HOUSEHOLD ADAPTIVE CAPACITY AND CURRENT VULNERABILITY TO FUTURE CLIMATE CHANGE IN RURAL NICARAGUA

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M.Sc., University of Lethbridge, 2014

A Thesis
Submitted to the School of Graduate Studies
of the University of Lethbridge
in Partial Fulfilment of the
Requirements for the Degree

[Master of Science]

Department of Geography
University of Lethbridge
LETHBRIDGE, ALBERTA, CANADA

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Acknowledgements

I would like to dedicate this thesis to my grandmother, Heléne Byrne, who has an endless passion for learning and who at 97 years of age, is still the most curious person I know.

I would also like to express my sincere gratitude to my Supervisory Committee who have provided me with invaluable guidance on my thesis research, and who have facilitated a wonderful learning experience for which I am eternally grateful.

My sincere thanks to my fiancé, Devin Cairns, who is always incredibly patient and supportive and who has been instrumental in helping me complete my thesis research.

Last but certainly not least, I would like to thank my family, Cindy, Paul, Justin and Kelcy Byrne, who have always encouraged and supported me to achieve, and been there to pick me up when I have failed.

Abstract

While there is a growing recognition of the impact that climate change could have on human development, there has been a shift in focus from an impacts-led assessment approach towards a vulnerability-led assessment approach. Since many of the most extreme impacts of climate change over the coming years will be on agriculture and food systems, the extent to which farming households and communities have the capacity to respond or adapt to these changes has important implications for development at the national, regional and household levels. This research examines the adaptive capacity of rural Nicaraguan farm households in the face of current and future climate change, and investigates how current vulnerability to future climate change varies on a municipio by municipio basis across the country. We find that household adaptive capacity varies significantly across regions in Nicaragua, and also when households display certain demographic characteristics. We also find that municipios in Nicaragua demonstrate diversity in terms of agricultural response to projected climate change and current adaptive capacity conditions. The results of this research can be used to inform policy decision making and serve as a basis for targeting policy interventions in rural Nicaragua

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

The study of vulnerability to climate change has been a topic of recent research, motivated by the increasingly visible impact of anthropogenic influences on the Earth's climate. While climate change is a global phenomenon, scientists and policy experts agree that the effects of climate change in Less Developed Countries (LDCs) will be "disproportionate and severe" (Kumssa & Jones, 2010, p. 453). Geographic regions within the same country will experience the effects of climate change differently, and given varying levels of adaptive capacity, their inhabitants will respond differently too. It is projected that regional differences in agricultural production will grow stronger through time, leading to greater disparity between More Developed Countries (MDCs) and LDCs, with the most severe impacts occurring at the margins (Rosenzweig, Iglesias, Yang, Epstein, & Chivian, 2001). Therefore, place-based assessment of vulnerability to climate change in LDCs is critical for effective policy targeting intervention that can prevent negative outcomes before the outcome itself materializes. Turner et al. (2003) demonstrate support for vulnerability analysis at a sub-national level by stating, "the strong variation in vulnerability by location, even to hazards created by global-scale processes and phenomena, however, elevates the role of 'place-based' analysis," (Turner et al., 2003, 8076).

In recognition of the importance of place-based analysis and the challenges that climate change poses to LDCs, this thesis research focuses on vulnerability to climate change in Nicaragua from an agricultural perspective. In brief, this research explores the following two main interconnected topics, but examines them at different scales: 1) relative adaptive capacity at a household level, and 2) relative vulnerability of administrative units, or municipios. Vulnerability to climate change is studied from an agricultural perspective, and incorporates crop modelling to determine how projected changes in climate will impact agricultural yield, and an analysis of the current adaptive capacity of those whose livelihoods are directly linked to agriculture.

Adaptive capacity is an integral component of the vulnerability framework and is considered a critical piece of a vulnerability assessment. The first part of this thesis research presents a methodology for measuring the adaptive capacity of rural households involved in farming, relative to other rural households involved in farming. This is done by creating a Rural Farm Household Adaptive Capacity Index (RFHACI) that: 1) captures the theoretical determinants of adaptive capacity, and 2) specifically targets our study population. Household survey data from Nicaragua is applied to the RFHACI and statistical tests are done to determine whether there are significant differences in household adaptive capacity by geographic region, or when households exhibit various demographic traits.

The second part of this thesis research (Chapter 4) operationalizes the Intergovernmental Panel on Climate Change's (IPCC's) definition of vulnerability to climate change, to determine how vulnerability to climate change varies spatially across rural Nicaragua. The research presented in Chapter 4, builds on our adaptive capacity research by scaling up the RFHACI to the municipio level and incorporating it with the crop yield modelling results, to present a clear picture of current vulnerability to future climate change. The result is a vulnerability map, identifying the most and least vulnerable municipios in Nicaragua.

The three main objectives for the research described above, are:

1) Create an index that: a) assesses relative adaptive capacity at a household level, and b) specifically targets rural[1] households that depend on agriculture for some portion of their income.
2) Determine if there are significant differences in adaptive capacity between households that: a) are located in different climate regions in Nicaragua and, b) exhibit certain demographic traits?

[1] Where the term 'rural' is defined by the Living Standards Measurement Survey (LSMS) as a location where the population concentration is less than 1000 inhabitants per village.

3) Determine how the spatial distribution of current vulnerability to future climate change varies across rural Nicaragua.

The remainder of this thesis is structured in the following way. Chapter 2 provides a brief review of relevant literature that is not included in either of the main analytical chapters. The first analytical chapter, Chapter 3, presents the adaptive capacity index development and the subsequent statistical analysis of significant differences in household adaptive capacity. The second analytical chapter, Chapter 4, presents the research on vulnerability to climate change at the municipio level. Chapters 3 and 4 are written in a paper format whereby with some changes, they will be fit to submit to a journal for publication. Finally, Chapter 5 provides an overall conclusion to this thesis work.

Chapter 2: Literature Review

2.1. Vulnerability to Climate Change

Vulnerability to climate change has become a hotly debated and increasingly researched subject with climate change research shifting from an impacts-led approach, to a vulnerability-led approach (Turner et al., 2003). In the simplest terms, vulnerability is a measure of potential future harm (Hinkel, 2011). Unfortunately, the concept of vulnerability, and specifically vulnerability to climate change, is far from simple. The subject of 'vulnerability to climate change' (hereafter referred to as 'vulnerability') overlaps with many different disciplines (Brooks, 2003), from ecology, to sociology, to health sciences, economics, climatology and beyond. The number of definitions and conceptualizations of vulnerability and similarly related terms is staggering (Brooks, 2003) with some researchers arguing that vulnerability cannot be defined at all (Brooks, 2003).

According to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), vulnerability is described as a function of exposure, sensitivity and adaptive capacity (McCarthy, Canziani, Leary, Dokken, & White, 2001b) where 'exposure' is defined as the degree to which a system experiences climate change stresses; 'sensitivity' is the degree to which a system responds to climate related stimuli; and 'adaptive capacity' is the ability of a system to adjust to actual or expected climate stresses or to cope with the consequences (McCarthy et al., 2001b). Since TAR, this definition of vulnerability and its sub-components have been utilized by many researchers including Adger (2006), Metzger, Leemans, and Schröter (2005) and O'Brien et al. (2004), to name a few. This is not to say that all vulnerability research has accepted this definition as many others, including Turner et al. (2003), view vulnerability as a function of exposure, sensitivity and resilience, or view vulnerability simply in terms of exposure and sensitivity. The lack of coherent, consistently defined diction has led to numerous issues (Adger, 2006; Hinkel, 2011; Ionescu, Klein, Hinkel, Kumar, & Klein, 2009; Wolf et al., 2010) including preventing clear communication across disciplines (O'Brien, Eriksen, Schjolden, & Nygaard, 2009), hindering the comparability of studies (Eakin & Luers, 2006), clouding the distinction between cause and effect (Dilley & Boudreau, 2001), increasing confusion among policy makers (O'Brien et al., 2009), and has just generally slowed overall progress in this field. On the other hand, Eakin and Luers (2006) argue that the diverse approaches to vulnerability are essential to addressing the complex nature of the concept to the social-environmental system, and can even be viewed as complementary to one another.

While research on the determinants of vulnerability to climate change is still at an early stage (Adger, Brooks, Bentham, Anew, & Eriksen, 2004), the way vulnerability is defined is of critical importance to multidisciplinary research, as it directly affects how climate change research is designed, carried out and understood by all involved parties (O'Brien et al., 2009). Vulnerability can either be viewed as a ‘starting-point’ where vulnerability is caused by numerous environmental and social processes, and exacerbated by climate change, or as an ‘end-point’, where one considers the residual impacts of climate change after adaptation efforts have been made (Kelly & Adger, 2000). Viewing vulnerability as a starting point allows for an understanding of how climate change impacts will be distributed and is used to identify how vulnerability can be reduced (O'Brien et al., 2009). In viewing vulnerability as a ‘starting-point’ (as our research does), climate change acts as a “magnifying glass” where populations that already exist at the margins of society are likely to experience climate change more acutely, which further prevents them from participating equally in any solution or accessing necessary adaptation measures (Lambrou & Paina, 2006; Masika, 2002; Skinner, 2011; Tanner & Mitchell, 2008). In light of the mounting evidence that vulnerability to climate change is closely tied to other deprivations, climate change has emerged as not only an urgent environmental issue, but as an urgent development issue as well (Skinner, 2011).

