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Food Security and Climate Change Adaptation in Guatemala

by

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Abstract

The challenges of ending hunger and adapting to the impacts of climate change are high on the global development agenda and they are highly interdependent. Managing these challenges requires understanding of physical, social, political and environmental systems, their emergent properties and their interactions across scales — from individual perspectives to global processes.

The Central American Dry Corridor (CADC) is a climatologically and politically defined region running through Central America, which is considered one of the most vulnerable regions in the world to the impacts of climate change. This research presented an attempt to apply cross-disciplinary approaches to the issue of food insecurity and climate impacts in the CADC, focusing in Guatemala. Applied methods range from ethnographically informed interviews and household case studies, to quantitative analyses with regional or globally standardized indices and data including household surveys, climate observation and climate impact modelling.

A complex picture of the climate-food system is constructed through this integration of methods. For example, statistical analyses at the regional or national level evidenced: the risks of severe food insecurity during household transitions towards market participation; the association between agricultural labour income and severe food insecurity experiences; the association between the severity of the mid summer drought and prevalence of stunting; the association between changes in food insecurity classification used for early warning systems and drought indices (including the duration and magnitude of the mid summer drought); and the role assets and livestock (and the capabilities they represent) play in mediating climate impact and adaptation. Of the included variables across analyses, climatic and non-climate drivers differed in their relative importance regionally within Guatemala. However, this is not a complete picture, as some key findings from the individual and household level interviews were unable to be represented and tested in analyses at this scale.

The main barrier to integrating participants narratives and knowledges into protocol for broad scale assessment, monitoring and decision-making — in this research — was the way in which top-down understanding and problem framings still shape what data is systematically collected and available. Recommendations identify how transdisciplinary approaches that engage iteratively with stakeholders at all levels of design, data collection, and analysis can be applied to contribute to overcome this limitation.

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This thesis is dedicated to the participants who shared their stories with me.

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Acronyms

SDG Sustainable Development Goals

CADC Central American Dry Corridor

MSD Mid Summer Drought

ENSO El Niño Southern Oscillation

HFIAP Household Food Insecurity Access Prevalence

GCM Global Climate Models

RHoMIS Rural Household Multi-Indicator Survey

PPI Poverty Probability Index

TLU Tropical Livestock Units

AIC Akaike Information Criterion

FEWSNET Famine Early Warning System Network

CDD Consecutive Dry Days

IPC Integrated Phase Classification

DHS Demographic Household Surveys

GWR Geographically Weighted Regression

SST Sea Surface Temperature

WHO World Health Organisation

CHIRPS Climate Hazards group Infra-Red Precipitation with Station

OLS Ordinary Least Squares

VIF Variance Inflation Factor

IPCC Intergovernmental Panel on Climate Change

Rationale for alternative format

The justification for an alternative format thesis is that this research has applied a broad range of methodological, theoretical and epistemological approaches to the problem of food security and climate change in Central America. This cross-disciplinarity means that the presentation of a set individual papers is a more appropriate format, as each chapter has its own framing, set of methods, and conceptual framework within which the results are contextualized and published.

An introduction to the location in which the research is embedded (Central America), and the different scales and system boundaries of research presented in each chapter is provided in the introduction. Chapter 2 and 4 are both published peer-review articles with the PhD candidate as the primary author, all work presented in these publications is the sole work of the PhD candidate, with the exception of contributions of co-authors recognised in the preceding declaration of authorship. Chapter 3 is presented as in a pre-submission format. The inclusion of these three chapters meet the criteria for alternative format thesis stated in the protocol for the submission of an alternative style of doctoral thesis including published material for the Faculty of Environment.

These results are then integrated into a single contribution to knowledge in the discussion and conclusion. The presentation of this body of work as a single coherent thesis enables inter-comparison and critical discussion of the different evidence bases forming around the issue of climate and food security in Central America, the effect of methods choice, scales of evidence, with implications for policy and intervention decision-making in the region.

Declaration of authorship

The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to work of others.

The publication Beveridge, L., Whitfield, S. and Challinor, A., 2018. Crop modelling: towards locally relevant and climate-informed adaptation. Climatic change, 147(3-4), pp.475-489., is included as Chapter 4 of this thesis.

The text was written by the candidate, with minor contributions to text from S Whitfield, and comments from all co-authors. The candidate performed data analysis and produced all figures. A Challinor provided meta-data of crop modelling outputs used for the meta-analysis.

The publication Beveridge, L., Whitfield, S., Fraval, S., van Wijk, M., van Etten, J., Mercado, L., Hammond, J., Davila Cortez, L., Gabriel Suchini, J. and Challinor, A., 2019. Experiences and Drivers of Food Insecurity in Guatemala's Dry Corridor: Insights from the Integration of Ethnographic and Household Survey Data. Frontiers in Sustainable Food Systems, 3, p.65. is included as Chapter 2 of this thesis.

The text was written by the candidate, with minor contributions to text from S Whitfield and S Fraval, and comments from all co-authors. Survey data was provided by J v Etten and M v Wijk. The statistical analysis was carried out by the candidate and S Fraval. The interview data collection and translation was carried out by the candidate and L M Cortez. The analysis of interview data and case studies was carried out by the candidate. The integration and triangulation of analyses was carried out by the candidate. The candidate produced all figures.

The manuscript Beveridge, L, Oldroyde, R, and Muller, A (in preparation for submission) Applying Drought Indices to Characterise Climate Impact on Malnutrition in Guatemala. is included as Chapter 3 of this thesis.

The text was written by the candidate with comments from all co-authors. The candidate performed data analysis and produced all figures with comments and feedback from all authors.

Chapter 1

Cross-disciplinary approaches to studying food insecurity and climate adaptation

1 Introduction and motivation

Achieving food security and adapting to climate change are two strongly interlinked and high priority global challenges. The sustainable development goals (SDG) set the targets to end hunger globally and to take climate action by 2030 (United Nations 2018). A significant portion of global food insecurity is situated within rural agricultural contexts in low-economically developed countries and is strongly associated with low production, labour-dependent markets, conflict and politically instability, and natural disasters including extreme weather events like flooding and drought (Food Security Information Network 2019). Rural livelihoods, agriculture, poverty and hunger are therefore strongly interdependent and agriculture has often been at the forefront of global development initiatives for food security (Mondiale 2008). The impact of — and adaptation to — global climate change has also been increasingly conflated with development targets and initiatives, as its potential to cause human suffering and threaten or reverse progress towards the SDGs has been recognized and evidenced (Porter et al.; Olsson et al.; Ripple et al. 2019).

Designing research and intervention to address complex global challenges such as food insecurity and climate change adaptation requires the navigation of what appear to be paradoxes of scale; working to meet global goals such as to end hunger and account for the impact of global processes of climate change, while being able to derive understanding and appropriate management within the context of place, in response to societal and individual priorities and perspectives.

For example, to end hunger requires understanding of the full range of factors that are driving peoples experiences of food insecurity and biophysical outcomes within the context of their health, home, community and socio-economic situation. To adapt to climate change requires an understanding of how local weather processes will change under projected scenarios of an anthropogenically perturbed global climate system, and how impacts will propagate through systems to affect livelihoods. To climate proof intervention requires understanding of how adaptation is embedded in an ongoing process of livelihood change shaped by context: capabilities, culture, history, values, environment, power and agency.

Food insecurity and climate adaptation are two issues that are both political, contested, and contain high amounts of uncertainty in their assessment and management, given their complexity and interaction across systems and scales. This is justification for the application of multiple approaches in agricultural adaptation and development research, in order to access multiple framings and find a more broadly informed perspective from which to identify knowledge gaps in understanding and discourse, rather than closing down pathways of research and evidence building towards the reductive and quantifiable (Stirling and Scoones 2009; Leach et al. 2010; Whitfield 2015).

In cases of both high incertitude and contestation it is important to represent multiple perspectives in evidence building, including the transparent inclusion of the knowledges and framings of the participants who's lives are being studied, assessed and engaged in intervention; the central tenet of the broadly accepted movement towards participatory approaches within agricultural development practise (Chambers 1995; Chambers and Henman 1994). While participatory approaches have sometimes failed to address the influences of existing power structures and have had limited effectiveness in including marginalised people and perspectives — largely due to ingrained social, political and institutional barriers (Cooke and Kothari 2001) — they are still being widely accepted and integrated into practise e.g. through farmer first movements, rapid rural appraisal methods, and community based adaptation programs. There are some obvious incompatibilities between participatory objectives to devolve decision-making to fit a local context and the imperative of up-scaling adoption and impact that is often central to agricultural development initiatives. At the level of assessment and monitoring, to build evidence for intervention, there are still methodological (as well as the social, political and institutional) barriers to the inclusion and integration of participants' narratives and framings, especially where such protocols have been widely standardised and institutionalised, and designed for the production of evidence and attribution at scale.

The development of cross-disciplinary research methods can contribute to understanding and potentially overcoming this paradox. Disciplines across physical and social sciences have distinct system boundaries and scales of study within the food-climate system, which can both ground understanding in local context and knowledge, or test its relevance and significance at broader spatial scales. Global or regional scale approaches, for example, contribute understanding of the potential progression of future climate change and its impact on food production (Challinor et al. 2014), and global indicators to enable monitoring of the progress towards SDGs (United Nations 2019). Studies situated in the context of a specific place can create understanding that is locally relevant, for example the study of the future impact of climate change on coffee production in Nicaragua (Läderach et al. 2017), or a study of the food security discourse developed by Honduran peasants unionists within the context of the transnational Via Campensina movement (Boyer 2010). While approaches that engage with participant's stories, framings and knowledge's are essential for grounded and participatory understanding of the context of food insecurity and adaptation (Richardson-Ngwenya et al. 2018; Zavaleta et al. 2018).

This thesis investigates how cross-disciplinary approaches can contribute to integrating methodologies and evidence across these scales, to acknowledge the individual, the local, the regional and the global experiences and drivers of food insecurity. To do so, this research applies and integrates multiple research approaches across the physical and social sciences, across a range of scales but centered in Guatemala and the Central American Dry Corridor (CADC) (Figure 1.1).

2 Case study: Guatemala

There are many countries suitable for studying the intersection between climatic and non-climatic drivers of food insecurity. As the signal of anthropogenic climate change is increasingly observed within patterns of weather variability (IPCC 2014) there are numerous emerging, but often debated, narratives that attribute climate change as a driver of risks to human health and wellbeing such as drought, storm and heatwave events as well as resulting food shortages, conflict and movement of people. These narrative are emerging globally, including many of the global food insecurity hot-spots across the Americas, Africa and Asia (Obokata et al. 2014; Levy et al. 2017; Owain and Maslin 2018; Abel et al. 2019; Craig et al. 2019). An interesting and unique case study could be produced through unpacking, empirically exploring and giving socio-political context to the narratives of climate-driven impact in each and any of these regions. In any case, identifying the interactions between climatic and non-climatic drivers of change in the context of household and community systems will be key to understanding the role of climate change impacts and adaptation in ongoing development and intervention.

Central America and Guatemala is the chosen case study for this piece of research, as it is one of the regions where the climate signal is strong. The relationship between seasonal weather patterns in Guatemala and the global ENSO telecommunication and sea surface temperatures is significant and relatively well understood (Taylor and Alfaro 2005; Hidalgo et al. 2017; Anderson et al. 2019). It is a country where food insecurity, poverty and out-migration are directly associated with drought, both locally and in global media (ICRS 2019; Guardian 2019). There are several multi-million pound projects working on climate resilience and agricultural development in Guatemala (FAO 2017, 2019b,c). The established network of development organisations in Guatemala also enable this research to be conducted because: these provide gatekeepers to households for conducting interviews; access to data from multiple household surveys carried out during various intervention programs; and the existence of this network also provides an interesting socio-political backdrop and history of development intervention within communities, to enable to consider community dynamics and governance of development resource.

According to the World Food Program, Guatemala has the 5th highest prevalence of malnutrition in the world, which disproportionally affects the indigenous population, whom have been historically marginalized and oppressed (WFP 2019a). Food insecurity in Guatemala is most often experienced in the context of multiple deprivations, confounded with ill-health and poverty, and vulnerabilities are considered multi-dimensional (Cardona et al. 2012). Despite a growing economy, the proportion of the population living in poverty is increasing, and indicators of economic and social inequality often fall within the global top ten (World Bank 2019).

Three development targets for Guatemala as prioritized by FAO and the government of Guatemala, based on the SDG framework are: to end food insecurity and malnutrition; drive rural development through agriculture and growth of the rural economy; and the adaptation and mitigation of climate change, including to improve resilience and manage natural resources (Original text in Box 1.1 from FAO Guatemala (2017)). Food insecurity, climate change and rural development are all strongly linked in Guatemala as rural subsistence and rural economies are both highly dependent on agricultural production, in a region prone to agricultural drought and high variability in rainfall patterns from year to year. The problem of food insecurity however, is magnified by multiple factors and contexts across Guatemala (ICRS 2019). Access to health care providers is often unstable, limited or expensive — and sometimes absent — in more remote, rural and impoverished communities. Coverage of health centers has been highly dependent on private and charity organizations to make up a shortfall in government run services (USAID 2018). Violence and conflict are also very high in the region, where organized crime and gang violence affect security, and are two factors that both drive and are driven by out-migration (Moran-Taylor and Taylor 2010; Taylor et al. 2006; Ambrosius and Leblang 2018; Rodriguez et al. 2017). A string of corrupted presidencies and governments, and corruption embedded across levels of governing and policing institutions also limits the capacity for effective governance of these issues (CICIG 2019; Congressional Research Services 2019).

Box 1.1 Three development targets for Guatemala as prioritized by FAO and the government of Guatemala based on the SGD framework, quoted as reported by FAO Guatemala (2017)

- ***Área A:*** *Seguridad Alimentaria y Nutricional, seleccionada dada la alta prevalencia de inseguridad alimentaria y desnutrición crónica, así como el interés que el gobierno de Guatemala da al tema con la definición de una estrategia para prevenir la desnutrición crónica.*
- ***Área B:*** *de Desarrollo Rural Territorial, ha sido seleccionada dada la concentración del hambre y la pobreza en el área rural, pero sobre todo por el potencial que tiene la agricultura y la economía campesina de constituirse en motor del desarrollo rural territorial.*
- ***Área C:*** *Adaptación y mitigación al cambio climático para mejorar la resiliencia, y manejo integral de los recursos naturales renovables. Esta área es priorizada dada la necesidad de avanzar en la gobernanza de los recursos naturales en Guatemala y en la adaptación y mitigación de los efectos del cambio climático para la resiliencia.*

Due to its locality in respect to the CADC (Figure 3.1), vulnerability to climate and drought is high on the agenda of research, development, and humanitarian organisations (FAO 2019a). The CADC is a non-administrative boundary defined by its climatology, it extends through parts of Costa Rica, Nicaragua, Honduras, El Salvador, and Guatemala, has a drier climatology than the surrounding regions and is prone to the impacts of agricultural and hydrological drought (Lopez-Ridaura et al. 2019; Quesada-Hernández et al. 2019) (Figure 1.1). Acute malnutrition episodes have occurred recently during the El Niño phases of El Niño Southern Oscillation (ENSO) in 2018-2019, 2014-2016 and 2009-2010 (FAO 2019a; NOAA 2019; FAO 2019b).

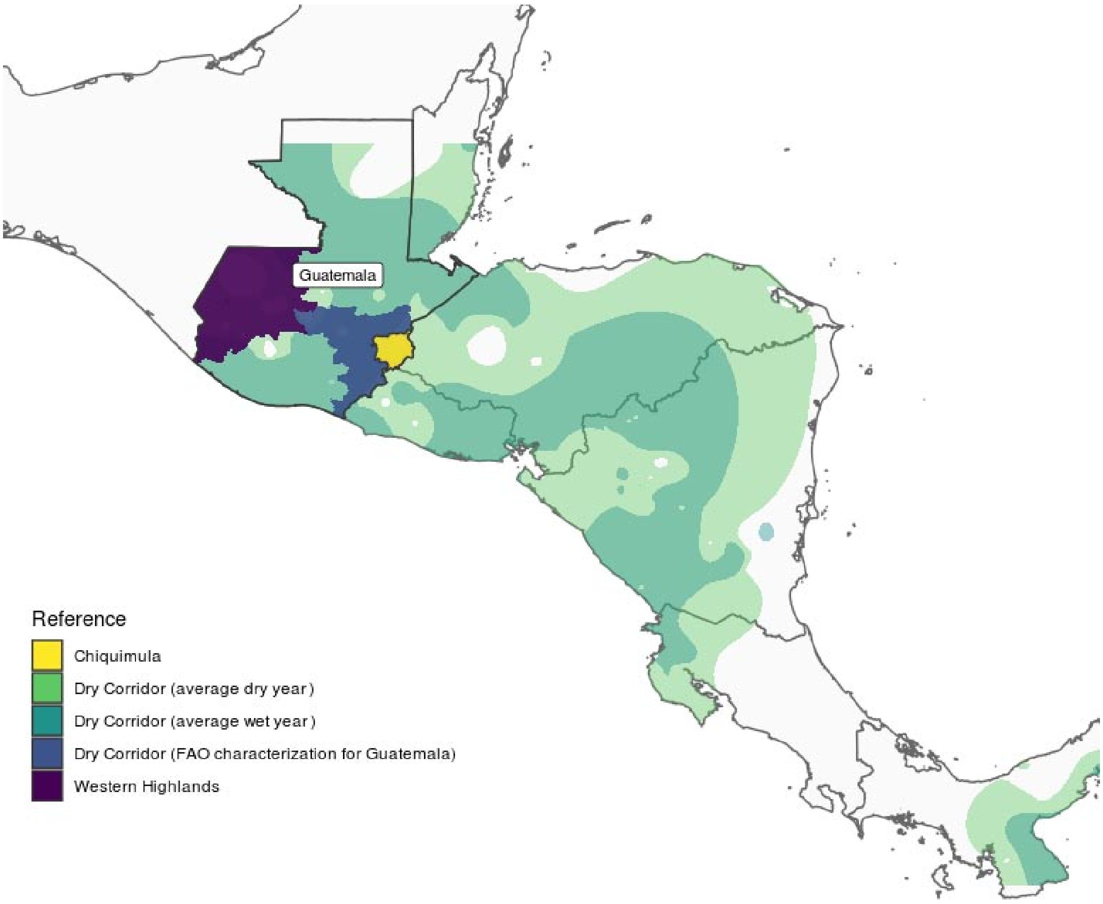

Figure 1.1: Map of reference points of interest in Guatemala; the Western Highland region defined in USAID (2013), the dry corridor region defined in FAO (2012), the Department of Chiquimula, and the climatological delimitation of the dry corridor during a typical wet and dry year across Central America as defined in Quesada-Hernández et al. (2019)

The rainy season in the CADC (May-October) is characterised by a bi-modal distribution with an extended dry-spell in the middle (July-August) due to a depression in sea surface temperatures that drive rainfall (Taylor and Alfaro 2005). This mid-season depression creates an extended dry spell (also known as the mid-summer drought (MSD)) during the principle-growing period. The two main growing seasons primera and postrera are managed around this dry spell, but its length and severity have a significant effect on agriculture and livestock production (Calvo-Solano et al. 2018; Alfaro 2019). Maize and beans (milpa) are the main subsistence crops in Guatemala, grown mainly through the June-October rainy season, while coffee is the principle export crop and source of labour based income in rural households, especially during the annual harvest (November-January). The lean season typically falls in March-June, when household food reserves have been diminished, the demand for labour is reduced and inputs for the next season are needed (FEWSNET 2013) (Figure 3.2).

The year 2014 was the most recent episode of severe drought and food insecurity. The MSD during the 2014 growing season had a record 45 days without rain, and saw harvests of bean and maize reduced by up to 70% and 80% of the 2013 production respectively (UN Guatemala 2014). In a population of around 15.5 million, 1.2 million people in Guatemala were recorded as moderately or severely food insecure by November 2014 – prior to the lean season, and a $23.8 million response plan was coordinated by the UN, which was proceeded by a series of large scale international projects to develop climate resilience in the region (UN Guatemala 2014; World Bank 2020).

The CADC region is considered one of the most vulnerable to the impacts of climate change globally, through the effects of increasing extremes in rainfall and the severity and duration of the MSD (Calvo-Solano et al. 2018). Future climate projections indicate a strong and robust projection of a drying trend in the region (Maurer et al. 2017; Anderson et al. 2019), but within this century the trend continues to be characterised by high inter-annual variability. There is a regionally consistent trend of increasing duration of the MSD, but high spatio-temporal variability in trends of change of the intensity of the MSD, which is strongly linked to processes of ocean-atmosphere circulation (Ibid.).

The projected impact of climate change on subsistence crops shows high spatial variability in its distribution, but will have a significant effect on rural livelihoods with estimated decreases of up to 40% of current production in some regions by 2050. The impact is expected to be most severe in the South and Eastern Borders, and North Peten (Schmidt et al. 2012). The land area suitable for the cultivation of coffee, a key export crop providing rural labour, is also expected to decrease. Projections of coffee yields show average decreases of 6.4% by 2020 and 38% by 2100, largely associated with projected increases in temperature (CEPAL 2014). The impact of climate change is projected to decrease the production of all the major coffee production zones in Central America, but show a substantial climate driven decline in production in the major coffee-producing region spanning across the border region of Honduras, El Salvador and South Guatemala, which falls within the CADC (Ibid., Figure 1.2).

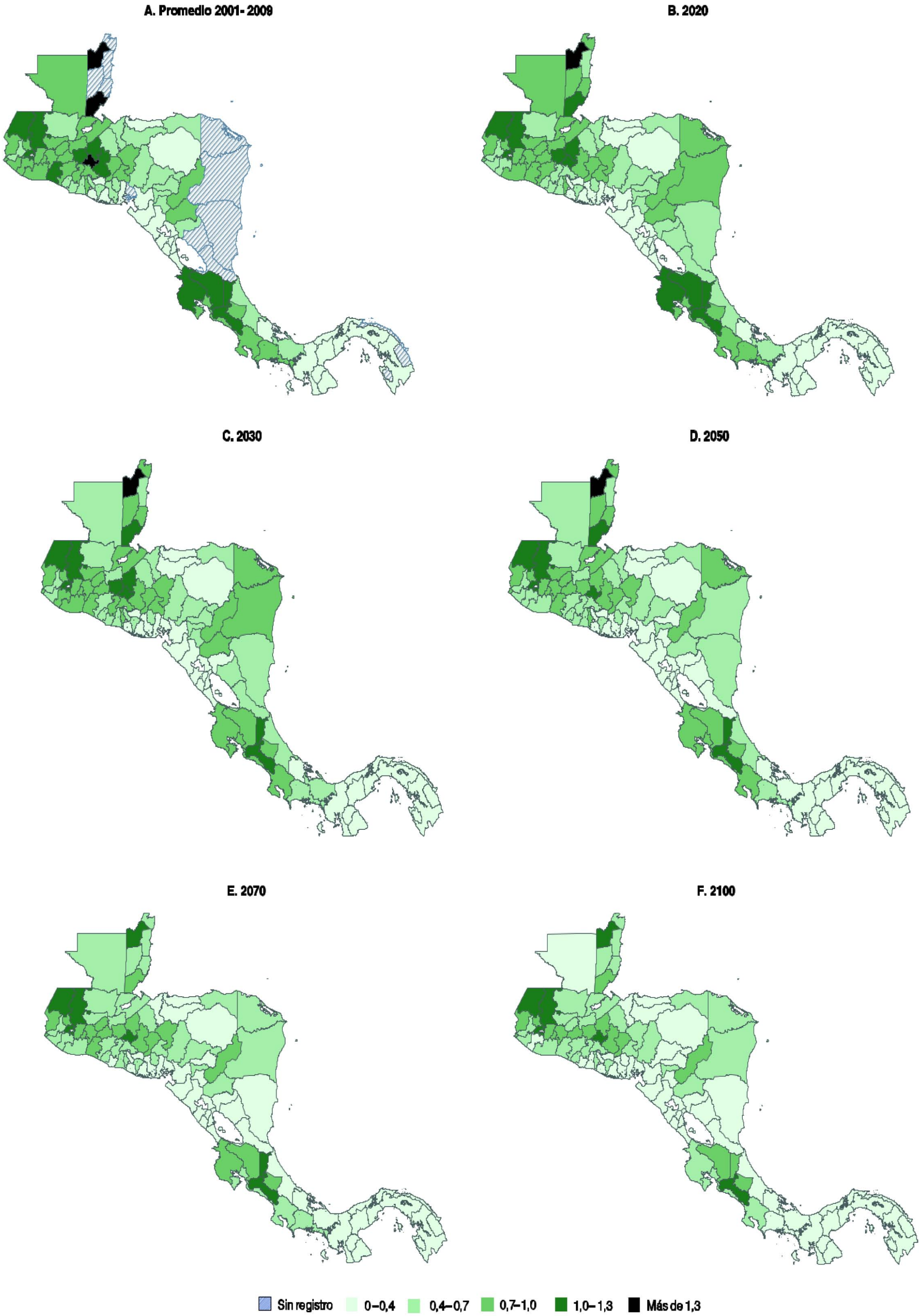

Figure 1.2: Map of projected coffee production in Central America, modelled using the AR5 global climate model ensemble average provided by Worldclim to project future climate change under the B2 scenario, with the mean production (shown as tonnes per hectare) from 2001-2009, with projections up to 2100, as printed in CEPAL (2014) — page 106

As a result of the high exposure of rural communities and agricultural systems to climate variability and change, the CADC is a priority region for the investigation and application of technologies for climate adaptation and resilience, as well as ongoing aid, intervention and agricultural development aimed to address chronic poverty, malnutrition and low-productivity (USAID 2013; Calvo-Solano et al. 2018; WFP 2019b).

3 Research objectives

This thesis therefore sets out a cross-disciplinary research project, utilising multiple approaches in order to gain different perspectives on the challenge of food insecurity and climate adaptation in Guatemala. Methodologies from across multiple disciplines are integrated within each chapter, and the range of scales of study span from individual perceptions and experiences to global modelling. The cross-disciplinary and multi-scale approach therefore enables this thesis to address the first overarching objective:

- To analyze food insecurity experiences and outcomes in Guatemala, with a focus on the interaction between climatic and non-climatic drivers

The inclusion of both social and physical sciences evokes discussion of the benefits and challenges of integrating research and evidence across disciplines, reflecting on these benefits and challenges represents a second objective:

- To reflect on what can be learned about complex challenges of food security and climate change adaptation by applying cross-disciplinary approaches; to identify the challenges and opportunities associated with this integration of methodologies, framings and problem perspectives.

4 Conceptualising the food-climate system

Figure 1.3 presents a conceptual diagram of the relationships between key concepts — climate impact, adaptation, livelihoods, wellbeing and food insecurity — as understood and applied in this thesis, and as explored through the contributions to research made in the three empirical chapters. The diagram is constructed based on the following understanding: Assessing climate impact requires knowledge of local weather processes and broad scale climate drivers e.g. ENSO, and their interactions across scales, while future climate impact relies on highly complex sets of projections of how these will change in scenarios of a perturbed future climate. Climate impact and adaptation (introduced in Section 4.3) are both processes that are embedded across multiple scales and systems, but play out in the context of individual livelihood change and wellbeing (introduced in Section 4.4), which mediate food insecurity outcomes (introduced in Section 4.2). Food insecurity experiences are therefore understood as an intrinsic part of wellbeing, but food insecurity outcomes can be also conceptualized and measured across scales and systems, from individual experiences to the prevalence of a condition within a population.

Assessments of food insecurity and its drivers, a climate impact, or climate adaptation can therefore take more or less of these systems and scales into account, based on the disciplinary focus, methodological and epistemological approach and system boundary of study (introduced Section 4.5). The system boundary of each empirical chapter is indicated in Figure 1.4, and applied methodological approaches are mapped onto triple axes of individual, place-based, and regional to global scales of study in Figure 1.5.

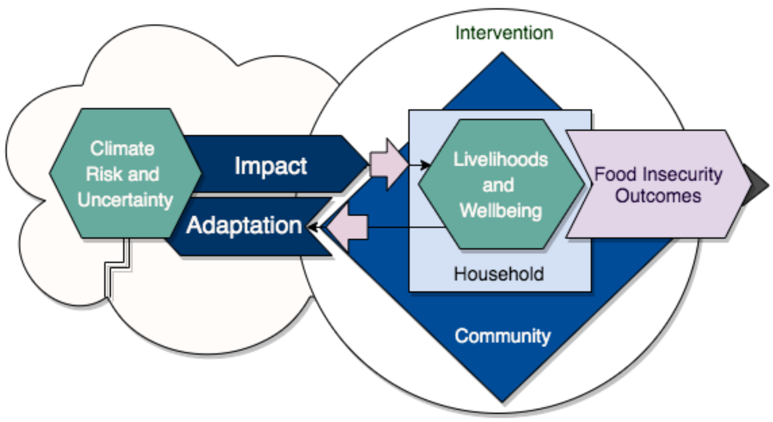

Figure 1.3: Conceptual diagram of the climate-food system as understood and investigated in this thesis

4.1 Thesis structure and contribution

Chapter 2 presents the most grounded and abductive form of analysis; applying in-depth interviews and life histories to gain an understanding of the drivers and experiences of food insecurity in the dry corridor region of Guatemala. Abductive analyses are neither top down (deductive) or bottom up (inductive) but recognise the processes of collecting data, defining the research question, analysis and narrative construction occur in iterations, and are driven both by interest, goals and perspectives of the researchers, but also align with the content of the rich and ethnographic data-set and the knowledge and judgement of participants (Bajc 2012). In this chapter the understanding of the drivers and experiences of food insecurity is contextualised within stories of livelihoods and wellbeing, exemplified through case studies, and integrated with household survey data in an iterative analysis. The grounded understanding of food insecurity developed in Chapter 2 is applied as the foundation for a national scale analysis of food insecurity outcomes across Guatemala, presented in Chapter 3. In Chapter 3 the impact of drought on food insecurity outcomes is assessed across Guatemala. Spatial analysis is applied to an analysis of health, climate and socio-economic indicators to investigate the spatial distribution of the associations between food insecurity outcomes, climate and socio-economic variables. The presented results and discussion challenge assumptions over what scales statistical models of food insecurity — and resulting understandings of food insecurity — can be generalised and scaled.

Considering the highly contextual nature of food insecurity and climate impact evidenced in Chapter 2, Chapter 4 goes on to justify the need for adaptation planning that is both locally relevant and climate informed.

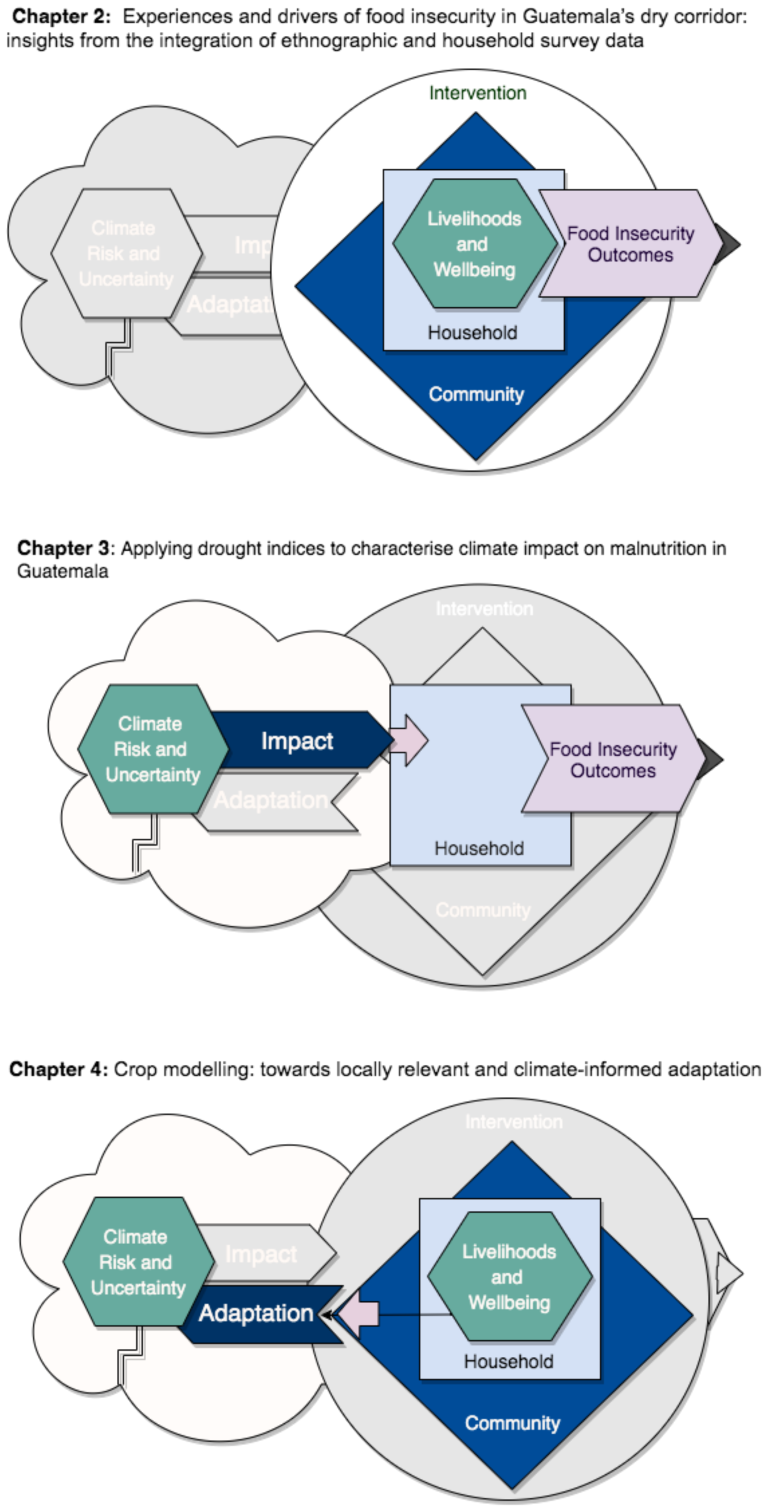

Figure 1.4: Conceptual diagrams identifying the contribution of empirical chapters .

In Chapter 4, I apply a meta-analysis of agricultural adaptation research to investigate the role climate projections and climate impact modelling can play in informing locally based development and adaptation planning in the region. The working definitions of adaptation as applied in climate-impact modelling and place-based research are derived and are critically reviewed to inform a discussion of how these two communities of practice can move towards integration across disciplines, to provide locally relevant and climate informed intervention.

