the population in the territory lives in poverty. Santa Catarina Mita (M5+) itself showed a relatively high rate of extreme poverty in stakeholder interviews, along with a high unemployment rate and a moderately high illiteracy rate. Feelings of marginalization were not notably high in this municipality. Santa Catarina Mita (M5+) was considered an improving municipality in this study.

Results and discussion

Food security (and its related concepts) is a central variable in the majority of the resulting CLDs. The results and analysis are organized according to each of the four main pillars of food security, as defined by the FAO: availability of food, access to food, utilization of food, and system stability over time. As food security is an important (though not sole) causal factor in malnutrition, it is appropriate to examine malnutrition through the lens of these attributes. Endogenous structures that may be responsible for long-term improvements, stagnation, or worsening of malnutrition and food insecurity in different regions are discussed.

When analyzing the following CLDs, it is important to note that they offer only a qualitative view of the food security dynamic. Reinforcing and balancing feedback loops can be identified to inform potential policy leverage points. However, quantitative predictions of policy impacts cannot be made at this stage. For such a purpose, the CLD diagrams would have to be transformed into quantified system dynamics models, at which point quantitative predictions and scenario analysis could be conducted (Inam *et al*., 2017a, 2017b; Malard *et al*., 2023a, 2023b). As elaborated upon above, this paper seeks to highlight how communities can experience divergent outcomes in food security even when these communities are within socioeconomic territories sharing a relatively homogenous socioeconomic composition. Table 2 seeks to provide several key metrics that contextualize the socioeconomic state of the various municipalities under evaluation, and show how outcomes of malnutrition are present in municipalities with differing socioeconomic states. For example, the percentage of chronic malnutrition in the two studied municipalities within the *franja transversal* may, at first glance, be at odds with the rates of extreme poverty in each municipality—the municipalities have similar rates of chronic malnutrition, but large variation in rates of poverty. As another example, the relationship

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Table 2. Comparison and summary of key system differences and feedback loops in studied municipalities

	Population density (people/km^2)	Human development index (0–1)	NBI sanitary service (%)	Extreme poverty (%)	Chronic malnutrition (%)	Key balancing (B) and reinforcing (R) loops which encapsulate key system differences
Noroccidente (territory 1)						
San Martín Jilotepeque (M1+)	178.13	0.59	12.20	18.30	46.90	R: General education. B: Familiarity with health services; applying health education.
San Juan Chamelco (M1−)	291.25	0.44	20.86	38.20	58.5	R: Hygiene education; poverty alleviation
Franja Transversal (territory 2)						
Cubulco (M2+)	84.27	0.52	45.52	28.50	47.50	R: Female empowerment; Spending on illness; access to health services; marginalization. B: Social support
Chisec (M2−)	86.73	0.51	30.89	52.00	45.80	R: Production for own consumption; land maintenance; child care/illness
Costa Sur (territory 4)						
San Juan Ermita (M4−)	162.88	0.55	51.91	11.60	59.80	R: Spending on illness; economic production; energy for work. B: Use of health services
Oriente (territory 5)						
Santa Catarina Mita (M5+)	118.22	0.64	32.80	13.10	17.20	R: Community development; agricultural support; proper administration of money

between the varying presence of sanitary services and differences in rates of chronic malnutrition in the *noroccidente* territory may be illuminated by further analysis of CLDs focused on these socioeconomic factors. A summary of the key resulting feedback loops, organized by location, is provided in the rightmost column of Table 2. These feedback loops will be discussed more thoroughly throughout the rest of this section (in context with their corresponding CLDs) to illustrate key system differences existing between municipalities. The metrics provided have been calculated by the Instituto de Investigación y Proyección sobre Ambiente Natural y Sociedad (IARNA) and do not represent the results of this study. They include: Population Density (people/km^2), Human Development Index, NBI Sanitary Service rating (measured as the percentage of households that do not have access to an adequate sewage disposal system), Extreme Poverty percentile (measured as the number of households below the national poverty line) and Chronic Childhood Malnutrition percentile (in children 6–9 years old) (Gálvez *et al.*, 2015a).

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Food availability

Several causal loops defined in this study have shown that food availability is one of the primary concerns related to malnutrition in Guatemala. However, other key variables (e.g. agrochemicals, education, and childcare) and the impacts of socioeconomic realties (e.g. corruption) are also shown to impact food availability.

The agriculture sub-diagram from Chisec (M2−), a municipality in Franja Transversal (territory 2), describes several concepts related to the availability of food (Figure 1).

In Figure 1, the "Production for own consumption" loop (R1) reflects the relationship between food security, diversity, and availability. As noted by the stakeholders, having a diverse variety of food available for production and consumption helps reduce food insecurity by protecting availability. Maintaining greater crop diversity is also recognized as an approach to fortifying food system resilience, in light of shocks imposed by climate change (Zsögön *et al.*, 2022). This loop assumes that families own land, which they use to produce food for their own consumption. If the condition of land ownership is met, the loop reinforces the family's ability to strengthen their food security. This reinforcing loop shows that merely adding food to a food system is not enough to truly mitigate food security—attention must be paid to the *quality* of food that a population consumes. A diversity of crops reinforces the choice of nutritious food, which could alleviate food insecurity and create positive change in the region. This corresponds to the situation in Chisec (M2−), where employment of community members is mainly dependent on the large-scale agricultural industry. The prevalence of large-scale agriculture, as a primary source of income, presents a challenge to the ability of individuals to maintain diverse smallholder farms, as much of their land is used for a single crop, as illustrated by the interaction between the "Production for own consumption" loop (R1) and "Land maintenance" loop (R2). Large-scale agriculture may displace smallholder production, to the detriment of family farmers; in a highly Indigenous region such as Chisec (M2−) it becomes clear that the impact of the large-scale agriculture industry may contribute to the historical and ongoing marginalization of Indigenous populations (who are often smallholder farmers). The implications of this marginalization is important to consider when identifying important barriers to the community's food security.

Similar themes regarding availability of food can be seen in Figure 2, the economic sub-diagram from Santa Catarina Mita (M5+), a municipality in the *oriente* region. The "Agricultural support" (R2) and "Proper administration of money" (R3) loops in this diagram show that stakeholders considered factors of availability (e.g. for supplies, education, and employment) to be critical for food security.

In Figure 2, the availability of supporting materials like agrochemical supplies was noted as contributing to the production of food for personal consumption.

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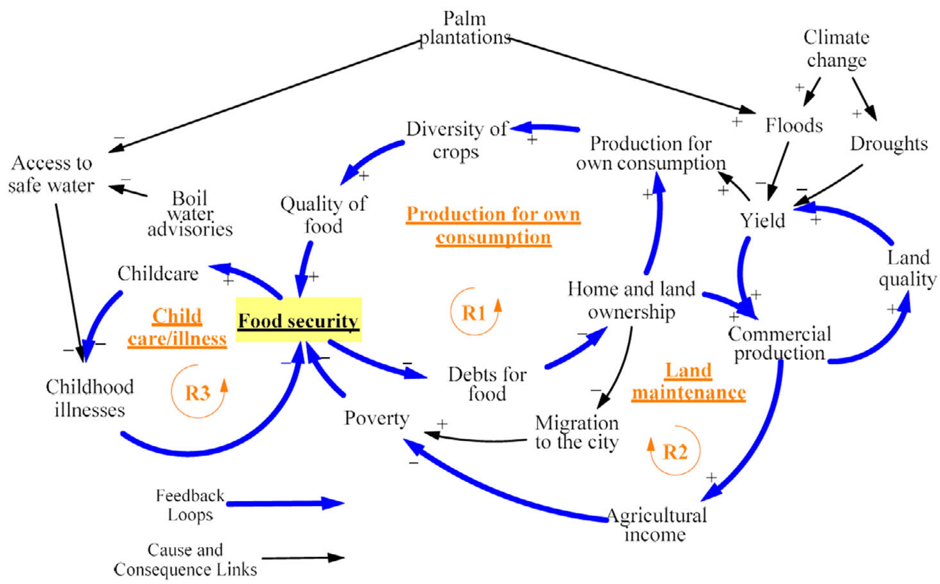