2.1.1. Vulnerability Assessments

The scopes of vulnerability assessments vary, are done at different scales, have different purposes, and are targeted at different audiences. Vulnerability assessments may look only at social vulnerability, (a term that is often associated with adaptive capacity (Füssel & Klein, 2006)), only at environmental vulnerability, or consider the interplay of both human and environmental vulnerability (Füssel, 2007). Vulnerability assessments can also be classified by purpose and may be carried out with the intent to: 1) compare between communities, nations, or regions, 2) assess future threat, or 3) enhance the understanding of factors that cause vulnerability so that vulnerability may be reduced (Adger et al., 2004). Recent advances in vulnerability research emphasize the importance of considering climate change effects on the human-environment coupled system (Füssel, 2007; Polsky, Neff, & Yarnal, 2007; Turner et al., 2003). Analysis of vulnerability can be performed at many different scales including at a regional or country level, a sub-national level, a community level and even a household or individual level. Each study must consider the scope, purpose, scale and audience for their research.

2.1.2. Issues with Quantifying Vulnerability

Aside from the issues that arise from confusion over terminology, there are many other issues that arise when attempting to measure vulnerability. First, vulnerability is not a tangible thing, making it very hard to accurately quantify (Vincent, 2007). To mitigate this issue, some researchers such as O'Brien et al. (2004) have used comparative studies, where the focus is on differentiating ‘relative’ vulnerability. Secondly, vulnerability is a process and is constantly in a state of evolution or flux (O'Brien et al., 2009), making it impossible to accurately measure at any point in time without real-time data. This brings us to a third issue – data availability. Data availability plays a huge role in measuring vulnerability and is often one of the major driving forces behind vulnerability indicator selection (Hinkel, 2011). Perhaps the most important issue in measuring vulnerability arises from the complexity of human response. Changes in climate affect people differently, and ceteris paribus, people will respond differently to the same event. Therefore it is difficult to quantify vulnerability; however, to minimize negative outcomes and foster human development, we must try.

2.1.3. Measuring Vulnerability using Indicators

Although there is not a perfect way to measure vulnerability, indicators are a commonly used tool in vulnerability assessments. While they have proven useful for identifying vulnerable communities, regions, or groups of people (Hinkel, 2011), developing vulnerability indicators poses a major set of challenges. According to Hutchinson (1992), there is an "almost infinite" number of indicators that may be used to measure vulnerability. To narrow down this list, Adger et al. (2004) have come up with that indicator selection/development criteria which state that one must consider the following when selecting or designing a vulnerability indicator: 1) decide whether the focus is future, or present-day vulnerability, 2) ensure that the indicator is robust, precise, objective and transparent, 3) confirm that stakeholders recognize the indicator as valid, and 4) make sure the indicator is apt for the scale at which one is working at (Adger et al., 2004). To add to the complexity of designing vulnerability indicators, indicators must be sensitive enough to display subtle variation and yet broad enough to be transferable (Vincent, 2007). Perhaps most importantly, a theoretical understanding of vulnerability is required to create useful indicators (Vincent, 2007); however the vagueness and inconsistent definition of vulnerability only further adds to the complexity of designing or selecting indicators. Just as with many other facets of vulnerability, there is no clear consensus in the literature on the validity of using vulnerability indicators. Hinkel (2011) believes that vulnerability indicators are only useful at the local level, but many studies use them in regional and national assessments (Adger, 1999; Challinor, Wheeler, Garforth, Craufurd, & Kassam, 2007; Eriksen & Kelly, 2007; O'Brien et al., 2004; Thornton et al., 2008; Vincent, 2004, 2007)

2.1.4. Mapping Vulnerability

Spatial analysis is a tool that is often used by policy makers for targeting, intervention and pre-emptive planning (Davis, 2003). Mapping is a particularly useful tool in the analysis of vulnerability to climate change because: 1) climate is spatially distributed, and 2) natural resources that will be affected by climate change are difficult to capture using conventional variables (Davis, 2003). Mapping vulnerability to climate change using an approach that encompasses both the human and environmental systems facilitates identification of areas where support can be spatially targeted preventing vulnerable groups from sliding into destitution when shocks occur (Ellis, 2003). It is important to keep in mind that spatial analysis allows us to see visual correlations but not necessarily causal linkages (Davis, 2003).

2.2. Adaptive Capacity

In the field of vulnerability analysis, extensive research has been done on the elements of exposure and sensitivity, while adaptive capacity has only recently begun to be explored (Vincent, 2007). Like vulnerability, adaptive capacity has been defined many different ways, by numerous scholars. For example, sometimes adaptive capacity is considered a separate entity from vulnerability, instead of a component of vulnerability, and sometimes the term is used interchangeably with resilience[2] or social vulnerability. The IPCC definition of adaptive capacity states that adaptive capacity is the ability of a system to adjust to actual or expected climate stresses or to cope with the consequences (McCarthy et al., 2001b).

While adaptive capacity exists at varying scales, it is fundamentally dependent on access to social, human, institutional, natural and economic resources (Adger, 2003; Adger, Huq, Brown, Conway, & Hulme, 2003; Cassidy & Barnes, 2012; Wall & Marzall, 2006). At a household or community level, adaptive capacity to climate change depends on "factors such as knowledge base, which may enable [households] to anticipate change and identify new or modified

[2] Resilience refers to the ability of a system to maintain its basic function or return to the original state after the stressor (Füssel, 2007).

livelihood opportunities; and their access to further resources required to achieve this" (Vincent, 2007, p. 12).

One thing is for certain, adaptive capacity is a critical element in determining the impact of climate change (Smith, Klein, & Huq, 2003; Vincent, 2007). If a population is exposed to significant changes in climate but is not negatively affected by those changes, they are not vulnerable to climate change (Smith et al., 2003). In contrast, even small changes in climate can have significant negative effects on populations where the capacity to adapt to those changes is low or non-existent, making it crucial to consider adaptive capacity when assessing vulnerability.

2.2.1. Measuring Adaptive Capacity

Measuring adaptive capacity is difficult, since adaptive capacity is essentially measuring the 'potential' to respond to changes in climate or climate related disasters. An asset based approach is often taken as a way to measure the potential. Despite the uncertainty in assessing adaptive capacity, there remains a policy need for empirical assessment so that policy makers can turn assessment into practical measures (Vincent, 2007). Much of the work done on adaptive capacity to date, has favored national level assessments that utilize indicators and indices; however there has been research on identifying adaptive capacities at various scales (Brenkert & Malone, 2005; Brooks, Adger, & Kelly, 2005; Cassidy & Barnes, 2012; Haddad, 2005; Leichenko & O'Brien, 2002; Moss, Brenkert, & Malone, 2001; Yohe & Tol, 2002).

2.3. Nicaragua

Nicaragua, a country with a population of 5,869,900 (UNDP, 2011), has a complex political, economic and environmental history. The country suffered through ten years of civil war between 1980 and 1990, and endured an economic crisis that began in 1987 (IFAD). The toll of such events caused the collapse of the country's economy and while they are trying to re-build, Nicaragua is still the second poorest country in the western hemisphere.

Climate related disasters have only exacerbated the country's troubles, and especially the plight of the poor. There have been 44 registered "extreme weather events" in the past 20 years and a 2013 report by Germanwatch ranked Nicaragua as third most vulnerable country in the world in terms of climate change (Harmeling & Eckstein, 2012). Hurricane Mitch, which struck the country in November of 1998, was particularly devastating to the county causing extensive destruction and loss of life (IFAD).

2.3.1. The Nicaraguan Rural Poor

Although there is a global trend toward urbanization, approximately 47 % of Nicaragua's population still live rurally (World Bank, 2013). Many of the country's poorest live in rural areas where they depend on fishing and agriculture to make a living (FAO, 2012). As agriculture is a major source of income for rural households in Nicaragua, and is almost completely rain-fed (less than 2% of households reported using irrigation in the 2001 National Household Survey on Living Standards Measurement), changes in precipitation, could have a severe negative impact on the rural population. Agriculture also plays in significant role in Nicaragua's economy, accounting for 21.5% of value added GDP (World Bank, 2013) and employs nearly 47% of the country's population (Abdulai & Eberlin, 2001). Beans and maize – both of which are staple foods in Nicaragua (Abdulai & Eberlin, 2001) - are disproportionately grown by landless and small farmers who perform much of the agricultural labor by hand without sufficient agricultural inputs, and as a result yields tend to be low (Pfister & Baccini, 2005). Non-farm income is critical to the survival of rural Nicaraguan families and in most of these households there is at least one member that has off-farm employment (IFAD). While Nicaragua's rural people face more challenges than just climate change, climate change is something that could significantly exacerbate their situation and cripple development of the country for years to come.