4.2 Food Security

The general definition of food security applied in this thesis is the commonly cited World Food Summit 1996 definition, that food security is met on the condition that "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (Declaration 1996). This definition provides an idealized scenario, such that food insecurity, by definition, then occurs when this condition is not met. Under this broad definition food insecurity can be conceptualized and measured in multiple ways: as a constraint to access or consumption of food, a biological outcome as malnourishment, or an experience such as worry, suffering or social exclusion. Monitoring of progress towards Sustainable Development Goal II to 'end hunger' applies indicators that reflect both experiences of food insecurity, and biometrics including wasting and stunting of children under 5 years of age (United Nations 2018).

Throughout the thesis I draw on multiple conceptualizations and measurements of food insecurity to generate a multi-dimensional understanding of food insecurity across different contexts and scales.

Standard indicators such as wasting, stunting and the Household Food Insecurity Access Prevalence (HFIAP) relate to specific food insecurity dimensions and outcomes, are designed and derived deductively, and as such are constant in their application geographically and overtime. They form the backbone of household food security and health assessments (surveys) used to inform and monitor intervention in programs and policies targeting food insecurity, and to analyse the drivers and associates of food insecurity outcomes as applied in Chapters 2 and 3. Analysis of such indices can produce an understanding of food insecurity that is significant at scales relevant for decision-making. However, in the application of statistical-based analyses of household data, without a strong theoretical grounding of food insecurity drivers, causality between associates cannot be assumed due to issues of endogeneity (Pearl 2000). As reviewed in Chapter 2, research that acquires an understanding of food insecurity using grounded approaches such as interviews, ethnographies, observation, community or participatory methods, have developed more in-depth, mechanistic, and socially embedded understandings of food insecurity. These disciplines have also historically acknowledged and developed the discourse around an alternative set of drivers from mainstream quantitative food insecurity literature, such as the role of policies, politics and power (Altieri and Toledo 2011; Chappell et al. 2013; Alonso-Fradejas 2015; Fischer and Victor 2018). Grounded analyses can produce a more inductive and participant derived understanding of the personal, contextual and subjective lived experience of food insecurity, with strong case-by-case attribution of food insecurity outcomes to a set of circumstances and underlying drivers. However evidence in this form and scale is difficult to translate into intervention design and decision-making, due to limited representability and perceived incompatibility with a protocol built on statistical reductionism and attribution.

There is therefore potential for the integration of grounded analyses to make participant derived understandings of local food insecurity experiences more accessible and visible in evidence building for intervention. Chapter 2 outlines one approach to this methodological integration of socially grounded approaches with broad scale quantitative surveys. I take an iterative approach in order to integrate ground-based understanding into the design of statistical analysis, and use case studies to identify the local complexity of food insecurity experiences within the context of livelihoods. The nature of the derived understanding of food insecurity produced from these respective and combined analyses are then discussed, in the context of informing food insecurity intervention and scales of evidence. Up-scaling of evidence is further tested in the extrapolation of a grounded understanding of food insecurity and its drivers to the national scale in Chapter 3. The discussions of chapters 2 and 3 aim to address the question of how food insecurity is conceptualized and understood differently across scales; make methodological contributions towards bridging scales; and reflect on the appropriateness of upscaling intervention for food security.

4.3 Adaptation

The concept of adaptation is explored through multiple disciplinary lenses in Chapter 4. Adaptation is defined by the Intergovernmental Panel of Climate Change as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (Barros et al. 2014). Adaptation is a term used to describe changes made across several scales and mechanisms in practice or policy (Adger et al. 2005; Smit et al. 2000), see (Smit and Skinner 2002) for a typology. Adaptation can be driven from within a household (autonomously), or through the actions of an external group (by intervention). It can be serendipitous as an unintended result of development interventions; achieved through climate-proofing an existing intervention; or managed directly through discrete climate focused intervention (Mcgray 2007).

Adaptation hereafter will refer to adjustive or transformational changes made by households — autonomously or through intervention — in response to experienced climate variability and its effects, or the threat of future climate change. Intervention describes any changes in households that are driven or implemented by external stakeholders, which may or may not be a climate adaptation. In Chapter 2 I identify and discuss a broad set of factors that contribute to a process of change in livelihoods, that could also be described as adaptation as it is conceptualised in some social disciplines e.g. Eriksen et al. (2015), however I use the term livelihood change to maintain consistency within the chapter.

Adaptation in mainstream literature is increasingly understood and framed as a socio-environmental process, that is political and contested, and that has outcomes that are context and location specific (Klein et al. 2014; Eriksen et al. 2015). A prerequisite for successful adaptation planning — from an agricultural development perspective — is a contextual understanding of the local socio-political processes and knowledge systems within which adaptation is taking place (Eakin et al. 2014). As well as being locally-relevant, intervention also needs to be informed by an understanding of global climate change, future climate variability and the associated uncertainty bounds, in order to avoid maladaptation (Klein et al. 2014). It remains unclear to what extent adaptation research and assessment is managing to successfully integrate place-based knowledge with an evidence-based assessment of future climate variability. In Chapter 4 I present an assessment for Central America, and use this analysis to make recommendations for bridging research communities working on agricultural adaptation at local and regional to global scales.

4.4 Livelihoods and Wellbeing

Livelihoods is a central concept in agricultural development, with its origin in a simple and broad definition “the means of gaining a living” by Chambers (1995). A livelihoods approach is intended to enable a cross-sectoral and system framing and encourage joined-up and locally grounded decision-making and intervention. The term, however, is applied across multiple aspects of research and development, including as a theoretical framework, a methodology, and a basic concept, as defined above. In sustainable development literature, livelihoods approaches aim to incorporate local perspectives in line with the participatory development approaches. The ‘livelihood pathways’ concept, developed by the STEPS Centre at the University of Sussex, specifically encourages a 'directional' and 'longitudinal' analysis, which emphasize processes of change, including coping strategies, diversification, resilience, adaptation and transformation (Scoones 2009). Livelihoods therefore provides an ideal theoretical framing and terminology for this cross-disciplinary study of change and food insecurity in rural agricultural households, in the context of rural development intervention and climate adaptation.

Definitions and conceptualizations of wellbeing are wide ranging and although wellbeing is often presented qualitatively, some quantitative application of wellbeing indices have also been applied to household surveys and monitoring within development projects. While in health disciplines wellbeing tends to refer to mental health outcomes more specifically as it is conceptualized in the FAO Five Well Being Index (WHO 1998). In the context of development a wide range of indicators are accepted under the umbrella of 'wellbeing'. Multidimensional wellbeing indicators tend to include three dimensions: health, education and living standard. Specific indicators included pertain to physical and mental health outcomes, emotional and cognitive development outcomes, education outcomes, household materials, sanitation, access to family planning, income, and food and nutritional status (Chaudry and Wimer 2016; Alkire and Santos 2013; Elizabeth House et al. 2016; Haq and Zia 2013). However, an understanding of wellbeing can also be acquired through more individualistic and grounded methodologies, such as focus groups and ethnographic interviews. This serves to enable a more flexible and self-defined framing of the positive and negative lived experiences, and work with a concept definition of wellbeing that is most relevant to the participant(s) rather than using a top-down definition (Strang and Quinn 2019). A flexible and individually grounded understanding of wellbeing is applied in this research as it enables a more deductive mode of analysis to identify changes in livelihoods and wellbeing and their drivers, as perceived and framed by participants. Maintaining this broad, and largely self-defined concept of wellbeing limits the direct comparability of experiences across households, but enables a more thorough analysis of the range of factors affecting participants, who may not all relate their own lived experiences to a narrower definition of wellbeing or a more specific problem definition, such as poverty or food insecurity.

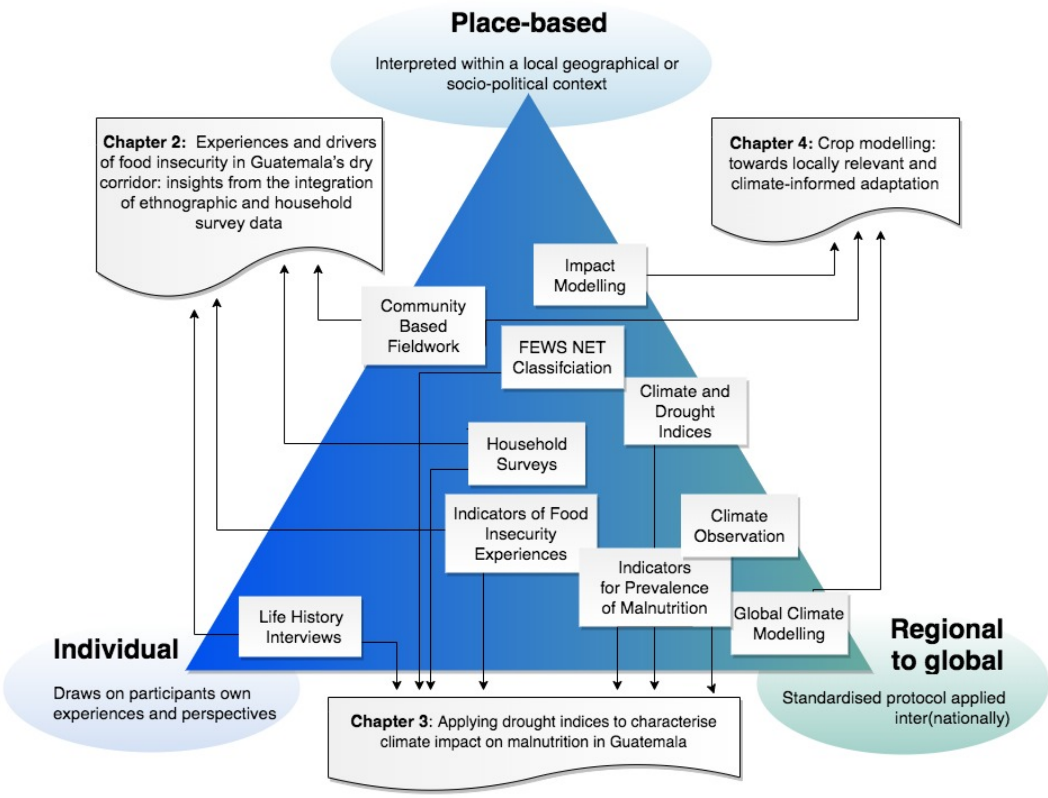

Figure 1.5: Methodological approaches applied in this thesis on a triple axis of scale, with arrows to illustrate the positioning and application in each empirical chapter

4.5 Scale and system boundaries of applied approaches

Figure 1.5 presents the methodological approaches applied in this research along triple axes. The three points represent different system boundaries that are applied across disciplines contributing to food insecurity and climate adaptation science identified through the review of literature presented in the introduction and empirical chapters. The three identified system boundaries of study are ‘individual’, ‘place-based’ and ‘regional to global’, which I present in more detail here as a typology of scale. ‘Individual’ refers to a research approach in which a participant’s perceptions, framing, or knowledge is essential to the produced understanding, as is commonly acquired through ethnographic, observatory or participatory methods, and a deductive or abductive approach to analysis, which aligns with a constructivist epistemology and ontology.

'Place-based' is used to describe a research approach in which the produced understanding is contextualised within a local geography and socio-political system, that may include individual perspectives, but that also applies some reduction of complexity to enable conclusions to be drawn that are representative of a locality or socially defined unit e.g. a community, sub-population, livelihood. This definition catches a wide range of research approaches, some examples include some survey applications, focus-groups, interviews, modelling, farm-based, and case-study research.

'Regional to global' describes research approaches that apply top-down methodologies or protocols standardized across regional to global scales, to enable representative analysis and inter-comparison of produced understanding across these scales. Examples of approaches include the gridded production and analysis of climatological time-series, the use of global climate models (GCM) to project climate variability under a range of future scenarios, and standardized indicators of malnutrition such as stunting and wasting.

Methodological justifications for the application of each approach are provided within each empirical chapter, or the associated supplementary material presented in the appendices, as this thesis is presented in published paper format.

5 Cross-disciplinary and critical approaches to studying complexity

Across the multiple disciplines that interface with global challenges such as food insecurity and climate change there has been a theoretical convergence in understanding issues through the lenses of complex realities and systems thinking, across a broad range of relevant topics e.g. in sustainability science, socio-ecological systems, climate systems, adaptation research. A shared concept behind these approaches is that challenges or issues embedded in a real-world context are complex, dynamic and interscalar. It follows that within such a complex and dynamic system, a large — unaccountable — number of interactions are occurring, resulting in a system behavior, which includes unpredictability, non-linearity, and emergent properties across scales (Simon 1996; Corrado 2019). Furthermore, challenges that engage with an aspect of humanity also need to be understood through realities of lived experiences, be situated in context, and recognizing of the influence of a set of interacting social-political and environmental 'macro-structures' or 'underlying drivers' (Scoones 2009; Leach et al. 2010; Frank et al. 2011).

A framework for knowledge mapping in risk assessment presented in (Stirling and Scoones 2009; Leach et al. 2010) has been applied specifically to the context of agricultural adaptation and development in Whitfield (2015), and identifies ranges of methodological approaches most appropriately applied in circumstances of incomplete knowledge, as identified in a typology of risk, uncertainty, ambiguity and ignorance (types of incertitude). For example, understanding the impact of climate on food insecurity if often approached as a risk assessment activity — suitable where the bounds of possibility and their probabilities of occurrence are well understood and unproblematic. However it could also contain sources of uncertainty - as it engages with highly complex, multi-scale systems with unaccountable number of interactions; ignorance — as there are persistent gaps in understanding, unexpected outcomes and novel conditions; and ambiguity — as there are contested framings, matters of ethics, equality, behaviour and political biases. In cases such as this, where multiple forms of incertitude are exhibited, alternative methodological approaches to risk assessment include: mapping of possibilities, outcomes and perspectives rather than reducing and aggregating probabilities; shifting from modelling to real-world observation; conducting targeted research into underlying drivers; and employing transdisciplinary approaches (Stirling and Scoones 2009). This framework therefore provides a theoretical justification for the protagonistic point of departure of the thesis: that through the application of multiple methodologies and gained perspectives, a more holistic view of the system and the challenges of managing issues of food insecurity and climate adaptation can be obtained, and from this broad cross-disciplinary perspective I will be able to review the applied methodological approaches, identify and discuss sources of incertitude in the types of knowledge and evidence produced, and apply questions outlined in Table 1.1 to guide these critical discussions.

Methodological discussion of cross-disciplinary approaches use the typology illustrated in Figure 1.6 based on reviews of sustainability and environmental literature in (Tress et al. 2005; Klein 2008; Mauser et al. 2013), where levels of cross-disciplinarity are assessed along two axes: the extent of integration across disciplines, and the extent to which participants perspectives have been engaged and represented in produced understanding. Critical discussion are based on the questioned outlined in Table 1.1. These critical methodological discussions are presented in the discussion sections of each empirical chapter as indicated, and then reflected on more holistically in the overall thesis discussion in Chapter 5.

1. What types of knowledge are produced, and over what scales are they representative and consistent?

   (Chapter 2, 3 and 4)

2. What are the capacities and limitations of each methodological approach? (Chapter 2, 3 and 4)

3. Where can expertise and approaches from other fields be drawn on to counter these limitations? (Chapter 2 and 4)

4. What is the boundary of the system being studied, and does the drawing of the system boundary -explicitly or implicitly- shape foredrawn conclusions? (Chapter 2 and 4)

5. What pathways to food security and intervention strategies are evidenced or supported by produced knowledge, and which are obstructed or overlooked? (Chapter 2 and 4)

6. How does the methodology affect participation and representation, including giving voice to those that have traditionally been marginalized or excluded? (Chapter 2)

Table 1.1: Questions for critical reflection and discussion of each methodological approach applied in the thesis

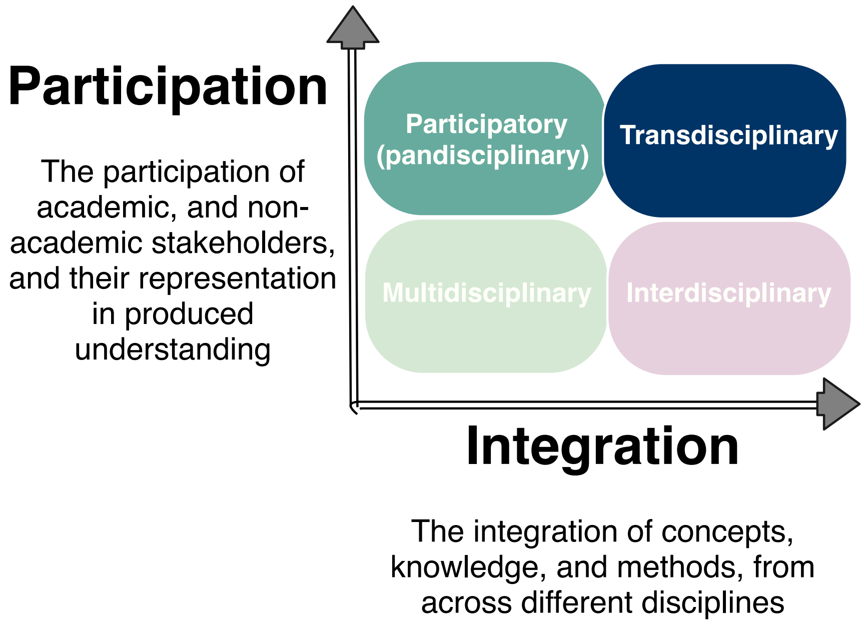

Figure 1.6: Typology of cross-disciplinary approach, based on levels of integration and participation, as understood in environment and sustainability literature. Source: Tress et al. (2005); Klein (2008); Mauser et al. (2013) with my own interpretation

Chapters 2 and 4 form the main contribution to integrating evidences across disciplines and scales and critically reflect on the process. Chapter 2 integrates evidence from a quantitative household survey analysis with a grounded qualitative analysis of food insecurity experiences and its drivers, carried out at the scale of the household. Triangulation and comparison of evidence generated through survey and interview approaches informs a discussion of the context in which food insecurity occurs, and its appropriate management. The benefits and challenges associated with the integrated analysis are discussed, along with critical reflections on each individual method applied. Chapter 4 takes a similar approach and structure, and is guided by the same set of critical questions (Table 1.1), but applied to the integration of evidences from quantitative crop-climate impact modeling and locally informed research on agricultural adaptation. The different conceptualizations of adaptation, system boundaries of study, and resulting understanding of adaptation derived from each approach are presented and discussed, along with challenges and recommendations towards better integration of the two disciplines working at two different scales.

Learning derived from each of these attempts to produce cross-disciplinary research on food insecurity and adaptation are then presented and reflected on in a critical methodological discussion in Chapter 5 (Section 3.1 and 3.2) with recommendations for future work (Section 3.3).

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Chapter 2

Experiences and Drivers of Food Insecurity in Guatemala's Dry Corridor: Insights from the Integration of Ethnographic and Household Survey Data

frontiers in Sustainable Food Systems

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Experiences and Drivers of Food Insecurity in Guatemala's Dry Corridor: Insights From the Integration of Ethnographic and Household Survey Data

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Eradicating hunger is a complex and multifaceted challenge, requiring evidence bases that can inform wide scale action, but that are also participatory and grounded to have local relevance and effectiveness. The Rural Household Multi-Indicator Surveys (RHoMIS) provides a broad assessment of household capabilities and food security outcomes, while ethnographic approaches evidence how individuals' perceptions, experiences and local socio-political context shape food security experiences and intervention outcomes. However, integrating these research approaches presents methodological and ontological challenges. We combine a quantitative approach with life history interviews to understand the drivers, experiences and outcomes of food insecurity in Guatemala's dry corridor region. We also reflect on the effectiveness and challenges of integrating the two methods for purposes of selective sampling, triangulating evidence, and producing a cohesive analyses of food insecurity in the region. Variables with a statistically significant association with severe food insecurity in the region are: coffee cultivation (when market participation is low), dependence on agricultural labor income, and poverty level. Drivers of food insecurity experiences most commonly identified by participants are: consecutive drought; ill health and displacement of income for medicine; social marginalization; high start-up costs in production; absence or separation of a household head; and a lack of income and education opportunity. Ethnographic approaches identify a broader range of drivers contributing to food insecurity experiences, and add explanatory power to a statistical model of severe food insecurity. This integrated analysis provides a holistic picture of food insecurity in Guatemala's dry corridor region.

Keywords: household survey, ethnography, food security, underlying drivers, Central America, participatory, agriculture, climate

INTRODUCTION

The 2015 Sustainable Development Goals (SDGs) and Agenda for Sustainable Development have created a political drive for action to end hunger and poverty by 2030, and a demand for metrics and monitoring of progress toward the achievement of these globally standardized goals. Food security is constructed as an overall goal in SDG II under two principle aims: "to ensure all people … have access to safe, nutritious and sufficient food all year round," and to "end all forms of malnutrition" (UN General Assembly, 2015).

Multiple indicators are increasingly applied to derive multidimensional food security information from household or nutrition surveys, reflecting food access, nutrition, utilization and safety. There is a drive toward standardization of surveys on food security (Nicholson et al., 2019), for example in the application of the Rural Household Multi-Indicator Survey (RHoMIS), which is increasingly used by CGIAR research institutes and their partners. RHoMIS has been designed to enable a more holistic assessment of progress toward the SDGs, specifically around goals 1, 2, 5, and 13 in recognition of the interdependence of issues of poverty, food insecurity and gender equality (Frelat et al., 2016; Hammond et al., 2017). It provides a standardized framework—based on best practice—which aims to improve consistency and comparability of data across sectors, organizations and regions, and provides a basis for regression modeling to determine household-level causes and correlates of food security. However, pathways to food insecurity are complex, and causal analyses of food insecurity are constrained by the feedbacks between food insecurity and other socio-economic variables, e.g., poverty, income, health, education. A grounded theoretical understanding of the system is therefore a necessary precursor to a statistical analysis of food insecurity (Pearl, 2009). Within household survey methodologies there are also limits to what can be understood about the context specific ways in which food insecurity is experienced and the contextual factors that shape these experiences. Grounding food security measurement in local context can contribute to a more complete understanding of the way that people experience food insecurity and exercise choice and agency with regards to food (Radimer et al., 1992; Wolfe and Frongillo, 2001; Frongillo et al., 2003), and expose some of the underlying socio-political drivers of food insecurity (Dreze and Sen, 1989).

The SDG mainstreaming framework and sectoral implementing organizations have recognized these contextual experiences, and the variety of drivers of food insecurity, as an integral part of food security assessment, often evoking the need to integrate participatory and ethnographic approaches with monitoring and assessment protocol (United Nations Development Group, 2017; FAO, 2018). Combining inductive ethnographic approaches and the deductive analyses of multi-indicator household surveys offers potential compatibilities, to build food security theory on the basis of observation while testing theory with empirical data. Combining such approaches raises challenges that are both practical and ontological. It requires a simultaneous recognition of food insecurity as both experience and outcome, the metrics of food security as both objective and subjective, and the drivers of food insecurity as both proximate (e.g., correlates of household characteristics) and underlying (e.g., linked to broader socio-political systems). Furthermore, the potential for systematic oversights or bias in the definition, measurement and management of food insecurity persists within each methodological approach, whether quantitative or qualitative. For example, single application recall surveys might overlook the dynamics of seasonal hunger, or participatory methodologies might give a platform to legitimize powerful voices and miss those that are marginalized (Mosse, 2001). The potential for oversight in any given framing or approach is a good justification for the use of combined methods and comparative analyses, to enable critical reflection on what might be missing from specific survey-indicators and whose voices or experiences may be excluded within our ethnographic processes.

In this paper we describe an attempt to combine an analysis of RHoMIS derived data with ethnographic research to better understand food insecurity. We focused on Guatemala's dry corridor region, an area where production is heavily affected by drought and where there is a substantial national and international effort to address food insecurity though intervention.

The study has a dual objective:

- To identify the underlying drivers and proximate causes of food insecurity experiences and outcomes
- To compare the insights that emerge from household survey and ethnographic methods, reflecting on the effectiveness and challenges of combining them for purposes of selective sampling, triangulating, and integrating evidence across scales

We conclude by discussing the implications of our description and measurement of food security for appropriate intervention aimed at building food security in the region. Furthermore, we discuss the ways in which new approaches to constructing the evidence base around food security can contribute to a rethinking of how we define, measure and manage this complex issue.

BACKGROUND

Conceptualizing, Measuring, and Analyzing Food Security

The conceptualization of food security has moved on significantly from the immediate post-Second World War era focus on food availability, in terms of both thinking about the pathways through which people become food insecure and how food insecurity is experienced. Sen's writing popularized the idea that access to food is a function of household entitlements and capabilities (Sen, 1982). Furthermore, Dreze and Sen (1989) and De Waal (1990) unpack the historical and socio-political factors that constrain household capabilities and entitlements and that are root causes of famine. The popularity of the household capabilities and entitlements framing is reflected in the increasing development and use of household survey instruments that capture a variety of socio-economic and physical variables that are known to influence capabilities and entitlements—assets, gender, social and natural capitals, etc. Within a capabilities framing of food insecurity, survey instruments that include multiple indicators (e.g., RHoMIS) are useful because standardization offer a means to replicable, statistical analysis, while multiple indicators work toward more holistic measurement of household capabilities and dimensions of food security outcomes. Standardization enables the relative comparison of socio-economic status and food insecurity outcomes spatially (e.g., between populations or regions) and temporally (e.g., before and after an intervention), and for these associations to be tested statistically (Fraval et al., 2018).

The World Food Summit (1996) provided a definition of food security as being a condition in which "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." This emphasis on personal preference and cultural appropriateness is supported by research that highlights food insecurity as experience (e.g., of cultural compromise, worry, limited activity) not just a capability (e.g., assets, income) or an outcome (e.g., hunger, malnutrition) (Radimer et al., 1992; Coates et al., 2006). However, the more contextual dimensions of food security, as in the World Food Summit definition, have proven harder to consistently capture within survey tools. Ethnographic methodologies include in-depth interviews, observations, or researcher embedded ethnographies. These approaches aim to produce a contextualized understanding of food insecurity that is grounded in participants' cultures, experiences and perspectives, and have identified inadequate food quality, insufficient quantity, uncertainty and worry, and social unacceptability as food insecurity experiences (Coates et al., 2006).

Ethnographic approaches also have application in explaining the cross-scale social, political and historical underlying drivers of household capabilities and experiences of food insecurity. In a variety of contexts and geographies, they have shed light on how food insecurity can be influenced by gender (Lemke, 2003; Nyantakyi-Frimpong and Bezner Kerr, 2017); age (in adults) (Vilar-Compte et al., 2017); governance (Pérez-Escamilla et al., 2017); participation and institutions (Leach et al., 2006); food knowledge, preference and education; quality, availability and access to hunted food; addiction (Beaumier and Ford, 2010); political violence and political movements (Wittman, 2009; Altieri and Toledo, 2011; Woertz, 2017); migration (Covarrubias and Maluccio, 2011; Davis and Lopez-Carr, 2014; Aguilar-Støen et al., 2016); land governance, class differentiation and exploitation (Li, 2010; Nyantakyi-Frimpong and Bezner Kerr, 2017); poverty, histories and path dependencies (Yesuf and Bluffstone, 2009). These studies often uncover phenomena or mechanisms that are otherwise difficult to identify, because they are specific to particular contexts or are contingent on other factors. However, limited representativeness across temporal and spatial scales can result in a perceived incompatibility between the evidence produced and the scale of analysis and intervention required by agendas of donors and governments.

Within the Central American Dry Corridor (CADC) specifically, participatory research approaches have been mainstreamed into development practice, for example through the implementation of integrated context analysis, community based participatory planning, and farmer field schools in recent projects. However there still exists a tension between the need to represent local knowledge, preference and context within measurement and decision-making processes, whilst also evidencing scaling-up of solutions, technology and impact (e.g., WFP, 2015; CATIE, 2017; CCAFS, 2017; FAO, 2017a,b). A role for research, embedded in this context, is to critically consider the capacity of methodological approaches to provide a contextually grounded evidence base for intervention decisions.

Food Security in the Central American Dry Corridor

The Central American Dry Corridor (CADC) is a region on the Pacific side of Central America, passing through Nicaragua, Honduras, Guatemala and El Salvador. Over the last decade, a series of abnormal weather events including extreme precipitation, drought, and heat waves have been attributed as the main driver of a series of food insecurity episodes amongst the rural population (FAO, 2017a).

Episodes of acute malnutrition within the CADC have been attributed to cycles of the El Niño–Southern Oscillation (ENSO) with extended drought occurring in El Niño years, as well as to variability in market prices for coffee, maize and beans, and recently also the impact of coffee rust, a fungal disease that drastically reduced the harvest of coffee, the main cash crop in the area (FEWSNET, 2018). These immediate biophysical triggers of food insecurity occur within a socio-economic context that makes rural families vulnerable to external disturbances. Hunger is generally characterized as "seasonal," and typically occurs during April-August during which time stored food or income from previous harvests has often been used up; investment is needed for fertilizer through the May-October growing season; and peak demand for unskilled labor has passed (October–March) (FEWSNET, 2018). There is also a high prevalence of "hidden hunger" in Latin America where individuals have sufficient calorie intake but micronutrient deficiency (Kennedy et al., 2003), while the proportion of overweight individuals is also increasing (FAO, 2017b).

The presence of international organizations in the region is strong; there exists a complex network of organizations running programs on issues of healthcare, hygiene, family planning, technical training, gender equality, livestock, livelihood diversification, education, reforestation, and others (CATIE, 2017). Among the larger efforts, an agricultural focused World Food Program (WFP) project "Response to the El Niño Phenomenon in the Dry Corridor" (WFP, 2017) responded to the consecutive occurrence of mild to severe drought during 2014–2016, and its accumulated impact on the nutritional status of households affected. The project strategy consists of trainings in water and soil conservation practices such as terracing, irrigation, and organic fertilizer; fruit tree planting; packaging of produce; education in nutrition, finances and crop management, and provides resources including tools such as backpack-sprayers, and seedlings (WFP, 2017).

Food sovereignty scholars and campaigners, who have a particularly strong history in the Latin American context, highlight the political economy of neo-liberal markets, and issues of food distribution, governance, justice and waste as intrinsic to the persistence of food insecurity in the region (Boyer, 2010; Jarosz, 2011). Furthermore, a history of political instability and violence across the "Northern Triangle" (Honduras, El Salvador, and Guatemala) that includes armed conflict, coups, and corruption, has shaped current patterns of gang violence, narcotic trafficking and organized crime, affecting people's security, experiences of violence and extortion, and out-of-country migration (Eguizábal et al., 2015).

The last major El Niño event in 2014-2015 caused estimated losses of 80% of crop production in Guatemala, and the WFP reported that $75 million was needed for emergency food provision in Central America following the loss (WFP, 2015). The problem of food insecurity over this period was conflated with violence, corruption, health epidemics and the movement of people (ICRS, 2019). The crisis in 2014 saw a surge in border crossing to the United States from Central America, evoking a $750 million of foreign assistance from the US, and a further $5.4 billion from the "Northern Triangle countries" own funds, toward addressing poverty, violence, corruption, and toward the development of rural business, agriculture, education and energy infrastructure (U.S. Global Leadership Coalition, 2019). Despite these interventions, 2019 has seen food insecurity crises in multiple regions (FEWSNET, 2019), and a significant spike in the number of reported cases of apprehensions and inadmissibles at the U.S Southwest border, with increasing proportions of unaccompanied minors and women with children (Customs Border Protection, 2019), while journeys continue to pose severe risk, and human rights abuses are reported at multiple stages along the route and on arrival (ICRS, 2019). The percentage of the population experiencing food insecurity has increased from an average of 15.6% between 2014–2016, to 16.4% between 2016-2018 (FAO, 2019).

These broad climatic, political and economic processes interact with household level dynamics of resource endowment, access to markets and infrastructure, political marginalization and more to shape individual experiences of food insecurity (Corbera et al., 2007; Jarosz, 2011; Webb et al., 2016). Considering the complexity and interdependence of issues interacting with and exacerbating food insecurity in the region—and the influx of funds and intervention targeted to address these issues—insights into the lived experience of affected people are essential to align the problem framing and management of issues with the complex reality in which intervention is received.

MATERIALS AND METHODS

This analysis was focussed on the Chiquimula Department of Guatemala within the CADC. Chiquimula covers 237,600 ha of land, 55% of which is cropped [GFSAD data as described in Massey et al. (2017)], and at the 2002 census contained a population of 302,485 (Censo, 2002).

A sequential method for integrating household survey and in-depth ethnographic interview methods was followed in this study. It began with the use of household survey data as a basis for categorizing household food security status and sampling households for conducting follow-up in-depth life history interviews. From these interviews, common drivers of food insecurity were inductively derived, and the significance of their association to food insecurity outcomes within the larger household survey data set. These steps are described here.

Household Survey

Lists of households were collated from organizations active within the CADC region, community groups and community centers. Two households were selected from each participating community to undertake a household survey following the RHoMIS format. Toward the end of the dry season, in March 2015 local technicians carried out the surveys. The RHoMIS method asks a set of standardized questions about the household, livelihoods, agriculture, income and diet, using locally adapted indicators and examples when required, for example in the use of country specific indicators of poverty in the Poverty Probability Index® (PPI). Survey responses were used to calculate a set of socio-economic and food security indicators, by applying a standardized R-script also described in Hammond et al. (2017). **Table 1** has been modified from Hammond et al. (2017) to describe the main indicators used in this study and their ranges, and methods of calculation.

Selecting Participant Using Survey Data

From the 220 surveyed households across 110 communities, in-depth interviews were conducted in 14 communities. The location of communities included in the quantitative survey analysis, and communities where additional life-history interviews were carried out are illustrated in **Figure 1**. A purposive sampling strategy was used to identify a range of household types based on production characteristics. Following a maximum variation sampling strategy (Patton, 2002) we analyzed the RHoMIS data to select households that had highest variation in Household Food Insecurity Access Prevalence (HFIAP), livestock holding, crop area cultivated, and market participation, which have relevance to the agricultural development strategies being implemented in the region promoting the production of poultry, livestock and increasing crop production (for subsistence crops and coffee as a cash crop). A total of 28 households in 14 communities were visited during the fieldwork period (September-December 2017). Wilcoxon signed-rank test was used to test for a significant difference in socio-economic indicators between the interviewed subsample and the greater surveyed population to check for representability.

There was no significant difference between socio-economic indicators derived from the RHoMIS between the interviewed sub-sample and the larger surveyed population, with the exception of livestock holding, which was overrepresented in the interview subsample (**Table 2**). Values for key socio-economic indicators were also similarly distributed when comparing the survey and follow up interview subsamples (**Figure 2**).