Fig. 1. Agri-economic sub-diagram from Chisec (M2−). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

Without such resources, residents might have to work in large-scale agriculture, which does not offer direct opportunities to feed a family in the way that smallholder agriculture does because the food produced from large-scale agriculture does not directly go into the community. In addition, Figure 2 shows that sales of crops produced by smallholders could increase family income throughout the year; this helps mitigate food insecurity and childhood malnutrition, but can only be achieved with resources and support. As in Chisec (M2−), interviewees in Santa Catarina Mita (M5+) noted a threshold of resources must be reached before availability of food is guaranteed. However, in the improving region of Santa Catarina Mita (M5+), the reinforcing "Agricultural support" loop (R2) supported increasing access to food; i.e. agricultural yield increased with increased resources. When the conditions for success are met—in that supplies and resources for smallholder production are available—agricultural yield can increase access to food in this improving region and mitigate childhood malnutrition. Without considering that threshold of conditions, it is impossible to determine the factors that lead to malnutrition or food insecurity in the region or country. Thus, availability of food, and of resources, must be analyzed and implemented in conjunction with external factors.

Food accessibility

Unlike availability, which focuses on the physical presence of food for an individual or a family, access to food considers economic and social barriers that may lead to food insecurity.

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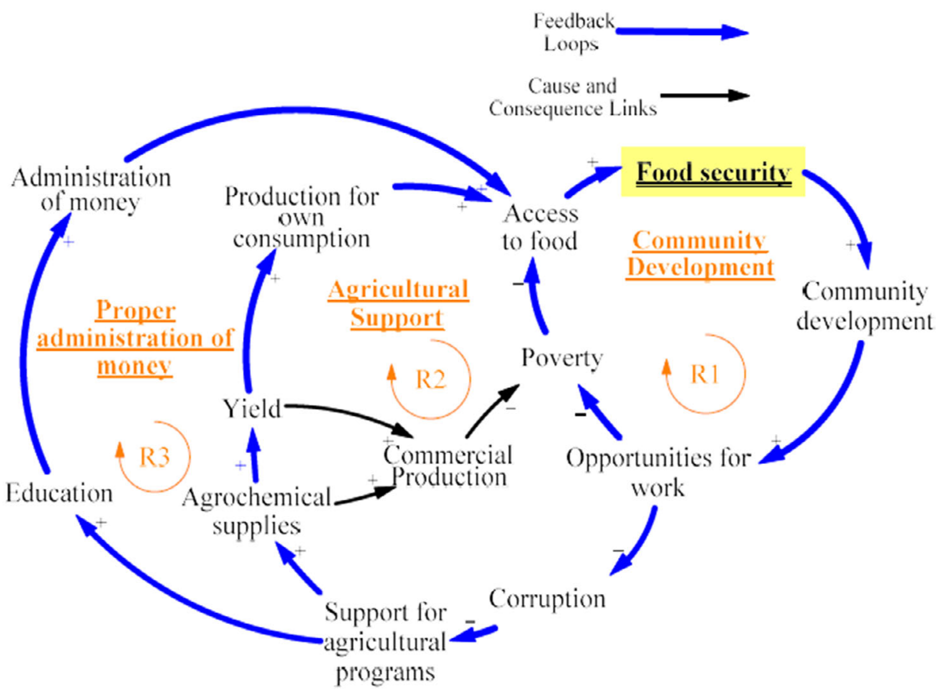

Fig. 2. Economic sub-diagram from Santa Catarina Mita (M5+). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

The economic sub-diagram for Santa Catarina Mita (M5+) showed that access to food and availability of food were intertwined concepts. The "access to food" variable in Figure 2 is tied to three major loops—"Proper administration of money" (R3), "Agricultural support" (R2), and "Community Development" (R1). Within loop (R1), "Opportunities for work" is a major variable. Employment and the ability to earn an income is an imperative step toward improving food accessibility. Many studies have focused on household income as an indicator of food security for a household; however, at times, this income status can be misleading as it may be seasonal or underreported (Méthot, 2014). Despite Santa Catarina Mita's (M5+) status as an improving region, stakeholders interviewed for this study noted high rates of unemployment. The reinforcing (R1) loop showed that citizens were interested in community development to support new opportunities for employment. However, this loop was tied to several important variables which may present a challenge to creating these opportunities—namely, corruption and administration of money. It is not enough to create development opportunities without ensuring that they are also correctly administered. Ignoring these concerns led to increased poverty, which led back to malnutrition and food insecurity. It was important to note that the "administration of money" variable was found in the (R3) loop, but is also related to community

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development. The administration of social programs and community development could have effects not only on current opportunities, but also on opportunities in the future, through education. The sub-diagram for Santa Catarina Mita (M5+) shows this through the importance of the education variable. Education can empower community members with further financial and agricultural knowledge, which in turn can help increase agricultural yields and contribute to more food availability. Santa Catarina Mita (M5+) is located in the *oriente* region where a majority of the population depends on agricultural income, particularly from crops like corn and coffee (Gálvez *et al.*, 2015a). In the sub-diagram from Santa Catarina Mita (M5+), stakeholders noted that government or municipal support for agriculture, through programs or resources, leads to both better agricultural yields and increased access to education. Citizens who benefited from this increased access to education were able to be trained for jobs in agriculture, which provides citizens further means to generate more income, consequently fueling the local economy. From this sub-diagram, the dynamic relationship between education, resources, and food security is elucidated. Resources and investments help support education, which in turn supports community development and helps mitigate childhood malnutrition and food insecurity, further improving resources and investments.

Agriculture was not the only factor related to income and access to food. In CLDs from many municipalities, the gender disparity of income was noted as a contributing factor to the lack of food accessibility. In Cubulco (M2+), the agricultural sub-diagram (Figure 3) shows that “empowerment” is a key variable contributing to access to food.

Like Santa Catarina Mita (M5+), Cubulco (M2+) is dependent on agriculture as a primary source of income. In the agricultural sub-diagrams for Cubulco (M2+), however, female empowerment was noted as a variable which could increase smallholder production. A higher income from a dual-income family generally increased access to food. The Cubulco (M2+) sub-diagram demonstrates how an increase in the access and availability of education positively supports “Female empowerment,” which increases smallholder production and more access to food. However, the loop was also noted as a reinforcing loop tied to food insecurity, showing that women’s employment was not the only factor which needed to be addressed to mitigate the overall issue. Indeed, those interviewed in Cubulco (M2+) noted high rates of unemployment, despite its status as an improving region. For this reason, it was important to examine secondary and tertiary variables in the sub-diagram. During the interview process, it was a challenge to address the political and economic structures that resulted in fewer opportunities for rural communities. Several interviewees noted that *machismo*, a sense of conservatism, was an obstacle to female empowerment. These sociopolitical and economic hurdles reduce access to education and business opportunities for women. System stability and equity is a key factor in allowing for