Chapter 3: Adaptive Capacity of Rural Nicaraguan Farm Households

3.1. Introduction

Some of the most profound impacts of climate change over the coming years will be on agriculture and food systems (Brown & Funk, 2008) and the extent to which households have the capacity to respond or adapt to these changes has critical implications for human development at the household, community, national and global level. Nicaragua, a country with a population of 5,869,900 (UNDP, 2011), is the second poorest country in the western hemisphere where approximately 47% of the population live in rural areas (World Bank, 2012). While income inequality is widespread throughout the country, the disparities between urban and rural populations are vast, with over three quarters of the poorest people living rurally where they rely on climate sensitive industries, such as agriculture and fishing, to make a living (Abdulai & Eberlin, 2001; Pan American Health Organization, 2012). Thus climate change not only threatens their environment, but for many rural households it threatens their livelihood as well. Small-holder agriculture in rural Nicaragua is almost completely rain-fed, and therefore even small changes in climate could have severe and negative impacts on rural incomes as well as local food supply. From a policy perspective, building rural farm households' adaptive capacity to cope with climate change is of paramount importance to the development of Nicaragua.

Adaptive capacity can be defined as the ability of a system to adjust to actual or expected climate stresses or to cope with the consequences (McCarthy et al., 2001b), and is most consequential as a local characteristic (OECD, 2009; Smith et al., 2003). While adaptive capacity exists at varying scales, it is fundamentally dependent on access to social, human, institutional, natural and economic resources (Adger et al., 2003; Cassidy & Barnes, 2012; Wall & Marzall, 2006). According to Vincent (2007), household adaptive capacity in the context of climate change depends on "factors such as knowledge base, which may enable [households]to anticipate changes and identify new or modified livelihood opportunities; and their access to further resources required to achieve this" (Vincent, 2007, p. 13).

The concept of 'adaptive capacity' was first introduced in the IPCC Third Assessment Report (Adger et al., 2004; Vincent, 2007) and has been integrated into the mainstream of climate change research appearing in the literature with increasing frequency, but it has rarely been converted into practical measures that support policy design and intervention (Nelson, Brown, Darbas, Kokic, & Cody, 2007). According to Vincent (2007) sub-national indices that identify populations with the lowest adaptive capacities are required by national and local governments, bi-lateral donors and NGOs. The results of this research will fill the gaps identified by Nelson et al. (2007) and Vincent (2007) by providing a sub-national assessment of rural Nicaraguan farm households' adaptive capacity, which can be used to support policy design and intervention. This paper provides a methodology for assessing the relative level of adaptive capacity at a household level, through the creation of an index that specifically targets our study population – rural[3] households that depend on agriculture for some portion of their income. Although the paper examines households in Nicaragua, the index is generalizable to rural households in other less developed countries.

The second part of the research utilizes the results of the index to answer the following questions: 1) are there significant differences in adaptive capacity between households located in the each of the three main climatic regions in Nicaragua? and, 2) are there significant differences in adaptive capacity between households with certain demographic traits? The results of this research can also be used to inform policy decision making, and improve targeting of policy intervention.

The remainder of the paper is organized as follows. The next section describes our data sources and methodology, and presents an explanation and justification of the adaptive capacity sub-indices and indicators. Section 3 presents the results of the Rural Farming Household Adaptive

[3] Where the term 'rural' is defined by the Living Standards Measurement Survey (LSMS) as a location where the population concentration is less than 1000 inhabitants per village.

Capacity Index (RFHACI) and the subsequent statistical analysis of differences in household adaptive capacity by geographic region and demographic characteristics. Section 4 discusses the findings by analyzing them within the context of Nicaraguan society. Section 5 considers the concerns related to data and methodology limitations, and finally, section 6 summarizes and concludes the research.

3.2. Data & Methods

To understand how adaptive capacity varies across rural Nicaraguan farm households, an adaptive capacity index was created using theory-driven indicators and sub-indices that capture the theoretical determinants of adaptive capacity based on the literature. Indicators and indices are commonly used tools when attempting to capture a complex reality, such as adaptive capacity (Vincent, 2007). We then used the Rural Farming Household Adaptive Capacity Index (RFHACI) in combination with household survey data to calculate relative adaptive capacity scores for each rural Nicaraguan household in our sample and tested whether there were statistically significant differences in adaptive capacity when the households were grouped according to various demographic characteristics.

It is important to note that adaptive capacity in this research only represents the subjects' potential to adapt, rather than their actual actions of adaptation; that being said, there is a strong body of literature that captures the conceptual components of adaptive capacity. We acknowledge that there is an inherent risk that the chosen indicators may oversimplify the concept of adaptive capacity; however, adaptive capacity here represents the potential to respond to climate change and is never absolute, making it difficult to quantify and verify (Adger & Vincent, 2005). Thus we have adopted an approach that captures a household's adaptive capacity *relative* to other households.

Figure 1 outlines the structure of the RFHACI, showing the composite sub-indices and their component indicators.

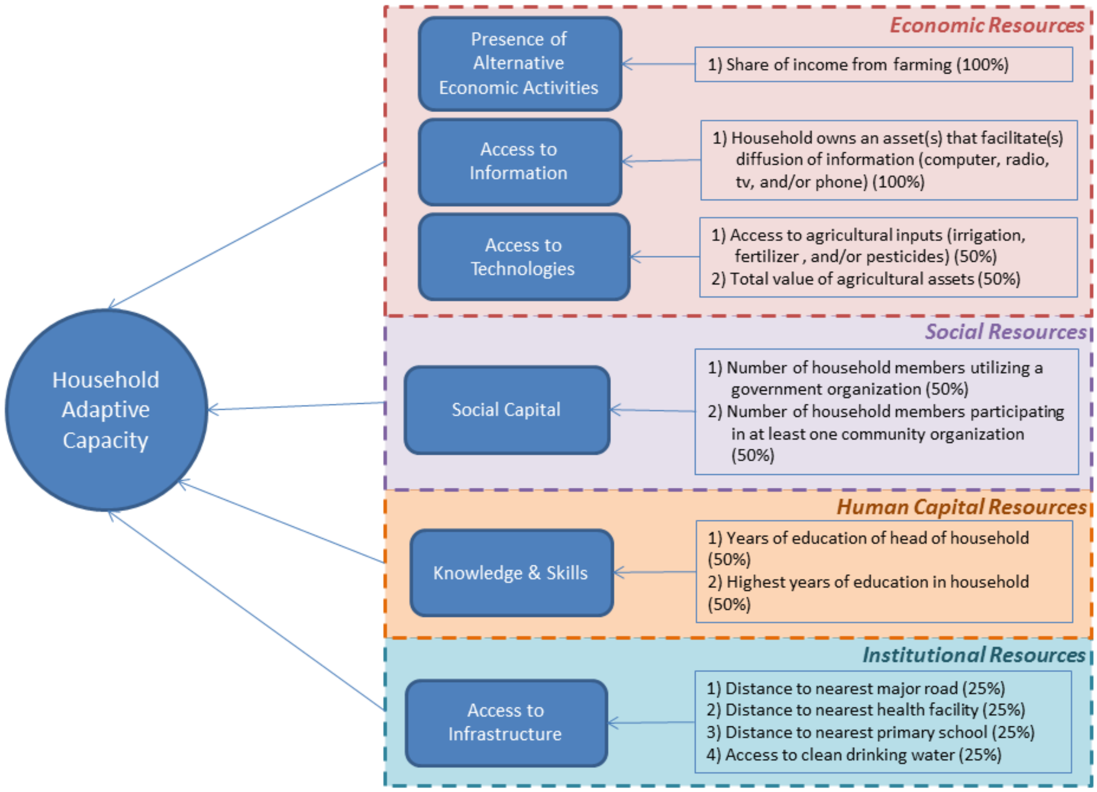

Figure 1 Rural Farm Household Adaptive Capacity Index (RFHACI) structure

3.2.1. Sample Data

The sample data used in this study consisted of 1,212 rural Nicaraguan households, all of which reported obtaining a share of their income from farming. This sub-set of household data was drawn from the 2001 National Household Living Standards Measurement Survey (LSMS) and represents 66% of the total rural surveys collected. The data set was provided by the Food and Agriculture Organization of the United Nations (FAO UN)[4]. The LSMS data can be generalized to: 1) the national total, 2) urban and rural populations, and 3) the macro regions (Managua, Pacific, Central and Atlantic).

[4] The Living Standards Measurement Survey (LSMS) was undertaken in 2001 by the Nicaraguan National Institute of Statistics and Census with technical and financial support from the world Bank, United nations Development Program, the Swedish international l Development Agency and the Social Emergency Investment Fund

3.2.2. Calculating the RFHACI

The first step in the approach involves calculating the RFHACI using indicators and sub-indices. This was done by selecting indicators that represent access to economic, social, human and institutional resources that directly or indirectly influence agricultural production.