Life Histories and Interviews

Ethical consent to carry out life history interviews was granted by the Environment Faculty Research Ethics Committee at the University of Leeds. The field research team also reflected on issues of ethics and participation iteratively after each interview and by obtaining feedback from participants on their experience

TABLE 1 | Food Security and Socioeconomic indicators calculated using RHoMIS methods from survey data, adapted from full method description in Hammond et al. (2017).

Indicator	Indicator description	References
Household Food Insecurity Access Prevalence (HFIAP)	The prevalence of experiences of food insecurity is captured using a set of 9 questions defined by Food And Nutrition Technical Assistance (FANTA) (full list in **Supplementary Information**). These provide a progression of questions that start by asking about the frequency of worrying about food and conclude by asking about the frequency of days where the respondent was not able to access a meal. Reponses categorizes households based on severity as: Food Secure, Mildly Food Insecure, Moderately Food Insecure, or Severely Food Insecure. Severe food insecurity is defined as households frequently eating smaller meals or skipping meals, or occasionally lacking access to food.	Coates et al., 2007
Poverty Probability Index (PPI®)	Poverty Probability Index uses country specific indicators to assess the likelihood that a household is living under FAO defined poverty level $1.25 per day. It is implemented by asking 10 questions, e.g., What is the main construction material of the residence's floors? (full list in **Supplementary Information**). The PPI is used to rank households to study relative poverty, but not to measure changes a specific household over time.	PPI®, Desiere et al., 2015
Tropical Livestock Units (TLU)	A common unit used to count the abundance of livestock a household keeps, weighted by different type of livestock, based on size and value.	Jahnke, 1982
Market participation	Market participation a proportion (0–1) of on-farm production that is sold to generate income, rather than consumed or traded.	Hammond et al., 2017

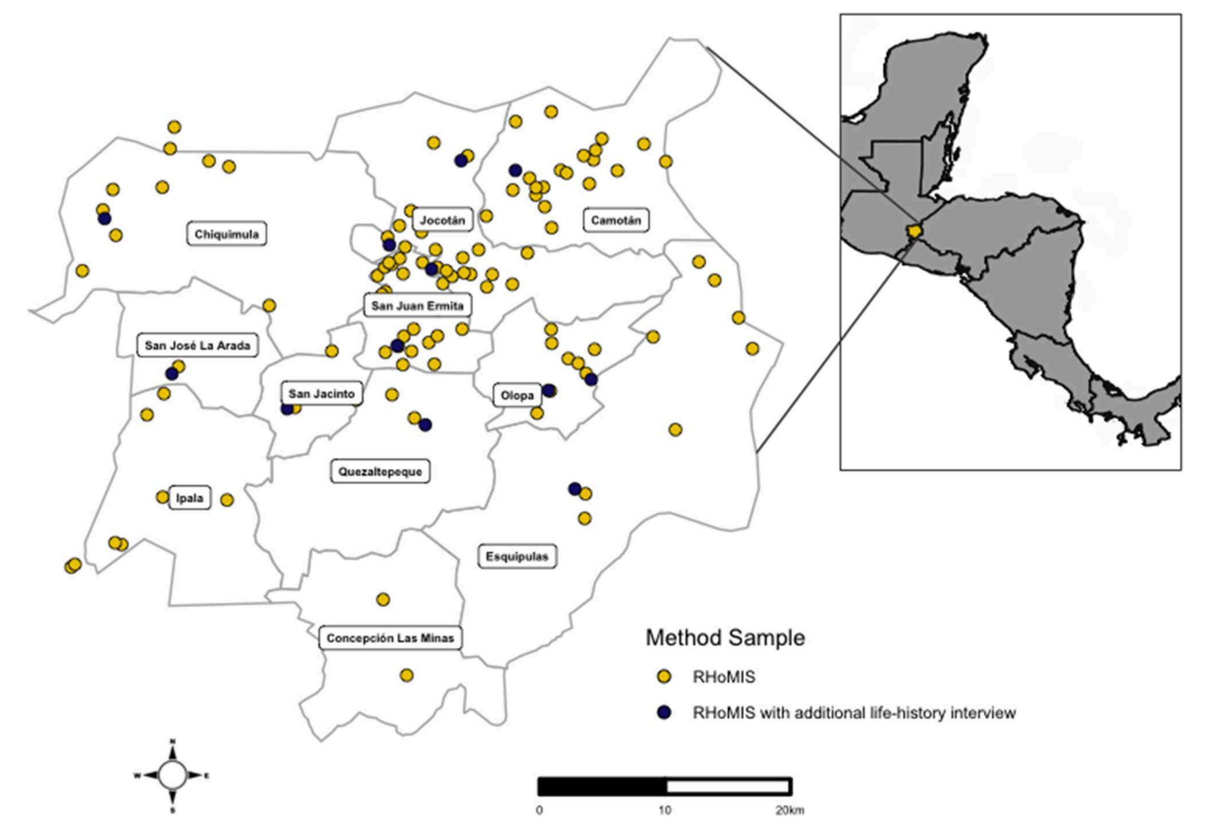

FIGURE 1 | Municipality boundaries in the Chiquimula Department of Guatemala, Central America. Points show the locations (with jitter) of communities included in the Rural Household Multi-Indicator Survey sample (yellow) and communities where households were selected for additional life-history interviews (blue).

of the interview process and decision to participate. Informed consent was obtained verbally from all participants. In-depth interviews, conducted in participants' own homes, started with a life histories activity (based on Goldman et al., 2003), where participants and the interviewer together built a timeline of key moments and changes within the participants' lifetime. We then used semi-structured questions following the timeline as a prompt for discussion about the factors that contributed to

TABLE 2 | Summary statistics for households the dry corridor of Guatemala by interviewed subsample, all values give the median with inter-quartile range in parenthesis.

Variable	Surveyed population (excluding subsample)	Interviewed subsample	Test for significance
n	195	25	
Household size	5.5 (4.5)	5 (3)	ns
Land cultivated (ha)	0.7 (0.6)	0.9 (0.9)	ns
Land Owned	0.92 (1.79)	0.71 (1.25)	ns
Market Participation (proportion of produced calories sold)	0.11 (0.43)	0.03 (0.15)	ns
Livestock holding (TLU)	0.1 (0.2)	0.24 (0.5)	*
Total Income	752 (1779)	905 (2136)	ns
Nearest town (walking hours)	4 (3.1)	3.3 (2.5)	ns

*ns, no significant difference. *P < 0.05 Wilcoxon signed-rank test.*

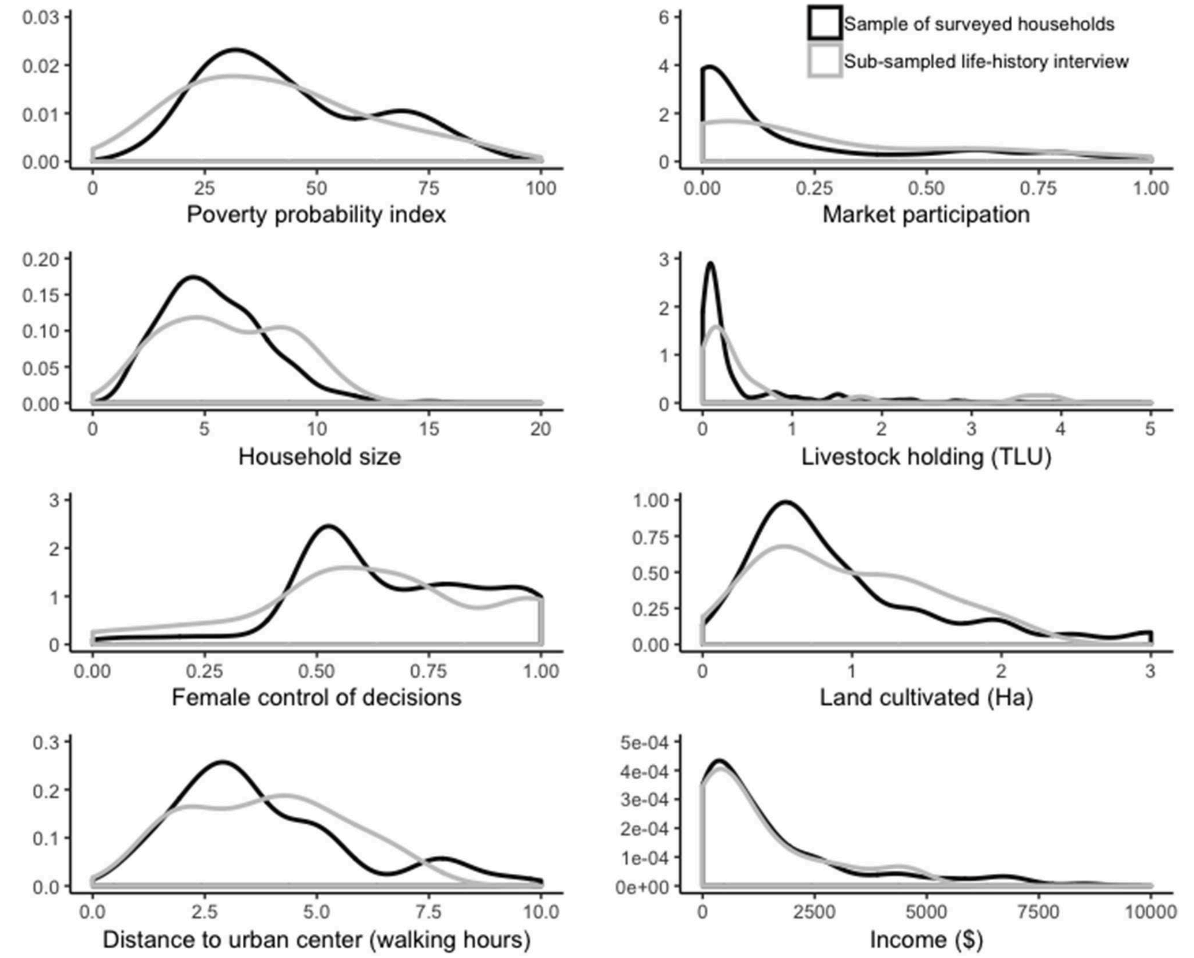

FIGURE 2 | The probability density function (PDF) of socio-economic indicator values derived from the Rural Household Multi-Indicator Survey (RHoMIS). Black and gray illustrate the PDF for the total survey population, and the sub-sample of households visited for follow up life-history interviews, respectively.

that livelihood change. Interview transcripts were first coded inductively (Glaser and Strauss, 1967; Harry et al., 2005), then more deductively by applying a simple categorization to list the factors that contributed to a reported positive and negative change in well-being, maintaining a broad and participant-defined concept of well-being. For experiences identified as moments of difficulty or crisis, any described coping strategies were also coded. Pseudonyms have been used to protect the identity of participants in all case studies.

Survey Analysis

RHoMIS derived socio-economic indicators were used as inputs to a regression model, in order to gain insight into which factors were significantly associated with severe food insecurity on a broad scale, at the time of the survey. Households were classified as being "food secure," "mildly food insecure," "moderately food insecure," or "severely food insecure" using the HFIAP indicator (described in **Table 1**). The associations between food security classification and selected socio-economic indicators were modeled using logistic multiple regression. The log odds of being "severely food insecure of access" given socio-economic predictors (Equation 1) were estimated using base R (R Core Team, 2014).

$$logit\left(p\right) = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots \beta_k x_k \quad (1)$$

Where p is the probability of being severely food insecure, β_0 is log odds when all other predictors are zero and $\beta_1 x_1$, for example, is the log odds of being severely food insecure as x_1 changes, holding all other predictors ($\beta_2 x_{2\ldots}$ $\beta_k x_k$) constant. Models were built in an additive fashion, assessing all potential socio-economic variables and interactions that could influence food security of access. Model over-fitting was evaluated using the Akaike Information Criterion (AIC). As this study does not have a predictive objective, variables were retained even with an increase in AIC <5% change, even though this can slightly increase out-of-sample error.

Potential sources of endogeneity in the model include measurement error, simultaneity and omitted covariates of the dependent and an independent variable. Measurement error has the potential to bias beta coefficients downwards (attenuation bias) and would be most prominent in income and crop yield variables. Simultaneity has the potential to result in overestimated coefficients and inconsistency (Verbeek, 2012). Omitted variable bias can result in various biases, including a reversal of the direction of association. The potential biases from simultaneity and omitted variables in the model were assessed iteratively with reference to causal mechanisms identified in life-history interviews and expert opinion. These potential biases are noted along with coefficient estimates in **Table 4**.

RESULTS

Characterizing Households and Food Insecurity Status

Life history interviews contextualize and elaborate on the food security status of households recorded in the survey, providing a narrative of participants experiences of food insecurity in the context of a given socio-economic status, but also recognizing that "status" as an outcome of a dynamic history of livelihood change and multi-generational processes. Experiences of food insecurity described in interviews are generally concurrent with the survey derived HFIAP status, as exemplified in stories from Manuel and Paula, and Viviana, described here:

> *Manuel and Paula and their children live a recently finished brick household, reported as mildy food insecure, they grow maize and beans, raise chickens and a pig, but concentrate primarily on producing coffee on a parcel of their own land. They both described growing up in poverty, moving around the country in search of labor work. Manuel contrasted his experiences of food insecurity growing up, and now as he supports his own household and production "Between 12 and 14 years old we worked in Zacapa [Department of Guatemala], we went to work in a place where they grew melons. There we would work until 23:00 pm, but we did not eat during the day, so we worked hard and we starved… Then we went to Izabal [Department of Guatemala], but there we suffered, as we were hungry. We had taken a week's supply of maize, but the tortillas became spoilt, so we continued to suffer." Then in reference to his current situation "Thanks to God my children have had food to eat, sometimes a little, but always something. We sow, and we continue to sow, and I have also planted lot of trees for wood. I have to provide, because if not my family does not eat. But as long as I am healthy and there is a good harvest then we can have tortillas and beans."*
>
> *Viviana lives in a single room with her 3 young children, a household reported as severely food insecure. She had some chickens and a small amount of maize and beans on her sister's plot, "In my case we are poor, so I raise little animals, and when I can, sell a chicken to earn some money, apart from that I cannot do anything," she explained. Keeping "patio chickens" to consume or sell as a way of making income and a coping strategy is a common practice in the region, and Viviana had learnt it her from her mother. Income that her husband earns working by traveling to find labor work around the Country is essential for purchasing food and farm inputs, but Viviana regularly depends on borrowing to be able to buy maize when they don't produce sufficient from their own plot. When asked about the role of organizations she said they had not come to her community, and about the government aid program she noted "There [at meetings] they gave flour, beans and oil every month" but explained that one year she was part of the program and the next year she was not included, but she didn't know why "I don't know why, they didn't tell us, they said they were going to take other people into account" she off hand remarked a suggestion "maybe the leader [town mayor] knows who needs more help." She saw this as a reason not to go to meetings and participate in groups within her community "as I say, they choose, and that's why I don't go."*

References to "suffering," "hunger," "not being able to do anything" in these accounts are reflective of experiences of food insecurity that are largely commensurate with, although not directly translatable into, the HFIAP statuses derived from household survey data. However, in a small number of cases there was variance or inconsistencies between the survey data and the subsequent in-depth interviews. This could be the result of error introduced due to limitations of survey and interview methods. Discrepancies can be due to a change in participant(s) present for the survey and life history interviews (and therefore personal perspective). In other cases, the circumstances of the household

TABLE 3 | Self-identified limiting factors, positive factors (in the context of a change in well-being), and coping strategies mentioned during interviews with 24 participants, with count of mentions (*n*).

n	Limiting factor	*n*	Positive factor	*n*	Coping strategy
13	Consecutive drought events	9	Coffee production	9	Use savings
9	Labor work availability	8	Poultry production	9	Migration for labor
7	Cost of medicine	8	Training	8	Borrow
6	Fertilizer dependence	7	Education of children	5	Female household head sources income
4	Absence or separation of a household head	7	Participation in projects		
4	Limited participation	6	Pig production		
4	Loss of income due to ill-health	6	Remittance		
4	Limited education opportunity	6	Children work in labor		
		5	Cash crop production		
		5	Migration for labor		
		4	Cattle production		
		4	Children work in occupations		
		4	Administration of resources		

Codes are included if n > 3.

can have changed in the time between the survey and the life history interviews.

Understanding the Drivers of Food Insecurity

Participants stories illustrate some of the mechanisms by which households find themselves in situations of food (in)security, and give examples of some of the coping strategies that are employed. Experiences vary across the 24 interviewed households, **Table 3** summarizes the most frequently discussed positive and limiting factors during life history interviews, in the context of a participant's perception of their own well-being and food insecurity experiences, as well as coping strategies used in times of crisis. In comparison, the regression analysis identified that coffee cultivation, dependence on off-farm income from labor on other farms, and PPI are significantly associated with severely food insecure outcomes within the surveyed population (**Table 4**).

Some factors are directly comparable across interview and survey analyses (summarized in **Tables 3**, **4**, respectively), for example coffee cultivation, livestock, and remittance. Other factors identified in interviews could be indirectly related to an indicator in the survey, for example decision-making (reported as the proportion of household decisions controlled by a female or male household head) as a survey based proxy for the reduced capabilities perceived by some participants when their partner was separated or away from the households. Type of off-farm income also acts as a survey based proxy for the limitations described by labor-dependent households due to low wages, insecurity of income, and a lack of time to develop their own livelihood (**Tables 3**, **4**, Hector and Clara case study). A further set of factors raised in interviews were not present in the survey analysis, for example the supporting role of children's education and income, money administration, costs of medicine, and limited participation in working groups or local projects (**Table 3**).

TABLE 4 | Associations of socio-economic indicators with Household Food Insecurity Access Prevalence (HFIAP), logistic regressions using the rural household multiple indicator survey (RHoMIS) output from households in the dry corridor of Guatemala in 2015.

	Estimate (s.e.)†
Intercept	0.23 (0.79)
Household inhabitants (adult eq.)	0.03 (0.06)
Land owned	−0.02 (0.15)
Livestock holdings	0.13 (0.20) ‡
Market participation	−2.00 (1.03)
Coffee cultivated (yes)	0.83 (0.38) *
Gender female control of decisions	−0.57 (0.70)
Poverty Probability Index®	−0.03 (0.01) *
Distance to nearest urban center (walking hours)	0.04 (0.03)
Off-farm income from other farm in community	1.06 (0.34) **
Remittance	−0.95 (1.11)

*†Reference category is "not severely food insecure." *Pr(>|z|) < 0.05. **Pr(>|z|) < 0.01.*
‡Potential for overestimation from simultaneity with dependent variable.

Life history interviews identified a broader range of factors associated with food insecurity outcomes compared to survey analysis. The most commonly discussed limiting factors were: consecutive drought impacting crop or animal production; unstable or inaccessibility of labor work; the cost of medicine displacing income from food purchase, livelihood investment and creating debt; social marginalization; absence or separation of a household head; and the cost of fertilizer, considered essential to maintain a viable level of production (**Table 3**). Life history interviews also elicited important detail and context about a given factor. For example, the interviewees described the different mechanisms by which this reduced participation in community and programs had occurred, including the precarity of presence within the community due to migration periods, social relations within the household, and power dynamics and control of project resources within the community.

Regression analysis of the household data shows severe food insecurity is significantly associated with the receipt of income from other farms within the community and coffee cultivation. On the surface, this contradicts the results of the coding analysis of interviews, as coffee cultivation was the most commonly reported "positive factor"—identified by participants as contributing to an improvement in well-being (**Table 3**). It is important to realize, however, that the contribution of the different variables in a multiple regression model depends on the presence of the other variables. Coffee cultivation only appears as a significant variable when market participation is also included in the regression model (it is what is known as a "pipe"; Pearl, 2009). This means that coffee cultivation is significantly positively associated with severe food insecurity when market participation is held at its mean (0.19). This interaction nuances that it is households that cultivate coffee but that also have relatively low market participation that are more likely to be classified as severely food insecure (**Supplementary Table 2**).

Ethnographic insights can also contribute to our ability to interpret and make sense of this potential contradiction. The experience of Hector and Clara, whose household was recorded as severely food insecure in the 2015 survey, is summarized below:

> *Hector and Clara lived with their three children in two mud-walled rooms, they kept a small farm where they had recently invested in growing coffee and banana to sell, alongside the maize and beans they have always kept to feed their family. Clara described the impact of living without a shelter "If you don't have a house it is difficult, I appreciated the help when the mayor gave us some metal sheets to build a roof, but we still had no kitchen, so when it was raining we were dry, but we still went to bed without food." Clara identified the positive role of external support on their livelihoods, in terms of cash for food, training and family planning. As their first child was able to start working in labor, the extra income had been the catalyst for them to start cultivating their own coffee and banana. Hector explained "I started growing coffee 3 years ago when I left labor work. I was working with Hermano Pedro from church and he gave me the idea and knowledge that enabled me to start growing coffee. I learnt how to plant bananas [as shade] and how to make a nursery. I have always cultivated beans, but this idea to grow coffee was new. Now I work in coffee, I don't have to buy plants, I have my own seeds. Before I used to work for others until 18:00, and I didn't have time to work my own land, but now I do a small amount of labor [for others] and work on my own land. When I worked doing labor for another person I would get a quintal of fertilizer, but now when we buy the fertilizer the children have to put up with being hungry. We have to put up with being hungry sometimes because we have invested 3 years in the coffee, but I keep working, and so does my son."*

Hector described a dependence on off-farm labor despite its limited returns, and the trade-off between time spent in off-farm labor and managing his own production and food generating activities. This contributes to explaining the statistical association between off-farm income from other farms and severe food insecurity outcomes (**Table 4**), which has also been observed in other contexts (Jayne et al., 2014). In this case, the additional off-farm income contributed to the household by Hector's son had enabled their recent investment in cash crop production (coffee). Hector describes the sacrifice they have made to invest in coffee and the lead time to this becoming a marketable crop, which corresponds with, and adds explanatory weight to, the observation of market participation being a mediating factor between coffee production and food insecurity.

The interview with Juliana pointed to a further mechanism by which on-farm production and market participation was mediated, via an interaction between land access, participation in local programs and production.

> *Juliana lived in a single room with her 3 children, her husband was away looking for work. The household was recorded as severely food insecure. Juliana felt that their limited access to land was the main barrier to improving their livelihood "We only had 4 tareas [land unit], and we rent the land, so even when we have a good rainy season we don't have access to more land, so we cannot cultivate more to improve our livelihood." She felt mistrust of local groups after being promised tree saplings, seeds, and chickens through various projects, that had never arrived, and felt excluded from participating in several projects due to her lack of land and resource "The benefits from projects are good, but unluckily we are poor, so we don't receive any. Here is it the people who have the land who receive the benefits."*

PPI also has a significant association with food insecurity, and this is unsurprising as it represents a proxy for wealth (a higher score means lower probability of poverty). This association may relate to several causal pathways, however. Wealth may be associated with higher levels of savings that can be accessed in difficult times, as well as having increased capabilities (e.g., farm equipment, employment opportunities or social capital). Multiple causal pathways between PPI and food security outcomes were also evidenced in life history interviews, for example in the use of capabilities to develop multiple livelihoods in the case of Mavis, in stark comparison to the story told by Clara who had a limited capability to prepare food due to a lack of roof or kitchen in her home.

> *Mavis' household, which includes her husband and three young children, was recorded as food secure in the 2015 survey. She explained how cash crop production and diversification had successfully enabled them to incrementally improve their economic status and food security to reach a point where they feel comfortable and food secure. "The municipality gave us a greenhouse and we planted tomato, pepper, chili, coriander. The greenhouse was from a municipality led project, only a few people received the benefit, but my husband knew someone and so we got it. We planted onion too, and then we started to raise pigs and produce poultry. We also always planted beans and maize." Through these examples she illustrated how their access to credit from banks, friends and on-farm income itself had enabled them to keep investing in more strategies and build a diverse portfolio of income sources, including chickens, pigs, a range of crops, and most recently cars, buying two 4x4 cars to run a local school and taxi service.*

DISCUSSION

Local and National Scale Factors

Livelihoods in the dry corridor region of Guatemala are shaped by sets of highly contextualized, historic, social, political and environmental factors that have relevance for food insecurity outcomes (**Table 3**, **Supplementary Table 1**). These overlap with, and extend beyond factors included in the household survey. Analysis of a standardized set of survey variables, revealed the broad-scale association between severe food insecurity in households and coffee cultivation (when market participation is constrained), dependence on off-farm income from labor on other farms, and poverty. Interviews have identified where decision-making and trade-offs can be a proximate cause of food insecurity in households suffering from poverty and food insecurity, these trade-offs often involve survey-measured variables, but the interviews elicited detail of their interaction and dynamics, e.g., prioritizing fertilizer for coffee production over access to a sufficient diet during a 3 year investment, or time constraints from labor work limiting on-farm production. Interviews identified further underlying social-political factors that were not represented or paralleled within the survey, and would likely be challenging to categorize or enumerate within a survey setting, for example, the marginalization from groups that have control over development resources. Here we discuss four factors—cash crop production, health, participation and agricultural labor—to illustrate the explanatory power of integrating these two methods, compared to a single-survey application, and its relevance to intervention planning across scale.

Risks of Coffee Investment

Survey data showed that the relationship between cash cropping and food security was mediated by market participation, and that coffee-growing households with low market participation had an increased likelihood of being severely food insecure (**Table 4**, **Supplementary Table 2**). Interviews concurred that coffee is a high-risk strategy, given the challenges of drought and coffee rust affecting the region, and the long-term investment needed for crop establishment, but also indicated high-rewards when successful. Interviews detailed how establishment costs, lag times in producing marketable crops, land access, and levels of market participation shape households' experiences and success in cash crop production, which evidences the need for holistic and tailored strategies that go beyond general promotion of crops or agronomic practices. For those households that have few or no safety nets pursuing cash crop production, this finding highlights the severity of production and livelihood risks. Climatic variability and instances of crop disease can substantially reduce income; increased capital expenditure can deplete capital reserves, leaving no resources for crop inputs or other household needs. Provisioning of risk mitigating production support and safety nets will fall under the remit of a range of institutions and organizations, across scales.

Ill Health and Cost of Medicine

Although it would have remained unidentified in the survey application, participants commonly identified the burden of ill health and injury as a principle factor that displaced income away from food access or livelihood investment, foremostly via the cost of medicine, but also the loss of income. Within Central America, Guatemala has the highest rate of out-of-pocket expenditure for health (as a % of total expenditure) and the second lowest government health expenditure (as % of GDP) (World Development Indices, 2019). The financial burden of ill-health falls mostly on economically poor and rural households, due to lack of insurance and decreased access to public services (Bowser and Mahal, 2011), while exertion in labor work in unsafe and unhealthy working conditions can further contribute to the burden of ill health and loss of livelihood in labor dependent households (LO/FTF Council, 2014; Dally et al., 2018). In this case interviews have evidenced an underlying driver of food insecurity that is likely to require coordinated intervention or policy change at a national scale in order to address this constraint on the health, food security and production of households in the dry corridor region.

Participation

Inclusion and participation within existing support systems and structures was an important part of the stories of many of the households that were interviewed, but was not evidenced in the survey. Training and resources disseminated through existing farmer group networks were shown to be unlikely to reach severely food insecure households that are socially marginalized or have limited participation in local groups. These incidences of exclusion from projects also indicate a wider issue of representation in the local implementation of participatory development projects (cf. Cleaver, 2014). Multiple contexts for reduced participation or marginalization were identified, including corruption—indicating the need for independent processes by which to review the inclusion of participants in projects.

Agricultural Labor

The integrated analysis has identified the vulnerability and increased likelihood of severe food insecurity in households that are dependent on agricultural labor, through multiple mechanisms: low wages, instability of income, extortion, the risk of injury and ill-health, a lack of health care provision, restricted community participation and reduced household capabilities when household heads are traveling in search of available work. Improvements in working conditions of inter-regional day laborers have been identified in some productive regions in Central America through state commissions and workers unions. However, many labor markets remain informal, utilize private middlemen, recruit daily, provide little security of employment, protection, or health insurance, while hundreds of thousands of laborers are reported to work in unsafe and unhealthy working conditions, for example in Guatemala's agro-export processing centers. Corruption and disappearances of trade union leaders have also historically inhibited progress toward achieving labor rights in Guatemala (LO/FTF Council, 2014; Van Roozendaal, 2015). Implications for directing policy include the promotion of transparency and labeling in production chains, and creation, across ministries, of a policy environment that enforces safety standards, a fairer wage, and employment security within existing agricultural industries.

The complex and cross-scale mechanisms by which food insecurity comes about is such that climate conditions, crop choices, agronomic training, health, credit access, gender, market access, and social and political participation are all inherently wrapped up in the individual experiences and narratives of participants. Livelihood decisions, economic and social circumstances also mediate the exposure and vulnerability of households to dynamic stressors such as climate (consecutive drought), labor availability, and market prices. This observed transmission of risk and impact between non-climatic and climatic factors corroborates with ethnographical research on food insecurity in other regions in Latin America (Zavaleta et al., 2018). Purely relying on survey data may lead to interventions that are technical, but not holistic. An intervention designed to stimulate cash crop production, for example, that does not also coordinate effort to address issues of participation and access to land, water and health services, are likely to have limited effectiveness, and at worst entrench existing inequalities. Identifying these complex mechanisms and analyzing their prevalence requires integrated research methods. Below we reflect on the specific approach of integrating household survey data and ethnographic research adopted in this study.

Integrating Household Surveys With Ethnographic Approaches

This study used a multi-indicator household survey to assess what socio-economic factors were significantly associated with severe food insecurity, based on HFIAP scores. Indicators of households' production type were analyzed to select a subset of households -with maximum variation- to participate in life history interviews. Analyses were iterative, as interview derived understanding then further informed the building and interpretation of the regression model.

Ethnographic interviews revealed some of the important variables that were not represented in the survey. However, simply extending surveys to be all encompassing is unlikely to be a feasible response to the complexity and context dependency of the lived experience of food insecurity documented in this region, due to the pressure that would put on data quality, for example by increasing time-cost, participant fatigue and recall accuracy (Kilic and Sohnesen, 2015). Before extending surveys, it is important to address the current limitations to produce insight from surveys due to issues of data quality and biases, as detailed in Fraval et al. (2018). We also note that some experiences and topics do not fit the standardized structure of a survey. A validated approach to tackle sources of uncertainty in survey data is the use of multiple methods to test the consistency and quality of responses, by making more precise physical measurements with a subsample of the surveyed population. We have applied this approach to ethnographic methods, to provide both a broader evidence base, and enable triangulation of evidence from quantitative and qualitative sources. Triangulation of evidence from interviews in iterations of analysis and model building enabled us to shape the model around associations that have grounded evidence. Conversely, it also helped to identify and explore the presence of endogeneity, confounding variables or spurious associations when specifying the model.

The effectiveness of using qualitative data to inform quantitative analysis is dependent on the quality and quantity of interview data afforded. Low "positive" counts for qualitative factors derived from life-history interviews limited our capacity to test for statistically significant associations between reported positive or limiting factors and survey based food insecurity outcomes, e.g., the relationship between reports of consecutive drought and HFIAP status. However, these causal mechanisms identified ethnographically, can each now be explored across a range scales using alternative data with a grounded justification. Under time and resource restrictions the application of ethnographic methods to a stratified subset of surveyed households manifests as a trade-off to the sample size of the larger survey effort. However, a critical evaluation of survey data was able to capture significant differences and trends in survey indicators that are representative of the wider population using sample sizes of hundreds, while many survey efforts typically reach into the thousands suggesting there is room for the inclusion of more mixed methods in standardized assessment and monitoring protocol (Fraval et al., 2018).

Interview methods have their own set of biases and limitations for consideration, for example the breadth of issues raised in interviews is likely to be sensitive to the framing and biases of the researcher, as well as participant selection effects due to low sample sizes (minimized through purposive maximum variation sampling); effects of the interviewer identity and position; reliability of participants; accuracy of recall; and subjectivities in interpretations, coding and analysis (Alsaawi, 2014). Identifying drivers from qualitative interviews has limitations, especially in extrapolating to the wider population. The sub-sample of interviewed households is shown to be representative of the wider survey population, however the list of drivers is sensitive to recall biases relating to the timing of the interview, and hindsight bias relating to the exposure of interviewees to external narratives surrounding recent events. For example, at the time of this research there had recently been a drought and multiple intervention projects working in the region were framed around resilience to drought and climate; hence the prevalence of consecutive drought in the qualitative analysis is likely to have been—at least in part—a reflection of these effects. Results therefore need to be applied and interpreted within contextual bounds of the time and place of data collection.

The position of the researcher conducting life-history interviews and analysis will be an important methodological consideration when embedding ethnography into existing survey-based assessment or research protocol. Through critical reflections during fieldwork, we identified that perceived and explicitly stated independence of the interviewer from intervention-implementing organization was an essential methodological criterion to maximize representation of actors, narratives, and voices across the surveyed population. Some sensitive subjects raised by participants in interviews, such as processes of social exclusion, familial disagreements, gun violence, or alcoholism, were not represented in the survey, but are still likely to be under-represented in ethnographically informed interview approaches applied here. Furthermore, some social issues known to be present in the region, e.g., narcotic movement across country borders, or religious tensions, were not raised in surveys or interviews despite indicators of their presence within visited communities, suggesting that some narratives remained hidden. Through the use of more ethnographic approaches, such as including observation or photovoice, these limitations could be mitigated (Lykes, 2001; Lorenz and Kolb, 2009). Adding more in-depth ethnographic approaches in this case has potential to both expand the system boundary and deepen understanding, especially in the context of marginalized or disadvantaged individuals or communities (Lardeau et al., 2011), but integrated methods inevitably have a greater cost than singular methods applications. Integrated methods therefore require iterative methodological discussion between researchers about the trade-off between the depth of knowledge produced and its coverage—with respect to the system boundary of included topics and spatial scale.