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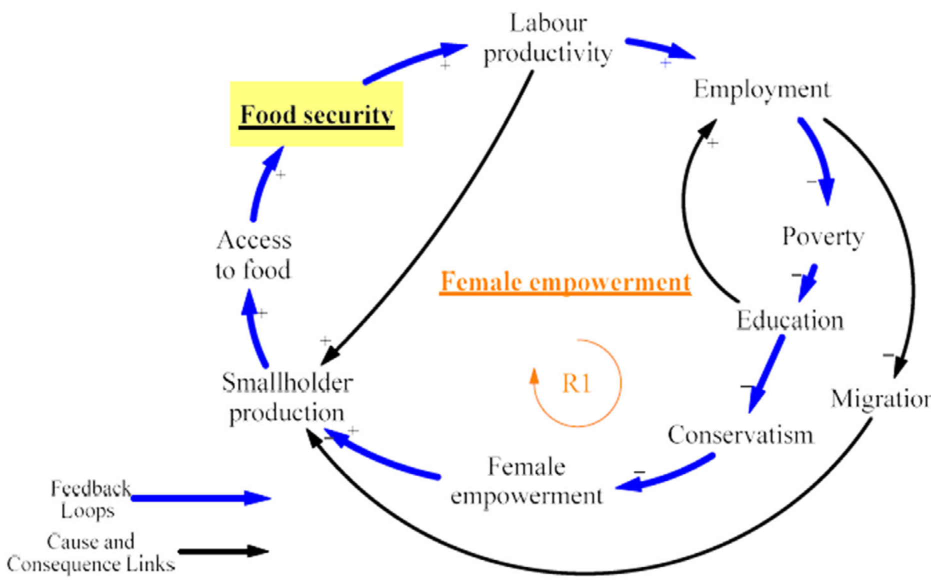

Fig. 3. Agriculture sub-diagram from Cubulco (M2+). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

dual-income households. According to the FAO, food system stability exists when all other attributes of food security—availability, access, and utilization—are stable over time (FAO, 2006). System stability is discussed throughout this paper, with particular emphasis in the "Food system stability" section.

Another factor that impacts access to food is health and healthcare access. This was noted in several sub-diagrams from across Guatemala, and was related in many ways to factors such as agricultural yield and income stability. The health sub-diagram from San Juan Ermita (M4−), a municipality in the *oriente* region showing a worsening trend, notes two main loops focused on access to healthcare and the expenses associated with being ill (Figure 4).

Loop (R1) "Spending on illness" indicated the close relationship between agricultural income, nutrition, and health in this region. High rates of malnutrition in San Juan Ermita (M4−) contribute to illness vulnerability; gastrointestinal, respiratory, and parasitic illnesses were noted as key concerns. The prevalence of these illnesses requires families or individuals to spend more of their income on treatment, a challenge for workers reliant on seasonal wages. The "spending on illness" (R1) loop is reinforcing; interviewees noted that higher spending on illnesses led to less availability of nutritious food, due to the high cost of nutritious food and the prioritization of healthcare. This contributes to childhood malnutrition. By analyzing this causal loop, it is possible to understand the targeted actions that could be taken to mitigate concerns of citizens. For instance, better universal access to healthcare could interrupt this reinforcing loop. "Spending on illness" (R1) demonstrates how

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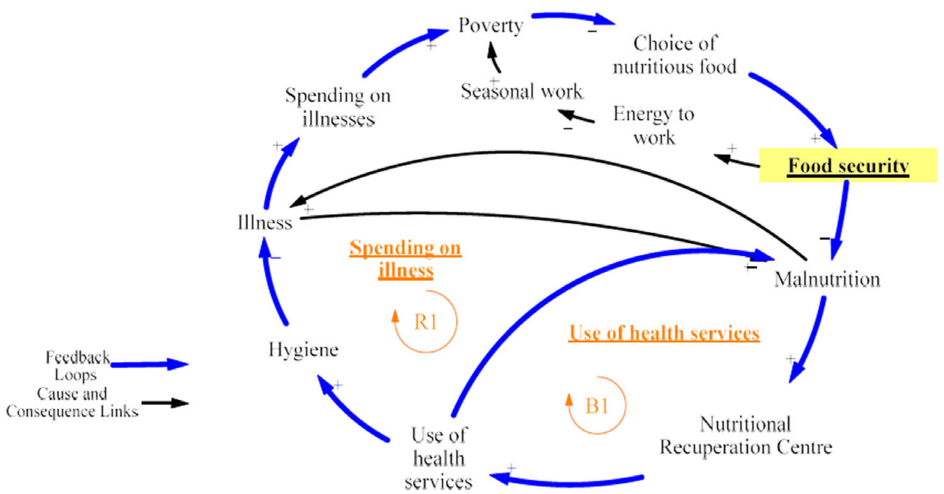

Fig. 4. Health sub-diagram from San Juan Ermita (M4−). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

community members are trapped in a cycle of unsustainable spending on illnesses, malnutrition, poor health, and poverty. The presence of respiratory illnesses as a main variable in the hygiene and illnesses sub-diagram in San Juan Ermita (M4−) also indicates possible external factors affecting health in the region. The majority of rural households in Guatemala used wood-fired stoves, which are often found in small enclosed spaces (Thompson *et al.*, 2011). Use of these stoves has led to higher exposure to particulate matter and carbon monoxide, which can contribute to respiratory illness (Thompson *et al.*, 2011). In San Juan Ermita (M4−), a municipality with a large rural population, the presence of factors like wood stoves may contribute more to respiratory illness than in other municipalities.

Utilization of food

Achieving community food security requires the appropriate utilization of food resources, which is supported by an adequate diet, clean water, the ability to sanitize food, and access to health care (FAO, 2006). This pillar describes the importance of non-food inputs in maintaining the security of a community's food system (FAO, 2006). The San Juan Ermita (M4−) health sub-diagram offers insight into this community's current food utilization reality. In Figure 4, (B1) "Use of health services" is a key balancing loop related to acute childhood malnutrition. Stakeholders rated the municipality poorly for access to sanitation services, which supports the presence of the "hygiene" variable in the (R1) loop. This in turn is tied to the "Spending on illness loop" (R1), a reinforcing loop which evaluated how spending on health services affected malnutrition. This relationship found that with

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higher spending on health—tied to gastrointestinal, respiratory, and parasitic illnesses—one's ability to afford nutritious food decreased. However, some types of healthcare spending did help mitigate high rates of malnutrition. For example, those interviewed in this region found that when nutritional recuperation centers were successful and accessible, children recovered better from early childhood malnutrition and were able to remain healthy. However, as seen in the "spending on illness" loop, these recuperation centers must be accessible regardless of income level to provide long-term success.

The Cubulco (M2+) health sub-diagram offers a similar perspective of the utilization of food and its relationship to health (Figure 5).

Both "Spending on illness" and "Access to health services" were noted as primary factors related to food insecurity. As in San Juan Ermita (M4−), childhood malnutrition stemming from food insecurity had led to an increase in childhood illnesses, shown in the (R1) "Spending on illnesses" reinforcing loop. According to interviewees in Cubulco (M2+), this leads to two important relationships. First, childhood illnesses require further health expenditures, which may contribute to poverty. Secondly, poverty—possibly due to health expenditures—is a barrier to the use of health services. In order to better understand the relationship between poverty and access to health services, the Cubulco (M2+) social sub-diagram was examined and a new loop appeared—marginalization.