The RFHACI is formed from the sum of the scores from the following six composite sub-indices: 1) presence of alternative economic activities; 2) access to technologies; 3) social capital; 4) knowledge and skills; 5) access to information; and 6) access to infrastructure. The sub-indices each represent one theoretical determinant of adaptive capacity. The approach of creating an aggregate index (the RFHACI) from several composite sub-indices was chosen to maintain transparency, which is critical for end-users as there are no absolute values in adaptive capacity (Vincent, 2007).

As seen in Figure 1, each of the sub-indices is made up of one to four variables that are representative of that respective theoretical determinant of adaptive capacity. Where the sub-index is comprised of more than one indicator, an average of those indicators was used so that each indicator in the index is weighted equally, and each sub-index is scored between zero and one. Assigning equal weight to indicators and sub-indices is consistent with the approach used by O'Brien et al. (2004), Patnaik and Narayanan (2005) and Vincent (2007) among others.

Individual indicators were chosen using a theoretical understanding of relationships between the conceptual component of adaptive capacity and the individual indicator. The sub-indices utilized a combination of binary and continuous variables. All continuous variables were scored according to the maximum observed value of that variable in the data set and were turned into proportional variables:

$$Indicator\ Score\ Household\ x = \left(\frac{observed\ value\ household\ x}{variable\ maximum\ value}\right)$$

Or,

$$Indicator\ Score\ Score\ x = 1 - \left(\frac{observed\ value\ household\ x}{variable\ maximum\ value}\right)$$

Where a score of '1' represents the best score for that variable (i.e. shortest distance to major road) and '0', the worst score (i.e. high dependence on farming as a source of income). This is consistent with the approach of finding the adaptive capacity of households relative to one another, and to ensure the indicators are sensitive enough to show differentiation. For variables with extreme outliers a rank order approach was taken to reduce the impact of outliers on our results[5].

The following table provides an example of how the individual index scores and overall adaptive capacity score were calculated for two households. In cases where the variables are binary, one represents a 'yes' and zero represents a 'no'.

Table 3-1 Calculating the RFHACI

Presence of Alternative Economic Activities			
Indicator 1: Share of Income from Farming			
	Proportion of income from farming	Calculation	Index Score
Household A	1	1-1	0
Household B	0.39	1-0.39	0.61

Access to Information						
Indicator 1: Household owns asset(s) that facilitate the diffusion of information						
	Owns Computer	Owns Radio	Owns TV*	Owns Phone**	Calculation***	Index Score
Household A	0	0	0	0	0/3	0
Household B	0	1	0	0	1/3	0.33

* Variable accounts for color and black and white televisions
**Variable accounts for both landlines and cell phones
*** 3 is the maximum number of assets owned by any household in the sample

Access to Technologies
Indicator 1: Access to agricultural inputs

[5] The rank order approach was used for certain variables in the Access to Infrastructure & Access to Technologies indices.

	Irrigation	Fertilizer	Pesticide	Calculation*	Indicator Score
Household A	0	1	1	2/3	0.67
Household B	0	1	1	2/3	0.67
Indicator 2: Total value of agricultural assets					
	Value (in Córdoba)	Rank Order	Calculation**	Indicator Score	
Household A	1630	730	730/1212	0.60	
Household B	875	618	618/1212	0.51	
Access to Technologies Index Score					
	Calculation	Index Score			
Household A	(0.67+0.60) / 2	0.64			
Household B	(0.67 +0.51) / 2	0.59			

*3 is the maximum number of agricultural inputs owned by any household in the sample

**1212 is the number of households in the sample

Social Capital			
Indicator 1: Number of household members utilizing a government organization			
	Number	Calculation*	Indicator Score
Household A	0	0/9	0
Household B	2	2/9	0.22
Indicator 2: Number of household members participating in at least one community organization			
	Number	Calculation**	Indicator Score
Household A	0	0/6	0
Household B	0	0/6	0
Social Capital Index Score			
	Calculation	Index Score	
Household A	(0+0) /2	0.00	
Household B	(0.22+0) / 2	0.11	

*9 is the maximum number of members in one household that were utilizing a government organization, in our sample

**6 is the maximum number of household members participating in at least one community organisation, in our sample

Knowledge & Skills			
Indicator 1: Years of education head of household			
	Years	Calculation*	Indicator Score
Household A	0	0/17	0.0
Household B	2	2/17	0.12
Indicator 2: Highest years of education in household			
	Years	Calculation** (21 is the maximum value in the sample for this variable)	Indicator Score
Household A	3	3/21	0.14
Household B	7	7/21	0.33
Knowledge and Skills Index Score			
	Calculation		Index Score
Household A	(0+0.14) / 2		0.07
Household B	(0.12+0.33) / 2		0.23

*17 is the maximum year of education of head of households for all households in our sample

**21 is the highest years of education in any household in our sample

Access to Infrastructure				
Indicator 1: Distance to nearest major road				
	Distance (km)	Rank Order	Calculation	Indicator Score
Household A	74	995	1 – (995/1212)	0.18
Household B	0	51	1 – (51/1212)	0.96
Indicator 2: Distance to nearest health facility				
	Distance (km)	Rank Order	Calculation	Score
Household A	9	936	1 – (936/1212)	0.23
Household B	4	614	1 – (614/1212)	0.49
Indicator 3: Distance to nearest primary school				
	Distance (km)	Rank Order	Calculation	Score
Household A	8	672	1 – (672/1212)	0.45
Household B	30	1119	1 – (1119/1212)	0.08

Indicator 4: Access to safe drinking water		
	Safe Water	Indicator Score
Household A	0	0
Household B	1	1
Index Score		
	Calculation	Index Score
Household A	(0.18+0.23+0.45+0) / 4	0.21
Household B	(0.96+0.23+0.08+1) / 4	0.63

Rural Farm Household Adaptive Capacity Index (RFHACI)		
	Calculation (sum of all index scores)	RFHACI Score
Household A	0+0+0.64+0+0.07+0.21	0.92
Household B	0.61+0.33+0.59+0.11+0.23+0.63	2.5

3.2.3. Indicator Selection

The following section provides the theoretical reasoning behind indicator selection, and is based on established works in the literature.

Presence of Alternative Economic activities

The degree to which a household is dependent on agriculture as a source of income can play a significant role in whether and/or how quickly, the household can adapt to climate change and variability given that agriculture is a particularly climate sensitive industry. Share of income from farming is used to represent the presence of alternative economic activities for that household and is based on the assumption that households would select to minimize their reliance on farming as a source of income if other profitable economic activities were readily available. This is a reasonable assumption given that agriculture in Nicaragua is typically associated with high risk and low economic returns and non-farm income is critically important to rural Nicaraguan households (Corral & Reardon, 2001), as is the case in many small agricultural operations, even in more developed countries.

Access to Information

Access to information can significantly impact the level of adaptive capacity at the micro level (Yohe & Tol, 2002), since information provides a basis from which households can anticipate or react to minimize the impact climate change has on their household. Access to information is measured based on household ownership of the following assets that assist in the diffusion of information: 1) computer, 2) radio, 3) television, and 4) telephone. It is assumed that households who own assets that assist in the diffusion of information have better access to information.

Access to Technologies

Access to technologies, and specifically agricultural technologies, is critical to a rural farm household's ability to adapt to climate change since agricultural technologies improve crop productivity and can reduce sensitivity to changes in climate (Matson, Parton, Power, & Swift, 1997). Yohe and Tol (2002) and the IPCC (2001) state that the range of available technological options for adaptation is a fundamental determinant of adaptive capacity. The access to technologies sub-index is calculated using the value of each household's agricultural assets as well as an assessment of whether the household reported having access to any of the following three important agriculture inputs: 1) irrigation, 2) fertilizer and/or, 3) pesticides. In this case, agricultural assets can be directly tied to household income, as our sample is farm households who make some portion of their income from farming.

Social Capital

Social capital is central to adaptive capacity, and is a critical element in any strategy for adapting to changes in climate or climate related hazards (Adger, 2003; Yohe & Tol, 2002). The term social capital describes, "the relations of trust, reciprocity and exchange; the evolution of common rules; and the role of networks" (Adger, 2003, p. 389). In the context of adaptive capacity and climate change, the most important component of social capital is the ability of a society to act collectively (Adger, 2003). It follows then that the ability to act collectively is enhanced by membership in social capital groups. Based on this assumption, social capital is measured using two indicators: 1) the number of government organizations in which the household participates, and 2) the number of household members participating in at least one community organization. Having indicators of membership in both government groups and community organizations allows us to evaluate a household's involvement in collective action at the community level, and it also encompasses some measure of access to institutional programs (i.e. government programs), providing a more robust measure of adaptive capacity.