CONCLUSIONS

Combining survey and life history interview approaches enabled us to evidence a broader set of underlying drivers of food insecurity, widening the system boundary of measurement, and extending it to review interactions between food security outcomes, intervention and policy at local and national scale. The analysis of a standardized set of surveyed variables enabled us to identify household characteristics that are significantly associated with the prevalence of severe food insecurity across the region, while our analysis of life history interviews is founded in a more constructivist epistemology to bear witness to the heterogeneous and context specific experiences and drivers of food insecurity, as identified through the participants' own narratives. Variables with a statistically significant association with severe food insecurity in the region are: coffee cultivation (when market participation is low), dependence on agricultural labor income, and poverty level. Drivers most commonly identified by participants are: consecutive drought; ill health and displacement of income for medicine; social marginalization; high start-up costs in production; absence or separation of a household head; and a lack of income and education opportunity. This evidences the need for more inclusive and joined-up policy-making, e.g., to tackle inequalities in wages and working conditions, access to land, resource, education, and health care, which current limit households' capabilities and capacity to participate in developing rural livelihoods. From this broader and grounded perspective, survey based insight can be critically viewed and contextualized. This approach aligned measurement and monitoring with the broadly accepted WHO 1996 definition of food security by visualizing elements of choice, culture and agency, and with the participatory agenda by conceptualizing food insecurity and its drivers through a process that includes both deductive and inductive evidence building.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because: they contain confidential information about participants, and could not be fully de-identified. Requests to access the datasets should be directed to LB, eelb@leeds.ac.uk.

ETHICS STATEMENT

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval was granted by: AREA 16-179 [approved 15/08/2017] ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee, University of Leeds.

INFORMED CONSENT

Informed consent was obtained verbally from all individual participants included in the study. Written consent was not obtained due to illiteracy or limited literacy proficiency of participants.

AUTHOR CONTRIBUTIONS

RHoMIS designed was developed by JH, MvW, and JvE, and the overall study was designed and developed by LB, SW, AC, JvE, and MvW. Survey data was designed and collected by JH, JG, LM, JvE, MvW, and analyzed by LB and SF. Interview data was designed and collected by LB and LD. The main body of text was written and compiled by LB and SW, with contributions from SF, MvW, JvE, LD, LM, JH, JG, and AC.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2019.00065/full#supplementary-material

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Chapter 3

Applying Drought Indices to Characterise Climate Impact on Malnutrition in Guatemala

Applying Drought Indices to Characterise Climate Impact on Malnutrition in Guatemala

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Abstract

Rural development in Guatemala is strongly tied to agriculture; a large proportion of rural household depend on rain-fed agriculture for subsistence and more commercial agriculture for a source of – often informal – employment and income. However part of Guatemala falls within the Central American Dry Corridor (CADC) and is prone to hydrological and agricultural drought. Climate is therefore an important driver of food insecurity outcomes and is factored into decision-making for both emergency responses to acute episodes of malnutrition and longer-term development of climate resilience in agriculture. Several cycles of acute malnutrition have coincided with the El Niño phases of El Niño Southern Oscillation. The main mechanism of impact is the loss of subsistence food and income from agricultural-labour due to an extended dry spell during the growing season (mid summer drought (MSD)). This study contributes the first attempt at a spatially disaggregated analysis of the association between the MSD and both acute and chronic food insecurity outcomes across Guatemala. Results of a geographically weighted regression show that the duration of the MSD is significantly associated with food insecurity classification and prevalence of stunting, a bio-

physical indicator of chronic food insecurity. Deterioration of the food insecurity classification (defined by the Famine Early Warning System Network) was also associated with an indicator of local extremes in the number of consecutive dry days (CDD) during the growing season, and the 30-day minimum rainfall during the MSD. These associations were contingent on the inclusion of indicators of socio-economic status in the regression model, indicating the importance of assets and livestock as coping mechanisms. The association with MSD indices were also strongly spatially disaggregated across food insecure regions, and models had stronger explanatory power in the CADC region than in the Western Highlands.

1 Introduction

In the Central American Dry Corridor (CADC) climate is an important driver of food insecurity outcomes and is factored into decision-making for both emergency responses to acute episodes of malnutrition and longer-term development of climate resilience in the agricultural sector. However, few analyses of the relationship between climate and food insecurity in the region are disaggregated to understand the geography of the association across spatial scales, or investigate how climate interacts and associates with both acute and chronic food insecurity outcomes.

In early warning systems for acute food insecurity, a range of indicators including climate indices are tracked to characterise the situation and to identify where and when conditions predispose an increase in prevalence of malnutrition. These systems of surveillance are designed based on an understanding of the drivers of acute food insecurity, availability of national scale standardised data, and the needs of decision-makers (IPC 2019; SESAN 2015; Muller et al. 2019). Such early warning indicators need to be spatially disaggregated - mapped - to enable their interpretation within a local situation and context (IPC 2019). However, analyses of climate impact are often produced at an aggregate (country or regional) scale, which limits the capacity for targeted intervention in decision-making (Muller et al. 2019).

Over longer time-scales of intervention; donor-driven research and development agendas associated with climate resilient agriculture and food systems (Lipper et al. 2014) are placing increasing emphasis on 'scaling-up' (Aggarwal et al. 2018); seeing successful practices, interventions, and technologies rolled out across contexts and systems to maximise their reach and contribute towards the ambitious universal goals of food security and resilience (Westermann et al. 2015). However, the transferability of successful intervention across regions also depends on the scale at which a climate driver and its impacts are conserved and relevant, as well as social, economic and cultural appropriateness of the intervention at the local level (Forsyth 2017).

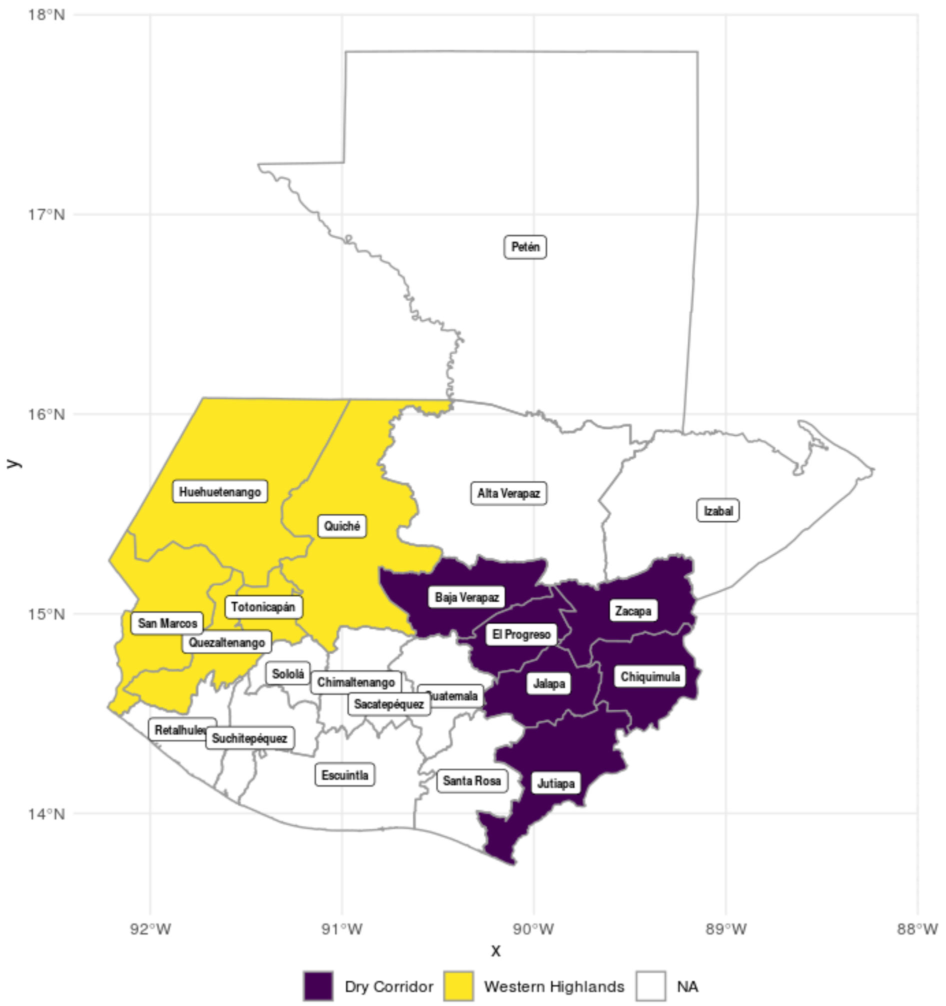

Figure 3.1: Map of the Departments in Guatemala indicating the dry corridor and western highlands regions

1.1 Guatemala and the Central American Dry Corridor

In Guatemala, there are two principal food insecurity hotspots: The Western Highlands where there is a higher proportion of Guatemala's indigenous Mayan population with one of the highest rates of chronic under nutrition (USAID 2018;

Lopez-Ridaura et al. 2019) and the South-East at the intersection with the CADC where acute malnutrition episodes are frequent.

1.1.1 Acute food insecurity

The CADC is an arid belt that extends through parts of Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala (Figure 3.1; FAO (2012)) where several cycles of acute malnutrition have peaked during El Niño phases of El Niño Southern Oscillation (ENSO) in recent years (2018-2019, 2014-2016, 2009-2010) (FAO 2019a; NOAA 2019; FAO 2019b). The dominant narrative in the development community in the CADC strongly associates acute food insecurity to drought, via its impact on household production and access to income. The area is also considered highly vulnerable to the impacts of climate change and therefore a priority area for developing adaptation and resilience (FAO 2019a; USAID 2013; Acción contra el Hambre 2015; UNDP Guatemala 2017; WFP 2019; Alfaro 2019). This understanding has shaped the focus of several major development projects (FAO 2019a). Place-based and ethnographically grounded studies in the CADC also evidence drought as an important driver; in a study of experiences of food insecurity in the Chiquimula department of Guatemala, drought over consecutive growing seasons was mentioned by over half the interviewed participants as having negatively affected their food security and wellbeing (Beveridge et al. 2019).

However, there is also recognition that within these food insecure contexts, different factors interact to shape vulnerability and food insecurity outcomes, and that climate is only part of a complex network of drivers playing out across different temporal and spatial scales (Müller et al. 2015). For example, during the 2014-2016 episode, a shortfall in access to health care exacerbated the food insecurity episode (USAID 2018). Deductive analysis of life history interviews identified that issues of health care access and costs; power and participation; access to land, water and resource; drought; educational opportunity; and the temporality of labour work and migration, were all built into participants narratives of their food insecurity experiences, and often interact to shape the experience and health outcome of an individual living in a food insecure household (Beveridge et al. 2019). A key coping mechanism, as also common in other contexts, was the use of household capabilities and assets including the drawing down of savings and assets (often also livestock) during a crisis or a stressor event, such as a climate shock.

1.1.2 Chronic food insecurity

The Western Highlands of Guatemala contain the highest proportional population classified as chronically food insecure. The region has a history of violence and oppression resulting in marginalisation and inequalities (Equizabel et al. 2015), while access to land, agricultural livelihood, and healthcare all affect rural livelihood development and health outcomes in the region (USAID 2013; Lopez-Ridaura et al. 2019).

A confluence of factors drive more chronic food insecurity outcomes across Guatemala, including in and out migration, violence and oppression, chronic poverty, environmental condition, water and land access, sanitation, health status, access to resource and education (UNDP Guatemala 2017; ICRS 2019; WFP 2019). The receipt of remittance has also been linked to improving health and nutrition outcomes in a national scale analysis. Remittance is generally received from a household member working abroad, and is associated with a decrease in child malnutrition and increased coping capacity when access to food is stressed due to drought or market price spikes (De Brauw 2011; Milan and Ruano 2014). Longer term strategies to address food insecurity being implemented across Guatemala include education in health and nutritional interventions, and a range of climate focussed interventions are being scaled up across the CADC countries, including coffee cultivation; diversification of gardens; drought-tolerant breeding programs; conservation agriculture; and re-forestation (CATIE 2017; CCAFS 2017; WFP 2017).

1.2 Research questions

In this study, we apply a theoretically grounded understanding of the drivers of food insecurity to shape a national scale analysis of food insecurity outcomes, focussing on a comparison between the CADC region and the Western Highlands. We focus on Guatemala's two principle food insecure regions to compare the mechanisms that shape both acute and chronic food insecurity. Using national and global scale data sets to produce climate and socio-economic indicators, we ask the question to what extent can an understanding of food insecurity drivers be reduced and evidenced at a national scale. We then assess how these nationally significant associations are disaggregated across geographies.

This research paper explores where and when drought is a driver of food insecurity outcomes in Guatemala by addressing the following research questions:

1. Are drought indices statistically associated with acute and chronic food inse-

curity outcomes at a national scale?

2. Are associations of food insecurity outcomes consistent across Guatemala, and specifically across different food insecure regions?

2 Background

2.1 Defining, measuring and modelling food insecurity

Whether a household or individual is experiencing food insecurity or not is frequently conceptualised and assessed either as a measure of a biophysical outcome e.g. stunting, wasting, weight loss (Croft et al. 2018); as a measure of consumed calories and nutrition e.g. food diary, or food balance sheets; or as an experience of food shortage or anxiety around food e.g. experience based indicators (Coates 2013). Equally, within a population and at the higher administrative level, food insecurity can be defined and identified using prevalence scores of malnutrition and experience-based indicators, but can also be understood more holistically, in the context of a time, place and set of circumstances, as applied in the Integrated Phase Classification (IPC) methodology used in famine early warning systems (IPC 2019).

These different conceptualisations are describing food insecurity as both an acute and chronic condition, for example, stunting is indicative of chronic illness or ineffective feeding practices, while wasting is indicative of short-term severe illness and acute malnutrition in a situation of a crisis at household or geographical scale. In an area like the CADC, where drought impact on malnutrition has been the focus of intervention for more than a decade (FAO 2019a), there is potential for both chronic and acute food insecurity outcomes to be associated with climatic factors.

In a range of geographical contexts, widely collected geospatial panel data such as USAID demographic household surveys (DHS) (ICF 2019, 2020) have been used to build statistical models of the relationship between biophysical indicators of food insecurity e.g. wasting and stunting, and a range of driving variables, including climate and environmental condition. For example, in the African context where this literature is well-developed, prevalence of stunting in children has been associated with climate-vegetation indices e.g. normalised difference vegetation index, and mean precipitation indices (Fink et al. 2011; Jankowska et al. 2012; Johnson and Brown 2014), as well as non-climate variables such as rural-urban environment, household assets, mothers age and education, number of children per household, access to drinking water, and sanitation practices (Menon et al. 2000; Fink et al. 2011; Darteh et al. 2014).

While logistical regression often suffices to identify the significance of relationships over large datasets and areas (Fink et al. 2011; Johnson and Brown 2014), it does not account for geographical dependencies in the dependent variable or in the relationship between the dependent and independent variables. Spatially weighted models, such as geographically weighted regression (GWR) have the capacity to identify the geographical dimension of the association and estimate local coefficients compared to a global model, therefore can identify where associations between food insecurity outcomes and independent variables are spatially distributed, and account for local factors (Jankowska et al. 2012; Spray et al. 2013; Darteh et al. 2014). These associations between environmental characteristics e.g. vegetation cover or average rainfall, and chronic health outcomes such as prevalence of stunting, are complex and mediated through longer term changes in socio-economic circumstance e.g. via food prices, income levels, and the interaction between them (Lloyd et al. 2019).

Spatial analyses, such as GWR also have useful application to model the more direct associations between extreme climate events and the immediate and acute change in food insecurity situations. Within the context of an early warning system for the deteriorating food insecurity in Guatemala, more disaggregated spatial analysis could better inform intervention as it could permit more specific targeting of intervention rather than scaled up responses, while decision-makers have also expressed preference for working with information at lower administrative boundaries (Muller et al. 2019).

2.2 Agroclimatology and the mid summer drought

The climatic phenomenon most strongly related to acute food insecurity outcomes in Guatemala is an extended-dry spell during the rainy season (May-October), which is the primary growing season for subsistence crops (Figure 3.2). A set of feedbacks between precipitation on the Pacific side of Central America and sea surface temperature (SST) in the Pacific drive the bi-modal distribution of rainfall during the May-October rainy season, and the extent and duration of the mid summer drought (MSD). Average rainfall is at its maximum in May-June and September-October. The depression in SST and rainfall is in July-August, which creates the MSD trend (Taylor and Alfaro 2005). While the origin of the MSD isn't fully understood, it correlates with multiple global climate indices, including ENSO, realised though changing SST conditions. When the ENSO is in an El Niño phase, there is more likely to be a drier rainy season and a stronger

MSD intensity (Maldonado et al. 2016).

The MSD occurs annually and crop calendars are managed responsively (Figure 3.2, FEWSNET (2013)), but consecutive years with drier conditions associated with multi-year ENSO phenomenon can magnify the challenge of managing food insecurity as it reduces the coping capacities of households and recovery time between growing seasons. Households in the CADC identified consecutive dry growing seasons as a key factor influencing their livelihoods and food insecurity outcomes, and specifically identified the severity of impact during the recent ‘three-year summer’ in reference to the 2014-2016 period (Beveridge et al. 2019), which we characterise here using MSD indices.

A climate index is a single value that summarises a characteristic of the distribution of a climate variable (e.g. rainfall) over a time period of interest, for example through the application of averages, ranges, thresholds, percentiles or more complex algorithms (Schulzweida 2019). The development of MSD specific climate indices based on the bi-modal rainfall distribution in Central America enables us to characterize and quantify different aspects of the drought during the El Niño phase and food insecurity episode in 2014-2016 (Maurer et al. 2017).

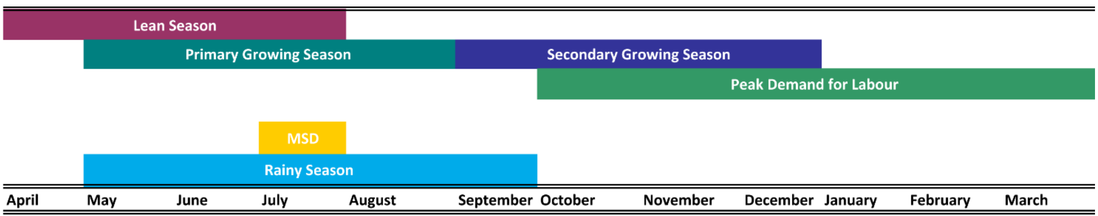

Figure 3.2: An agroclimatic calendar for Guatemala

3 Methods

We calculate MSD indices and a selection of standard climate indices at a 0.25 x 0.25 degree grid scale across Guatemala to investigate the relationship between the average climatology of an area and acute and chronic food insecurity. For the analysis of chronic under-nutriton and its relation to MSD indices, we use the DHS household survey data for 2015. For the analysis of acute under-nutrition we apply the FEWSNET food insecurity classification dataset and calculate the same set of climate indices with additional indicators of ‘extreme events’ defined and calculated using percentiles. This section introduces the different climate and non-climate indicators applied in this analysis (section 3.1), their calculation (section 3.2), and the methodology of the spatial analysis (section 3.3).

Index	Calculation and Units	Description and Interpretation	Reference
WHO Prevalence of Stunting in children under 5 years (Z-score)	Proportion of children between 6-59 months who have a height-to-age measurement 2 or more standard deviations below the standard mean.	Stunting in children under 5 provides an indicator of stunted growth, often as a result of chronic illness or feeding practice. Prevalence is reported as a percentage within a population. Where 20-29%, 30-39% and 40%+ are the WHO defined standards for medium, high and very high levels of stunting respectively.	Croft et al., 2018
WHO Prevalence of Wasting in children under 5 years (Z-score)	Proportion of children between 6-59 months who have a weight-to-height measurement 2 or more standard deviations below the standard mean.	Stunting in children under 5 provides an indicator of wasting (low weight for height), often resulting from acute malnutrition or illness. Though does not preclude a chronic condition. Prevalence is reported as a percentage within a population. Where 5-9%, 10-14% and 15%+ are the WHO defined standards for medium, high and very high levels of wasting respectively.	Croft et al., 2018
FEWSNET Food Insecurity Classification	Follows the ‘integrated phase classification’ methodology.	To classify the food insecurity status of each zone. This data is then downscaled to Municipality scale by FEWSNET to provide a spatially consistent dataset. The change in status was calculated as the difference between the July Food Security classification between 2014 and 2015. Classifies regions based on quantitative, context and expert opinion, to give a ranked classification: Minimum (1), Stressed (2), Crisis (3), Emergency (4), or Famine (5).	IPC, 2012

Table 3.1: Health indices are used to assess food insecurity outcomes

Index	**Calculation and Units**	**Description and Interpretation**	**Reference**
Consecutive Dry Day (CDD)	The maximum number of consecutive dry days (when measured daily precipitation mean is less than 1mm) during June-September (count of days)	An indicator of the length of drought during the season. During the June – September period this is likely to be associated with the MSD Duration. CDD however, reflect the period during which there is no rainfall (<1mm/day) rather than a depression in rainfall.	Schulzweida, 2019
Seasonal Rainy-Day Count	Count of days when measured daily precipitation mean is more than 1mm in June-September (count)	Indicates the number of days during the growing season that receive rain (June-September season has a total of 122 days). A general indicator useful to characterize the climatology of a region.	Schulzweida, 2019
Seasonal Precipitation Total	Total cumulative precipitation calculated by the sum of daily precipitation values through June-September (mm)	An indicator of much rainfall an area receives over the growing season, a general indicator useful to characterize the climatology of a region.	Schulzweida, 2019
Mid-Summer Drought (MSD) Intensity	The difference between the maximum and minimum precipitation values of the bi-modal seasonal rainfall distribution (in a rolling 30 days average of daily precipitation) (mm/day)	The intensity of the MSD indicates how strong the bi-modal distribution of rainfall is. High intensity indicates either high precipitation during peaks, or low minimum, or a combination of both, reflecting the strength of the climate phenomenon driving the MSD. The historical average range across the CADC is 4-16 mm /day.	Maurer et al., 2017
MSD Duration	The number of days between the two peaks of the bi-modal seasonal rainfall distribution (in a rolling 30 days average of daily precipitation) (days)	Duration of the dry period between the two peaks of the bi-modal distribution, so is an indicator of the length of drought. Historical averages range between 50 and 100 days across the CADC.	Maurer et al., 2017
MSD Minimum	The minimum value of daily precipitation taken between the two peaks of the bi-modal seasonal rainfall distribution (in a rolling 30 days average of daily precipitation) (mm/day)	Minimum precipitation is an indicator of how dry the MSD or 'canicula', and therefore indicates the severity of drought. The historical average range across the CADC is 0-12 mm /day.	Maurer et al., 2017

Table 3.2: Climate Indices

Index	Calculation and Units	Description and Interpretation	Reference
Assets Composite	A composite of four household asset-based questions asked in the DHS, 2015.	Scored based on the presence of electricity, radio, tv and a fridge within the household, each marked as a 1, if not 0. Averaged to derive a 0-1 score range. The presence of electricity, a radio, tv and a fridge are indicators of assets accumulation and the presence or absence in a household is a useful indicator differentiate socio-economic status, as well as an indicator of household capabilities.	ICF, 2015
Built-population	A proportional value from 0 - 1 is derived from Global Human Settlement Layer (GHSL) dataset from 2014	Build Population is a direct indicator of an urban or rural living environment. Distributed with DHS.	Pesaresi et al., 2017; Mayala et al., 2018
Livestock (cattle)	Derived from the Gridded Livestock of the World (GLW) v2.0 database produced in 2007	Densities of each of the main livestock kept by households in Guatemala. Distributed with DHS.	Robinson et al 2014., Mayala et al., 2018

Table 3.3: Socio-economic and environmental co-variables

3.1 Food security indicators household survey data and FEWSNET status

DHS population, health, and anthropomorphic data were collected at a national level in Guatemala in 2015 (IPC 2019). DHS uses a two-tier sample strategy, and weightings based on population density (urban or rural) and response rates to construct a sample of the population that is representative at national and regional scales (at the level of the Department administrative boundary in Guatemala), over 900 households were selected per department, with the exception of the Department of Guatemala, which had over 1200 to reflect the higher population density in and around Guatemala City. Thus, in the 2015 survey a total of 21,662 households were selected with a response rate of 99% of selected households completing the survey (MSPAS/INE/ICF 2017).

Data is geographically labelled at the level of a cluster of households, (ranging from 2-70 households per cluster) with random displacement of cluster coordinates to protect privacy of participants, by up to 5km in rural locations and 2 km in urban locations. This magnitude of displacement does not affect the accuracy of this analysis, as DHS derived health indices are aggregated to a 0.25 x 0.25 degree grid scale.

Two health indices derived from the DHS were selected to represent different health outcomes of malnutrition, among other drivers such as socio-economic status and illness, detailed in Table 3.1. World Health Organization (WHO) stunting and wasting indices, reported as prevalence in children under 5 years old (Table 3.1), are those most commonly used for development monitoring such as progress towards the sustainable development goals (United Nations Development Group 2017), for malnutrition monitoring and as an index of socio-economic development (UNICEF, 2015; World Development Indices, 2019).

Stunting and Wasting indices are calculated, using household weights and reported with the DHS survey data, as a z-score, where the standard deviation of height-for-age (stunting) and weight-for-height (wasting) are compared to the mean of a distribution measured in a health and nourished population as a standard. Wasting or stunting is defined as moderate if a child's measured score falls below two standard deviations of the mean standard, and severe if below three standard deviations of the standard mean (MSPAS/INE/ICF 2017).

FEWSNET provide an early warning system for famine prevention and produce a spatially disaggregated dataset of historic changes in food insecurity, a ranked categorical variable with five levels: Minimal, Stressed, Crisis, Emergency and Famine. The derivation of FEWSNET classification is based on a standardised assessment protocol 'integrated phase classification' that is informed by quantitative analyses of risk factors associated with food insecurity, such as climate indicators, market prices, and rapid food assessment, but also utilises expert analysis of these evidence in a local context. In this protocol the assigned status is considered a working consensus of a group of technicians who represent different in-country stakeholders, the iterative process of phase classification assesses evidence and guides a process of convergence and consensus building among the technicians (IPC 2019). The phase classification applies a multi-step conceptual framework, where the classification is ultimately guided by changes in nutritional status and related mortality. These are understood as outcomes of changes in food consumption, livelihood and health status, which in turn are driven by changes in food security (availability, access, and utilization) and nutrition (caring and feeding practises and health and sanitation services). Finally, these factors are all considered within the context of non-food related mortality, other acute events and ongoing conditions, existing vulnerabilities, resources and governance structures (Ibid.). We utilise the FEWSNET Food Security Phase Classification dataset, to provide a more responsive and locally grounded indicator of changes in food insecurity experiences that identifies the risk of acute under-nutrition, to complement the DHS derived biophysical indicators. It provides an indicator that is able to identify both positive and negative changes in food insecurity over relatively short time-scales, due to its triannual interval of classification updates.

Geographical co-variables were prepared and distributed with DHS data, and those included in this analysis are listed and detailed in Table 3.3. A composite indicator of household assets was also derived from the Guatemala 2015 DHS dataset, and aggregated to cluster then grid-scale following the same methodology as the DHS food insecurity indictors.

3.2 Climate data and calculation of climate indices

Climate indices included in the analysis are listed and described in Table 3.2. Climate indices were calculated from gridded daily precipitation observation data from Climate Hazards group Infra-Red Precipitation with Station (CHIRPS) at 0.25 x 0.25 degree grid resolution for all full-years available (1981-2017) (Funk et al. 2015). This high-resolution data-set has been shown to replicate key characteristics of precipitation across Central America despite its high spatial heterogeneity, this included its representation of the dry corridor region, which is the characteristic of importance to this analysis (Hidalgo et al. 2017). A range of drought-based indices were selected to characterise the precipitation profile that occurs during the June-September growing season, listed and described in Table 3.2. Indices were calculated from CHIRPS data, at the grid scale resolution, using the Climate Data Operator as documented in the CDO manual (Schulzweida 2019), apart from the MSD indices, that were calculated in R as described in (Maurer et al. 2017).

The intensity, duration and minimum precipitation of the drying phenomenon that tends to occur mid-growing-season, locally termed the 'canicula' (Figure 3.2), were calculated using MSD indices (described fully in Table 3.2). By applying a rolling window averaging over 30 days, the onset of the MSD is defined as the first peak precipitation day during May-October, and the end of the MSD is defined as the day of the peak precipitation on the ultimate peak also during this timeframe (normally the second of the season, in a bi-model distribution). MSD duration is defined as the number of days between the onset and end of the MSD, the minimum precipitation is the minimum precipitation between the two peaks, and the intensity is the difference between the minimum and an average of precipitation maximum at the two peaks (Maurer et al. 2017).

Climate data were analysed over different time periods in order to assess the relevance of climate to food insecurity outcomes over both acute and chronic timescales. For the acute food insecurity analysis, climate indices were calculated for the primary growing season in 2014; the principal growing season for subsistence crops prior to the lean season in early 2015 (Figure 3.2). Indices were calculated as absolute values, and extreme indices were also calculated to indicate if the 2014 value, for any given index, fell into the 5th and 10th or 90th and 95th percentile of the 1981-2017 distribution. For the chronic food insecurity analysis the climatological mean was also calculated by averaging across the 1981-2017 period.

3.3 Spatial and statistical analysis

The statistical model is applied in this analysis to test associations, their relative significance and spatial distributions, but not to build a predictive model of food insecurity outcomes.

DHS data downloaded as spatially tagged clusters of households was aggregated to the climate grid scale, DHS indices were first calculated at the cluster scale, using household weightings provided by DHS in averaging, these values were then averaged across all clusters in each grid. CHIRPS data is a global data set covering land and ocean; only grid cells that intersected with DHS data in Guatemala were selected for the spatial analysis. FEWSNET food insecurity classification data, and DHS co-variables were also up-scaled to match the CHRIPS grid, using a spatial weighted mean.

Food insecurity indices with higher prevalence and spatially distributed patterns of prevalence were selected to include within the statistical analysis. Separate models were built for acute and chronic food insecurity outcomes. Prevalence of stunting was selected as the dependent variable as an indicator of chronic food insecurity. For acute food insecurity changes in the prevalence of wasting values were regionally in the low-medium threshold, and the national average was less than 1% indicating no presence of widespread crisis or famine as defined and reported Guatemalan Ministerio de Salud Pública y Asistencia Social (MSPAS/INE/ICF 2017). FEWSNET classification change from July 2014 to July 2015 was therefore selected as the dependent variable as an indicator of the risk of acute food insecurity, due to the stronger signal and spatial distribution of the variable (Table 3.4, Figure 3.3).

Given the high variability in value ranges across variables, all independent variables that were not proportions were scaled and centred to input as a z-score. Ordinary least squares (OLS) regression models were built to explore the relative strength of each of the climate, socio-economic and environmental variables in each model (Venables and Ripley 2013). Variables in Table 3.1, 3.2 and 3.3, were added in a multi-directional stepwise approach to learn each model, by minimising the Akaike information criterion (AIC) at each step. Rainy Day Count and Total Seasonal Precipitation were used to characterise the climatology, but were not included as independent variables in the statistical analysis as they were strongly correlated to other included climate indices with more relevance to the research question (SI 1 and 2 - Appendix 2).

We selected socio-economic indicators most related to the grounded understanding of the drivers of food insecurity derived from interviews in the dry corridor in Beveridge et al. (2019): livestock density; household assets as an indicator of the use of savings and assets as a coping strategy and general household capabilities; and built population as a indicator of access to amenities. Tests of spatial correlation (if the median R^2 estimate > 0.6) and variance influence factor (VIF) (if the VIF > 10) were two criteria used to identify and reduce effects of collinearity and variable inflation, but none of the variables included in the learnt models met this criteria for exclusion.

As the dependent variable and some of the independent variables display significance of spatial heterogeneity, spatial correlations were plotted to identify in which regions correlations existed, and to signify how heterogeneous and spatially consistent the relationships between variables is (SI 1 and 2 - Appendix 2). Formulae learnt from the OLS based analyses (Table 3.4) were then input into a geographically weighted regression (GWR) model (Gollini et al. 2013). The optimal bandwidth was selected using the drop-one cross validation method to identify a globally-fixed bandwidth, applying a Gaussian kernel function to derive weights:

w(g) = e-(1/2)(d/h)2

Where w is the weight of an observation (g), d is the distance between an observation and a point of estimation (Euclidian distance), and h is the bandwidth (Brunsdon et al. 1996).

4 Results

4.1 The distribution of food insecurity outcomes in Guatemala

Acute and chronic food insecurity indices had different geographical distributions (Figure 3.3, SI 3 - Appendix 2). Figure 3.3 illustrates that the highest prevalence of stunting – an outcome of chronic food insecurity or illness- was located in the Western Highland region, which was also the region with the highest variance in the inter-quartile range of the geographically weighted average (Figure 3.3). The FEWSNET food insecurity classification is ranked from 1-5, where 1 is minimal food insecurity and 5 indicates the occurrence of famine, a positive change in classification therefore indicates a situation of deteriorating acute food insecurity, but only reflects the change, not the resulting severity of the situation. The strongest deterioration in the food insecurity situation between 2014 and 2015 was observed in Alta Verapaz, and a small section in the Western Highlands, and with high variance across the CADC region (Figure 3.3).

4.2 Characterizing drought in the three year summer

Climate indices characterising drought in the growing season of 2014 in Guatemala are displayed in a panel in Figure 3.4. Seasonal precipitation total, rainy day count, MSD Intensity and MSD Minimum have similar spatial distributions with drier conditions in a central band extending East to West, which corresponds to the average climatology (Figure 3.5) and aligns with previous characterisations of the CADC (FAO 2012; Quesada-Hernández et al. 2019). MSD indices in 2014 show a similar spatial distribution to the 1971-2017 averages, though the MSD was more intense, longer in duration and with a lower minimum precipitation in the 2014 season compared to average (Figure 3.4 and 3.5).

4.2.1 Correlations between drought indices

There was some level of spatial correlation between all climate indices (SI 1 - Appendix 2), which is unsurprising as they are all driven to a minimal extent by the ENSO phenomenon, but the strength of these correlations was also in some cases highly spatially disaggregated (SI 1 - Appendix 2). For example, the CDD is likely driven by the MSD, as a higher MSD Intensity is associated with a shorter CDD, but this relationship is only shown in the Western Highlands where the climatology is wetter. In the CADC the opposite observation was made; the mean CDD was very weakly and positively related to mean MSD Intensity. The 2014 CDD 95th percentile index also showed a very weak and localised positive correlation with 2014 MSD Intensity and Duration (SI 6 - Appendix 2).

The drought in Guatemala in 2014 was also characterised by an extended dry period compared to average, where the maximum number of consecutive dry days (where precipitation was less than 1mm) fell above the 95th percentile of the 1981-2017 distribution. This was observed in the North-East region (Figure 3.4) coinciding with the deterioration of acute food insecurity in the same location (Figure 3.3), and this association between variables is significant in the OLS model of acute food insecurity (Table 3.4).