As seen in Figure 6, participants in the study in Cubulco (M2+) tied "Marginalization" (R1) to social programs, and access to food. The Franja Transversal (territory 2), where Cubulco (M2+) is located, is predominantly Indigenous (82% of the population). A study in this region by Burton (2012), revealed that healthcare workers were often degrading or insulting to their Indigenous patients, dismissing their symptoms or neglecting to perform a full examination. In some cases, healthcare workers mocked the beliefs or culture of their Indigenous patients. These experiences led to a reluctance to use healthcare services for fear of ridicule or neglect (Burton, 2012, p. 122). The "Marginalization" loop in Figure 6 (R1) reveals important contributors to system stability and indicates key social variables (e.g. conflict and marginalization) that can create system instability. System stability refers to the state of social and economic conditions which allow people to achieve food security. One aspect of system stability is the ability to reliably access safe and unbiased resources (e.g. health services). Health services are highlighted, which can mitigate malnutrition by improving health education. This can facilitate an increased use of maternal and childhood nutrition programs. These resources are among the "non-food" inputs which support appropriate utilization of food and boost community food security. These studies in Cubulco (M2+, R1) and San Juan Ermita (M4−, B1) described how safe and unbiased health and sanitation services can improve access to food resources, and how marginalized communities may have more difficulty

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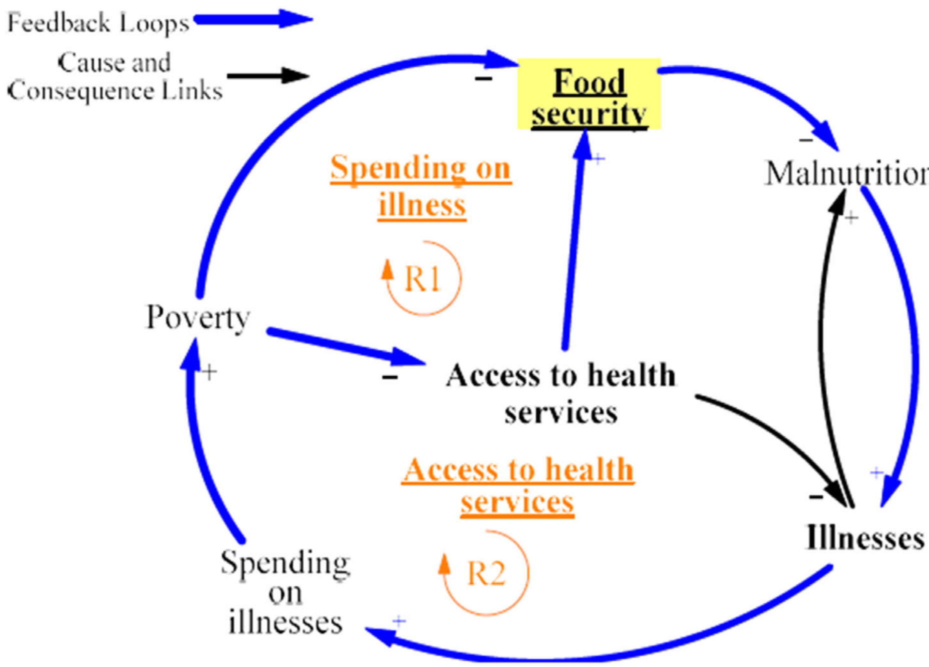

Fig. 5. Health sub-diagram from Cubulco (M2+). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

accessing these services. Achieving system stability, made possible through greater provision of safe and unbiased services, is seen to have a significant positive impact on food security.

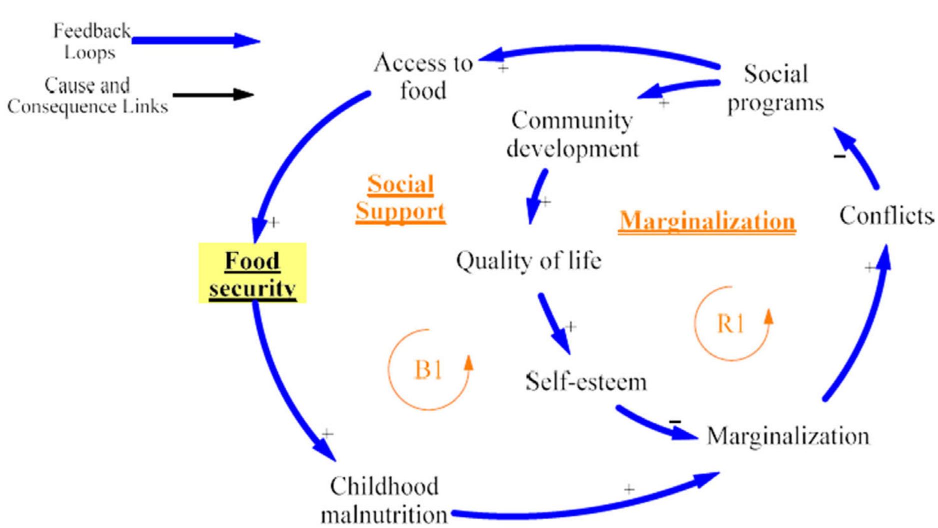

Fig. 6. Social sub-diagram from Cubulco (M2+). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

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Health education, as a key factor, was echoed in the sub-diagrams from two improving regions, San Martín Jilotepeque (M1+) and Santa Catarina Mita (M5+). Further research (Maupin, 2009) revealed that programs had been implemented to bring about this positive change, which is why (R1) "General education" is closely related to (B2) "Applying health education." Both are attributed to an improved food security status. Interviewees in San Martín Jilotepeque (M1+) and Santa Catarina Mita (M5+) each stated that with rising rates of malnutrition, federal or territorial governments feel more pressure to create assistance and social programs. These programs provide health services such as prenatal checks, nutritional programs, and well-baby checks, ensuring that maternal and childhood malnutrition can be addressed more efficiently.

In San Martín Jilotepeque (M1+), increased development and education contribute to higher incomes, which facilitate better access and awareness of health services, demonstrated by (B1) "Familiarity with health services" (Figure 7). The presence of these positive trends in an improving municipality suggests that health in the region is also improving, thereby cultivating better living conditions. After the abatement of Guatemala's civil war in 1996, access to health centers and hospitals in San Martín Jilotepeque (M1+) steadily increased as both governmental and nongovernmental organizations began implementing health programs (Maupin, 2009). The implementation of the Sistema Integral de Atención en Salud (SIAS) reduced the lack of

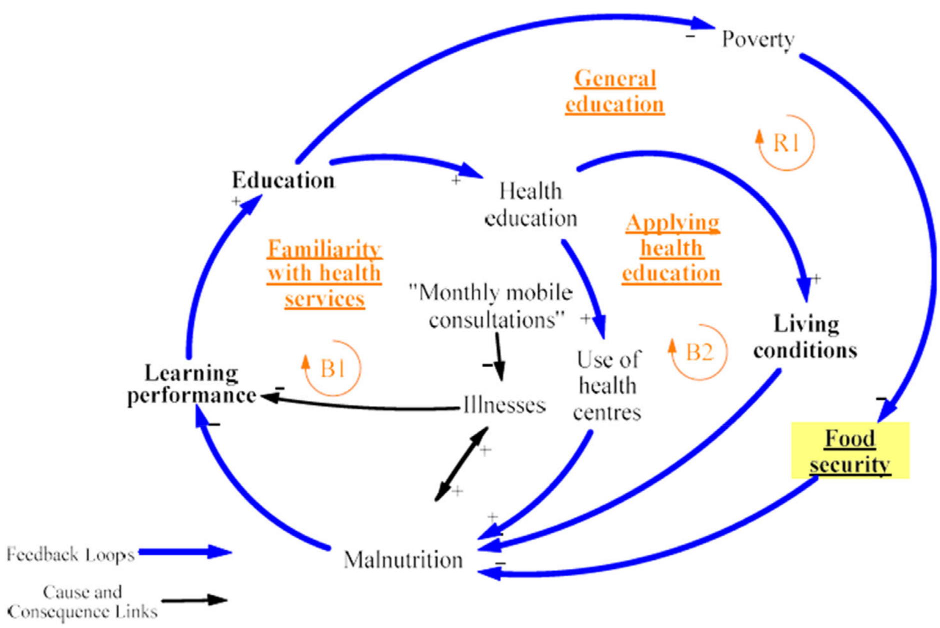

Fig. 7. Health sub-diagram from San Martín Jilotepeque (M1+). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

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access to health services to the population by over 35% (Maupin, 2009). SIAS has a good reputation in the region, especially with regards to patient satisfaction. As reported by stakeholders in San Martín Jilotepeque (M1+), tensions between patients and health workers are noted as a deciding factor in the effectiveness of health programs. As the research in San Martín Jilotepeque (M1+) and Cubulco (M2+) show, it is not merely the presence of health programs that affects their efficacy—it was also the way in which the health programs are administered.