The number of household members participating in at least one community organization, and the number of government organizations in which the household participates, also reflects adaptive capacity by measuring the range of social safety nets to which a household has access (Vincent, 2007). In addition, social capital groups have the informal function of providing a 'grassroots insurance', which would be highly beneficial in the face of a climate related shock (Vincent, 2007). We ascertained that the aforementioned indicators were a particularly apt measure of social capital for Nicaragua given that community based organizations have played a critical role in Nicaraguan society in terms of negotiating with local authorities for land and services as well as for coping with natural disasters (World Bank, 2010).

Knowledge & Skills

Household adaptive capacity in the context of climate change is directly influenced by the knowledge and skill that enable members of a household to anticipate changes and modify their livelihood opportunities in response to those anticipated changes (Vincent, 2007). To do this, it requires not only knowledge, but a certain level of experience that allows people to translate that knowledge into positive outcomes. Years of education has often been used as a proxy indicator of knowledge and skill, and exists as a key indicator in the United Nations Human Development Index. In a study by Abdulai and Eberlin (2001), the level of formal schooling was found to contribute positively to production efficiency of beans and maize in Nicaragua. Based on the assumption that years of education positively affects knowledge and skill, we have used years of education of the head of household and highest years of education in the household[6] as the two proxy variables to determine the level of knowledge and skills in the household.

Access to Infrastructure

The role of institutions in determining adaptive capacity is a widely accepted notion (Willems & Baumert, 2003), and infrastructure is one such institutional resource that is critical to adaptive capacity. Access to infrastructure was measured by using the following four variables: 1) distance from household to major road, 2) distance from household to nearest health facility, 3) distance from household to nearest primary school, and 4) whether or not the household reported having access to safe drinking water.

The term 'rural' inherently denotes some degree of isolation from the more developed infrastructure that generally exists in cities, thus the *relative*[7] proximity to various types of infrastructure was used to determine each household's access to infrastructure. The first indicator is 'distance to major road', as it can be a measure of physical access to markets, and the additional cost of fuel for farmers to transport their goods from the farm to the markets can be an often unconsidered burden (Brooks et al., 2005; Ziervogel et al., 2006). Two other indicators were selected - distance to nearest health facility and distance to nearest primary school - based on the assumption the distance to these locations has some influence on how likely households are to utilize these services, as just over 2% of the households sampled reported owning a car, truck and/or motorcycle (statistic computed by authors). The last indicator, access to clean drinking water, is an especially important measure of infrastructure, as water-borne illnesses often

[6] Imputed years of education for each member were obtained in the following manner: if highest degree was: Preschool and knows how to read and write: 3 years; Preschool and does not read or write: 1 year; Primary: 6 years; Secondary: 11 years; Basic Technical School: 6 years; Middle Technical school: 9 years; Superior Technical school: 12 years; University: 16 years. To these imputed years the approved years in their current studies, if any, were added. Household average years of education of adults obtained by averaging household members who are 12 years or older.

[7] To calculate distance to nearest major road, distance to nearest primary school, and distance to nearest health a rank-order approach was taken. Access to clean drinking water is a binary variable.

reduce the body's ability to absorb nutrients (Hutchinson, 1992), leading to malnutrition and other serious health issues, which would significantly hinder a household's ability to adapt.

3.2.4. Profiling Based on Demographic Variables

The next step was to determine whether there were statistically significant differences in household adaptive capacity once households were grouped based on various demographic characteristics.

The results of the one-sample Kolmogorov-Smirnov test showed that the RFHACI was not quite normally distributed (p=0.071), and therefore non-parametric statistical tests were used, where household adaptive capacity was the test variable, and the demographic variables were used to group the households in a way that is relevant and meaningful to Nicaraguan society.

Households were grouped based on the following characteristics: 1) geographic location, 2) household size, 3) number of males in the household, 4) number of females in the household, 5) the age of the head of household, 6) the relationship status of head of household, 7) whether the household had a female head , and 8) whether the household was indigenous.

Demographic variables two through five are continuous variables, and each was grouped into three sub-groups. Variables one and six are nominal variables that were also split into three groups. For each of the aforementioned variables (one through six), we ran the Kruskal-Wallis test with adaptive capacity as the test variable. Post-hoc Mann-Whitney U pairwise comparisons (adjusted with a Bonferroni correction) were performed to indicate the direction of the effect, where there was a statistically significant difference between groups.

Variables seven and eight are binary variables, and thus we used the Mann-Whitney U test to determine whether adaptive capacity scores vary significantly between the two groups. Again, pairwise comparisons (adjusted with a Bonferroni correction) were used to indicate the direction of effect when there was a statistically significant difference between groups.

3.3. Results

3.3.1. Regional Analysis

The Kruskal–Wallis test was conducted to determine whether there were differences in household adaptive capacity between households located in the three main climactic zones in Nicaragua: 1) the Pacific region, 2) the Central region, and 3) the Atlantic region[8]. The analysis disregards households located in the Department of Managua (which is technically located in the Pacific region) as Managua is primarily urban, contains the country's capital, is substantially more populated and has vastly superior infrastructure (Corral & Reardon, 2001), bringing our sample size for this test down from 1,212 to 1,208. The test results showed significant differences in household adaptive capacity between the three regions, Chi Square (1208) = 258.979, p=0.000. Post-hoc Mann-Whitney U pairwise comparison tests with a Bonferroni correction indicate statistically significant differences in adaptive capacity between households in the Pacific and Atlantic regions (p=0.00) and households in the Central and Atlantic regions (p=0.00), with households in both the Pacific and Central regions having significantly higher adaptive capacity than households in the Atlantic region. The median adaptive capacity scores are as follows: Pacific (2.341), Central (1.877), and Atlantic (1.365).

3.3.2. Characteristics of Head of Household Analysis

Age of Head of Household

The Kruskal-Wallis test was also conducted to evaluate whether the adaptive capacity of rural farm households differ as a function of the age of the head of household, where households with a head of household that was under 25 were considered to have a 'young' head of household (n=57), households with a head of household that was between 25 and 60 were considered

[8] The Managua zone includes the department of Managua. The 'Rest-of-Pacific' (or 'Pacific' as we will refer to it) includes the departments of Chinandega, León, Masaya, Granada, Carazo, and Rivas. The Central region includes the departments of Estelí, Madriz, Nueva Segovia, Boaco, Chontales, Matagalpa, and Jinotega. The Atlantic region includes the North Atlantic Autonomous Region (RAAN), the South Atlantic Autonomous Region (RAAS), and Rio San Juan department.

households with an ‘adult’ head of household (n=891), and households with a head of household that was older than 60 were considered household with a ‘senior’ head of household (n=264). The mean, median and standard deviation of adaptive capacity in each group is summarized in Table 3-2. There were no missing values for any of the groups. The Kruskal-Wallis test showed a significant difference in household adaptive capacity between the three age groups, Chi Square (1212)=9.504, p=0.009. Follow up Mann-Whitney U pairwise tests with a Bonferroni correction indicate that both households with an ‘adult’ head of household (p=0.033) and with a ‘senior’ head of household (p=0.007) had significantly higher adaptive capacity scores than households with a ‘young’ head of household.

Table 3-2 Age of head of household grouping: Descripitve statistics

Grouping	Mean	Median	St. Dev.	Min	Max
Young	21.91	22	1.672	16	24
Adult	41.82	42	9.708	25	59
Senior	69.72	67	8.368	60	95

Female Head of Household

A Mann-Whitney U test was conducted to test whether there were differences in household adaptive capacity between female headed households (n=160) and non-female headed households (n=1,052). Distributions of adaptive capacity scores for female headed households and non-female headed households were similar, as assessed by visual inspection. The median adaptive capacity of female-headed households was 1.811 (SD=0.678) and the median adaptive capacity of non-female-headed households was 1.883 (SD=0.662). The results of the test showed that there were no statistically significant differences in adaptive capacity based on gender of head of household, U= 79,939, p=0.206 (2 tailed).

Head of Household Relationship Status

A Mann-Whitney U test was conducted to determine whether there were differences in household adaptive capacity between households where the head of household identified themselves as single (n=220) and households where the head of household did not identify themselves as single (n=992), meaning that they could be coupled, separated, divorced, widowed or married. Distributions of adaptive capacity scores for single headed households and non-single headed households were similar, as assessed by visual inspection. The median adaptive capacity of single-headed households was 1.864 (SD=0.659) and the median adaptive capacity of non-single headed households was 1.857 (SD=0.665). The results showed that adaptive capacity was not statistically significantly different between the two groups, U=107,283, p=0.696, (2 tailed).

A Mann-Whitney U test was also conducted to test whether there were differences in household adaptive capacity between households where the head of household was married (n=566) and households where the head of household was not married (but not necessarily single[9]) (n=646). Distributions of adaptive capacity scores for the two groups were similar, as assessed by visual inspection. The median adaptive capacity of households with a married head of household was 1.840 (SD=0.683) and the median adaptive capacity of households with a non-married head of household was 1.875 (SD=0.647). Mann-Whitney U test results showed that median adaptive capacity in households where the head of household was married, was not significantly different than households where the head of household was not married, U=176,117, p=0.270.