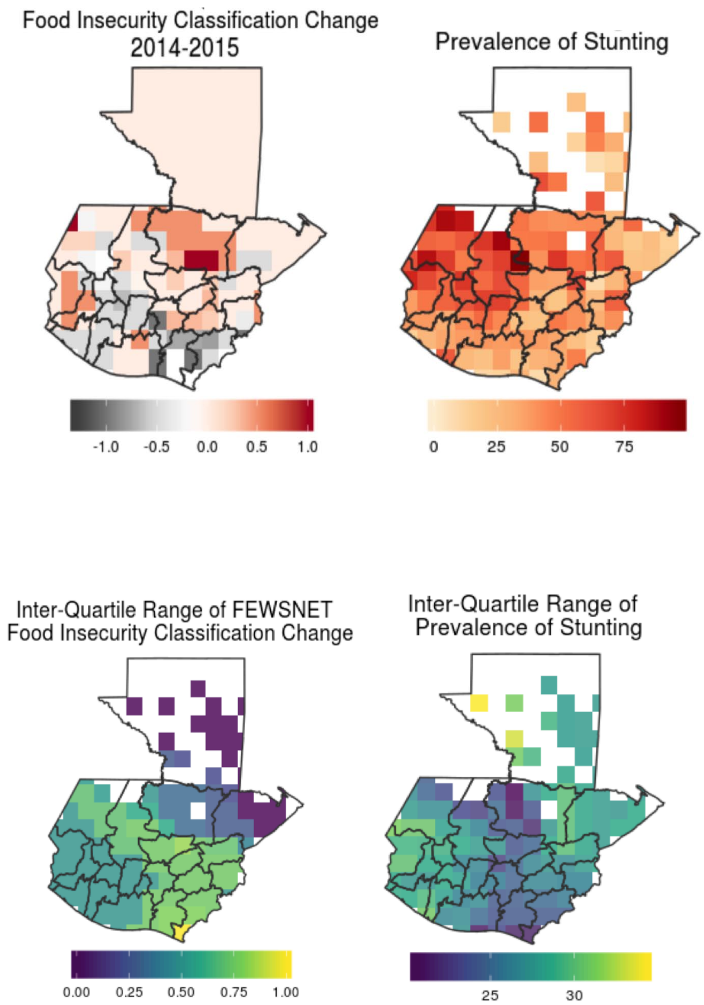

Figure 3.3: Map of prevalence of stunting and FEWSNET food insecurity classification in Guatemala

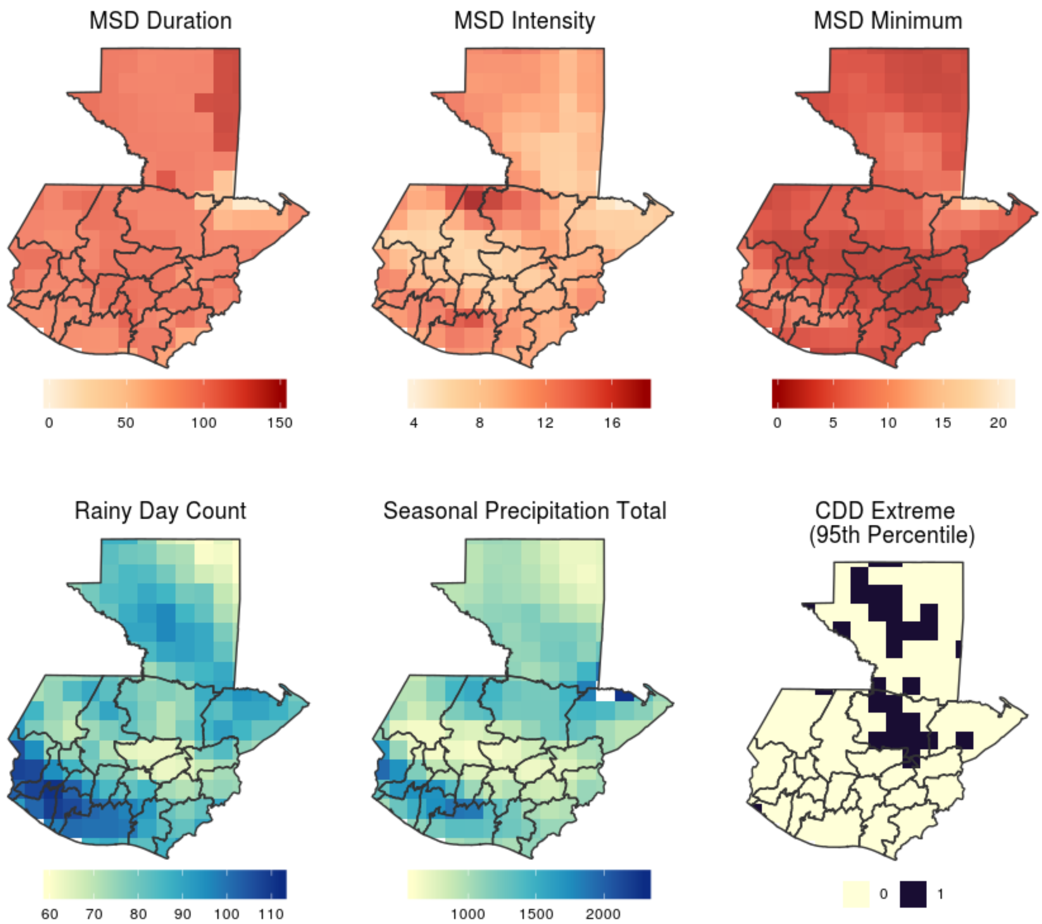

Figure 3.4: Maps of climate indices characterise drought and precipitation of the 2014 June to September growing season

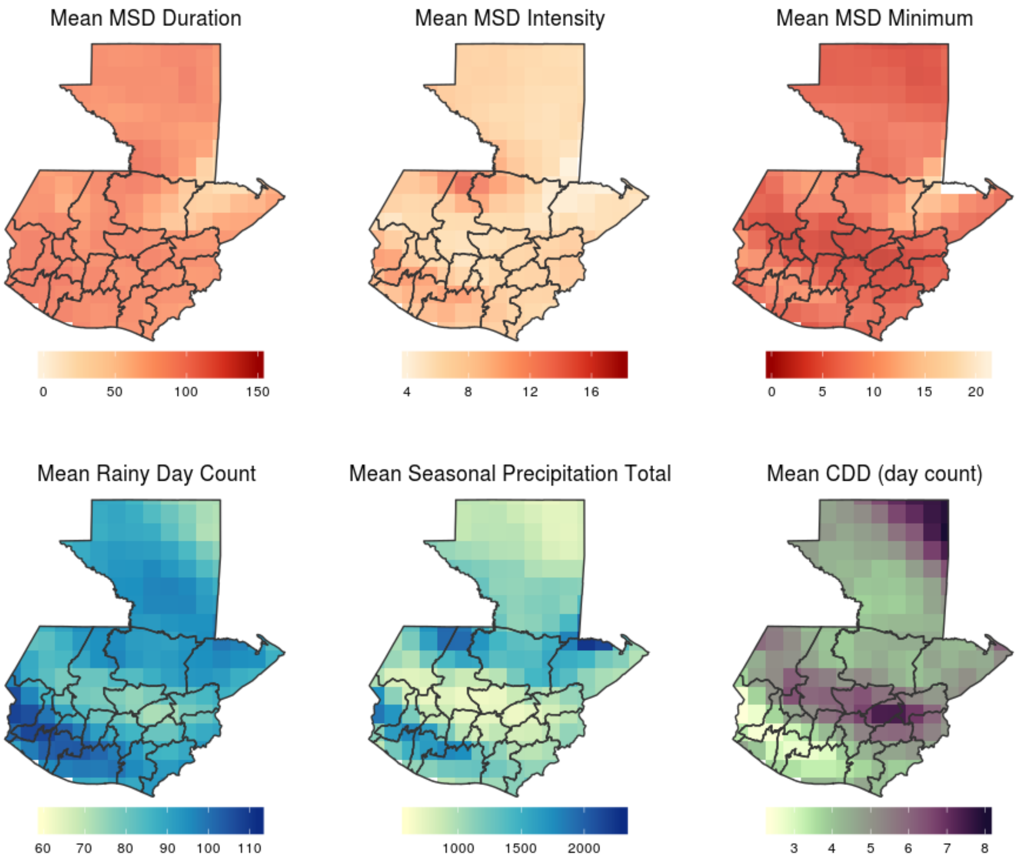

Figure 3.5: Maps of climate indices characterising drought and precipitation of the June to September growing season, average of 1981-2017 period

4.3 Model results

Both acute and chronic food insecurity outcomes were associated with an MSD index when socio-economic variables were included in the OLS model:

4.3.1 Chronic food insecurity

The average MSD duration was significantly positively associated with higher prevalence of stunting. Assets composite and livestock density were also both negatively and significantly associated with a higher prevalence of stunting (Table 3.4). These were all significant, though the estimate of assets composite had a large 95% confidence interval indicating a high degree of uncertainty in its effect. Variables not included in learnt OLS model were MSD Intensity, MSD Minimum, CDD, and built environment, as they did not contribute to a decrease in AIC in the stepwise model building process.

4.3.2 Acute food insecurity

The FEWSNET classification model result was more varied and included more climate variables relating to different aspects of the drought. MSD Duration, MSD Minimum and the 95th percentile CDD index values for 2014 were the climate variables included in the learnt model presented in Table 3.4. A longer duration of consecutive dry days and a lower minimum MSD rainfall were both significantly associated with a deteriorating food insecurity classification between 2014 and 2015. Assets composite was significantly negatively associated with a deterioration of food classification. Variables not included in learnt OLS model were livestock density and MSD Intensity.

These results indicate that it is possible to identify the association of drought with both acute and chronic food insecurity outcomes at a national scale, despite the complexity of food insecurity drivers and outcomes locally. However, the estimate effect is small (Table 3.4), illustrating that the models only explain a small proportion of the variability in food insecurity outcomes. The inclusion of assets and livestock in the model also indicate the importance of socio-economic status - a widely conserved finding in similar studies across countries and contexts (Phalkey et al. 2015). This association is supported theoretically as interviews with participants in the CADC region during this time period identified how the drawing down of assets and livestock were key coping strategies during the drought event, and acted as a buffer to the impact of drought on food insecurity outcomes (Beveridge et al. 2019).

4.4 Summary of spatial differences in model estimates

OLS modelling assumes that the process being modelled is spatially heterogeneous; conserved across geographies, and that there is no spatial auto-correlation within variables. The associations between drought and food insecurity outcomes however were not consistent spatially across Guatemala (SI 4 and 5 - Appendix 2). GWR results show that some variable effects are strongly spatially patterned, indicated by the range of local estimates displayed in Table 3.4 next to the presented OLS model global estimates. These ranges were (comparatively) highest for MSD Duration and assets variables in the chronic model, and CDD 95th percentile index and assets composite in the acute model. This spatial variability in estimate effects indicates spatial heterogeneity in the model, and justifies the use of a GWR to account for spatial autocorrelation in the modelling process.

The distribution of mapped local R^2 values indicates that both models have higher explanatory power in the CADC region (Figure 3.6), confirming that the climate-food insecurity relationship is most relevant and conserved in this region, while the Western Highlands region is less well explained by these models and is likely to have other more important drivers outside of those included within the bounds of this study.

A limitation of the use of GWR methods in this context is that the results are likely to be sensitive to the methods of data aggregation. For example, aggregation of data could explain why the association between assets and livestock was characterised by regions of both positive and negative estimates, which can be difficult to interpret (Brunton et al. 2017). Small pockets where livestock and assets negatively correlate with food insecurity outcomes (SI 4 and 5 - Appendix 2) could be a product of high inequality, as the average of the aggregated spatial unit (grid square) has potential to be positively skewed due to a small number of households holding a large amount of assets and livestock wealth — but this wealth has little affect on the general population and their food insecurity outcomes. The mapped local estimates can also be difficult to interpret directly when using a GWR because the estimate is an indicator of the effect of an independent variable on the dependent variable, but in interaction with all other included variables and their effects. This reduces the appropriateness of GWR analysis to directly inform targeted intervention, but it may have use to indicate key regions or variables that merit more in depth and exploratory analysis, which were not able to be identified in the OLS model result.

Despite this limitation to the interpretation of spatial patterns directly, the GWR results present robust evidence that the associations between climate indices and food insecurity outcomes are not spatially consistent across the country, and in the case of the CDD 95th percentile index, highly localised (Figure 3.4, Table 3.4, SI 1 and 5 - Appendix 2). The impact of drought is more closely associated with both acute and chronic food insecurity outcomes in the CADC region, compared to the Western Highlands (Figure 3.6), and that associates of food insecurity evidenced in broad scale analyses cannot be assumed to be spatially consistent across Guatemala despite significance of a global model.

	OLS Model Result			GWR Model Result				
	Estimate p-value	**OR**	**95% Confidence Interval**	**Min**	**1st Qt**	**Median**	**3rd Qt**	**Max**
Prevalence of Stunting (%) R-Sq = 0.32, p < 0.001, VIF = 1.5 (OLS)								
intercept	73 ***	6.3 ^{e31}	1.1 ^{e27} to 3.6 ^{e36}	22	66	79	92	111
MSD Duration	7.3 **	1.5 ^{e3}	7.5 to 2.8 ^{e5}	-42.4	0.5	4.5	8.7	28
Assets Composite	-57 ***	1.3 $^{e-25}$	9.0 $^{e-34}$ to 1.9 $^{e-17}$	-101	-79	-62	-45	38
Livestock density	-3.1 ***	4.7 $^{e-2}$	1.6 $^{e-3}$ to 1.4	-7.3	-3.6	-2.1	-0.6	6.9
FEWSNET Food Insecurity classification change (2014-2015) R-Sq = 0.17, p <0.001, VIF = 1.2 (OLS)								
intercept	-0.16	1.8	0.9 to 1.6	-2.78	-0.26	0.07	0.18	0.58
MSD Minimum	0.27 *	1.3	1.0 to 1.6	-1.78	-0.04	0.01	0.23	0.75
MSD Duration	0.26 *	1.2	1.0 to 1.5	-0.96	-0.07	0.01	0.27	0.83
CDD 95th Percentile	0.20 .	1.3	1.0 to 1.8	-0.39	0.06	0.39	0.58	2.26
Assets Composite	-0.55 *	0.6	0.3 to 1.0	-1.88	-0.50	-0.19	0.15	3.29

Table 3.4: Models of prevalence of stunting and change in FEWSNET food insecurity classification in Guatemala using ordinary least square (OLS) regression with R2 and Variance Influence Factor (VIF) for each model, and p-values of significance, odds ratios (OR), and 95% confidence interval for each variable estimate. Thresholds of p-value significance are indicate by: *** (0.001), ** (0.01), * (0.05) and . (0.1). Summary statistics of estimates for the same formula in a geographically weighted regression (GWR) are also given for each model

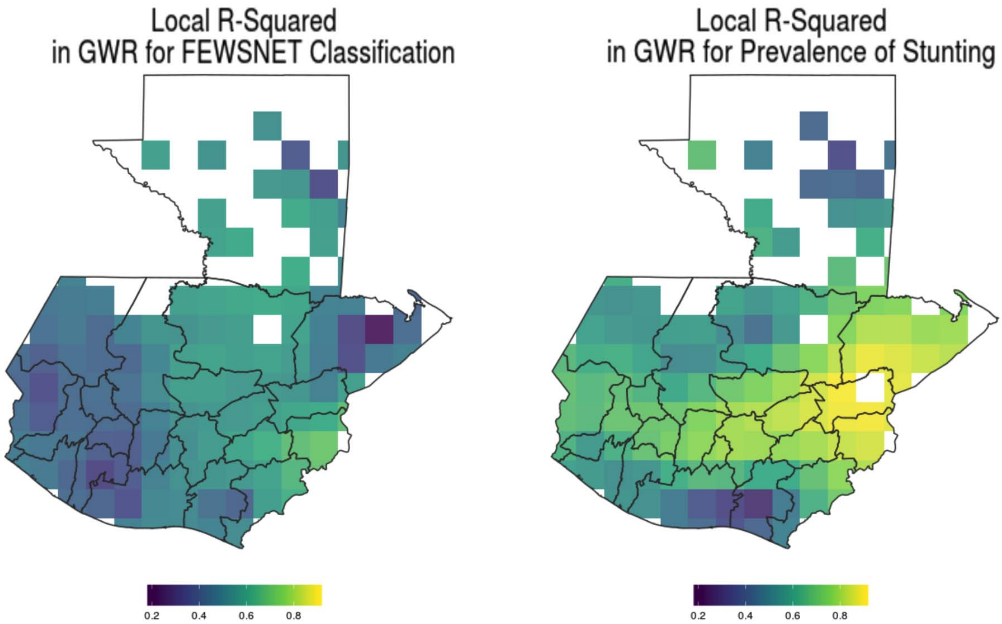

Figure 3.6: Local R^2 values for the geographically weighted regression models of prevalence of stunting and FEWSNET classification change between 2014 and 2015, indicate how the explanatory power of each model is distributed spatially across Guatemala

5 Discussion

5.1 Drought indices for food insecurity early warning

The association between both MSD and CDD extreme indices in the 2014 growing season and FEWSNET classification indicates their inclusions within a toolbox of indicators used in food insecurity early warning systems may be useful.

A government coordinated early warning system for food insecurity developed in Guatemala by La Secretaría de Seguridad Alimentaria y Nutricional currently uses a dry day count as its climate based index, which relates to the absolute CDD index used in this analysis (SESAN 2015; Muller et al. 2019). The significance of CDD 95th percentile index in the acute model supports the use of dry day count in this early warning system, but also illustrates that the CDD index calculated as a percentile may provide a more spatial distinct indication of the increased possibility of acute food insecurity outcomes. By identifying when a location (a grid cell in this incidence) is at a high or low extreme for its average distribution, the CDD 95th percentile index is defined by deviation from a local norm, thus is also normalised for the climatology of each region, and therefore also does not strongly correlate with other indices describing the general climatology of the growing season (SI 1 and 6 - Appendix 2). As this analysis was situated at a single time point, a useful next step would be a time-based analysis of the MSD, CDD and CDD percentile indices to better understand the dynamics of their spatial association, and their relationship to the driving phenomenon ENSO.

The CDD 95th percentile index – or similar indices of extremes based on local distributions – may be a useful addition to the early warning system as it is able to indicate locations when households are likely to be experiencing an unfamiliar (1 in 20 years if the 95th percentile is used) climate condition, therefore indicating where households are more likely to be employing adaptation or coping strategies, such as drawing down on assets or selling livestock (Beveridge et al. 2019) and entering the next lean season in a more vulnerable condition — an important precursor to a deterioration in food security identified by participants in the CADC (Ibid.).

5.2 Adapting for long term food security

Climate change projections in Central America show an increase in the duration of the MSD in specific locations (Anderson et al. 2019), and a general robust trend toward drier conditions, with impact model projections indicating severe effects on agricultural production as a result (Schmidt et al. 2012; Baca et al. 2014). To avoid food security deteriorating under future climate change, some households will need to integrate adaptation to a changing and potentially novel climate into livelihood decision making, however, the relationship between the MSD and food insecurity outcomes is not consistent across food insecure regions of Guatemala, and is contingent on socio-economic status. Adaptation and climate proofing of intervention will therefore require locally relevant information on changing climate and its impacts on agriculture rather than an imported set of climate resilient practises (Beveridge et al. 2018).

6 Conclusions

The duration of the MSD is projected to increase with climate change, and shows high inter-annual variability, which threatens food security through multiple pathways of impact, mostly relating to the effect on subsistence and commercial agricultural production. This study presented a spatially disaggregated analysis of the association between MSD indices and both acute and chronic food insecurity outcomes across Guatemala. Acute and chronic food insecurity indices had very distinct geographical distributions. Prevalence of stunting was highest and most variable in the Western Highlands region whereas the change in FEWSNET food insecurity classification was highest in concentrated pockets within the CADC, and most variable across the CADC region. The duration of the MSD is significantly associated with both prevalence of stunting, and the change in FEWSNET food insecurity classification in 2014-2015. Deterioration of the FEWSNET classification change was also associated with an indicator of local extremes in the number days without rain during the growing season, and the minimum 30-day rainfall average during the MSD. These associations were contingent on the inclusion of indicators of socio-economic status in the regression model, indicating the importance of assets and livestock as coping mechanisms. The association with MSD indices were also strongly spatially disaggregated across food insecure regions, and models indicate that climate is a more closely associated with food insecurity outcome in the CADC region, but that other factors – outside the system boundary of this study – are likely to be more important in the Western Highlands region.

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Chapter 4

Crop Modelling Towards Locally Relevant and Climate-Informed Adaptation

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Crop modelling: towards locally relevant and climate-informed adaptation

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Abstract A gap between the potential and practical realisation of adaptation exists: adaptation strategies need to be both climate-informed and locally relevant to be viable. Place-based approaches study local and contemporary dynamics of the agricultural system, whereas climate impact modelling simulates climate-crop interactions across temporal and spatial scales. Crop-climate modelling and place-based research on adaptation were strategically reviewed and analysed to identify areas of commonality, differences, and potential learning opportunities to enhance the relevance of both disciplines through interdisciplinary approaches. Crop-modelling studies have projected a 7–15% mean yield change with adaptation compared to a non-adaptation baseline (Nature Climate Change 4:1–5, 2014). Of the 17 types of adaptation strategy identified in this study as place-based adaptations occurring within Central America, only five were represented in crop-climate modelling literature, and these were as follows: *fertiliser*, *irrigation*, *change in planting date*, *change in cultivar* and *area cultivated*. The breath and agency of real-life adaptation compared to its representation in modelling studies is a source of error in climate impact simulations. Conversely, adaptation research that omits assessment of future climate variability and impact does not enable to provide sustainable adaptation strategies to local communities so risk maladaptation. Integrated and participatory methods can identify and reduce these sources of uncertainty, for example, stakeholder's engagement can identify locally relevant adaptation pathways. We propose a research agenda that uses methodological approaches from both the modelling and place-based approaches to work towards climate-informed locally relevant adaptation.

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1 Introduction

Effective adaptation of agricultural systems to climate change requires cross-scale and cross-disciplinary understanding. In order for agricultural technologies or livelihood changes to be accepted and maintained, they should be appropriate to local socio-cultural and agro-ecological conditions. In order to be resilient to future climates, agricultural and rural development must be informed and designed around an understanding of longer term climatic change, which often requires wider scale, longer term and proactive planning. Thus, adaptation strategies need to be climate-informed and locally relevant. Major complexities exist in both the study of agricultural livelihoods and the study of future climate change and its potential impact. Each research community has a unique set of challenges, assumptions and an associated epistemology. These differences are potential barriers to cross-disciplinary research and knowledge exchange, so it is important to ask where are the shared goals and commonalities that can be exploited to further the field of adaptation science.

There is a recognised need to develop an adaptation science that is not limited by discipline (Klein et al. 2014; Smit and Wandel 2006; Bhaskar et al. 2010) and is able to produce 'salient, credible and legitimate' knowledge that is relevant and responsive to the multiple temporal and spatial scales and the social, economic, political and environmental processes of agricultural systems (Keating and McCown 2001; Patt and Gwata 2002; Meinke et al. 2009). This is evident for example in the Future Earth strategic research agenda (Future Earth 2014), and in a growing variety of 'climate service' initiatives that seek to combine knowledge and disciplinary insights in contributing towards climate-informed locally relevant adaptation planning (WMO 2014). However, there are many barriers and challenges associated with cross-disciplinary research across individual, community and institutional levels (National Academy of Sciences 2005; Naess 2013; Shaman et al. 2013). For example, the socio-economic complexities of agricultural and non-agricultural pathways of decision-making and change can be difficult to represent within the limitations of physical simulation models. At the same time, the complexity of the physical science that underpins modelling approaches can be difficult to communicate to those without specific technical expertise (Whitfield 2013). These challenges can be compounded by the epistemological and cultural differences between physical science disciplines and the societal research and action.

In this paper, we specifically focus on the challenge of integrating place-based and crop-climate modelling research. Place-based research focuses on the local and contemporary dynamics of the agricultural system and in doing so can represent local and experiential knowledge. Complimentarily, climate-crop modelling has the capacity to project scenarios of future climatic variability and extend understandings of farming systems across spatial and temporal scales. For modellers, the process of working with stakeholders and place-based researchers can enable to identify a set of wider contributing factors that engage with and affect agricultural livelihood decisions and food security, such as food storage capacity, political security, policy incentives, capital, cultural identity, access to inputs and markets and sustainability goals. This breadth of system boundary and system thinking makes apparent the challenge of a robust predictive tool for the assessment of future food security (Whitfield et al. 2015a, b).

Through a systematic literature review, we identify the contribution that these distinct communities make to agricultural adaptation research. Through this analysis, we identify key areas where the two communities can learn from and inform each other, focussing on practical objectives for better integration of research, such as, how can crop models simulate more realistic adaptation? We first identify the epistemologies of adaptation research (Section 2.1), before going on to describe the two main approaches that we identify (-Section 2.2, modelling; and Section 2.3, place-based). Using the methods outlined in Section 3, we then employ this typology to analyse adaptation research in Central America and to identify the commonalities and differences between the two fields (Sections 4 and 5). The paper concludes with a suggested research agenda for tackling some of these asymmetries and building an interdisciplinary evidence base to inform agricultural climate change adaptation (Sections 5 and 6).

2 Background

2.1 Epistemologies

> "To understand the world it has seemed necessary to analyse it by breaking it into many pieces. But to act in the world, to try to address the issues for which highly specialized knowledge was presumably sought, we need somehow to reassemble all the pieces".
> Easton et al. 1991—"Divided Knowledge: Across Disciplines, Across Cultures"

As academic disciplines have evolved, they have inevitably developed their own theoretical bases, norms of investigation and accepted epistemologies. The characteristic positivism of the physical sciences underpins the systematic hypothesis testing and controlled experimentation that have become synonymous with these disciplines. This contrasts markedly with a constructivist epistemology that suggests that our knowledge of the world is not objective but subject to human constructs, which has become the basis of branches of sociological study and participatory forms of knowledge co-production (Berger and Luckmann 1966; Giddens 1976). Fundamental differences in philosophies of knowledge are manifest in diverse disciplinary cultures, approaches, methods and languages (Biglan 1973).

Developments in general systems theory (Von Bertalanffy 1968) are associated with attempts to reintegrate or work across disciplines as a means to understanding the complexities of the real world. It has broad applications in farming systems (Collinson 2000; Darnhofer et al. 2012), socio-ecological systems (Folke 2006; Young et al. 2006; Lambin and Meyfroidt 2010) and climate systems (Franzke et al. 2015). Real-world systems are inextricably physical, natural, social, economic, cultural and political in nature, resulting in system behaviours that individual disciplines lack the tools to understand and predict. The physical processes of climatic change, for example, are not independent of the underlying social, economic, political causes of anthropogenic emissions, which are themselves not independent of the agricultural and land management choices or market properties that shape vulnerabilities to different climate regimes. One of the important contributions of general systems research has been recognition of valuing local and contextual knowledge. Farming systems research, in particular, has been synonymous with innovations in participation and the 'farmer first' movement in research in developing country contexts (Chambers 1990; Scoones et al. 2009). Tools of participatory rural appraisal and participatory crop breeding engage stakeholders within the research process, recognise the relevance and value of local knowledge and thus have sought to make it central to intervention planning within farming systems. But the integration of these place-based knowledge with those of physical and modelling science has continued to represent a challenge which is arguably an epistemological one (a challenge of different understandings of knowledge) as much as it is a methodological and practical one.

2.2 Modelling approaches

The modelling community that is addressing agricultural adaptation generally subscribes to top-down approaches described in Intergovernmental Panel on Climate Change (IPCC) Assessments (Mimura et al. 2014), as depicted in Fig. 1a, using simulations to project a future impact as a starting point. The term 'Crop modelling' refers here to studies that use process-based crop models to simulate the impact of weather, climate and management decisions on yield. Crop-climate modelling is further distinct in its use of general circulation models (GCMs) with crop models to project the impact of future climate change scenarios on yield or production. This approach has been applied from field to global scales (e.g. Jones et al. 2003; Challinor et al. 2004, 2014). Research to date has highlighted where significant changes in productivity are expected in response to climate change across the world, as well as modelling changes in crop suitability (Lane and Jarvis 2007; Rosenzweig et al. 2014; Rippke et al. 2016). Vermeulen et al. (2013) illustrate how crop-climate modelling and analyses can pre-emptively inform the magnitude of adaptation required across a range of time scales. Process-based crop models have also been applied to direct future research and crop breeding (Heslot et al. 2014; Falloon et al. 2015; Challinor et al. 2016). The benefits of different adaptation strategies have often been compared by their relative impact on yield (e.g. Meza et al. 2008; Lobell et al. 2008; Challinor et al. 2009).

Challenges facing crop modellers attempting to inform adaptation are detailed in Challinor et al. (2018), to summarise: there is currently a limited model representation of the true dynamic adaptive management used by farmers (Quinn et al. 2011); there is an inherent difficulty in the attribution of a yield change to an adaptation compared to a non-adapted control (Lobell 2014); and there is the responsibility for research to contribute to knowledge and address societal challenges (Lubchenco 1998). The agricultural model intercomparison project (AgMIP) has explicitly recognised the need

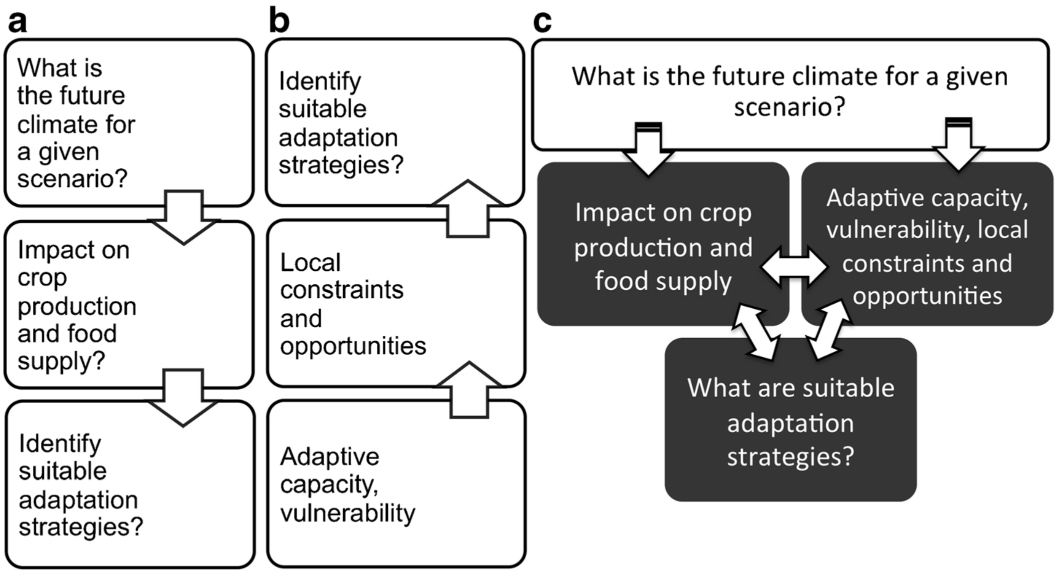

Fig. 1 Diagram of workflow typically used in top-down (**a**) and bottom-up (**b**) approaches to studying adaptation, developed from IPCC SREX Report (IPCC 2012) and Mimura et al. (2014), and a proposed iterative and interdisciplinary workflow (**c**)

for modelling communities to engage with stakeholders throughout the modelling process (Rosenzweig et al. 2015). However, the black-box nature of process-based crop models can be a barrier to their use in adaptation research as processes of parameterisation, bias correction, model stacking, and ensembles can propagate uncertainty, such that setting up of simulations and interpretation of output to determine risk requires a high degree of skill- and discipline-specific knowledge (Whitfield 2013).

2.3 Place-based approaches

"Place-based" is a term used here to describe methodological approaches that encounter context specific knowledge, as in place-based modelling for natural-disaster response, place-based policy and place-based teaching in education (Cutter et al. 2008; Barca et al. 2012). In the context of this research, we use the term place-based to refer to approaches that use context-specific or site-specific information and knowledge to inform adaptation research, akin to the term bottom-up in IPCC literature (Mimura et al. 2014), as depicted in Fig. 1b. Such approaches frame adaptation within a local context, considering factors that are specific to the geographical boundary in which the study occurs, for example livelihoods, culture, agro-ecology and constraints and opportunities experienced by stakeholders (e.g. Smit and Piliosova 2003; Claessens et al. 2012; Mimura et al. 2014). Place-based approaches may represent the influence of social structures, such as external actors, power and governance on the adaptation process (e.g. Arora 2012). Multiple framings and theoretical approaches can be encompassed within place-based research by this definition, including the application of adaptive capacity and vulnerability assessments (Olsson et al. 2014), studies of historical adaptation (Campos et al. 2013) and studies of agricultural decision-making and risk (Orlove et al. 2010).

The term "local knowledge" is used here to describe the knowledge held by a given society in a specific location. It is used to represent multiple sources of knowledge such as local ecological knowledge, indigenous knowledge or scientific knowledge, with recognition that these sources are not always distinct (Agrawal 1995). From an underlying constructivist epistemology, the drawing on and integration of local knowledge, as a way of interpreting context-specific realities, is a common trait of place-based research (Dessai et al. 2004). The World Bank handbook 'Participatory scenario development approaches for identifying pro-poor adaptation options' (The World Bank 2010) serves as an example of an applied methodology that engages stakeholder to inform adaptation decisions.

A limitation of place-based adaptation research is the capacity to work across scale: generalising results outside of the study group, study area and across timescales. The dynamic process of adaptive agricultural decision-making is an outcome of experience, histories (Dixon et al. 2014) and future perceived risk. In-depth but timeframe-specific studies therefore lack the temporal scale needed to understand cycles of adaptation, which can often be generational (Feola et al. 2015). An understanding of how risks may be reinforced or dampened by future climate change is also missing from place-based adaptation research that does not engage with climate and impact knowledge.

3 Methods

A meta-analysis of simulations of climate change impact on yield (with and without adaptation) was used to evaluate crop impact modelling literature. A database of over 1700 simulations, from 91 studies, as described in Challinor et al. (2014) and IPCC (2014) was used as an initial source of studies. Known relevant studies published since 2014 were added. Place-based literature on adaptation was evaluated through a separate strategic literature review of adaptation research that focussed within the case study region of Central America. A full description of the criteria for inclusion, and information recorded from included studies, is detailed in Table 1 of Supplementary Material.