This hypothesis is supported by the health sub-diagram from Santa Catarina Mita (M5+) (Figure 8), located in the department of Jutiapa, which exhibits high rates of the vector for Chagas disease, a parasitic disease caused by *Trypanosoma cruzi* (Pennington *et al.*, 2017).

Jutiapa had, in the past, the second-highest population in Guatemala at risk of infection, mainly due to the prevalence of unplastered houses and lack of sanitation services, which increase the risk of infestation by *T. cruzi*'s vector (Weeks *et al.*, 2013). In recent years, various mitigation strategies have been implemented to stop the spread of *T. cruzi* including an ecosystemic approach and the government's preferred approach of conducting insecticide sprayings. The ecosystemic approach included replastering of houses using local materials, promotion of reforestation, and crucially, informal education regarding prevention and treatment of the spread of vectors (Monroy *et al.*, 2009). By bringing public health workers into communities, researchers showed that access to preventative health services could help mitigate vectors which carried diseases. In examining strategies to reduce the spread of *T. cruzi*, the authors found an important element of improvement in this causal loop—accessibility of health services. Analyzing the causal loop in conjunction with research conducted in the region reveals the importance of increasing accessibility and objectivity of health services, and particularly health education. In Santa Catarina Mita (M5+), informal health

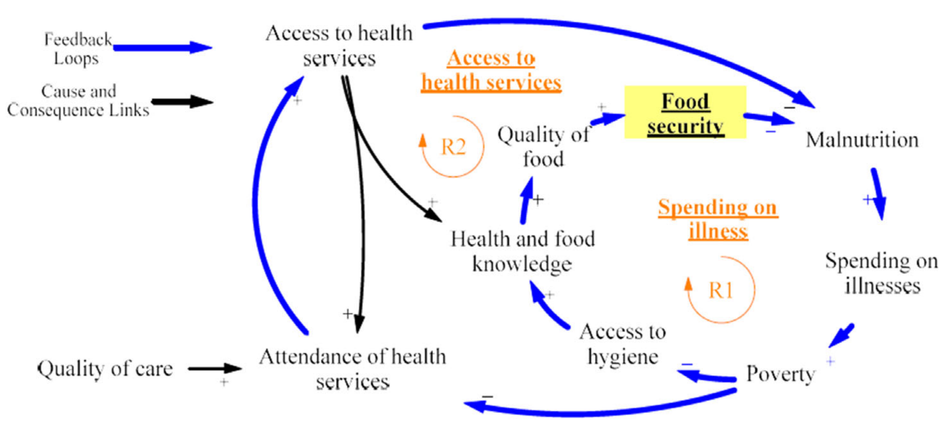

Fig. 8. Health sub-diagram from Santa Catarina Mita (M5+). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

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education and its economic and social accessibility to all members of the population is a leading factor in the increased use of health services. Notably, difficulty accessing health centers led to lessened use of health services, while improving the quality of patient care promoted attendance and use of health centers. Similarly, as seen in Figure 7, in San Martín Jilotepeque (M1+) the presence of mobile health units (*consultas móviles mensuales*) contributes to a mitigation of illnesses among children and, in turn, to better education. Each of these causal relationships reduces the presence of malnutrition, particularly among children, in these municipalities.

Several aspects of utilization of food require consideration, including the role of access to sanitation, the role of education, and maintaining a healthy diet (Méthot, 2014). These variables were discussed above in regard to food accessibility, but they influence utilization of food as well. The relationship between education and hygiene (Figure 9) was strongly identified in both causal loops and previously conducted research.

Education can improve a child's quality of diet, if the school institution is able to provide healthy choices during school meals. As well, education is shown to be a viable method for providing (R1) "Hygiene education" and education on nutrition. However, some students feel discriminated against in their school and for a multitude of reasons leave before finishing their education. Interviewees also stated that women who were literate often had living conditions with better sanitation and fewer latrines, and that nutritional quality of food improved in their household. A key catalyst in this feedback loop would be a focus on access to education, particularly (R1) which shows access to hygiene as a means to create improved quality of life and ultimately support the cycle of (R2) "Poverty alleviation" (contributed by improved sanitation, access to education, and the empowerment of women and children). This cycle provides community members with more resources to prioritize the appropriate utilization of food and fortify their "Food security."

These examples help define aspects of utilization of food critical in mitigating food insecurity. The causal loops from the above regions offered important insights into the value of investments in programs that address childhood malnutrition or food insecurity, or provide children with the knowledge to seek more nutritious food options.

Food system stability

In each sub-diagram analyzed above, it is evident that system stability influences all other aspects of malnutrition and food security. Food system stability is affected by climate, and political or economic conditions (FAO, 2006). Before concluding that any one action can be used to mitigate malnutrition

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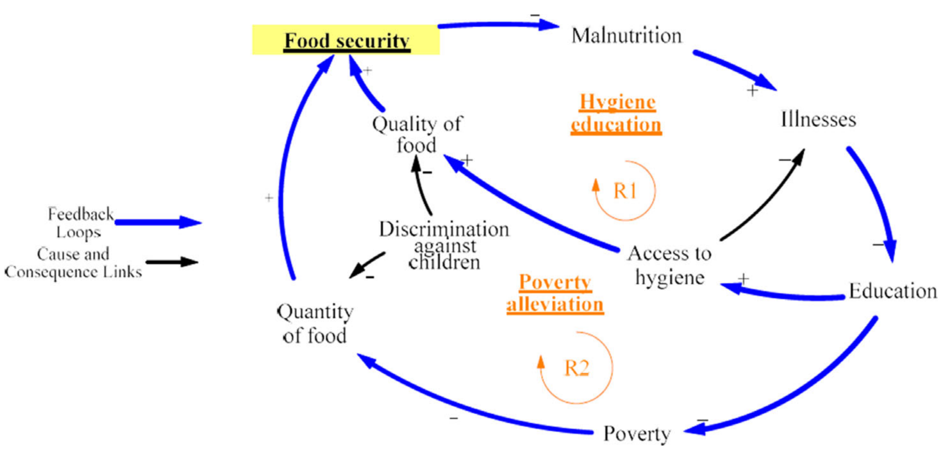

Fig. 9. Quality of food sub-diagram from San Juan Chamelco (M1−). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

and food insecurity, it must be assessed through the lens of system stability to better understand potential intrinsic barriers to success.