The Kruskal-Wallis test was conducted to evaluate whether the adaptive capacity of rural farm households differs between households based on whether the head of household was single (n=220), married (n=566), coupled, separated, divorced, or widowed (n=426). There were no missing values for any of the groups. There was no significant difference in household adaptive capacity based on the relationship status of the head of household, Chi Square (1,212)=2.170, p=0.338

[9] The heads of household in this group could be coupled, separated, divorced, widowed or single.

3.3.3. Characteristics of Household Analysis

Household Size

The Kruskal-Wallis test was conducted to evaluate whether the adaptive capacity of rural farm households differ as a function of household size where 'small' households are defined as those with four or less household members (n=358); 'medium' households are those with five to seven household members (n=489); and large households are those with eight or more members (n=365)[10].The mean, median and standard deviation of each group is summarized in Table 3-3. There were no missing values for any of the groups. The results of the Kruskal-Wallis test showed there were significant differences in the household adaptive capacity between the three household size groups, Chi Square (1212)=13.523, p=0.001. Post-hoc Mann-Whitney U pairwise comparison tests with a Bonferroni correction for the number of comparisons, indicate that medium sized households (p=0.001) had significantly higher adaptive capacity scores than 'small' households.

Table 3-3 Household size grouping: descriptive statistics

Grouping	Mean	Median	St. Dev.	Min	Max
Small	3.2	3	0.907	1	4
Medium	5.96	6	0.807	5	7
Large	9.75	9	1.945	8	19

Number of Males & Females in the Household

The Kruskal-Wallis test was conducted to evaluate whether the adaptive capacity of rural farm households differ as a function of number of males in the household and/or number of females in the household. The sample range for number of males in a household was between zero and eleven and the range for number of females in a household was between zero and ten. Households with a 'small' number of males were defined as households where there were between zero and two males, a 'medium' number of males was defined as between three and four, and a 'large'

[10] Where household members are defined as those people who usually eat and sleep at home and who have been at home for at least three of the last 12 months preceding the survey (Instituto Nacional de eStadística y Censos de Nicaragua, 2001)

number of males was defined as five or more males in the household. The number of females in the household was grouped and defined in the same way. The mean, median and standard deviation of adaptive capacity in each group is summarized in Table 3-4. There were no missing values for any of the groups. The findings showed no significant difference in household adaptive capacity based on the number of males in the house, Chi Square (1,212)=2.772, p=0.250, and for number of females in the house, Chi Square(1,212)=0.502, p=0.778.

Table 3-4 Number of males & females in the household grouping: descriptive statistics

	No. of Males						No. of Females					
Grouping	**n**	**Mean**	**Med**	**St. Dev.**	**Min**	**Max**	**n**	**Mean**	**Med**	**St. Dev**	**Min**	**Max**
Small	475	1.61	2	0.514	0	2	547	1.47	2	0.623	0	2
Medium	480	3.41	3	0.492	3	4	452	3.39	3	0.489	3	4
Large	257	5.89	5	1.176	5	11	213	5.89	5	1.210	5	10

Indigenous Status of Household

A Mann-Whitney U test was conducted determine whether there were differences in household adaptive capacity between indigenous households (n=62) and non-indigenous households (n=1.150). Distributions of adaptive capacity scores for indigenous and non-indigenous households were similar, as assessed by visual inspection. The median adaptive capacity score of indigenous households was 1.073 (SD=0.512) and the median adaptive capacity of non-indigenous households was 1.920 (SD=0.651). Median adaptive capacity in non-indigenous households was significantly higher than the median adaptive capacity in indigenous households, U=12,885, p=0.000 (2 tailed).

3.4. Analysis & Discussion

3.4.1. Regional Analysis

We found that rural farm household adaptive capacity in Nicaragua varies significantly by region, with households in the Pacific and Central regions having higher adaptive capacity than households in the Atlantic region (see Figure 2). Even after removing indigenous households (who are heavily concentrated in the Atlantic region and have significantly lower adaptive capacity, as discussed later in this section) from our analysis, we found that households in the Atlantic region still had significantly lower adaptive capacity than households in both the Pacific (p=0.000) and Central (p=0.000) regions. The policy implications of this finding are not insubstantial, and further attention needs to be paid to building the adaptive capacity of households located in the Atlantic region, especially given that this region is more prone to experiencing destructive tropical storms and hurricanes (Library of Congress, 1993).

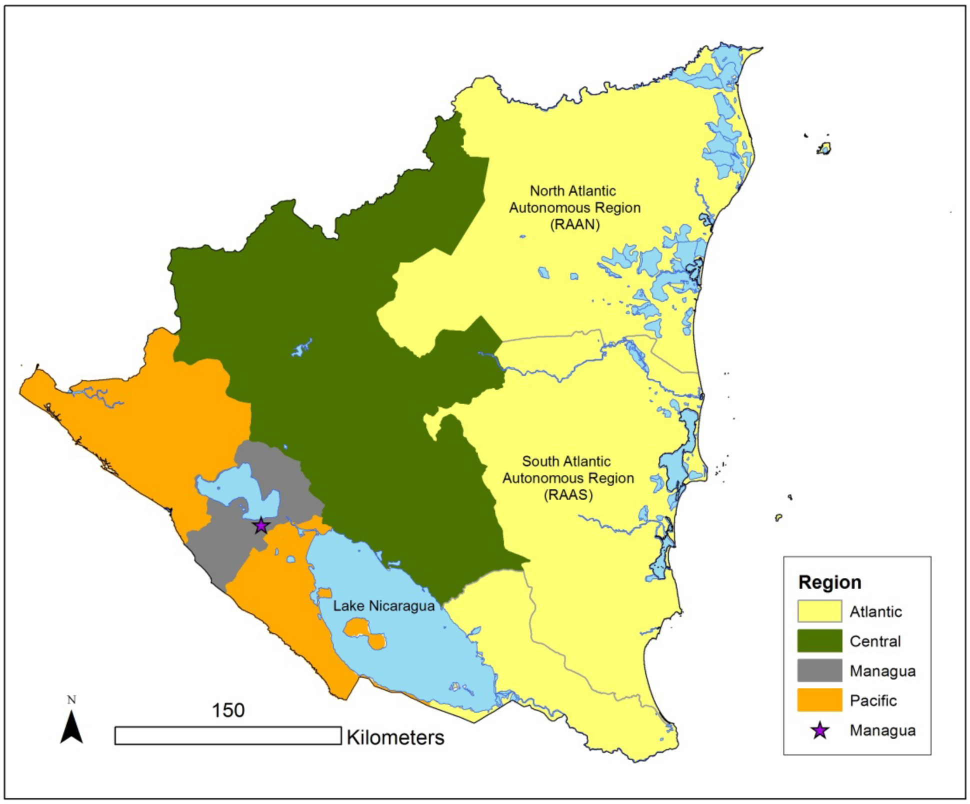

Figure 2 Regions of Nicaragua

Low adaptive capacity of households in the Atlantic region may be linked to: 1) the central government's resistance to adhere to the Autonomy Law which grants regional autonomy to much of the Atlantic region (the North Atlantic Autonomous Region (RAAN) and the South

Atlantic Autonomous Region (RAAS), but not Rio San Juan), 2) the ambiguity of the Autonomy Law, and 3) the geographic distance between the Atlantic region and the political and economic heartland of Managua. Since 1987 RAAN and RAAS, which make up the majority of the Atlantic region, have been under the autonomous model of governance which in theory, allows RAAN and RAAS to be self-governing collective entities that act within the national political sphere (Cott, 2001). The Autonomy Law, which was established in 1990, effectively ended the war between the Sandinista government and the indigenous people, but has never been enabled to function properly (Feiring, 2003). In principle, the law allows direct representation of ethnic groups and indigenous peoples and indigenous organizations to participate in elections; however, in 2000 the liberal government prohibited the participation of social movements in the elections (Feiring, 2003), thus effectively excluding many groups representing Atlantic interests from participating in the national political agenda. The central government's reluctance to transfer power and resources to the Atlantic region (Cott, 2001) has also likely contributed to the low levels of adaptive capacity in the region as good governance is key in adaptive capacity at the national level (Brooks et al., 2005). Although there are likely a variety of other issues contributing to our result, we would argue that since good governance connects individuals and households with organizations, agencies and institutions (Folke, Hahn, Olsson, & Norberg, 2005), the issues with the Autonomy Law are useful in hypothesizing as to why there is such a significant difference in household adaptive capacity between regions.

3.4.2. Characteristics of Head of Household

Turning now to the analysis where households are partitioned based on demographic characteristics of the head of household.

Female headed household & relationship status of head of household

We find that there is no significant difference in household adaptive capacity based on the head of household's gender, or whether they are married or single. While at first this may seem surprising, it should not be interpreted to mean that the average welfare of female-headed households is equal to that of male-headed households[11], or that the welfare of single headed households is equal to that of households where the head of household is, or has been, receiving support from a partner.