4 Results

4.1 Adaptation strategies

The findings of the review indicate the limited proportion of on-farm strategies that climate-crop impact models currently represent in their application to the study of adaptation. Of the two different approaches, the range and focus of adaptations assessed in crop-modelling literature are only a sub-section of the range represented in place-based studies; fertiliser, irrigation change in cultivar, change in planting date and change in area cultivated were represented in modelling studies. These and 12 others were represented in place-based studies in Central America with a greater range of adaptation types (Fig. 2 and Table 2 of Supplementary Material).

4.2 Assessing adaptation outcomes in a place-based context

Out of the nine fully reviewed place-based studies, six reported practices for agricultural adaptation without attributing a change in production to the specific adaptation. Rather, qualitative evidence for the benefit of a practice was the cumulative result of questionnaires and focus groups with farmers based on their own perceived experiences of climate impacts on their crops, livelihoods and adaptation (Campos et al. 2013; Baca et al. 2014; Bacon et al. 2014; Eakin et al. 2014; Milan and Ruano 2014; Rahn et al. 2014). Porch et al. (2007) did calculate changes in production to assess the relative effect of climate variability as a driver of migration. They use their analysis to stress that vulnerability will be exacerbated by climate change, but without use of future climate scenarios or projections. Only four studies used climate projections to construct a quantitative scenario of future climate impact as a baseline for adaptation: Baca et al. (2014) and Rahn et al. (2014) both used downscaled GCM projections from SRES A2a, to drive a climate suitability model (MAXENT) to produce an indicator of exposure to climate change. This indicator of climate change exposure was then used as a point of discussion with stakeholders with the aim to identify locally relevant adaptation strategies based on this information. Ruane et al. (2013) and Schmidt et al. (2012) used future projections to drive process-based crop models; DSSAT, Ecocrop and CERES-Maize models were utilised to give a quantitative projection of future yield change. Ruane et al. (2013) illustrates the importance of household variables as input parameters to improve impact projections for yield on a regional scale. The study by Schmidt et al. (2012) uses crop impact models with climate projections (for maize-bean systems) and household information to calculate a household-specific indicator of exposure to climate change and adaptive capacity. This has enabled them to produce information that is informed by large-scale modelled future climate scenarios (A2, business as usual) with quantified uncertainty (generated by use of GCM ensembles, input in to DSSAT), but that is also locally relevant to

Fig. 2 Adaptation strategies represented in place-based literature, with a cross to denote those also represented in crop-modelling literature. Types of adaptation include change to inputs (orange), water management (blue), crop management (green), crop type (yellow), crop insurance (red) or livelihood (purple)

the specific area using local case studies. Studies by Baca et al. (2014) and Rahn et al. (2014) and Ruane et al. (2013) all discussed adaptation options post-impact assessment; there were no examples of studies that used an iterative process between researchers (impacts modeller, social scientist) and farmers to model the impact of local relevant adaptation strategies on households.

5 Discussion

Arnell's (2010) review of adaptation studies illustrated a gap between the potential and practical realisation of adaptation reported in literature. He suggests that local context might be a factor missing from existing adaptation studies that has the potential to bridge this observed gap. Our study has used a strategic review to assess whether place-based research that typically engages with local knowledge and local conditionality is being integrated with conventional physical modelling approaches to studying adaptation. In doing so, we identified explicitly the differences in approach, scope and aims of the two communities.

One of the key differences between approaches used by the modelling and place-based communities is the breadth of the systems studied (the system boundary, in modelling parlance). The crop-modelling studies reviewed simulated the crop, the climate, soil and sometimes to a limited extent, management practices. Their scale was field, regional or global, and they tended to focus on the accuracy and precision of yield prediction, uncertainty in future climate change and mitigation potential. Staple crops, namely wheat, rice or maize, were the represented crops in the majority of studies. The objective of adaptation was framed in model studies as to maintain or optimise yield under future climate conditions. The aim of crop-climate modelling studies was rarely to inform farm-level adaptation decisions, which may in part explain the limited capacity of crop-climate models to represent the range of adaptation occurring at that scale. However, these results suggest that given the flexibility and range of adaptation used by farmers, the comparatively limited range used in crop climate modelling may systematically bias projections of climate impact at regional to global scales if the error introduced at a plot scale is propagated through the up-scaling process (Hansen and Jones 2000). The regional scale of the place-based literature review (Central America) means that while identifying key limitations in modelling approaches, this study will only have highlighted a portion of the plethora of adaptation strategies used globally. Although crop-modelling effort to date has focussed on improving simulations of these five adaptation strategies, there is potentially greater understanding to be generated by starting to address the breadth of adaptation used in real-life farm management.

In comparison, place-based studies tended to have a broader scope, in systems terms, than modelling studies. The researchers or participants often defined the scope during the process of discussing and identifying relevant adaptations. This area of literature included a much wider range of adaptations, including crop insurance an economic adaptation, and more transformational type changes, such as diversification of livelihoods to change crops, introduce livestock or supplement income with off-farm sources. Other crop management-based adaptations included planting an over-story (agro-forestry), fruit tree planting (as individual crop or agro-forestry system), intercropping, windbreaks, reduced tillage (conservation agriculture) and crop-residue, manure or mulch (conservation agriculture), all of which affect production through interactions with soil-nutrient balance, soil-water balance, soil-water structure or wind, pest and disease damage. Finally, direct water management was another type of adaptation that aimed to reduce the impact of water stress on production by stabilising water access through water harvesting or changes in irrigation. The potential impact of an adaptation was more often informed by qualitative information, rather than discreetly calculated as a yield change. Adaptation recommendations made were therefore the most relevant at a local scale and at the time of the study. Regarding the use of climate information, Ruane et al. (2013) provide an example of how a place-based study can incorporate GCMs to make risk-based projections of possible future climates to inform adaptation decisions. However, we found that in some other studies, the magnitude or nature of future climate change was discussed only as a justification, rather than given as a calculated risk based on current climate science. The focus of place-based studies was often the household or community, a measure of production, income, wellbeing, climate exposure or resilience. This reflects the broader set of objectives and drivers of household scale adaptation, which although are often related to agricultural production and food security are not centrally framed around maintaining maximum yield.

Given the corresponding strengths and limitations of each approach discussed so far, summarised in Table 1, an obvious potential development for adaptation research is to integrate the capacities of each approach to enable local knowledge and context to inform modelling research approaches and vice versa. A mechanism for doing this is by integrating the previously identified top-down and bottom-up approaches from Fig. 1a, b, into the process represented in Fig. 1c. In this new framework, place-based and crop-climate modelling methodologies are both equally viable starting points to identify relevant adaptation strategies. Through a clockwise or counter-clockwise workflow, the local viability and impact of a strategy, given a future climate scenario, can then be assessed in iterative cycles in a participatory way. It is in this iterative link between disciplines where asymmetries may become most apparent as a barrier to progress, especially with respect to the differences in scale of systems being studied and data availability. But equally, this suggests it is the interface where productive steps forward in understanding and integration can be made. The following section sign-posts four pathways to enable better knowledge and information exchange between communities to work towards this iterative adaptation research process, and these are as follows: (i) descriptions of practices, (ii) developing adaptation within crop-climate modelling, (iii) modelling with stakeholder engagement and (iv) understanding the objectives of adaptation.

5.1 Descriptions of practices

A shared understanding and definition of an adaptation strategy is a pre-requisite of knowledge and information transfer between communities. In some cases, general terms and titles are used in place-based literature, such as conservation agriculture or agro-forestry. While these terms have general agreed definitions within social literature, they are open to interpretation (to enable locally appropriate adaptation). This makes forming an evidence base, datasets and model parameterisation from which to assess their potential impact across temporal or spatial scales difficult. Explicit descriptions of an adaptation, where discussed, would aid translation between place-based and modelling research. For example, Rahn et al. (2014) describe their use of the term ‘soil conservation’ was specifically in reference to planting within contour lines and using organic fertiliser and pesticide inputs. This could be more easily translated into a model impact assessment through adjusting soil-water retention, pest-and-disease or nutrition

Table 1 A summary of the strengths (+) or limited capacity (−) of crop-climate modelling and place-based approaches to studying adaptation

Crop-climate modelling	Place-based
+ Calculating risk and uncertainty of climate impacts	+ Identifying local constraints and opportunities for adaptation
+ Quantifying the impact of an adaptation on yield or production	+ Integrating local values and knowledges
+ Representing a range of possible future outcome through socio-economic scenarios	+ Representing the multiple aspects of food security and trade-offs between them
+ Providing food availability trends for regional-global scales	+ Assessing the equability of an impact within communities and identifying vulnerable groups
+ Spatial and temporal scaling	+ Engaging with stakeholders
− Representing the breadth and agency of farm scale adaptation decisions	− Assessing the impact of adaptation under future climate variability
− Identifying and addressing locally critical factors	− Scaling up from local

stress parameters, depending on the level of process detailed in the crop model, and where suitable data exists. Other reviewed studies used the same term 'soil conservation' more ambiguously, without a description of which specific practices were being referred to, which removes the possibility of assessing the potential benefits of the adaptation under future climate projections.

5.2 Developing adaptation within crop-climate modelling

A logical step forward for the crop-modelling community is the improvement of adaptation within modelling studies (Challinor et al. 2018). We further highlight the need to include new types of adaptation into the scope of modelling studies, as well as the existing focus on improving simulation of the five identified strategies. We have illustrated how strategically reviewing local place-based literature can identify the most relevant adaptations (geographical, culturally or socio-economically) to consider. Engagement of stakeholders such as farmers and agronomists using place-based methods is an alternative methodological approach to refine almost infinite combinations of potential adaptation strategies into manageable scenarios that are relevant to the study area and scale. Simulating complex, and locally parameterised, land management, such as conservation agriculture or crop-livestock interactions (particularly so that temporal change in these systems might be analysed) represents an area for potential development. Windbreak impacts, for example, might be integrated into crop models through a modification of evapotranspiration values. Where an identified adaptation cannot be integrated into crop-climate modelling effort directly, e.g. a livelihood shift away from agriculture, this process still enables a researcher to highlight an assumption of the study. Sensitivity analysis of the impact of local and relevant adaptations (e.g. to evaluate long-term requirements for water harvesting to address crop water deficits) on production may be a good starting point for the crop-climate modelling community to gain perspective on the magnitude of change associated with more realistic adaptation. Crop models developed for small-scale farm decision support have already developed parameter sets for some of these more refined management-based processes such as tillage, mulching or intercropping, and their impact on soil-water processes and production (Jones et al. 2017). The main factor stopping these processes of management and adaptation from being scaled up with crop climate modelling studies is the perceived lack of, or lack of access to, data on management strategies at relevant scales for climate impact studies (Rivington and Koo 2010), which further supports the need for detailed descriptions of practices to enable systematic collection of management and adaptation data.

5.3 Modelling with stakeholder engagement

As well as being predictive, modelling approaches can be utilised as a tool to build a shared understanding of a concept, and for knowledge exchange as acquired though the process of model building and assessment. In this way, participatory modelling can be used to aid communication and integrate stakeholder and scientists held knowledge (Jakku and Thorburn 2010). This type of participatory approach has also been shown to increase the uptake and use of resulting climate information, due to the trust gained through the interaction between stakeholder and researcher (Ziervogel and Opere 2010). Thus, to develop place-based adaptation strategies that are informed by climate projections and impact models requires communicable and transparent modelling efforts (Whitfield 2014). This may contradict a current trajectory of crop-climate modelling research towards investment in ever-greater model complexity and increasing computer power (Whitfield 2013).

5.4 Understanding the objectives of adaptation

Modelling approaches commonly represent management with either no adaptation or optimised decision-making (adaptation for optimal yield) (Easterling et al. 2003). However, place-based research has provided evidence that challenges the appropriateness of this binary view, where specific management strategies are being favoured due to drivers other than yield optimisation. For example, in rural developing conditions, strategies such as keeping fruit trees and crop diversification contribute significantly to maintaining household nutrition, sometimes at a cost to optimising yield or income (Fanzo et al. 2013; Pellegrini and Tasciotti 2014). Similarly, agro-forestry can contribute to both food and sustainability goals through simultaneous production and carbon sequestration. Household agricultural decisions are also often made to reduce or spread risk rather than optimise production, especially in food insecure households where income diversification is common (Dercon and Krishnan 1996). Risk is increased in low-income agricultural households when strategies such as borrowing money, or selling assets and livestock, are used to generate the income needed to purchase inputs seasonally, which results in a debt or loss of capital that is expected to be repaid on harvest. But other adaptation strategies such as buying crop insurance, participating in payment for work programs or sourcing off-farm income can enable farmers to innovate taking a bigger risk, for example, trying a new variety, investment in cash crops or implementing a new soil management practice (Eakin 2005). These contextual objectives of agricultural change and decision-making are overlooked by traditional yield-centric modelling approaches, but could start to be addressed though an iterative research cycle with input from stakeholders (Fig. 1c). If crop-climate modelling studies are able assess and communicate the risks associated with different adaptation strategies in a local context but across future projections, the chance of unexpected negative outcomes from adaptive intervention can be reduced (Whitfield et al. 2015a, b).

6 Conclusions

The challenge of producing locally relevant and climate-informed adaptation strategies for agriculture is complex. Adaptive decisions transcend spatial and temporal scales and interact with social, economic and environmental systems. Cross-disciplinary approaches can build our capacity to identify and understand critical factors that drive and limit agricultural adaptation at the local scale. They can also be used to assess the potential impact of an identified adaptive strategy across spatial and temporal scales, including under future climate change scenarios, which is of particular relevance to policy decisions. There are practical steps needed for successful iterative working between crop-climate modelling and place-based communities. Crop-climate modelling research needs to better address adaptation in climate change studies. A meta-analysis of modelling studies projected a 7–15% mean yield change with adaptation compared to a non-adaptation baseline (Challinor et al. 2014). These studies collectively represent adaptation through five strategies (irrigation, planting date, cultivar, fertilisation, planted area); however, this approach does not represent the diversity and breadth of adaptation strategies used by farmers. To better represent adaptation, crop-climate modelling approaches may need a paradigm expansion to be implemented within more system and place-based approaches that can represent local context, knowledge and aspects of food security other than availability (e.g. nutrition, access, utilisation and stability). A collective action towards building consistent and accessible datasets on management and adaptation is also a pre-requisite to incorporating more adaptation processes into crop-climate modelling studies. Building trust between researcher and stakeholder will be essential for successful iterative research and assessment of locally relevant adaptation. Participatory and iterative modelling, as commonly used in place-based approaches, is a potential tool to do this, by aiding communication, developing a shared understanding and set of definitions between researchers from different backgrounds and stakeholders and improving impact and uptake of adaptation science.

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Chapter 5

Discussion and Conclusion

In Chapter 1 I presented two overarching research objectives addressed across the three empirical chapters, these questions are discussed here in turn.

1. To analyze food insecurity experiences and outcomes in Guatemala, with a focus on the interaction between climatic and non-climatic drivers

2. To reflect on what can be learned about complex challenges of food security and climate change adaptation by applying cross-disciplinary approaches; to identify the challenges and opportunities associated with this integration of methodologies, framings and problem perspectives.

Relating to the first objective Section 1 discusses the empirical findings of this research focused on conceptualising and understanding food insecurity and climate adaptation in the CADC. Section 2 presents my own reflections on the process of undertaking cross-disciplinary research and how the overarching research objectives evolved through the process. Relating to the second objective Section 3 presents a critical methodological discussion informed by the application of cross-disciplinary approaches to this case study.

1 Conceptualising the food-climate system in Guatemala

The conceptual diagram presented in the introduction (Figure 1.3 - Chapter 1) illustrated a climate-food system in which climate impact and adaptation were both processes that are embedded across multiple scales and systems (e.g. household, community, intervention), but play out in the context of individual livelihood change and wellbeing, which mediated food insecurity experiences, and their measured outcomes. The following sections present the understanding of food insecurity and climate adaptation that was developed in place-based or grounded research approaches and framed through livelihood changes, wellbeing and experiences (1.1). Sections 1.2, 1.3 and 1.4 then present and discuss the understanding of food insecurity and adaptation derived from analyses at regional and national scales, focusing on the role of climate (1.3) and socio-economic factors (1.4). The implications of the research are discussed in section 1.5.

1.1 Understanding impact, adaptation, and outcomes through wellbeing and livelihoods

From life history interviews in the CADC, a broad range of factors contributing to positive and negative changes in wellbeing and food insecurity experiences were identified. As Chapter 2 concludes, these included, but were not limited to: consecutive drought; ill health and displacement of income for medicine; social marginalisation; high start-up costs in production; absence or separation of a household head; and a lack of income and education opportunity. The main factors identified as contributing to improved wellbeing and food security experiences were: keeping and breeding livestock (poultry, pigs and cattle); cultivation of cash crops (coffee) for market participation; children working in occupations after completing education; and remittance. These also related to commonly discussed coping strategies that included the drawing down of savings and assets (including livestock); migrating to find labour-work in other parts of the country; and formal or informal borrowing.

1.2 Scaling up understanding of drivers of food insecurity

I then built on this broad and grounded understanding with quantitative statistical analyses of different food insecurity outcomes, to see if the key narratives derived from interviews could also be evidenced at scales that may find use as evidence for decision-makers. This was first carried out within the dry corridor region in Guatemala using HFIAP indicator of household food insecurity experiences collected in RHoMIS (Chapter 2). This analysis only included household survey data therefore the assessment was limited to non-climatic drivers only. Chapter 3 made a further broad scale (national) analysis of household data that includes climatic and non-climatic variables. The indicators of food insecurity used in this analysis were prevalence of stunting collected in the DHS, and the famine early warning system network food insecurity classification published by FEWSNET. The results of these broader scale analyses are summarised here.

The HFIAP indicator assigns each household into a category of food secure, or mildly, moderately, or severely food insecure, based on a nine questions that relate to the occurrence and severity of food scarcity and anxiety about food scarcity during a recall period e.g. worry about lack of food, smaller meals, eating inappropriate foods, or missed meals (Appendix 1). The inclusion of HFIAP and a wide range of questions and indices relating to the production and income strategies of households' enabled the application for this dataset to derive a scaled up understanding of the associations between agricultural strategy, socio-economic status and food insecurity experiences in Chapter 2. As all data was collected within the same survey this analysis was made at the level of the household.

Within the surveyed population in the dry corridor region in Guatemala, HFIAP status was significantly associated with: coffee cultivation (when market participation is low), dependence on agricultural labour income, and poverty level. This integrated analysis evidenced the importance of contextual understanding, for example coffee cultivation was associated with severe food insecurity when market participation was low, and case studies identified the mechanisms behind this interaction as: the lengthy and large investment needed before a productive crop can be obtained and high exposure of this investment to climate variability, pests and diseases. Case studies also evidenced a wider range of barriers to participation in markets, including land access, start up capital, and time investment, as well as social and power structures that mediate access to knowledge, training and resources.

1.2.1 Including climate

In interviews in the dry corridor region the impact of drought has been an important part of many household narratives of wellbeing and livelihood change in recent years. A broader national scale statistical analysis (OLS regression) was therefore used to characterize the drought and its impact on chronic food insecurity outcomes and changes in food insecurity monitoring classifications during a severe drought event in Chapter 3. Multiple climate indicators were included to represent the different characteristics of the MSD phenomenon, to identify what aspect of drought was associated with food insecurity outcomes, and over what spatial scale this impact was conserved. In this analysis some variables and associations were strongly spatially distributed, so an additional GWR analysis was justified to account for spatial processes such as autocorrelation in variables, and explore the variance in the model across different regions in Guatemala.

Prevalence of stunting in children less than 5 years old is a commonly applied indicator of a chronic situation of food insecurity or ill health, and has relevance to decision making in Guatemala as it is used monitor development progress, and is included in the list of indicators for SDG 2 to end hunger. Spatial statistics indicated that stunting was most prevalent in the Western Highlands of Guatemala, and was associated with the duration of the MSD, however the GWR model that associated MSD and stunting prevalence had most explanatory power within the dry corridor region of Guatemala, indicating other and important factors also drive prevalence of stunting in the Western Highlands, unaccounted for in this analysis.

The FEWSNET food insecurity classification data-set is published on a triannual basis at the municipality scale, and has it has high relevance to short-term decision-making in response to acute malnutrition events. The FEWNSET classification data was used to derive the change in food insecurity situation during the last severe food insecurity event, which was during the period of consecutive dry conditions frequently discussed by households in the Department of Chiquimula (in 2014-2016) in Chapter 2. A deterioration in food insecurity status was associated with MSD Duration; the number of consecutive dry days where rainfall was less than 1mm; and the minimum 30-day average precipitation during the MSD. This GWR model also had the highest explanatory power within the dry corridor region of Guatemala, which is where the FEWSNET classification showed highest spatial variability.

In these analyses, measurement of stunting and socio-economic variables such as assets had to be aggregated (spatially averaged) from a household level up to the finest common resolution, which was the 0.25 x 0.25 grid scale of the climate observation data. FEWSNET data also had to be aggregated from municipality level to this grid scale. Therefore aggregation effects (e.g. the influence of a large and wealthy farm masking poverty through its impact on the spatial mean) limited the capacity to understand and interpret the specific role and patterns of the socio-economic drivers in this analysis, but also enabled climatic drivers to be considered.

Climate projections for Central America are characterized by high variability and uncertainty, due to its proximity to two large-scale weather driving phenomena (Pacific inter-tropical convergence zone and the Caribbean low-level jet); the significant and varied effect of the global climate phenomena (ENSO); and the strong effect of orography on local weather processes (Diro et al. 2012; Fuentes-Franco et al. 2015). Despite this complexity, MSD Duration has a positive trend across future climate change projections in Central America, though with high regional variability, and high inter-annual variability until the end of this century (Anderson et al. 2019). This analysis therefore indicates that a direct association between the climate drivers and food insecurity outcomes can be evidenced at a national scale, without intermediate analyses of impact and adaptation pathways.

Climate change projections of high inter-annual variability in the MSD duration, and a trend of increasing duration at the end of the century poses a strong threat to food insecurity outcomes in Guatemala — **if** current adaptation processes and the socio-economic context remain unchanged.

1.3 The interaction of climatic and non-climatic drivers

In all analyses presented in chapter 2 and 3, the impacts of climate on food insecurity outcomes were shown to be mediated by socio-economic context; and some of these mechanisms were conserved across scales of analysis. For example assets and livestock were both associated with positive wellbeing outcomes by participants in the CADC during interviews, and were commonly depended on as coping strategies in crisis events such as drought (Chapter 2). These two indicators were also both significantly associated with the prevalence of food insecurity in the national scale analyses presented in Chapter 3. This scale of aggregation applied in this analysis (to a 0.25 x 0.25 grid) however made interpreting the effects of socio-economic variables within the model difficult, compared to the regression analysis applied directly to household level data in Chapter 2. However, despite this limitation on spatial interpretation, the association of drought indices and food insecurity outcomes in these national scale analyses were contingent on the inclusion of the socio-economic variables. This therefore provides broader scale and quantitative evidence of the role assets and livestock (or the range of household capabilities they represent) play in mediating the impact of drought on food insecurity outcomes, following from the mechanisms identified in interviews in Chapter 2. The dependence of a household on agricultural labour for income was also an important limitation on livelihood development and food security reported by participants, that was also tested and found to be a significantly associated with severe food insecurity outcomes in the dry corridor region of Guatemala (Chapter 2).

Participants also related an improvement in wellbeing and food insecurity experiences to a family member gaining access to income through employment in an occupation or in another country. These positive factors were however not evidenced in up-scaled analyses, but have been in other analyses in similar contexts (Davis and Brazil 2016).

Socio-economic context was also shown to mediate household processes of adaptation to climate variability, and this was evidenced in the participants' discussions of coping strategies — when in the context of drought — presented in Chapter 2 and in the review of place-based literature on adaptation across Central America in Chapter 4. Grounded adaptation research carried out across a range of countries and contexts reviewed in Chapter 4 most often conceptualized adaptation as a process of livelihood change; deeply embedded in the household and community context, responsive to multiple stressors, of which climate is one, and shaped by a wide range of values and decision-making contexts.

1.4 Implications for intervention

This research has developed insight into the multiple scales at which drivers of food insecurity experiences can be observed, measured, and statistically modelled. Result have shown that food insecurity experiences are multi-faceted, nested within a multi-scale system that moderates the impact and outcome of an external stimulus, such as a climate stressor or an intervention (Chapters 1, 2 and 3).

Implications for policy and intervention include the need for more holistic or joined up management; and indicate the need to address the social and political barriers that are limiting the capacity of households to participate in developing rural livelihoods, such as health care provision, land access, or accountability and monitoring of informal employment in agricultural industries. Without addressing these underlying drivers, technological intervention to increase productivity or increase the resilience of existing agricultural production to drought are likely to have limited capacity to improve longer term food insecurity outcomes.

In Guatemala there are projects managing interventions around sanitation, skill training, and micro-finance e.g. Accion Contra Hambre (2018). A catalog of NGOs have been filling the gap in governmental health care provision, and other organizations have previously built community health insurance schemes (Ron 1999). Others projects are strongly focused around building resilience of agricultural systems and technologies to drought (Bouroncle et al. 2017). However this research found households going without, living in margins and excluded from this patch-worked support system. This development effort — a network of organizations active across different communities and issues — appears to be attempting to relieve the symptoms of the deeper underlying issue of ineffective governance and policy making for the development of rural economies, health and food security in Guatemala. Any policy implications of this research to improve food insecurity or facilitate adaptation to future climate change are therefore unlikely to have their well-intended consequences if implemented through existing over-stretched, unstable and corrupted systems of governance.

2 Reflections on a cross-disciplinary PhD

"Fieldworkers, it seems, learn to move among strangers while holding themselves in readiness for episodes of embarrassment, affection, misfortune, partial or vague revelation, deceit, confusion, isolation, insult, and always possible deportation. Accident and happenstance shapes fieldworkers' studies as much as planning or foresight; numbing routine as much as living theater; impulse as much as rational choice; mistaken judgements as much as accurate ones. This may not be the way fieldwork is reported, but it is the way it is done."

John Van Maanen on ethnography,
Tales of the Field (1988)

During my own fieldwork this introductory text to Tales of the Field provided me with some comfort in the face of the challenges and barriers I inevitably met on the way, as well as a preparedness to accept and embrace the huge unknowns typical of engaging with a new country, culture, and perspective. As I re-read this text during the write-up of my final chapters I felt familiarity and recognition in reflection of my own fieldwork experience, but I also noticed a strong parallel — excepting the possibility of deportation, this paragraph could easily be describing interdisciplinary research.

When we outlined the idea of a cross-disciplinary PhD the concept was simple and appealing to me: to become embedded in four or five different disciplines, applying each approach to the same issue, in the same geographical context, in order to gain a more holistic understanding and to enable to reflect critically on each approach. The issue in question was the challenge of food insecurity and climate adaptation in the CADC. From the outset I had made an assumption — one I was not cognitive of at the time — of a process of clarification and reduction in uncertainty through gained knowledges. I assumed that by adding disciplinary perspectives and neatly triangulating between them, I would be able to see issues and their management from a clearer and more informed vantage point. From this clarified perspective I would be able to produce evidence to inform decision-making.

The cross-disciplinary process uncovered and challenged this assumption. As I added new disciplines and perspectives I broadened the range of possibilities within which the reality or truth might sit, which increased my perception of uncertainty and more generally reduced my confidence. Though broadening my perspective I also started to see gaps in understanding and conflicting evidences, rather than going through a simple process of triangulation, clarification and reduction I had expected. I felt less certain of the capacity of my research, and the disciplines I *was working in to inform the decision-making context in a useful way. Issues I had earnestly categorised as the 'physical science' part of my cross-disciplinary research were also becoming increasingly political and complex in the real world of fieldwork and in the stories of participants. At this point I was introduced (or perhaps re-introduced) to the work of Stirling, Leach, etc. and a language with which to start thinking about and express these ideas.*

On some occasions triangulation and integration across disciplines did contribute to an increased sense of robustness and confidence in my own results, this was especially noticeable in cases where I could ground otherwise highly subjective statistical modelling with knowledge derived from fieldwork and life history interviews. For example, the analysis of household data presented in Chapter 2 was a process that took three years, most of the PhD. Prior to fieldwork, access to an exhaustively comprehensive data-set landed in my inbox, with thousands of households and hundreds of variables recorded for each one. I enjoyed exploring and visualising the data and I would move cyclically through analyses, but struggle to justify the reasoning behind the models and hypothesis testing, and therefore also struggle to trust and interpret my results. After fieldwork this process became much more informed, I felt justified and confident in selecting out the appropriate variables for analysis and interpreting my results within context.

On other occasions, as I tried to integrate across disciplines the space outside of each system boundary of study only grew; indicative of the space in which misinformation and ignorance might sit. In this growing volume of uncertainty I sometimes felt unwilling to tie myself to any specific approach in pursuit of a result because of the set of assumptions it required me to make, and opted instead to float around for a time in methodological apathy and paralysis — often until such time as I remembered, or was reminded of, my capacity for critical refection and its usefulness.

The process of this cross-disciplinary PhD, and undoubtedly my engagement with social sciences as part of that process has shifted my perspective towards critical thought and constructivism. Through fieldwork I became increasingly aware of my position as an outsider and how it limited my capacity to interpret, understand and represent the people I studied and worked with. Though applying multiple disciplinary approaches I became increasingly aware and critical of the assumptions my colleagues were making in their own disciplines, both explicitly stated in presentation and meetings, and implicitly within their language and protocol as well as disciplinary and institutional norms.

The cross-disciplinary approach also presented challenges in integrating evidence and collaborating with researchers across social and physical science disciplines, especially in terms of research design and the presentation and framing of re-

sults in publications. The qualitative methods applied in this research and the evidence they created were frequently overlooked or denied as legitimate contributions to knowledge by collaborators, despite a stated interest in engaging with cross-disciplinarity and the integration of social-science based approaches. This barrier inevitably shaped the ratio of approaches applied in my thesis towards the quantitative. My personal experience of working and managing collaboration across disciplines was that the recognition of the need for interdisciplinarity ended up being symbolic and remaining at a surface level when there were incompatibilities of ontological perspective between researchers; a difference in a deeply embedded – perhaps subconscious – understanding and expectation of what constitutes knowledge and evidence.

As a cross-disciplinary researcher, not being an expert in any one discipline was a fairly consistent worry, though not one that was realised anywhere near as often as I expected. It did however shape the content of my research. For example, the thesis and published work are fairly apolitical compared to my day to day discussions and reflections. I was guided away from diving into politically sensitive questions at several points during fieldwork by figures who held authority in the local context, and as a non-expert I felt that I lacked the knowledge and confidence to conduct and publish political content without putting myself or others at risk.

From these experiences and changes in perspective the second objective of my thesis developed and grew in importance. My aim moved away from the production of empirical evidence towards the application of critical methodological approaches; to understand disciplines, their system boundaries, how they interact, and how this influences understanding and evidence building.

In hindsight, applying multiple cross-disciplinary approaches has given me a more informed vantage point, but not from the perspective I was expecting. There was no empirical discovery or clear message waiting at the point in which disciplines and evidences converged, or really any clear pattern of convergence at all. But I do feel less ignorant of the broader system in which each of my contributions to research sit; the limitations of science based-evidence building for decision-making in complex and political contexts; and more able to interpret and critically review evidence relating to food insecurity and adaptation.

3 Cross-disciplinary and critical approaches to studying complexity

Objective 2: To reflect on what can be learned about complex challenges of food security and climate change adaptation by applying cross-disciplinary approaches; to identify the challenges and opportunities associated with this integration of methodologies, framings and problem perspectives.

To address the empirical objective outlined in Section 1 a wide range of methodological approaches were applied in this cross-disciplinary research, spanning from individual interviews to global impact modelling studies. This section reviews contributions of this research to developing cross-disciplinary approaches, and discusses how interdisciplinarity can enable critical methodological reflection.

There are many theoretical justifications for the application of cross-disciplinary research to complex real-world challenges: when there is high uncertainty or ambiguity around pathways of evidence building; when there are significant gaps in knowledge; and when systems exhibit unexpected behaviour or intervention has unintended outcomes (Stirling and Scoones 2009). While the application of multiple disciplines in research is important to understand and address different sources of uncertainty (Bhaskar et al. 2010), interdisciplinary working is further required for the evidence produced across disciplines to be integrated in a way that is useful for decision-making. Furthermore, when a system of research includes participants, for example in the design of agricultural intervention, then participatory or transdisciplinary working provides a further level of cross-disciplinarity to align research framings and outcomes with the knowledge and needs of stakeholders (Mauser et al. 2013; Lemos et al. 2012) (Figure 1.6 - Chapter 1).

The point of departure of this research outlined in Chapter 1 was that cross-disciplinary approaches that combine social and physical disciplines will be able to integrate understanding from across the systems and scales that drive food insecurity outcomes and processes of climate impact and adaptation, as conceptualised in Figure 1.2 (Chapter 1). Here I reflect on the types of cross-disciplinarity achieved in each chapter, including the successes and challenges of both integrating approaches and evidences across disciplines and integrating participant derived knowledge and framings into methodologies used for evidence building at scale.

Chapter 2 presented a novel combination of ethnographically informed approaches (participant interviews) with a household survey that was designed to produce a standardized but holistic understanding of rural agricultural livelihoods (RHoMIS). This grounded understanding derived from interviews also informed a broader scale quantitative analysis in Chapter 2 and 3. In these analyses I enact multiple levels of cross-disciplinarity as I have: applied multiple disciplines in the same context; integrated evidence from across social and physical science disciplines in iterative analyses and discussion; and developed a methodology that enabled participants narratives to shape broader-scale evidence building. In Chapter 4 I also applied meta-analysis and systematic literature review to identify barriers to cross-disciplinary working and steps towards transdisciplinary approaches e.g. participatory modelling of adaptation.

Cross-disciplinary methods applied across this research have also enabled me to critically reflect on the capacities and limitations of individual disciplinary approaches. Critical discussion of methodologies was informed through the inter-comparison of concept definitions; system boundaries of study; problem framings; and a comparison of the understanding produced in association with each method or discipline.

3.1 Conceptualisations and system boundaries in food insecurity and adaptation research

Concepts of food insecurity included in this research range from individuals' experiences of food insecurity, to the globally standardised indices of food insecurity experiences, and biophysical outcomes e.g. stunting. Though identifying and applying these different understandings of food insecurity, I was able to draw comparison between the causal and grounded understanding of drivers identified by participants that ranged though physical, social, political contexts and the statistical model of food insecurity outcomes in Chapter 2 and 3. Similarly, the concept and system boundaries of agricultural adaptation were identified and critically compared in Chapter 4, and ranged from an understanding of adaptation as an ongoing process of livelihood change, to an understanding of adaptation as set of parameterisations in crop-climate modelling that relate to planting date, fertiliser and water-use.