Accessibility of health services was one of these intrinsic barriers. Marginalization of Indigenous peoples or those living in poor conditions was a barrier to effective treatment of malnutrition. As patients in Baja Verapaz noted, when healthcare workers were not sensitive to the beliefs of their patients, patients were unwilling to return for follow-up healthcare (Burton, 2012). It was not enough to provide healthcare centers throughout the country; in order to overcome bias and make health education accessible, programs must be organized in a way that addresses subconscious biases. Regions where marginalization has been addressed through targeted and specialized programs are displaying decreasing rates of malnutrition. For example, in San Martín Jilotepeque (M1+), organizations like the Maya-Kaqchiquel Coordination of Organizations for Equitable and Sustainable Development (COMKADES) provided informal education which could be structured around the traditional agricultural workday and brought mobile health units to rural areas. Investing in such targeted programs could help support the long-term effects of initiatives like neonatal and childhood nutrition, leading to an overall stability of the food systems in these regions.

Another important aspect of food system stability is ecological stability, particularly around climate change and land-use change (Méthot, 2014). Méthot (2014) noted that ecological resilience affects social stability; ecosystem services such as climate regulation can influence a population's ability to support themselves. It is clear from several sub-diagrams that economic stability is directly tied to productivity of the agricultural ecosystem, and that both are necessary factors in achieving food security.

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Stakeholders in Chisec (M2−) (Figure 1) specifically mentioned that flooding, deforestation, and large-scale commercial agriculture were contributing to lowered agricultural performance on small farms. In reference to the agriculture sub-diagram (Figure 1), palm production is identified as a leading factor in deforestation. Deforestation leads to floods, which in turn contribute to lower crop production and poverty, as described in Figure 1. Therefore, land-use changes, such as palm plantations, and their peripheral effects on water and land, also had an impact on economic development of the municipality. Figure 1 further describes the impact of land use changes on health and hygiene, particularly that of children. Lack of access to potable water was noted by stakeholders to have an impact on childhood illness, which exacerbated food insecurity. These impacts can be seen both from agricultural activities (e.g. palm plantations) and from a lack of infrastructure around sanitation (denoted by the frequency of boil water advisories).

In Figure 10, climate change was mentioned as a factor affecting agricultural yield, which could in turn affect family income, food security, and nutrition. In these sub-diagrams, reduced precipitation, increased temperature, and a rise in extreme weather events were all mentioned as threats to agricultural productivity. As in Figure 1, Figure 10 highlighted the connections between large-scale agricultural development, water quality, and climate change. Climate change, particularly more frequent droughts, impacts both smallholder production and access to potable water—both noted throughout the CLDs as key elements that impact malnutrition and food security. Because agricultural productivity is closely tied to economic productivity for subsistence farmers, the effects of land use change and climate change have led to a reduction in food production ("yield") and increased malnutrition. This relationship is exemplified in Figure 10 within the interaction between the (R2) "Economic production" and (R1) "Energy for work." The problem may then be exacerbated by the impacts of water contamination from agricultural or sanitary sources, leading to further cases of illness and malnutrition.

A further effect of ecological instability could be seen in the number of regions where greater community migration occurred due to the increase in large-scale agriculture. In the Chisec (M2−) agricultural sub-diagram (Figure 1), it was noted that if land quality was poor or agricultural supplies were not accessible, yield from the land was low and families could not support themselves on this income alone. If this was the case, some chose to sell their land and move to a city center, where other income sources were available.

Agricultural seasonal migration was one factor contributing to system instability which must be analyzed in order to understand what programs or efforts can be implemented to mitigate food insecurity. In addition, the

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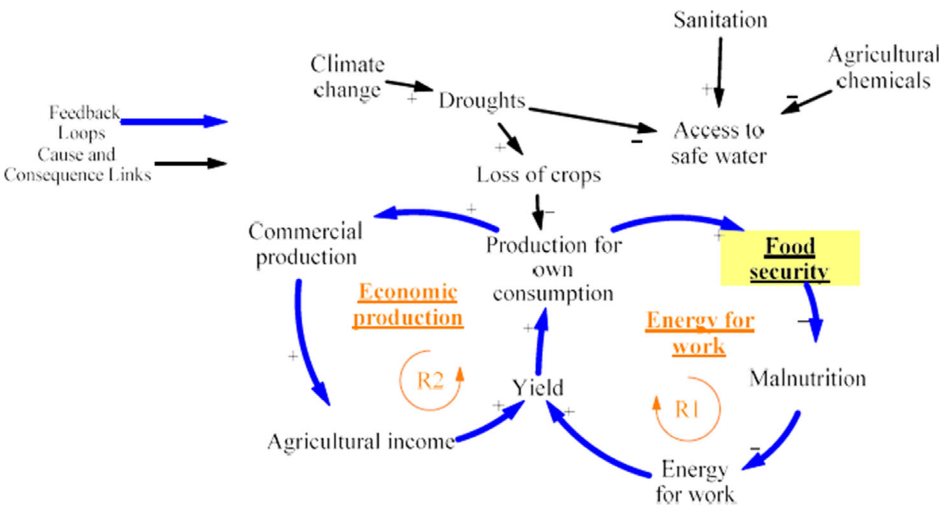

Fig. 10. Social sub-diagram from San Juan Ermita (M4−). The key variable, food security, is highlighted [Color figure can be viewed at wileyonlinelibrary.com]

relationship between agrochemical supplies, large-scale agriculture, and migration helped explain the presence of an organization like Fontierras, the Land Fund, in Chisec (M2−). Their goals include a focus on sustainable agriculture and improving access to land for Indigenous citizens and women. The founding principles of Fontierras define actionable goals for sustainable and equitable development, which can be a response to the cycle of monoculture, smallholder production, and migration.

Viewing the sub-diagrams which mentioned migration through their categorization as an "improving" or "deteriorating" territory, as defined in the "Study area" section, offered a perspective on the nuanced nature of food security. The Chisec (M2−) and Cubulco (M2+) sub-diagrams mentioned migration as a factor contributing to the main variable of malnutrition or food insecurity. Chisec (M2−) was noted as a deteriorating municipality, while Cubulco (M2+) was improving. The way in which interviewees discussed migration in these towns mirrored this categorization. In Chisec (M2−), migration to the city was due to low yields on smallholder farms, driven by a lack of access to supplies or climatic conditions. Ecosystem stability should be evaluated in conjunction with local conditions in order to better understand factors contributing to food security and food access; organizations like Fontierras show an example of how considering climate stability can also provide opportunities for education and development.

Many stakeholders from several regions noted that paternalist government programs and negative attitudes toward certain demographics (e.g. Indigenous community members) negatively affected mitigation of malnutrition and food

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security. This was seen in the disregard of Indigenous patients by the healthcare system as well as in the often prevalent perspective that many who suffer from chronic malnutrition are relying too heavily on government aid. This was evident in the welfare loops found in many sub-diagrams, including the social sub-diagram from Santa Catarina Mita (M5+). At times, there was a potential to rely on the narrative that those in need of aid were overly reliant on the aid and could not be helped unless they changed their ways. This attitude led to the creation of ineffective programs and an unwillingness to work toward a joint solution. Collaborating with local organizations who can help to uphold the perspectives of the affected communities is recommended to mitigate these biases.

Overall, the inclusion of a diversity of municipalities, both improving and worsening, allowed for the identification of key feedbacks and processes determining malnutrition and food (in)security trends in the country. Stakeholders from Chisec (M2−) noted the importance of the impact of agricultural diversification on food availability and security. Stakeholders from Cubulco (M2+) presented the importance of women's empowerment as a means to improve agricultural yield and food availability. In particular, marginalization (of many kinds, but especially of Indigenous or poorer communities), was a recurring theme. The issue of marginalization and barriers to access in healthcare (and the corresponding reinforcing loop trapping communities in a cycle of poverty and illness) were however present in many regions, including Cubulco (M2+) as well as municipalities with worsening trends (e.g. San Juan Ermita [M4−]). Interestingly, however, San Martín Jilotepeque (M1+) and Santa Catarina Mita (M5+), both improving municipalities, highlighted the reinforcing loop of quality health care, social programs, and community investments and the positive impacts that these have on social cohesion, nutrition, and food security. The fact that similar concepts (such as health care) appear in both their positive and negative forms in municipalities with opposite trends suggest that these key variables, when pushed in the correct direction by locally appropriate social programs, do have the potential to drive key reinforcing loops in a positive direction.