Not all female headed households in our sample were single headed households (in approximately 22% of female headed households the female was not single); however, we still found no significant difference in adaptive capacity between single female headed households (n=125) and non-single female headed households (n=35) (U=2382, p=0.422, n=160). At first glance, our findings contradict much of the literature that states that female headed households and single headed household in Latin America are more likely to be poor and disadvantaged; however, non-differences tend to be neglected in the gender literature and differences are often over-emphasized. Quisumbing, Haddad, and Peña (2001) found that differences in poverty between male and female headed households were only significant in one-fifth, to one-third of datasets in their study of poverty in ten developing countries. Thus we feel it is important to put the non-significant finding into context and hypothesize as to why there was not a significant difference in adaptive capacity between on the gender of household headship. The non-significant gender findings may help be explained by: 1) the historical context of intergenerational land transmission in Nicaragua, and 2) inter-household asset ownership. The historical context of intergenerational land transmission has affected the social context in which women live, which in turn has affected the their ability to share in the ownership of household assets (Deere & Leon, 2001), and is directly linked to adaptive capacity.

In Nicaragua, no legal gender discrimination exists in property rights (Social Watch, 2000), and because of the history of proletarianization and landlessness that denied both males and females

[11] The concept of household headship says nothing about gender inequality, wage-earning gaps, or even intra-dispersion of household resources and labor (Ferreira, Lanjouw, & Neri, 2003), nor does it say anything about providing a meaningful contribution to the household.

ownership of property, the patriarchal system of inheritance has not disadvantaged women in Nicaragua as much as it has in other Latin American countries where an established system of land inheritance has favored male heirs (Bugajski, 1990; Massey, Fischer, & Capoferro, 2006). Also since Nicaragua has been engaged in vigorous land titling efforts in recent decades and joint titling of land to couples in such programs has been mandatory since 1995, (Deere & Leon, 2001), this has protected women's rights to land in the event of a divorce, separation or death of her husband. This is not to say that Nicaraguan cultural norms do not discriminate against women (Ellsberg, Peña, Herrera, Liljestrand, & Winkvist, 1999), just that when our sample of rural farming households is compared to similar samples in other Latin American countries, there may be less gender inequality in Nicaragua. Findings from a 2010 conference paper show that the female asset ownership is less unequal in Nicaragua than originally thought, with women owning 36-41% of the household physical wealth (Deere, Alvarado, & Twyman, 2010). Since access to resources and household assets are directly connected with adaptive capacity, this finding could also help explain our result.

It is harder to explain the non-significant difference between single-headed households and married-headed households, and this is partly because of the definitions of these categorizations. The LSMS survey classifies household headship relationship status in one of the following ways: married, coupled, separated, divorced, widowed or single. Our research only tested for differences between single headed households and 'non-single' headed household and again between married headed households or 'non-married' headed households. Both the 'non-single' and the 'non-married' group potentially encompass a diverse group of relationship statuses and each of those relationship statuses likely interact differently with household adaptive capacity. Therefore, it is very hard to make any sound interpretations based on this finding.

Age of Head of Household

Adaptive capacity varies significantly based on age of head of household, with households that have an 'adult' or 'senior' head of household, exhibiting higher adaptive capacity than households where there is a ‘young’ head of household. The finding is not completely surprising since adaptive capacity is primarily about having access to adequate resources (social, human capital, economic, institutional) so it seems logical that households with older and more established heads would have more potential to adapt than households where the head of household has had less time to build social capital, expand their asset base and the develop knowledge and wisdom that can come with age. It should also be noted that in the life course context, increasing head of household age is connected to the growth in household labor pool and decline in number of dependent children (Perz, 2001). Our result is in agreement with a finding from Cassidy and Barnes (2012) where age of head of household was positively correlated with higher livelihood diversity, adaptive capacity and resilience in households in a rural community in Botswana. Similarly a German case study that utilized a socio-economic model that included age as an independent variable found that age was a significant predictor of residents proactive damage to prevention in three out of four adaptation behaviors (Grothmann & Patt, 2005). While we don’t necessarily think there is a direct relationship between age and adaptive capacity, age relates to life course and time to build an asset base, which can be used advantageously to respond to gradual changes in climate, or climate related disasters.

3.4.3. Household Demographic Variables

While there were no significant differences in adaptive capacity between households based on the number of males in the household or females in the household, we did find significant differences based on both household indigenous status and household size.

Indigenous Households

Although indigenous[12] households only make up 5.1% of our sample[13], it is important to analyze their level of adaptive capacity relative to other rural farm households, as indigenous households

[12] In Latin America, the term indigenous is usually used to represent people who maintain a distinct native language and preserve some element of pre-Hispanic culture (Bugajski, 1990).

in Latin America tend to be overrepresented among the poorest, and most vulnerable in society (Lunde, 2007). Not surprisingly, we found that indigenous households had significantly lower adaptive capacity than non-indigenous households in rural Nicaragua. They also tended to be concentrated in the Atlantic region, far away from the economic and political heartland of Managua, and the rest of the more developed Pacific region.

Indigenous people in Nicaragua[14] are underrepresented in the political and economic decision making process (Feiring, 2003; Library of Congress, 1993), a factor that may negatively influence their ability to respond or adapt to changes in climate.

Upon further statistical analysis we found that indigenous households differed significantly from non-indigenous households for all indicators and all sub-indices used in the calculation of the RFHACI except the number of government organization in which the household participated[15]. Post-hoc tests revealed some surprising results: 1) indigenous households were located closer to health facilities (p=0.000) and primary schools (p=0.000) than non-indigenous households, and 2) indigenous households scored better in terms of years of education of the head of household (p=0.013) and highest years of education in the household (p=0.012). While these results were unexpected, they can help be explained by two main factors: 1) traditional healers that are responsible for a large share of health care in the Atlantic region (Dennis & Herlihy, 2003), where most of the indigenous population resides, and 2) the establishment of the University of the Autonomous Regions of the Caribbean Coast of Nicaragua (URACCAN) in the early 1990s (Feiring, 2003). URACCAN, which has received government funding since 1996 (Dennis & Herlihy, 2003), is a regional university in the Atlantic region that offers education to indigenous people from pre-school to university (Feiring, 2003).

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[13] This is to be expected as the UN estimates that indigenous people make up approximately 3-4% of the population (Feiring, 2003).

[14] The major indigenous groups in Nicaragua are the Miskitu, Mayanga, and Rama (Feiring, 2003).

[15] Access to safe water was not tested as it is a binary indicator and could not be tested by using the Kruskal-Wallis test.

While indigenous households are often over-represented among the poorest and most disadvantaged (Lunde, 2007) there is a hopeful story to tell in Nicaragua. We found that the indigenous households in rural Nicaragua had significantly higher highest years of education in household, and their heads of household had higher years of education than non-indigenous households. If indigenous households are able to utilize their formal schooling knowledge in combination with asset of traditional cultural knowledge, they may have an advantage in terms of adapting to climate change. A study by Karfakis, Knowles, Smulders, and Capaldo (2011) also found that affiliation with an indigenous community was positively and very significantly correlated with land productivity in rural Nicaragua. The cultural traditions and cultural knowledge of the indigenous population (which was not captured in this study) may have significant and beneficial consequences in terms of ability to adapt to a changing environment, and should be studied further.

Household Size

We found that medium sized households had significantly higher adaptive capacity scores than 'small' households, when 'small', 'medium' and 'large' households were defined as households with four or less members[16], between five and seven members, and eight or more members, respectively[17]. This finding is particularly interesting when put in contrast to a finding published in an FAO working paper by Davis and Stampini (2002), where they found that smaller household size was a characteristic of rural Nicaraguan households exiting poverty. Our finding potentially helps delineate low adaptive capacity from a lack of financial resources, and shows the importance of non-economic indicators such as social capital. As family relationships were not considered a measure of social capital in our index, our finding reinforces the importance of social capital in adaptive capacity. Our finding is supported by a study from Cassidy & Barnes

[16] Household members are all those people who eat and sleep usually at home and have been for at least three of the 12 months preceding the survey.

[17] Because of high fertility and presence of relatives beyond the nuclear family make, Nicaraguan households are commonly made up of 6-8 people (Fussell & Palloni, 2004; Library of Congress, 1993).

(2012) where household size was positively correlated with adaptive capacity in households in a rural community in Botswana.

Our findings imply that medium households are able to achieve some economies of scale over smaller households. We find support for this idea in a study done by Deaton and Paxson (1998) where the authors found that smaller households require more resources per capita than larger households. However, our results suggest that a larger household size may be beneficial to adaptive capacity, but only to a point, as there was no significant difference in adaptive capacity between small and large, nor medium and large households.