Physical based disciplines and quantitative regional scale analyses tended to elicit very different types of understanding to the place-based analyses applied in this research. Grounded methodologies tended to identify a broader range of variables i.e. drivers of food insecurity in Chapter 1, and types of adaptation in Chapter 3. This breath often came from the broader system boundary of study that included social and political processes, compared to a more narrow system boundary dominated by bio-physical and economic processes. Grounded approaches also tended to create knowledge that evidenced the need for more 'connected' or 'joined-up' design of intervention or policy-making, and identify limitations of technocratic intervention to address issues embedded in social and political context (Chapter 1 and 3).

3.2 Working across scales for food insecurity and climate adaptation

Chapter 1 sets out the protagonist argument, that within agricultural development research there exists a paradox of scale; the need to engage individual view points and devolve decision making to fit local knowledge and context, while up-scaling intervention impact and evidence. The methodological development presented in Chapter 1, 2 and 3 attempted to overcome this apparent paradox: to integrate participant derived narratives and understanding into broader scale analysis used for evidence building and decision-making. The success of these attempts is reflected on here.

Where quantitative and qualitative analyses were combined in this research, grounded understanding was able to inform and shape broader scale analyses. While the translation of narrative to variable — qualitative to quantitative — did conserve some aspects of participants' narratives, others were lost, or lost meaning, in the process of translation and scaling up. This was evidenced across chapters on food insecurity and adaptation, for example social issues of power and participation were unable to be represented in the quantitative analysis of household survey data in Chapter 2. Similarly, adaptation practises evidenced in place-based research with farming households in Central America fell outside the bounds and definition of adaptation applied in crop modelling studies of climate impact in Chapter 4.

Critical approaches have often illustrated where the cycles of problem definition, measurement and resulting analysis can lead to evidence building that is focused around existing dominant narratives, and potentially close down alternative pathways of understanding and management (Whitfield 2015). The following observations evidence that this circularity has also played out within this research. The presented methodological approaches have set out to integrate participant narratives and framings into broader scale analyses, but critical reflection has identified a significant caveat; that this process of up-scaling and the quantification of narratives and understanding — as applied here — is biasing the produced understanding towards topics and variables that are more easily quantified.

Quantitative analyses were often unable to account for social and politically sensitive drivers of food insecurity such as: barriers to participation; social dynamics that shape resource distribution; or the effects of violence, extortion or ill-health on livelihood decisions and outcomes. The quantitative analyses were also shaped and filtered by the types of data that have been systematically collected and made available at the regional or national scale. Some variables where data were sought were unable to be included due to the difficulty of acquiring access to records of sufficient quality and consistency e.g. health center spending and closures.

The integration of participant derived understanding and regional to national scale analysis presented here is therefore unlikely to be contributing methodologically towards the up-scaling of grounded understanding, knowledge and contextual framings, or towards fairer representation of narratives that are currently marginalised in mainstream development discourse. The following section outlines suggestions for overcoming some of the identified challenges and barriers to participatory and transdisciplinary working in this context, including this circularity in problem framing and evidence building.

3.3 Towards transdisciplinary

The inclusion of grounded and ethnographical research in the design — and application — of household surveys, could enable moderation of household survey content to closer reflect the lived experiences of participants, and the issues and drivers identified within their narratives of lived experiences and livelihood change. While many issues would remain difficult to represent in a standardised survey question, content could more closely reflect the range of drivers affecting measured outcomes. The modular design of household surveys does already enable marginal flexibility to select for the most relevant topics relevant in the country or region of application, but is currently used in a more limited biophysical application, for example in the Malaria module in the DHS, or the crop management module in RHoMIS. This structure could be expanded upon to account for a locally relevant set of factors, and include more variables aligned to local social and political factors. These could be drawn from existing successful political household surveys e.g the Afrobarometer in Africa.

A second recommendation to work towards transdisciplinary approaches, is the framework for participatory modelling of crop impact and adaptation presented in Chapter 4; developing locally relevant adaptation pathways or scenarios to improve the representation of adaptation processes in impact modelling, and working to engage participants directly in modelling of impact and uncertainty. To achieve the latter is likely to require more transparent and interpretable approaches to assess and communicate climate uncertainty and impact. For example, aligning with co-production methodological development in climate services and the storyline approach to climate impact — recognising possibilities and exploring their outcomes and management in order to reduce the current level of dependency on calculation of risk and probabilities; which can conceal uncertainty or ignorance generated through stacking of models and assumptions implicit to the system boundary of model representation.

A third, related, recommendation is recognition and acknowledgement of system boundaries in research intended to inform decision-making for food insecurity and adaptation. Integrated working across disciplines and participatory research approaches would be facilitated by more open reflection of the system boundary of research approaches as applied: the processes considered and not considered; assumptions on which the produced knowledge is conditional; and the scales at which significant relationships and drawn conclusions are conserved. These conditions on which produced understanding is valid are generally well-recognised and reflected on implicitly within communities of practise, but could benefit from being presented upfront with results and conclusions drawn.

4 Conclusion

The collection of research presented in this thesis spans across disciplines and problem framings from food insecurity to climate impact and adaptation. The presented analyses draw from these literatures and methodologies where appropriate to build a broader and deeper understanding than offered by any single discipline. This mixed methods approach has been successful in building that wider and contextualised understanding, even if the resulting picture is more clouded and complex than any of its components. Due to this cross-disciplinary and contextualised style of investigation, summarising the key finding of this research in a reduced and simple set of learned truths is challenging.

Applying a livelihoods framing through fieldwork enabled to consider both the climatic and non-climatic drivers of wellbeing and resulting metrics of food insecurity at two scales: within individual and household case studies and at a broader level in regional and national scale analyses of survey data.

At an individual and household scale, wellbeing and food insecurity outcomes were always narrated as an outcome of a combination of factors that can be collectively represented as: health, political, historical and socio-economic context. In many cases a fifth category was represented — agro-ecological — where climate, specifically drought, was a very important part of many individual and household narratives of their wellbeing and food insecurity experiences in recent years (Chapter 2). Each of these five elements (health, political, historical and socio-economic and agro-ecological) however, were rarely if ever presented as independent drivers of an outcome, and exemplified interactions between them were many, a small selection of which were discussed in Chapter 2. In Chapter 2 it therefore emerged that climatic and non-climate drivers are high interdependent and interactive in their impact on livelihoods and wellbeing and on food insecurity experiences and outcomes.

Broader scale analysis of the role of climatic and non-climatic drivers of regional prevalence of food insecurity echoed this interdependency. In a spatially disaggregated national scale analysis of stunting indicators, climatic indices relating to drought severity and duration were included in optimised regression models, but only when socio-economic context was also accounted for by its inclusion in the model. This disaggregated analysis also identified regions where climatic drivers were more associated to chronic food insecurity (indicated by prevalence of stunting) and acute food insecurity (indicated by a deterioration in FEWSNET status). This association was strongest in the South and East of Guatemala corresponding to the dry corridor region (in its political delimitation rather than its climatological delimitation as presented in Figure 1.2, Chapter 1). In the western highlands region however, non-climatic drivers were more strongly associated with acute and chronic food insecurity outcomes compared to climatic drivers (Chapter 3).

Even where climatic drivers are shown to be highly important that does not equate to the need for climate and crop centered adaptation strategies, even though that may be the main mechanism of impact. There is currently a strong focus on promoting climate resilient agriculture in the region, and globally. However, adaptation research in the region that draws on local knowledge and perspective (place-based) very often identified that households were: using a range of strategies much broader than the set of practises conventionally defined as agricultural adaptation; often included transformational as well as incremental adaptation; and drew on many kinds of asset, capital and capabilities (many outside of agriculture) in the process. In this broader and contextualised study of adaptation, drought tolerance and climate smart agriculture were rarely the unique or preferred response pathways in the face of drought. By contrast, much of the regions rural development relies on these technologies to an extent that is often exclusionary of alternatives (Chapter 4). This may be a result of the technocratic problem framing of food insecurity that pervades through research and assessment systems and the institutions who coordinate them.

Surveys widely applied to measure and monitor households' situations and outcomes lack political and social dimensions. There are many easy adjustment that can be made to re-politicise and contextualise survey content, and doing so will be essential to gain an understanding of the structures that engender the persistence of food insecurity in the region. For example, the additional open-ended or in-depth interviews in a sub-sample of households with every survey application. Survey development should also prioritise the addition of a module that assess the political and social situation.

The main contribution of this research is not in the lines of the conclusion but is in the small joints fabricated between distant and foreign disciplines. I refrain from policy suggestions because I see no fixes or silver-bullet solutions to the problem of food insecurity and climate change in Guatemala until we better understand the intersection of climate and non-climate drivers including a stronger focus on governance, corruption, knowledge and power politics. But the research process has, in it's own doing, challenged disciplinary norms and translated across disciplined languages. I have observed a process of change in myself and my colleagues, which is ongoing, and hope the publication of these chapters will assist others in each of their respective disciplines to be more reflexive and work towards transdisciplinary too.

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Chapter 6

Appendices

Supplementary Material

1 Questions used in the Household Food Insecurity Access Prevalence (HFIAP) Indicator, directly quoted from Coates et al. (2007)

1. In the past four weeks, did you worry that your household would not have enough food?

2. In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?

3. In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?

4. In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?

5. In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?

6. In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?

7. In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?

8. In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?

9. In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?

Reference

Coates, J., Swindale, a & Bilinsky, P., 2007 Household Food Insecurity Access Scale (HFIAS) for measurement of food access: indicator guide. *Washington, DC: Food and Nutrition Technical ….* (August), pp. Version 3.

Supplementary Material

2 Questions used to derive Poverty Probability Index (PPI), for households in Guatemala, directly quoted from the Simple Poverty Scorecard for Guatemala, constructed with Guatemala's 2014 Household Living Standards Survey, by Mark Schreiner. Accessible from *www.povertyindex.org*

1. How many members does the household have?
A. Eight or more (0)
B. Seven (6)
C. Six (11)
D. Five (15)
E. Four (19)
F. Three (28)
G. Two (35)
H. One (45)

2. How many rooms does the household use (excluding kitchen, bathrooms, hallways, garages, or rooms used only for business)?
A. One (0)
B. Two (4)
C. Three (7)
D. Four or more (10)

3. What type of toilet arrangement does the household have?
A. Latrine, covered pit, or none (0)
B. Hand-pour toilet, or toilet connected to septic tank or to sewer system (3)

4. Does the household possess, own, or have access to a stove (gas or electric)?
A. No (0)
B. Yes (4)

5. Does the household possess, own, or have access to a refrigerator?
A. No (0)
B. Yes (3)

6. Does the household possess, own, or have access to a blender?
A. No (0)
B. Yes (3)

7. Does the household possess, own, or have access to an electric iron?
A. No (0)
B. Yes (4)

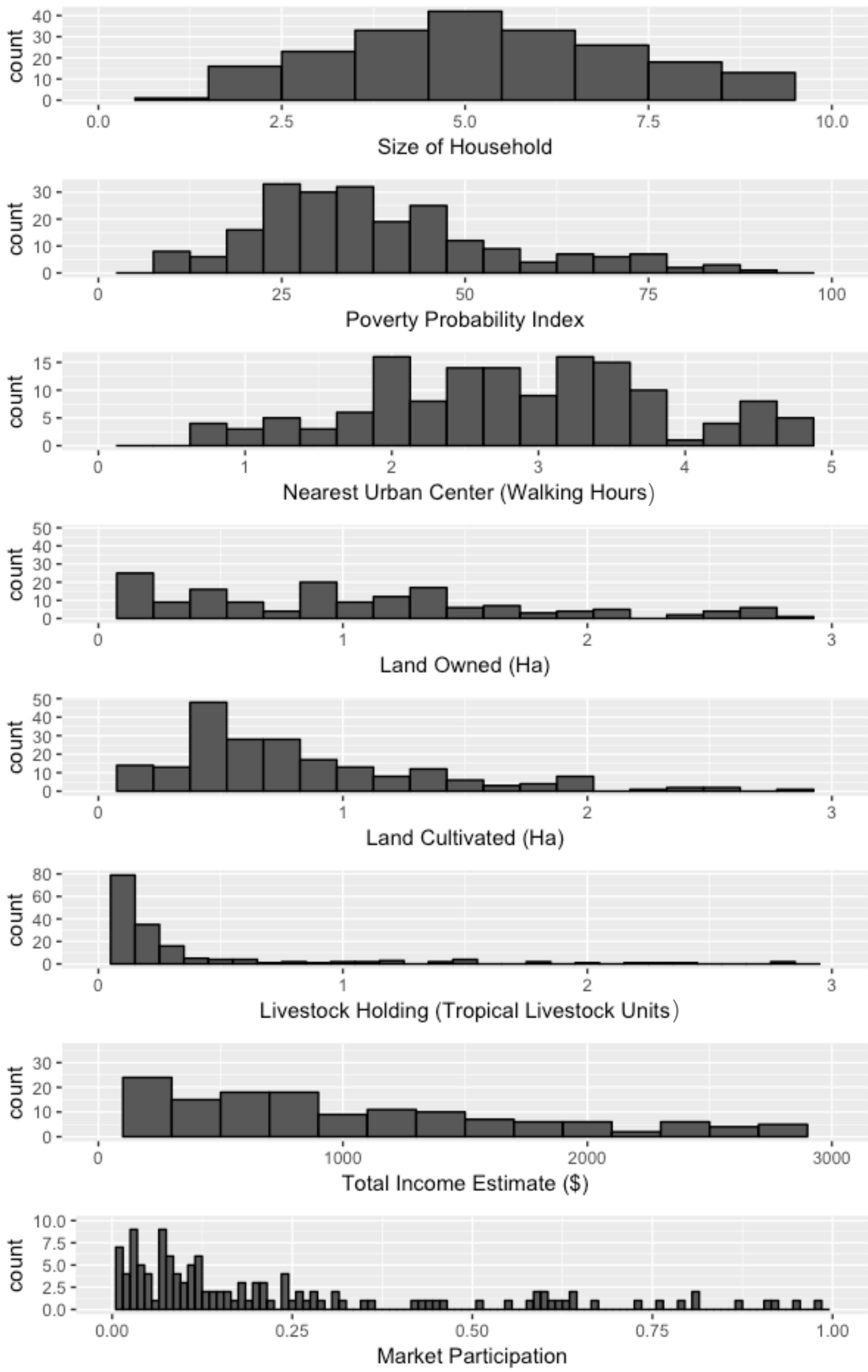
8. Does the household have cellular-phone service?
A. No (0)
B. Yes (5)

9. Does the household possess, own, or have access to a television with cable service?
A. No (0)
B. Only television (without cable) (3)
C. Cable (Regardless of television) (7)

10. Does the household possess, own, or have access to a bicycle, motorcycle or scooter/moped, or passenger car, pick up, van, minivan, SUV, or truck?
A. No (0)
B. Only bicycle (without any others) (2)
C. Motorcycle or scooter/moped (without car etc., and regardless of bicycle) (7)
D. Car etc. (regardless of any others) (16)

Supplementary Material

3 **Figure 1** Histograms of the independent variables included in quantitative analysis



4

Table 1 Full list of codes raised in interviews with households with count (n) of mention (n total = 24 interviews) coded under three themes: factors that have contributed to a positive and negative change in wellbeing, and coping strategies used during times of difficulty or crisis

n	Limiting Factor	**n**	Positive Factor	**n**	Coping Strategy
13	consecutive drought impact on production	**9**	coffee production	**9**	use savings
11	labour work availability	**8**	poultry production	**9**	migration for labour
7	cost of medicine	**8**	training	**8**	borrow
6	fertiliser dependence	**7**	education of children	**5**	female household head sources income
4	absence or separation of a household head	**7**	participation in projects	**3**	sell poultry
4	limited participation	**6**	pig production	**2**	adapt agricultural technology
4	loss of income due to health	**6**	remittance	**2**	crafts
4	limited education opportunity	**6**	children work in labour	**2**	buy and sell
3	limited production	**5**	cash crop production	**1**	sell livestock
3	land access	**5**	migration for labour	**1**	aid
3	alcoholism	**4**	cattle production		
2	water access	**4**	children work in occupations		
2	robbery	**4**	administration of resources		
2	limited support from parents	**3**	children under 18 work in labour		
2	price of food in market	**2**	aid		
2	extortion	**2**	help from community		
2	disease in animals	**2**	commercialization		
2	debt	**1**	contracted employment		
2	costs of children		payment for forest protection on owned land		
1	instability of labour work				
1	coffee rust				
1	low price received for produce				
1	loss of land				
1	cost of livestock inputs				
1	low labour wage				

Table 2 Mean market participation by food security status and coffee cultivation

	Food secure	Mildly food insecure	Moderately food insecure	Severely food insecure
Do not cultivate coffee	0.32	0.17	0.1	0.09
Coffee cultivated	0.47	0.49	0.34	0.16

6 **Table 3** Self-identified limiting factors, positive factors (in the context of a change in wellbeing), and coping strategies reported by interviewed households, and their associated food security and poverty indicator scores as derived from the RHoMIS, including: Probability of Poverty Index (PPI), Household Food Insecurity Access Prevalence (HFIAP), Household Diet Diversity Score (HDDS) in the good (G) and lean (L) season. HFIAP has 4 categories: Food Secure, Mildly Food Insecure (Mildly FI), Moderately Food Insecure (Moderately FI), and Severely Food Insecure (Severely FI)

Food Security and Poverty Indicators				*Interview Derived Aspects of Lived Experience*		
PPI	**HFIAP status**	**HDDS (G)**	**HDDS (L)**	**Limiting Factors**	**Positive Factors**	**Coping Strategies**
64	Food Secure	10	11	drought impact on crops, disease in livestock	cash crop production, cattle production, pig production, poultry production, participation in projects, commercialisation	borrow, use savings
69	Mildly FI	NA	NA	alcoholism, absence or separation of a household head, labour work availability	poultry production, remittance	sell poultry, use savings
48	Moderately FI	8	4	child costs, cost of medicine, loss of income due to health	aid, help within community	borrow, aid
43	Moderately FI	11	1	land access, limited participation, robbery, labour work availability	cash crop production, cattle production, coffee production, remittance, administration of resources	sell livestock, adapt technology, use savings
65	Mildly FI	5	3	drought impact on crops, food cost, price received for produce, low production, livestock input costs	pig production, coffee production	use savings, female household head sources income
54	Food Secure	NA	NA	limited participation, food cost, fertiliser dependence	cattle production, pigs production, coffee production, remittance, children work in labour, children work in occupations	borrow
52	Mildly FI	4	3	drought impact on crops, extortion, fertiliser dependence	remittance, children work in labour	borrow, use savings
86	Food Secure	NA	NA	drought impact on crops	education of children, cash crop production, participation in projects, remittance,	adapt technology, use savings

Supplementary Material

					children work in occupation, training, commercialisation	
46	Severely FI	8	7	alcoholism	education of children, children working in occupation, training	use savings
24	Mildly FI	7	3	drought impact on crops, cost of medicine, loss of income due to health, limited education opportunity, labour work availability	migration for labour	migration for labour
43	Severely FI	10	7	drought impact on crops, fertiliser dependence	cattle production, coffee production, participation in projects, training, payment for ecosystem service scheme	use savings
21	Severely FI	6	5	land access, water availability for household use, drought impact on crops, limited support from parents, limited participation, labour work availability	poultry production, local migration for labour	borrow, local migration for labour
40	Moderately FI	9	5	drought impact on crops	education of children, pig production, poultry production	None
24	Severely FI	1	0	land access, drought impact on crops, fertilizer dependence, labour work availability	children work in labour, local migration for labour	crafts, local migration for labour, female household head sources income
11	Severely FI	2	3	child costs, cost of medicine, loss of income due to health, low labour wage, fertiliser dependence	education of children, coffee production, aid, children work in labour, training	borrow, local migration for labour, buy and sell, female household head sources income
40	Moderately FI	NA	NA	disease impact on crops, absence or separation of a household head	education of children, coffee production, participation in projects, children work in labour, training	use savings
20	Mildly FI	8	6	costs of medicine, low production, limited education opportunity	education of children, cash crop production, pig production, poultry production, contracted employment, coffee production, children work in occupations, participation in programs, training	local migration for labour, female household head sources income

31	Severely FI	6	3	alcoholism, extortion, limited education opportunity, labour work availability	coffee production, participation in projects	local migration for labour
11	Mildly FI	7	3	drought impact on crops, fertilizer dependence , robbery, labour work availability	coffee production, administration of resources	local migration for labour
34	Severely FI	7	3	drought impact on crops, cost of medicine, loss of land, labour work availability	children work in labour, administration of resources	
26	Moderately FI	7	3	drought impact on crops, debt, limited support from parents, disease in livestock, cost of medicine, labour work instability, labour work availability	poultry production, children work in labour, training, money administration, local migration for labour	borrow, local migration for labour
31	Severely FI	5	5	water availability for household use, debt, limited participation, cost of medicines , low production, absence or separation of a household head, labour work availability	local migration for labour	sell poultry
23	Moderately FI	1	0	loss of income from health, limited education opportunity, labour work availability	pig production, poultry production, children work in labour	borrow, female household head sources income
80	Moderately FI	9	7	absence or separation of a household head	education of children, cash crop production, poultry production, participation in projects, remittance, help from community, children work in labour, training	crafts, buy and sell, sell poultry

Supplementary Information: Applying drought indices to characterise climate impact on malnutrition in Guatemala

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SI 1 Spatial correlations co-efficient matrix of climate indices

Corelations between climate indices (1981-2017)		Minimum	1st Quantile	Median	3rd Quantile	Maximum
Seasonal Precipitation Total (1981-2017)	MSD Minimum (1981-2017)	0.850	0.917	0.947	0.976	0.987
Seasonal Precipitation Total (1981-2017)	MSD Duration (1981-2017)	-0.828	-0.720	-0.391	0.044	0.230
Seasonal Precipitation Total (1981-2017)	MSD Intensity (1981-2017)	-0.403	-0.067	0.607	0.889	0.910
Seasonal Precipitation Total (1981-2017)	CDD (1981-2017)	-0.868	-0.826	-0.779	-0.688	-0.551
Seasonal Precipitation Total (1981-2017)	Rainy Days Count (1981-2017)	0.635	0.795	0.830	0.864	0.904
MSD Minimum (1981-2017)	MSD Duration (1981-2017)	-0.929	-0.901	-0.726	-0.104	0.109
MSD Minimum (1981-2017)	MSD Intensity (1981-2017)	-0.627	-0.433	0.230	0.782	0.830
MSD Minimum (1981-2017)	CDD (1981-2017)	-0.849	-0.786	-0.692	-0.552	-0.410
MSD Minimum (1981-2017)	Rainy Days Count (1981-2017)	0.562	0.694	0.738	0.804	0.874
MSD Duration (1981-2017)	MSD Intensity (1981-2017)	0.267	0.367	0.466	0.680	0.779
MSD Duration (1981-2017)	CDD (1981-2017)	-0.421	-0.278	0.135	0.320	0.473
MSD Duration (1981-2017)	Rainy Days Count (1981-2017)	-0.634	-0.464	-0.183	0.318	0.448
MSD Intensity (1981-2017)	CDD (1981-2017)	-0.822	-0.745	-0.514	-0.094	0.190
MSD Intensity (1981-2017)	Rainy Days Count (1981-2017)	-0.331	-0.031	0.559	0.797	0.861
CDD (1981-2017)	Rainy Days Count (1981-2017)	-0.986	-0.983	-0.967	-0.931	-0.906

Correlations between climate indices (2014)		Minimum	1st Quantile	Median	3rd Quantile	Maximum
Seasonal Precipitation Total 2014	MSD Minimum 2014	0.862	0.913	0.931	0.941	0.951
Seasonal Precipitation Total 2014	MSD Duration 2014	-0.816	-0.739	-0.313	-0.207	-0.039
Seasonal Precipitation Total 2014	MSD Intensity 2014	-0.330	-0.026	0.793	0.882	0.923
Seasonal Precipitation Total 2014	CCD 2014	-0.783	-0.751	-0.630	-0.397	-0.308
Seasonal Precipitation Total 2014	Rainy Days Count 2014	0.524	0.642	0.772	0.862	0.878
Seasonal Precipitation Total 2014	CCD 95th Percentile 2014	-0.172	-0.064	-0.018	0.063	0.212
MSD Minimum 2014	MSD Duration 2014	-0.840	-0.816	-0.306	-0.114	-0.041
MSD Minimum 2014	MSD Intensity 2014	-0.538	-0.337	0.570	0.687	0.768
MSD Minimum 2014	CCD 2014	-0.735	-0.709	-0.560	-0.340	-0.267
MSD Minimum 2014	Rainy Days Count 2014	0.511	0.558	0.696	0.816	0.851
MSD Minimum 2014	CCD 95th Percentile 2014	-0.210	-0.079	-0.039	0.045	0.177
MSD Duration 2014	MSD Intensity 2014	-0.341	-0.245	-0.070	0.391	0.549
MSD Duration 2014	CCD 2014	0.007	0.115	0.226	0.344	0.573
MSD Duration 2014	Rainy Days Count 2014	-0.546	-0.450	-0.304	-0.274	-0.073
MSD Duration 2014	CCD 95th Percentile 2014	-0.112	-0.043	0.026	0.155	0.250
MSD Intensity 2014	CCD 2014	-0.700	-0.624	-0.433	-0.051	0.133
MSD Intensity 2014	Rainy Days Count 2014	-0.320	-0.080	0.491	0.713	0.792
MSD Intensity 2014	CCD 95th Percentile 2014	-0.045	0.054	0.202	0.289	0.372
CCD 2014	Rainy Days Count 2014	-0.899	-0.859	-0.820	-0.595	-0.426
CCD 2014	CCD 95th Percentile 2014	0.245	0.293	0.327	0.362	0.408
Rainy Days Count 2014	CCD 95th Percentile 2014	-0.192	-0.156	-0.135	-0.112	-0.012

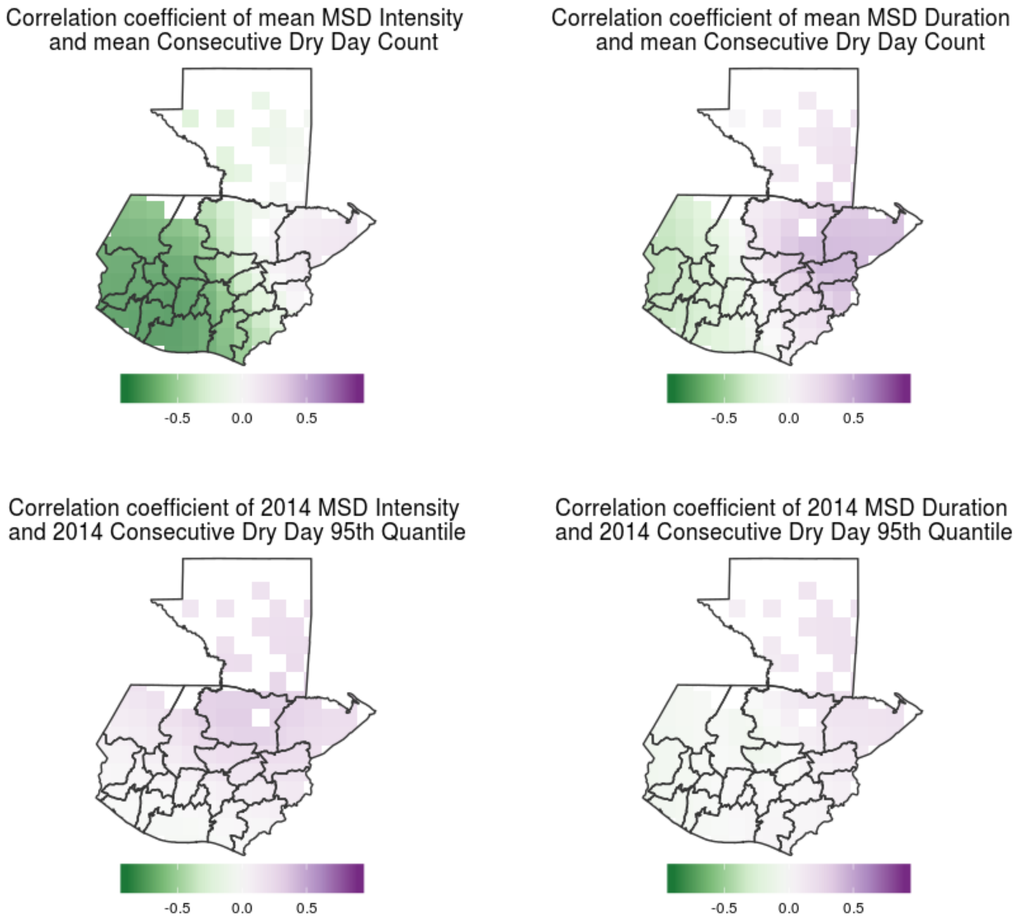
SI 2 Spatial correlations co-efficient matrix

Spatial correlations co-efficient matrix of socio-economic indices, and between dependent and independent variables for prevalence of stunting and FEWSNET food insecurity classification change

Correlations between Socio-economic indices		**Minimum**	**1st Quantile**	**Median**	**3rd Quantile**	**Maximum**
Assets Composite	Built Population	0.571	0.626	0.656	0.692	0.787
Assets Composite	Livestock Density	0.030	0.170	0.248	0.340	0.494
Built Population	Livestock Density	-0.092	-0.030	0.035	0.119	0.301
Correlations between food insecurity outcomes and independent variables		**Minimum**	**1st Quantile**	**Median**	**3rd Quantile**	**Maximum**
Prevalence of Stunting	Assets Composite	-0.760	-0.713	-0.661	-0.623	-0.537
Prevalence of Stunting	Built Population	-0.406	-0.290	-0.254	-0.169	-0.035
Prevalence of Stunting	Livestock Density	-0.379	-0.342	-0.318	-0.282	-0.203
FEWSNET classification	Assets Composite	-0.481	-0.378	-0.261	-0.142	-0.048
FEWSNET classification	Built Population	-0.277	-0.137	-0.098	0.009	0.123
FEWSNET classification	Livestock Density	-0.228	-0.121	-0.093	-0.025	0.091
FEWSNET classification	Seasonal Precipitation Total 2014	-0.097	0.044	0.066	0.113	0.210
FEWSNET classification	MSD Minimum 2014	-0.017	0.051	0.102	0.130	0.225
FEWSNET classification	MSD Duration 2014	-0.179	0.023	0.074	0.118	0.305
FEWSNET classification	MSD Intensity 2014	-0.113	0.026	0.111	0.243	0.353
FEWSNET classification	CCD 2014	-0.109	-0.009	0.105	0.262	0.393
FEWSNET classification	Rainy Days Count 2014	-0.432	-0.320	-0.260	-0.058	0.020
FEWSNET classification	CCD 95th Percentile 2014	0.039	0.241	0.355	0.414	0.618
Prevalence of Stunting	Seasonal Precipitation Total (1981-2017)	-0.157	-0.120	0.041	0.129	0.178
Prevalence of Stunting	MSD Minimum (1981-2017)	-0.122	-0.087	0.009	0.081	0.126
Prevalence of Stunting	MSD Duration (1981-2017)	-0.387	-0.195	-0.031	0.057	0.125
Prevalence of Stunting	MSD Intensity (1981-2017)	-0.360	-0.270	-0.102	0.163	0.334
Prevalence of Stunting	CDD (1981-2017)	-0.172	-0.045	0.103	0.242	0.353
Prevalence of Stunting	Rainy Days Count (1981-2017)	-0.350	-0.232	-0.145	-0.038	0.093

SI 3 The relationship between mid summer drought and consecutive dry day indices

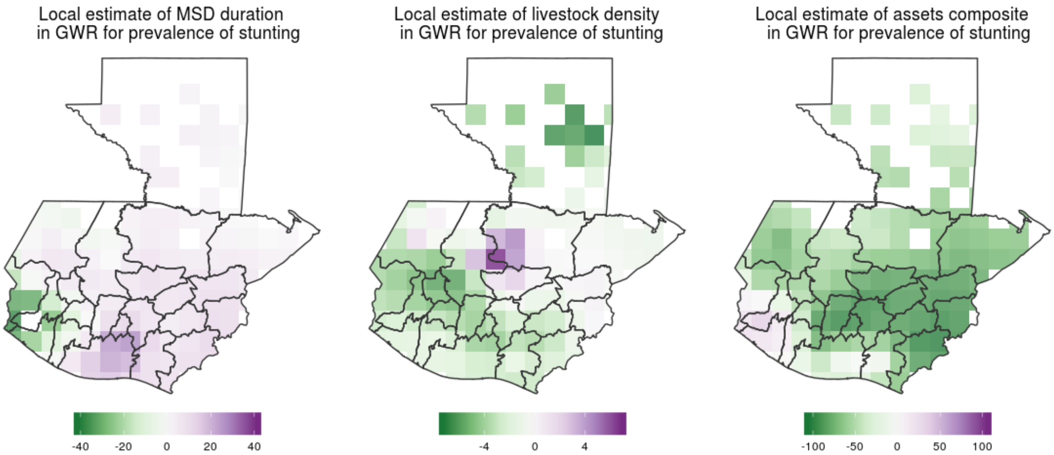
Spatial correlation coefficients between the consecutive dry day count (CDD) (the maximum number of days with less than 1mm of rainfall mm/day during the growing season) and two mid-summer drought (MSD) indices representing the duration (length of days between the two peaks of the smoothed bi-modal distribution) and intensity (the difference between the two peaks and trough of the bi-model distribution) of the MSD.



The average CDD is negatively related to the average MSD Intensity in the Western part of Guatemala, indicating a stronger MSD intensity is associated with shorter CDD in this region, however this relationship is not upheld in the center of the dry corridor region, where the CDD is longest. There was a weak positive relationship between MSD duration and CDD in the dry corridor region, and the opposite trend in the Western Highland region. The spatial distribution of the occurrence of a CDD length in the highest 95th quintile of the 1981-2017 distribution (a high extreme) was positively but very weakly associated with MSD Intensity.