Conclusion

Malnutrition and unstable food security are far-reaching problems with various causes and effects which disproportionately affect rural children in Guatemala. The manifestation of food insecurity and malnutrition is related to a range of interrelated variables which span, but are not limited to, the social, political, environmental, economic, educational, and racial domains. Each of these domains influences stakeholders' food systems and imposes

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intrinsic barriers, biases, and thresholds. The cumulative reality of this complex food security and malnutrition dynamic is that some stakeholders are disproportionality disadvantaged (mainly Indigenous community members) and cannot equally make use of resources or programs currently in place. Using CLDs allows researchers to apply input from local stakeholders to better understand the current complex food security and malnutrition dynamic.

In total, across the six municipalities considered, 10 CLDs are presented. Within these, 16 key reinforcing loops and four key balancing loops have been identified (see Table 2 for a summary). These loops capture the perspectives offered by stakeholders and provide the context to infer why adjacent municipalities, even in the same socioeconomic territory, can experience such divergent outcomes in their food security. A summary of the key results, their interaction and their implications, is presented here.

The reinforcing loop "Marginalization" is identified by multiple stakeholders across multiple municipalities (directly in Cubulco [M2+] and Chisec [M2−]), and impacts all four pillars of FAO-defined food security: availability of food, access to food, utilization of food, and system stability over time. In Cubulco (M2+), the interaction between (R) "Spending on illness," (R) "Access to health services," and (R) "Marginalization" highlights a problematic cycle which undermines food security. This cycle is shown to be balanced with (B) "Social support." However, in San Martín Jilotepeque (M1+) the interaction between increased (R) "General education" and (R) "Familiarity with health services" was shown to have a balancing effect on the food system, demonstrated by (B) "Applying health education." Trends visible in Figure 7 are associated with less prevalent marginalization concerns and this region (San Martín Jilotepeque [M1+]) is notably recognized for its improving food security status. In Chisec (M2−), large-scale agriculture was linked to (a) the historical and ongoing marginalization of Indigenous populations, and (b) the reduction of small-scale farmers' ability to plant a wide variety of crops, which reduces community food availability and diversity. These trends are attributed to undermining community food security, as reported by stakeholders in Chisec (M2−) in the interaction between (R) "Production for own consumption" loop and (R) "Land maintenance" in Figure 1. This trend appears to be exacerbated by climate change. This lack of diversity and availability is also associated with the exacerbation of food security and illness (demonstrated in Figure 1 by [R] "Child care/illness"). This highlights the significant and negative implications of marginalization and the rise in large-scale agriculture. Targeted programs that address marginalization, are culturally sensitive (especially toward Indigenous community members), and increase resilience to climate change are needed to stabilize the food system and provide community members with more resources (mainly financial and social services) to improve their

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own food security. Government and private collaboration with local organizations, who can uphold the perspectives of marginalized communities, is recommended. As well, this kind of collaboration may help to reduce corruption, increase transparency and accountability, and ultimately lead to the creation of food security solutions which can have a greater positive impact. Lack of availability of key resources like fertilizer, education, and employment opportunities are shown to directly impact community food security, as reported by stakeholders in Santa Catarina Mita (M5+) whose perspective is reflected in Figure 2 by the interaction between (R) "Community development," (R) "Agricultural support," and (R) "Proper administration of money." Increasing availability of these key resources was associated with balancing behavior (B) "Familiarity with health services" in San Martín Jilotepeque (M1+) and balancing behavior in San Juan Ermita (M4−) (B) "Use of health services" (see Figure 4). Additionally, increasing availability of education opportunities, for women especially, was shown to reinforce (R) "Female empowerment" in Cubulco (M2+), which further supports the fortification of community food security. Overall, increasing access and availability of essential resources was shown to have a compounding positive impact on community food security. These results identify key intervention points to support different and more beneficial outcomes for food and economic security; thus, programs that sustainably increase supply and availability of these key resources are encouraged. Stakeholders in Chisec (M2−) and San Juan Ermita (M4−) highlighted the interconnection between large-scale agricultural development, urbanization, water and land quality and accessibility, climate change, drought events, and the negative implications this can have on yield. The interaction between these variables is shown to have the potential to undermine (R) "Economic production" and degrade (R) "Energy for work," which is attributed to a degradation in food security, as reported by stakeholders in Chisec (M2−) and San Juan Ermita (M4−) (Figures 1 and 10). This dynamic may help policymakers understand why two otherwise similar municipalities ultimately experience varying outcomes and success of programs aimed at reducing chronic malnutrition.

This research indicates that designing policies at a national scale, without local consideration, is often too broad of an approach to create meaningful outcomes. Various problems affect diverse regions differently, even at the municipal scale. Using CLDs allows for more holistic solutions to be proposed, aiming to address not only the issue of malnutrition, but also the specific root causes in each region. The knowledge gained by comparisons of causal relationships with demographic data from across Guatemala provides the needed context to formulate important recommendations for future development and policy-making. Likewise, involving those who are part of

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the communities that suffer from malnutrition can help create more effective programs.

As has been demonstrated, the inclusion of local perspectives can provide context that can support the creation of focused, targeted policies to address subtle variables contributing to malnutrition, while also reacting to large-scale changes which affect food security. In regions which show tendencies toward improvement, causal relationships shed light on which factors are likely contributing to positive change and vice versa. The data shown here support the inclusion and involvement of latent stakeholders in rural Guatemala in the creation of social resources and programs. Their input to the CLDs illustrates the many important relationships highlighted above which may have otherwise been overlooked, and which could be addressed through initiatives such as mobile health units or organizations focused on sustainable agriculture. Without input from Indigenous organizations, organizations focused on sustainability, and local leaders and resources who know their municipality best, resources are often ineffectively deployed and inaccessible. The use of causal relationships was also used to highlight ecosystem instability. These CLDs provide the context necessary for examining the complex relationships between ecology, social structure, and the national and global economy.

The unique interactions between social and ecological variables identified allowed for the formulation of these key conclusions and recommendations. They are positioned to provide policy-makers and public and private entities with holistic but specific information that can be applied to best address the malnutrition and food insecurity issues currently impacting community members in Guatemala. As seen in the regions surveyed, conditions are rarely uniform even across similar or adjacent municipalities; thus, national or even regional-scale policy may miss critical segments of the population. Development of CLDs, and including marginalized communities, can provide an opportunity for policymakers to create more targeted and actionable programs. The participatory development of CLDs can continue to be used as a tool to analyze the dynamically shifting landscape of nutrition in Guatemala and identify key areas in programs that can be locally adapted to meet the unique needs of a community. Observing the relationship between these key feedback loops can provide key actors with the context to make inferences about the food security and malnutrition issues across all of Guatemala. We recommend that future nutritional policy in Guatemala (a) be developed in a participatory manner with diverse stakeholders from affected communities; (b) aim to identify and redress the root causes of food insecurity rather than addressing symptoms, by taking advantage of reinforcing feedback loops to catalyze lasting change; and (c) prioritize locally developed solutions and programs tailored to individual regions instead of relying solely on “blanket” and uniform national-level policies.

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Conflict of interest statement

The authors declare that they have no conflicts of interest.