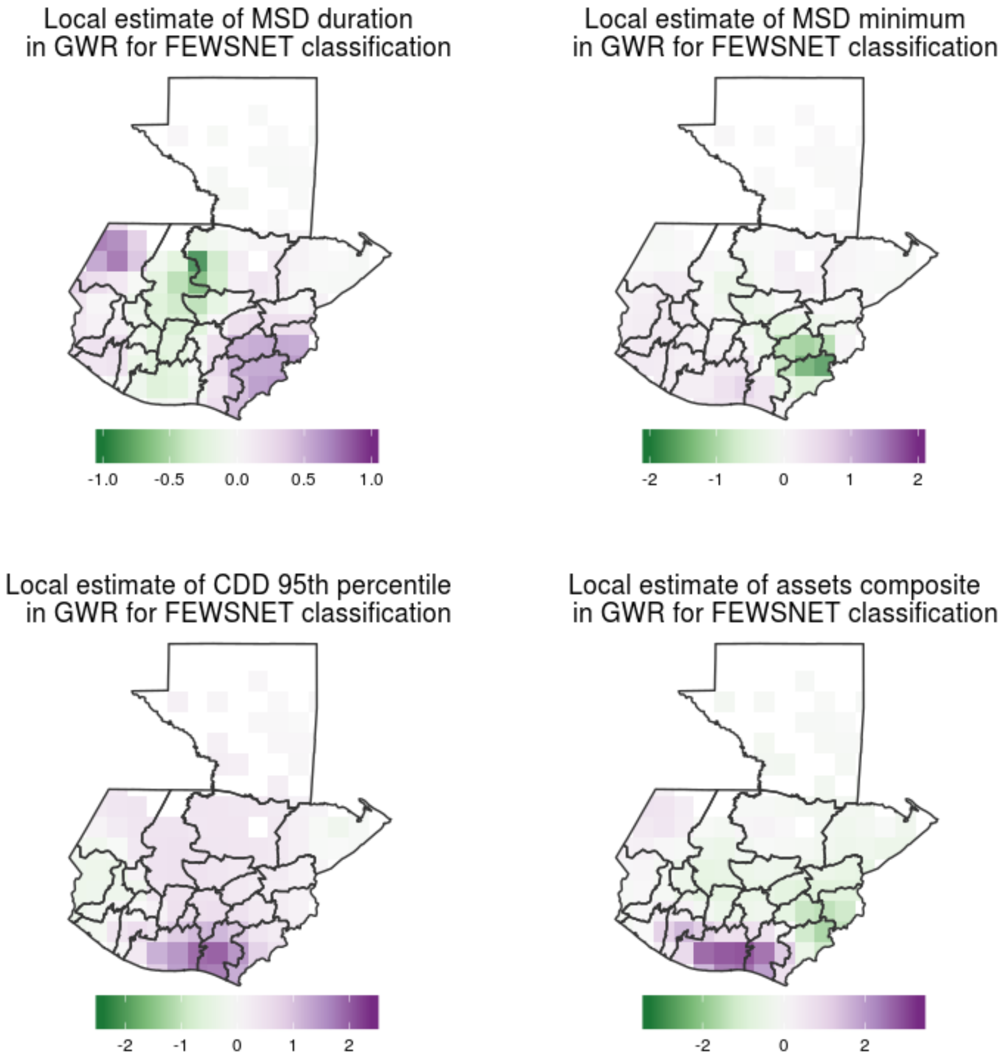
SI 4 Local estimates for GWR model of prevalence of stunting

Panel diagram maps of geographical weighted regression estimates for prevalence of stunting in Guatemala in 2015



SI 5 Local estimates for GWR model of change in FEWSNET food insecurity classification

Panel diagram maps of geographical weighted regression estimates for FEWSNET food insecurity classification change in 2014-2015, in Guatemala



Supplementary Material

Crop modelling: towards locally relevant and climate-informed adaptation

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Literature Search Methods

A combination of the following search strings were used to search for current place-based literature on climate change adaptation in Central America, using Web of Science advanced search criteria:

1. TI or TS= (agriculture OR farm* OR food NEAR production OR ”food security” OR subsist*)
2. TS= (”climate change” OR adapt* OR vulnerability OR climate OR rain* OR drought OR temp*)
3. AD or TS= (belize OR ”el Salvador” OR ”Costa Rica” OR Guatemala OR Honduras OR Nicaragua OR Panama OR ”Central America”)
4. Year Published = 2000-2016
5. Language= ‘English’ or ‘Spanish’

Criteria for exclusion and stage of review [Title, Abstract or Full-Article]	Information collected from included articles
Is the study (at least partly) within a Central American country [Title and Abstract]	Scale of the study
The study focus is relevant to a household or small-scale farming (self-defined or less than 5 ha) [Title and Abstract]	Adaptation strategies represented
The study discusses an agricultural practice that have been assessed, recommended or implemented to increase adaptation (resilience, or decrease vulnerability) to climate change and/or variability [Title, Abstract, and Full-Article]	Are outcomes or benefits of an adaptation measured? If so, is a control used for comparison (attribution) and what form is the outcome measured in (e.g. yield, economic, food security)?
The study uses data (physical or social) [Full-Article]	Use of climate data, climate projections, impacts models, type of data, type of model
	Were climate data used in an analysis of adaptation outcomes?
	Is more than one discipline used?

Table 1 Criteria for the inclusion of searched articles into the systematic review with stage of review denoted by square brackets, and the information collected from the resulting included studies during the review process

Adaptation Strategies References

Adaptation Strategy	Place-based References	Crop-modelling References
Crop diversification	**7** [4, 17, 29, 34, 38, 5, 7]	**0**
Cultivar change	**4** [4, 17, 33, 34, 37]	**24** [3, 8, 13, 15, 18, 19, 20, 21, 22, 23, 25, 28, 31, 30, 32, 35, 36, 39, 41, 43, 44, 45, 46, 48]
Conservation agriculture (and soil conservation)	**4** [4, 17, 34, 5]	**0**
Shade management (tree canopy)	**4** [4, 17, 34, 5]	**0**
Fruit trees	**3** [34, 38, 5]	**0**
Fence, windbreak	**2** [34, 38]	**0**
Fertilizer	**2** [34, 37]	**3** [2, 40, 43]
Irrigation	**2** [34, 4]	**10** [6, 9, 10, 11, 16, 21, 24, 26, 42, 47]
Livelihood diversification	**2** [29, 38]	**0**
Livestock	**2** [34, 38]	**0**
Planting date	**2** [37, 7]	**22** [1, 3, 6, 11, 13, 14, 15, 18, 21, 23, 25, 27, 31, 35, 36, 39, 41, 43, 45, 46, 47, 48]
Seed (access and storage)	**2** [5, 7]	**0**
Cropping area	**1** [17]	**1** [12]
Crop type	**1** [4]	**0**
Crop insurance	**1** [34]	**0**
Honey production	**1** [34]	**0**
Water harvesting	**1** [38]	**0**

Table 2 References from place-based and crop-modelling literature that address each of the adaptation strategies included within the analysis, bracketed numbers respond to included reference list

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UNIVERSITY OF LEEDS

University Research Ethics Committee - application for ethical review

Please email your completed application form along with any relevant supporting documents to ResearchEthics@leeds.ac.uk (or to FMHUniEthics@leeds.ac.uk if you are based in the Faculty of Medicine and Health) at least 6 weeks before the research/ fieldwork is due to start. Dentistry and Psychology applicants should follow their School's procedures for submitting an application.

Ethics reference (leave blank if unknown)	Student number (if a student application)	Grant reference (if externally funded)	Module code (if applicable)
	200976421		

Faculty or School Research Ethics Committee to review the application (put a 'X' next to your choice)		Arts and PVAC (PVAR)
		Biological Science (BIOSCI)
	x	ESSL, Environment and LUBS (AREA)
		MaPS and Engineering (MEEC)
		School of Dentistry (DREC)
		School of Healthcare (SHREC)
		School of Medicine (SoMREC)
		School of Psychology (SoPREC)

Indicate what type of ethical review you are applying for:	x	Student project (PhD, Masters or Undergraduate)
		Staff project (externally or internally funded)

Section 1: Basic project details			
1.1 Research title	Improving evidence bases for food security in Central America		
1.2 Research start date (dd/mm/yy)	Proposed fieldwork start date (dd/mm/yy)	Proposed fieldwork end date (dd/mm/yy)	Research end date (dd/mm/yy)
01/10/2015	01/09/2017	09/02/2018	01/04/2019

Yes	No	
x		1.3 I confirm that I have read and understood the current version of the University of Leeds Research Ethics Policy. *The Policy is available at http://ris.leeds.ac.uk/ResearchEthicsPolicies.*
x		1.4 I confirm that I have read and understood the current version of the University of Leeds Research Data Management Policy. *The policy is available at http://library.leeds.ac.uk/research-data-management-policy.*
x		1.5 I confirm that I have read and understood the current version of the University of Leeds Information Protection Policy. *The policy is available at http://it.leeds.ac.uk/info/116/policies/249/information_protection_policy*
x		1.6 I confirm that NHS ethical review is not required for this project. *Refer to http://ris.leeds.ac.uk/NHSethicalreview for guidance in identifying circumstances which require NHS review*
		1.7 Will the research involve NHS staff recruited as potential research participants (by

		virtue of their professional role) or NHS premises/ facilities? *Please note: If yes, NHS R&D management permission or local management permission may also be needed. Refer to http://ris.leeds.ac.uk/NHSethicalreview.*

Section 2: Contact details	
2.1 Name of applicant	Louise Beveridge
2.2 Position (eg PI, Co-I, RA, student)	PhD Student
2.3 Department/ School	School of Earth and Environment
2.4 Faculty	ICAS & SRI
2.5 Work address (usually at the University of Leeds)	10.128/g School of Earth and Environment, University of Leeds,
2.6 Telephone number	+44 7774508963
2.7 University of Leeds email address	eelb@leeds.ac.uk

Section 3: Summary of the research
3.1 In plain English provide a brief summary of the aims and objectives of the research. (max 300 words). The summary should briefly describe • the background to the research and why it is important, • the questions it will answer and potential benefits, • the study design and what is involved for participants. *Your answers should be easily understood by someone who is not experienced in the field you are researching, (eg a member of the public) - otherwise it may be returned to you. Where technical terms are used they should be explained. Any acronyms not generally known should be described in full.*
45% of children in Guatemala are malnourished, seasonal hunger, in the dry season is the most common type of food insecurity. My partner organization (CGIAR) approach monitoring of large-scale donor funded food security and climate adaptation projects using broadly applied household surveys. These use widely validated food security indicators such as FANTA. This shorter survey style is designed to enable a sample size (of around 2000 households) sufficient for statistical significance of trends that can be representative of a wider population. However, existing analysis have recognized that in attempts to find broad relationships between strategies and food security, these analysis tend to overlook important variability between households, often lack the information to explain observed trends, and do not enable the researcher to identify different pathways out of food insecurity. Therefore triangulation with more in-depth analysis is recommended, especially to understand mechanisms and processes of changing food security. This research will be carried out in an area that has been surveyed as part of a program run by the organization Bioversity (of CGIAR). We aim to compare food security as defined and analyzed in survey data (top down) with the lived experience of food security as reported and experienced by households (bottom up). Another aim is to identify the social mechanisms and processes behind observed trends in survey data that cannot be explained or interpreted through econometric analysis. Findings will inform future survey design directly but also is bridging research across the two disciplines; knowledge guided network analysis will be investigated as a tool to integrate local knowledge gained from participatory research with existing survey analysis approaches. I have carried out a traditional econometric analysis of these data to identify patterns and drivers of food security within the population, and identify a stratification of the survey population from which I will sample for this proposed fieldwork. With 20-50 households that agree to participate from this sub-sample, I plan to use participatory and farmer led approaches to try and access and record individuals definition, perceptions and lived experiences of food security. I estimate that this will take between 2

hours to 2 days of their time, which is a high time demand, but required to gain in depth understanding, hence the low sample size to avoid over extractive research. This time will be tentatively broken down into a shorter period, up to half a day, of discussion through interview, farm walks, or a transects. A longer time-frame would only be required in the case that observation techniques are employed.	
3.2 Where will the research be undertaken?	Central America; multiple countries
3.3 Who is funding the research?	NERC and Bioversity
NB: If this research will be financially supported by the US Department of Health and Human Services or any of its divisions, agencies or programmes please ensure the additional funder requirements are complied with. Further guidance is available at http://ris.leeds.ac.uk/FWAcompliance and you may also contact your FRIO for advice.	

Section 4: Research data and impact
You may find the following guidance helpful:

- Research data management guidance
- Advice on planning your research project
- Dealing with issues relating to confidentiality and anonymisation
- Funder requirements and University of Leeds Research Data Management Policy

4.1 What is the data source? (Indicate with an 'X' all that apply)	
x	New data collected for this research
x	Data previously collected for other research
	Data previously collected for non-research purposes
	Data already in the public domain
	Other, please state: ______________________________.
4.2 How will the data be collected? (Indicate with an 'X)	
x	Through one-to-one research interviews
x	Through focus groups
	Self-completion (eg questionnaires, diaries)
x	Through observation
	Through autoethnographic research
	Through experiments/ user-testing involving participants
x	From external research collaborators
	Other, please state: ______________________________.

4.3 How will you make your research data available to others in line with: the University's, funding bodies' and publishers' policies on making the results of publically funded research publically available(in compliance with UK data protection legislation)? (max 200 words)
All data collected using NERC funding must be made available to NERC data centers 2 years after data collection ends. Data collected in this research will be in the form of transcripts, notes, and summaries. In order to make data accessible, with the permission of participants, anonymous transcripts (without names, or village names, or GPS) could be submitted to the NERC data center. In each case I will review the anonymity of the interviewee from the transcript, and if anonymity cannot be guaranteed the data will be withheld from entry into the database. It is feasible that on removal of information that could be used to identify an individual, the data will no longer be able to be interpreted in a useful way for other researchers accessing the data center. The decision as to whether to upload the data or not will be taken in light of this conflict of requirements at the time, however anonymity and ethics will be given priority over the funding requirement in this case.

4.4 How do you intend to share the research data, both within and outside the research team? (Indicate with an 'X)	
	Depositing in a specialist data centre or archive
	Submitting to a journal to support a publication
x	Depositing in a self-archiving system or an institutional repository
	Dissemination via a project or institutional website
x	Informal peer-to-peer exchange
	No plans to report or disseminate the data
	Other, please state: ____.
4.5 How do you intend to report and disseminate the results of the study? (Indicate with an 'X)	
x	Peer reviewed journals
x	Internal report
x	Conference presentation
	Publication on website
	Other publication
	Submission to regulatory authorities
	No plans to report or disseminate the results
x	Other, please state: Through partners at CGIAR working in region.
4.6 Give details of the expected impact of the research. Further guidance is available at http://www.rcuk.ac.uk/innovation/impacts. (max 200 words)	

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This research aims to have a direct impact through increasing the understanding of food security experienced in an area being targeted by CGIAR led food security and adaptation projects. It also aims to inform design of food security analysis and monitoring (surveys) carried out by CASE partners at Bioversity. A more indirect impact intended is the insight gained into the types of evidence produced by specific methodological approaches (survey versus participatory), and the representation and weighting of the use of these types of evidence in current rural policy in Guatemala.

Section 5: Protocols		
Which protocols will be complied with? (Indicate with an 'X'). There may be circumstances where it makes sense not to comply with a protocol, this is fine but should be clarified in your application.	x	Data protection, anonymisation and storage and sharing of research data
		Informed consent
	x	Verbal consent
	x	Reimbursement of research participants
		Low risk observation

Section 6: Additional ethical issues	
6.1 Indicate with an 'X' in the left-hand column whether the research involves any of the following:	
x	Discussion of sensitive topics, or topics that could be considered sensitive
	Prolonged or frequent participant involvement
	Potential for adverse environmental impact
	The possibility of harm to participants or others (including the researcher(s))
	Participants taking part in the research without their knowledge and consent (eg covert observation of people in non-public places)
	The use of drugs, placebos or invasive, intrusive or potentially harmful procedures of any kind
	Food substances or drinks being given to participants (other than refreshments)
	Vitamins or any related substances being given to participants
	Acellular blood, urine or tissue samples obtained from participants (ie no NHS requirement)
	Members of the public in a research capacity (participant research)
	Participants who are particularly vulnerable (eg children, people with learning disabilities, offenders)
	People who are unable to give their own informed consent
	Researcher(s) in a position of authority over participants, eg as employers, lecturers, teachers or family members
	Financial inducements (other than reasonable expenses and compensation for time) being offered to participants
	Cooperation of an intermediary to gain access to research participants or material (eg head teachers, prison governors, chief executives)
	Potential conflicts of interest
	Internet participants or other visual/ vocal methods where participants may be identified
	Scope for incidental findings, ie unplanned additional findings or concerns for the safety or

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	wellbeing of participants.
	The sharing of data or confidential information beyond the initial consent given
x	Translators or interpreters
x	Research conducted outside the UK
x	An international collaborator
x	The transfer of data outside the European Economic Area
	Third parties collecting data
	Other ethical clearances or permissions

6.2 For the ethical issues indicated in 6.1 provide details of any additional ethical issues the research may involve and explain how these issues will be addressed. (max 200 words)

Discussion of sensitive topics, or topics that could be considered sensitive:
Food insecurity and poverty are likely to be sensitive topics for many participants: this may be apparent in an unwillingness to discuss certain aspects of food security experienced or in the 'playing down' or 'covering up' of their real lived experience due to embarrassment. To reduce this source of stress and the chance of participants wanting to drop out of the research due to sensitivity the topic of the research and expected areas covered will transparently discussed prior to their recruitment.

Working with field assistants and translators:
To establish an appropriate wage I will spend time talking to colleagues and initial contacts in country. I will also have a frank conversation with my research assistant during recruitment about expected living arrangements prior to the start of field-work. Following recruitment I will spend a few days of training and preparation, where by I will make sure my field assistant (also acting as a translator) is aware of the goals of the research; will together work through the ethical issues, how to treat and approach participants, participants right to leave the research without reason, interviewing and participatory methodologies and skills, potential problems that could arise during field work, managing their risk and protocols for their occurrence. During fieldwork, I will arrange a debriefing session between myself and the assistant, to go over each data collection event: how it went, what we have learnt, ways to improve, and general wellbeing. To insure confidentiality I will recruit a research assistant that is regionally local, but not from the direct villages that we will be working in. This is because the existing relationships between participants and research assistant would be likely to create more influential power dynamics, change participants responses, and risk a breach of confidentiality.

Research conducted outside the UK:
As this research is conducted in a country and culture different from my own, I am aware of the impact this difference will have on my interactions with participants, my perceptions of them, and their own perception of me as an individual. Using a translator is intended to reduce some of these perceived difference, to make participants feel more comfortable being able to talk with someone of a more relatable background. Although my presence will still likely have an effect. If after a time I fell I have established a strong working relationship with my assistance whereby s(he) is able to discuss the aims and outcomes of interviews with me in a critical way, I will consider asking them to do some solo interviews or activities with a small subset of participants to investigate if my presence is affecting the outcomes. In this case I will allow time for us to go over the transcripts together to interpret them and debrief fully after each event.

Participant fatigue and perceptions of researchers
As all participants have been part of a project run by CGIAR, mostly led by European and American scientists, and hence participants will be likely to draw strong associations between myself and the CGIAR. To avoid this bias or prejudice in their responses, I will make my and my research assistants independent stance very clear during our introduction of the research at the beginning of each data collection event, and throughout the interview or activity if I notice un-comfort, shyness or signs that we are being associated with the CGIAR. Incase participants feel a sense of fatigue from being part of research over an ongoing period, I will make it very clear at the beginning, and throughout research that they are always free to stop participating and remove themselves from the study.

An international collaborator: Collaborator at CGIAR are likely to have a set of expectation regarding the outcome of the research. I have made my collaborators aware that I will produce outputs that may use critical methods and perspectives regarding the impact of their projects and monitoring, and they have agreed that this critical insight should make for interesting conversations.

Section 7: Recruitment and consent process For guidance refer to http://ris.leeds.ac.uk/InvolvingResearchParticipants and the research ethics protocols.
7.1 State approximately how much data and/ or how many participants are going to be involved.
20-50 households (one individual per household)
7.2 How was that number of participants decided upon? (max 200 words) *Please note: The number of participants should be sufficient to achieve worthwhile results but should not be so high as to involve unnecessary recruitment and burdens for participants. This is especially pertinent in research which involves an element of risk. Describe here how many participants will bruited, and whether this will be enough to answer the research question. If you have received formal statistical advice then please indicate so here, and describe that advice.*
Determining an appropriate (and not overly extractive sample size): For each village, a sample of 7 households will be the target (7*6 = 42 total), but this will be reduced if reach saturation is observed, where themes of discussion and information becomes redundant due to repetition without new insight.
7.3 How are the participants and/ or data going to be selected? List the inclusion and exclusion criterial. (max 200 words)
I have carried out a traditional econometric analysis of these data to identify patterns and drivers of food security within the population, and identify a stratification of the survey population from which I will sample for this proposed fieldwork. 6 villages that have households representative of each stratification grouping will be used as centers of investigation. Household within villages and stratified groups will be selected randomly, on conditions of access (both physical and social). Households will be contacted though a gatekeeper (a contact who organized the initial surveys), however they will be asked not to be present during the data collection, to be able to insure independence from CGIAR, and to avoid conflict of interest. No specific exclusion criteria needed. No groups will be excluded.
7.4 For each type of methodology, describe the process by which you will obtain and document freely given informed consent for the collection, use and reuse of the research data. Explain the storage arrangements for the signed consent forms. *Guidance is available at http://ris.leeds.ac.uk/InvolvingResearchParticipants. The relevant documents (information sheet and consent form) need to be attached to the end of this application. If you are not using an information sheet and/ or seeking written consent, please provide an explanation.*
Verbal Consent It is likely many of the participants will not have literacy sufficient to make a fully informed written consent. A transparent explanation of the research, aims and involvement costs will be written with the help of a local research assistant, to make it accessible and clear, this will be read to participants in a request for their agreement to participate at recruitment.

Consent as independent on ongoing CGIAR research It will be made clear to participant, their decision to participate in this research has no effect or relation to their ongoing participation in the CGIAR project and survey, and that their data and answers will not be accessible to anyone at CGIAR; only myself and my assistant.
7.5 Describe the arrangements for withdrawal from participation and withdrawal of data/ tissue. *Please note: It should be made clear to participants in advance if there is a point after which they will not be able to withdraw their data. See also http://ris.leeds.ac.uk/ResearchDataManagement.* (max 200 words)
Withdrawal from the study Permissions to use the data collected and the opportunity to withdraw from the study will be discussed again at the beginning and end of a participant's contribution to the research, at each separate meeting, by me or my research assistant. Follow up details will be provided, as will a date after which anonymised data can no longer we withdrawn their input to the transcripts. For participants without access to a phone or computer they will not be able to be removed from the study once I have left the study location. Once processed, data will only be kept in an anonymised format, at this point the removal of data from the study at the request of a participant will no longer be executable.
7.6 Provide details of any incentives you are going to use and explain their purpose. (max 200 words) *Please note: Payment of participants should be ethically justified. The FREC will wish to be reassured that research participants are not being paid for taking risks or that payments are set at a level which would unduly influence participants. A clear statement should be included in the participant information sheet setting out the position on reimbursement of any expense incurred.*
Reimbursement A fair reimbursement for travel and time-cost will be discussed with local contacts on arrival to ensure suitability in type and amount. Re-reimbursement will be discussed with participants and presented after we have agreed that they have reached the end of their contribution. This is so that their perception of myself as a researcher, their answers to questions, and their willingness to participate will not be biased by this reimbursement.

Section 8: Data protection, confidentiality and anonymisation *Guidance is available at http://ris.leeds.ac.uk/ConfidentialityAnonymisation*	
8.1 How identifiable will the participants be? (Indicate with an 'X').	
	Fully identifiable
x	Identity of subject protected by code numbers/ pseudonyms
	Fully anonymised
	Anonymised but potentially identifiable
	Data only in aggregated form
	Other
8.2 Describe the measures you will take to deal with issues of confidentiality, including any limits to confidentiality. (max 300 words)	

Confidentiality in data collection The main method of providing confidentiality to the participants is through the anonymisation of the information they provide us. Pseudo name will be used from the start of data collection. The intended use of data will be discussed with the participants at the beginning and end of the data collection. These pre agreed channels of data use will then be respected by myself and my research assistant (through briefing and training). Recordings, notes and transcripts will only be accessible to us. Confidentiality will be protected by immediate anonymity of data, and the limited sharing of data in all formats (locked rooms, password protected, and encypted computer drives as discussed above). **Confidentiality: Data use in future training** I will ask permission of one or two participant for me to use their anonymised transcripts for future training purposes, where I am sure anonymity can be realised. **Confidentiality: Data use in publication** Permission to publish summarized results and select anonymised quotes in publications and my thesis will be obtained.
8.3 Describe the measures you will take to deal with issues of anonymity. (max 200 words)
Transcripts and notes will not use real names a pseudo-names will be used instead at the onset of data collection. A document linking code names to real names (and associated survey data) will be stored on a password-protected computer only. Where anonymity cannot be guaranteed, due to the capacity to identify individuals from their location and context of interview content, their agreement to still participate will be acquired after a discussion of any potential risks that could arise from the publication of the data they have provided along side their identity.
8.4 Who will have access to the research data apart from the research team (eg translators, authorities)? (max 100 words)
N/A
8.5 Describe the process you will use to ensure the compliance of third parties with ethical standards. (max 100 words)
As described above, a training period and continued debriefing throughout the research will ensure that any field assistant engaged in the research is also complying with all the ethical standards as set out here.
8.6 Where and in what format(s) will research data, consent forms and administrative records be retained? (max 200 words) *Please note: Mention hard copies as well as electronic data. Electronic data should be stored securely and appropriately and in accordance with the University of Leeds Data Protection Policy available at http://www.leeds.ac.uk/secretariat/data_protection_code_of_practice.html.*
Data Management Interviews transcripts and observational notes will be in paper format (kept on my person or in a locked room) and recorded on a dictaphone (also kept on my person or in a locked room); recordings and transcripts will be stored on an encrypted and password protected computer. I will undertake a data security briefing at the beginning of fieldwork and provided a data collection protocol to any translators engaged in the data collection, with continued discussions about the ethics and issue of

data security throughout the fieldwork if needed. When internet allows, transcripts and recordings will be backed up onto my M:drive on the university computer system.
8.7 If online surveys are to be used, where will the responses be stored? (max 200 words) *Refer to:* *http://it.leeds.ac.uk/info/173/database_and_subscription_services/206/bristol_online_survey_accounts* *and http://ris.leeds.ac.uk/SecuringResearchData for guidance.*
N\A
8.8 Give details and outline the measures you will take to assess and to mitigate any foreseeable risks (other than those already mentioned) to the participants, the researchers, the University of Leeds or anyone else involved in the research? (max 300 words)
Risks to participants Participants will not be put into any direct risk by participating. With more in depth interview and participatory methods there is the indirect risk of extractive research due to the time-cost. Reflection from participants on their own, expectations, involvement and time-cost, and desired outcomes will be encouraged throughout their engagement. The opportunity to leave the study at any time will be made clear. A gift that is considered a locally relevant reimbursement of time will be given to the participant when leaving the location. **Researchers (myself and one field assistant)** Researchers will not be put into any direct risk by conducting the research. A health and safety assessment has been carried out to make a full-informed assessment of risks to researchers.

Section 9: Other ethical issues		
Yes	**No**	(Indicate with an 'X')
x		9.1 Is a health and safety risk assessment required for the project? *Please note: Risk assessments are a University requirement for all fieldwork taking place off campus. The risk assessment forms and further guidance on planning for fieldwork in a variety of settings can be found on the University's Health & Safety website along with further information about risk assessment:* *http://www.leeds.ac.uk/safety/fieldwork/index.htm. Contact your Faculty Health and Safety Manager for further advice. See also http://ris.leeds.ac.uk/HealthAndSafetyAdvice.*
	x	9.2 Is a Disclosure and Barring Service check required for the researcher? *Please note: It is the researcher's responsibility to check whether a DBS check is required and to obtain one if it is needed.*
9.3 Any other relevant information		
This research will focus in a case study area called Trifinio, that is situated on the border between Guatemala, Honduras, and El Salvador. The existing survey data contains information of agricultural strategy (number of crops, livestock, on farm income), general socioeconomic data (number in household, off-farm income) and data to calculate the following indicators: Diet diversity (HDDS, FANTA) Experiences of food insecurity (HFIAS, FANTA) Progress out of Poverty (PPI)		

9.4 Provide details of any ethical issues on which you would like to ask the Committee's advice.
How to negotiate the conflicting requirements of making data available in a NERC data center and maintaining confidentiality?

Section 10: Further details for student projects (complete if applicable) Your supervisor is required to provide email confirmation that they have read, edited and agree with the form above. It is a good idea to involve your supervisor as much as possible with your application. If you are unsure how to answer any of the questions do ask your supervisors for advice.			
10.1 Qualification working towards (indicate with an 'X')			
	Bachelor's degree	Module code:	
	Master's degree (including PgCert, PgDip)		
x	Research degree (ie PhD)		

10.2 Primary supervisor's contact details	
Name (title, first name, last name)	Andy Challinor
Department/ School/ Institute	ICAS, School of Earth and Environment
Telephone number	
University of Leeds email address	A.J.Challinor@leeds.ac.uk
10.3 Second supervisor's contact details	
Name (title, first name, last name)	Stephen Whitfield
Department/ School/ Institute	SRI, School of Earth and Environment
Telephone number	
University of Leeds email address	S.Whitfield@leeds.ac.uk

Yes	**No**	10.4 To be completed by the student's supervisor
		The topic merits further research
		I believe that the student has the skills to carry out the research

Section 11: Other members of the research team (complete if applicable)	
Name (title, first name, last name)	Jacob van Etten
Role (eg PI, Co-I)	External Supervisor
Department/ School/ Institute	CGIAR
Telephone number	
University of Leeds email address	
Name (title, first name, last name)	Mark van Wijk
Role (eg PI, Co-I)	External Supervisor

Department/ School/ Institute	CGIAR
Telephone number	
University of Leeds email address	
Name (title, first name, last name)	
Role (eg PI, Co-I)	
Department/ School/ Institute	
Telephone number	
University of Leeds email address	

Section 12: Supporting documents		
Indicate with an 'X' which supporting documents have been included with your application. Wherever possible the research title on consent forms, information sheets, other supporting documentation and this application should be consistent. The title should make clear (where appropriate) what the research is about. There may be instances where a different title is desirable on information to participants (for example – in projects which necessarily involve an element of deception or if giving the title might skew the results of the research). It is not imperative that the titles are consistent, or detailed, but where possible then they should be. Supporting documents should be saved with a meaningful file name and version control, eg *'Participant_Info_Sheet_v1'* or *'Parent_Consent_From_v2'*. Refer to the examples at http://ris.leeds.ac.uk/InvolvingResearchParticipants.		Information sheet(s) *Please note: Include different versions for different groups of participants eg for children and adults if applicable. Refer to http://ris.leeds.ac.uk/InvolvingResearchParticipants for guidance in producing participant information sheets.*
		Consent form(s) *Please note: Include different versions for different groups of participants eg for children and adults if applicable. Refer to http://ris.leeds.ac.uk/InvolvingResearchParticipants for guidance in producing participant consent forms.*
		Recruitment materials *Please note: Eg poster, email etc used to invite people to participate in your research project.*
		Letter/ email seeking permission from host/ gatekeeper
		Questionnaire/ interview questions
		Health and safety risk assessment *Please note: Risk assessments are a University requirement for all fieldwork taking place off campus. The risk assessment forms and further guidance on planning for fieldwork in a variety of settings can be found on the University's Health & Safety website along with further information about risk assessment: http://www.leeds.ac.uk/safety/fieldwork/index.htm. Contact your Faculty Health and Safety Manager for further advice. Also refer to http://ris.leeds.ac.uk/HealthAndSafetyAdvice.*
		Data management plan *Refer to http://library.leeds.ac.uk/research-data-manage.*

Section 13: Sharing information for training purposes		
Yes	**No**	(Indicate with an 'X')
		I would be content for information in the application to be used for research ethics and research data management training purposes within the University of Leeds. All personal identifiers and references to researchers, funders and research units would be removed.

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Section 14: Declaration		
1. The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it. 2. I undertake to abide by the University's ethical and health & safety policies and guidelines, and the ethical principles underlying good practice guidelines appropriate to my discipline. 3. If the research is approved I undertake to adhere to the study protocol, the terms of this application and any conditions set out by the Research Ethics Committee. 4. I undertake to ensure that all members of the research team are aware of the ethical issues and the contents of this application form. 5. I undertake to seek an ethical opinion from the REC before implementing any amendments to the protocol. 6. I undertake to submit progress/ end of project reports if required. 7. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data. 8. I understand that research records/ data may be subject to inspection for audit purposes if required in future. 9. I understand that personal data about me as a researcher in this application will be held by the relevant FRECs and that this will be managed according to the principles established in the Data Protection Act.		
	Applicant	Student's supervisor (if applicable)
Signature		
Name		
Date		

The Secretariat
Level 11, Worsley Building
University of Leeds
Leeds, LS2 9JT
Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Louise Beveridge
School of Earth and Environment
University of Leeds
Leeds, LS2 9JT

ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee
University of Leeds

15 August 2017

Dear Louise

Title of study: **Interdisciplinary approaches to understand and measure household food**
Ethics reference: **AREA 16-179**

I am pleased to inform you that the above research application has been reviewed by the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
AREA 16-179 Ethical_Review_LB.pdf	1	30/06/17
AREA 16-179 Information sheet for fieldwork .pdf	1	30/06/17
AREA 16-179 FieldworkQuestions.pdf	1	30/06/17
AREA 16-179 FieldworkHandSForm.LouiseBeveridge.pdf	1	30/06/17

Committee members made the following comments about your application:

Application section	Comment	Response required/ amended application required/ for consideration
8.2	Some slight confusion between confidentiality and anonymisation – refer to the guidance: http://ris.leeds.ac.uk/ConfidentialityAnonymisation	For consideration
7.4	This section says "It is likely many of the participants will not have literacy sufficient to make a fully informed written consent" – this is just a question over why this approach will not then be used.	For consideration
Information sheet	The information sheet is very clear and contains relevant details. However, there are some minor grammatical errors that might cause problems with syntax in translation – perhaps these should be	For consideration

	amended prior to translation.	
Information sheet	Some information is needed about how data provided will be stored together with the potential for it to be archived.	Amend information sheet

Please notify the committee if you intend to make any amendments to the information in your ethics application as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation and other documents relating to the study, including any risk assessments. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, the Secretariat
On behalf of Dr Kahryn Hughes, Chair, AREA Faculty Research Ethics Committee

CC: Student's supervisor(s)