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APPENDIX A

This paper focuses on territory 1, 2, 4, and 5. See the legend "Territorio" to identify these territories by color.

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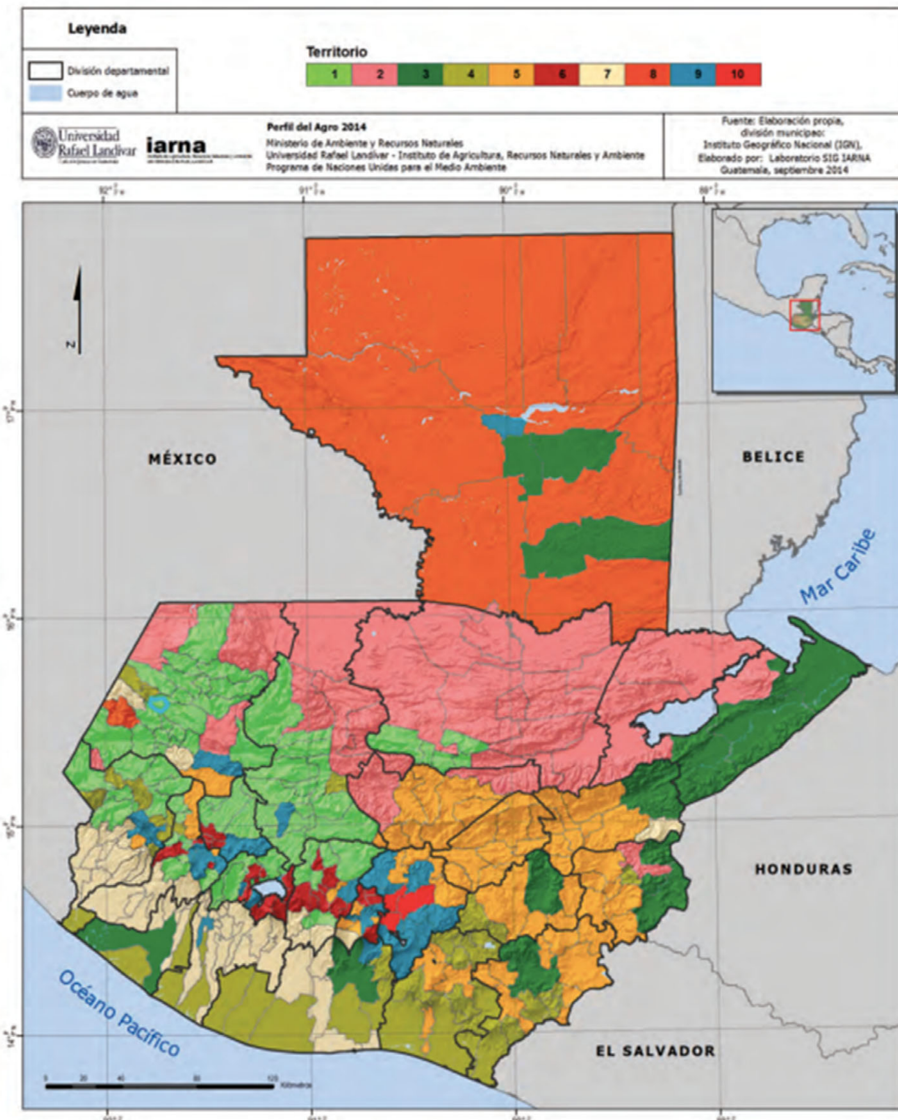

Fig. A1. Map of the 10 socioeconomic territories in Guatemala. Reproduced with permission from (IARNA, 2014). [Color figure can be viewed at wileyonlinelibrary.com]

APPENDIX B

These are the six municipalities identified to highlight how communities can experience divergent outcomes in the state of their food security, even when communities are within the same territory which have a relatively homogenous socioeconomic composition. Municipalities demonstrating an

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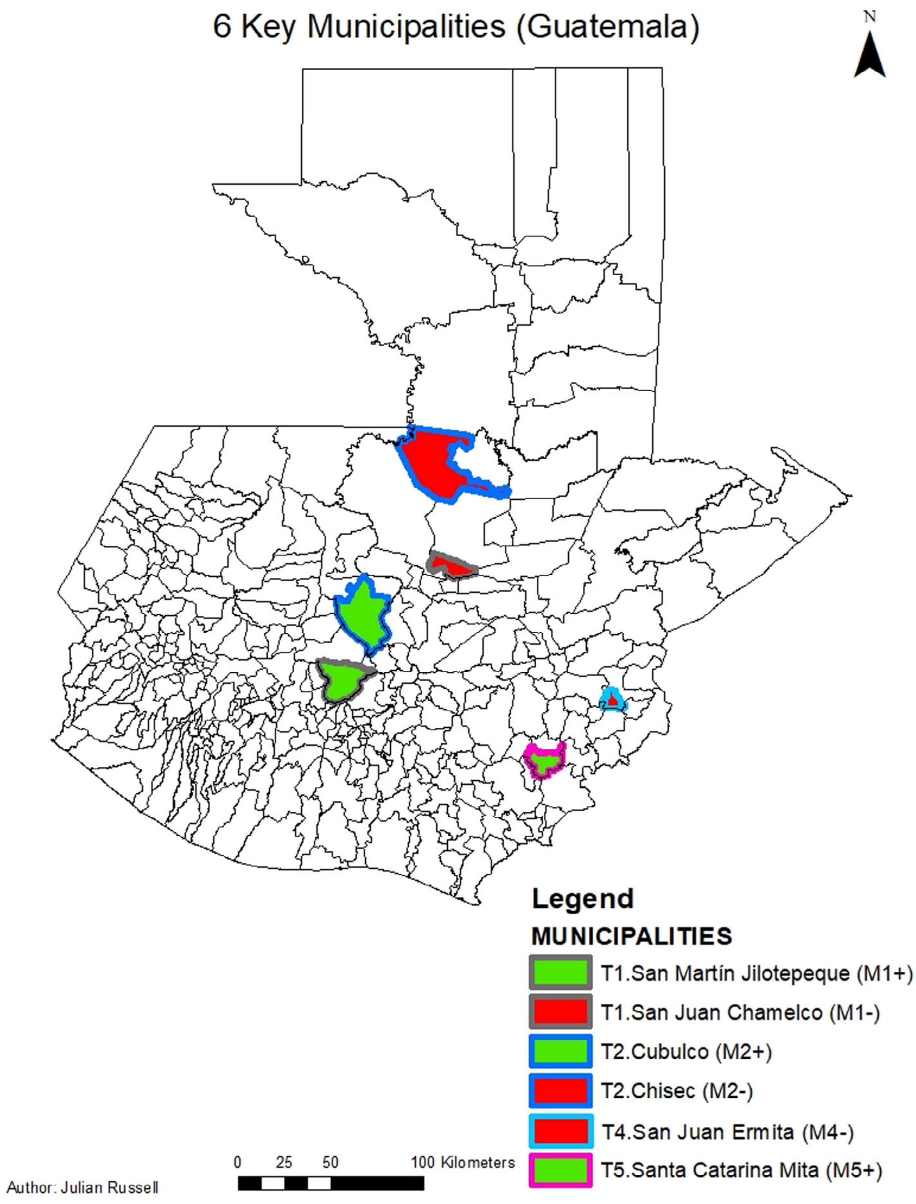
improvement in their food security status are green, and municipalities with a decline or stagnation of their food security status are red. The borders are used only to indicate if municipalities are within the same or different territory and the border color has no significance beyond this.

Fig. B1. Map of the 6 municipalities. [Color figure can be viewed at wileyonlinelibrary.com]



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