Therefore it can be concluded that, in terms of adaptive capacity, household size may be a double-edged sword, where an increased number of household members means more mouths to feed and bodies to clothe, it can also mean potentially mean more labor availability, an increased number of social connections and support within the household, and some economies of scale in terms of household resources. Labor availability and the grassroots insurance that can arise from a larger household and an increased number of social connections can be critical to implementing adaptation measures, and/or preparing for or responding to the impacts of extreme weather events. The demographic make-up of the household is likely more important than absolute household size, and specific attention should be paid to dependency ratios and each household member's relative contribution to household well-being.

In light of our findings, we hypothesize that inter-household member connection plays an important role in the household's capacity to adapt. Unfortunately the limitations of our sample data did not allow us to explore this further. It is likely that many of the medium and large households that scored well on the adaptive capacity index had low dependency ratios, as it is common for Nicaraguan households to contain relatives beyond the nuclear family unit, (a grandparent, an aunt, uncle, poor godchild, or daughter with children of her own) (Fussell & Palloni, 2004).

3.5. Limitations

All studies have limitations and this one is no exception. The limitations of the study are as follows:

- One of the major limitations is that we have captured relative adaptive capacity at one point in time and adaptive capacity varies between communities and households, over time (Adger et al., 2004). By using point in time data, we have failed to capture changes in adaptive capacity; however this study serves as a starting point from which further analysis can be performed.
- It should be noted that a limitation of the RFHACI is that it does not capture any environmental or biophysical component such as soil quality or access to groundwater, but due to lack of data we could not use access to groundwater as an indicator, and soil quality will be incorporated into a sensitivity under exposure index that shows the potential change in agricultural yield of beans and maize, which will incorporated into the analysis in Chapter 4. The approach of not including biophysical indicators at the household level is congruent with the idea that the environment in which the household exists is not necessarily specific to that household, but is shared by the households around them.
- The finding that households in the Pacific and Central regions of Nicaragua have significantly higher adaptive capacity than households in the Atlantic region may have been skewed as a result of data collection timing. Atlantic households were particularly hard hit by Hurricane Mitch in 1998 and may still have been recovering from the impact of that storm at the time the data was collected in 2001.
- This research attempts to situate current adaptive capacity in the context of future climate change because trying to project adaptive capacity into the future only compounds the uncertainty of climate change projections. Therefore a current analysis of adaptive capacity is a suitable proxy allowing us to identify ways in which adaptive capacity can be enhanced for the future (Adger, 2003; Adger & Kelly, 1999).

- The sample does not include rural farm households who are strictly subsistence based, as they would not have listed farming as a source of 'income'.

3.6. Conclusion

This study highlights how adaptive capacity of rural farm households varies across Nicaragua, and also how it varies by household demographic characteristics. The RFHACI presented in this paper provides a methodology for using household survey data to assess the relative adaptive capacity of rural farm households. In keeping with a growing body of literature on adaptive capacity, we contribute to the research gap that exists in sub-national assessments of Nicaragua, as well as the need for practical measures of adaptive capacity that support policy targeting and design.

This research has shown that in rural Nicaragua, household adaptive capacity significantly differed when households were grouped by climatic region, household size, indigenous status, and age of the head of household. It also showed that households located in the Atlantic region, small households, households with a young head of household, and indigenous households, had lower adaptive capacity than their counterparts.

Chapter 4: Rural Nicaragua's Current Vulnerability to Future Climate Change: A Sub-National Assessment

4.1. Introduction

Some of the most profound impacts of climate change over the coming years will be on agriculture and food systems (Brown & Funk, 2008) and the extent to which rural farm communities have the capacity to respond or adapt to these changes has important implications for human development at the household, community, national and global level. Changes in climate are especially important for Less Developed Countries (LDC's), which tend to have a higher rural population who are heavily reliant on agriculture as a source of food and as a means of generating income (Adger et al., 2003; Minaxi. R, Acharya, & Nawale, 2011; Parry, Rosenzweig, Iglesias, Fischer, & Livermore, 1999). It is these same LDC's that will be disproportionately affected by climate change and have fewer means and resources with which to respond or adapt (Adger et al., 2003; Smit & Pilifosova, 2003).

Nicaragua, a country with a population of 5,869,900 (UNDP, 2011), is the second poorest country in the western hemisphere, with approximately 17% of its population living in extreme poverty (FAO, 2012). Over 42% of the total population and over three quarters of the poorest live in rural areas where many of them struggle to make a living from fishing and agriculture(Karfakis et al., 2011; World Bank, 2011). Between 1971 and 2000, the mean temperature in Nicaragua increased by approximately 1.4 °C, which is significantly higher than the global average increase of 0.6°C over the same time period, indicating Nicaragua's high level of exposure to climate change (Karfakis et al., 2011). Climate change could have a severe negative impact on Nicaragua's rural population since agriculture is a major source of income for rural households, and is almost completely rain-fed (less than 2% of households reported using irrigation in a 2001 National Household Survey on Living Standards Measurement). Agriculture plays a significant role in Nicaragua's economy, accounting for approximately 19% of the country's GDP in 2008 (USAID,

2011) and employing nearly 47% of the population (Abdulai & Eberlin, 2001). This research specifically focuses on two important agricultural crops – beans and maize – which account for 63%[18] of the cropped area in the country (USAID, 2011). Perhaps even more importantly, beans and maize are primarily grown for domestic consumption and are staples of the Nicaraguan diet (Abdulai & Eberlin, 2001; USAID, 2011).

While the exact definition of vulnerability to climate change has been the subject of much debate, one thing is clear – that climate change will exacerbate the situation of those populations already situated at the margins of society. Therefore vulnerability provides a framework from which we can assess how the impacts of climate change will be distributed in order to target policy intervention efficiently and reduce potential harm (O'Brien et al., 2009).

The IPCC's Third Assessment Report (TAR) defines vulnerability to climate change as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2007; McCarthy, Canziani, Leary, Dokken, & White, 2001a; Metzger et al., 2005; O'Brien et al., 2004), where exposure is the degree to which a system is exposed to significant climatic variations, and sensitivity is the degree to which a system is affected by climate (McCarthy et al., 2001b). Adaptive capacity can be defined as the ability of a system to adjust to actual or expected climate stresses or to cope with the consequences (McCarthy et al., 2001b; O'Brien et al., 2004).

Following the approach of O'Brien et al. (2004), this research operationalizes the IPCC's definition of vulnerability in a sub-national assessment to understand how different factors that shape vulnerability to climate change vary within one country. We begin by examining the effects of projected changes in climate within Nicaragua on the yield reduction for beans and maize. We then use an indicator-based assessment of the adaptive capacity of Nicaraguan rural households and scale that assessment up to the municipio[19] level. The final step is to use the

[18] This statistic includes cropped area for rice.
[19] Departamentos and municipios are governmental administrative units. Nicaragua has 15 deparatmentos and two self-governing regions (autonomous regions). There are 153 municipios.

output from the two sub-indices to calculate a vulnerability score for each municipio and to display how current vulnerability to future climate change varies spatially across the country. Assessment of sensitivity and exposure to climate change, in conjunction with adaptive capacity, is critical for differentiating relative vulnerabilities in terms of climate change (O'Brien et al., 2004). Results of this research will provide policy makers with a vulnerability map for Nicaragua, presenting the spatial distribution of rural areas' current vulnerability to future climate change. This research aims to help fill a gap identified by Hitchcock (2002) and Corbett (1988) who call for research that increases synergies between the crop-climate modelling community and those who focus on food security, poverty, and coping strategies for environmental problems at the household and community level. Measuring vulnerability at the subnational level also provides policy makers with a tool that can be used to more effectively and efficiently target their scarce resources to places where adaptive capacities can be easily developed, or where the greatest need exists (Adger et al., 2004).

4.2. Data & Methods

This research was completed by creating two indices that capture the three components of vulnerability. These indices are Sensitivity Under Exposure Index (Section 2.1) and Municipio Adaptive Capacity Index (Section 2.2). We then used these indices to calculate a vulnerability score for each municipio.

4.2.1. Sensitivity Under Exposure Index

The Sensitivity Under Exposure (SUE) index encompasses two components of vulnerability – exposure and sensitivity. For each municipio the sensitivity of beans and maize to climate change was measured by modelling the yield reduction of each crop in multiple growing seasons over a one year period using geographic, climate, and soil characteristics representative of each municipio. This was done for three growing seasons of beans and two growing seasons of maize using climate normals from the reference period (1960 - 1990). Holding soil and cropping parameters constant, we modelled yield reduction of beans and maize again, this time using projected climate data for the A1B emissions scenario for the 2030's (2020-2049).

The SUE index was calculated by taking the difference in annual yield reduction of both crops (as calculated using the FAO's CropWat model) between the 2030's and the reference period. Therefore, a municipio with a high SUE value is projected to experience a much greater yield reduction in the 2030's than in the reference period, indicating a high sensitivity to climate change. The following is an example of how the SUE value was calculated for the municipio of Somoto (which is located in the departamento of Madriz):

Table 4-1 SUE index calculation example

	Beans[20]				**Maize**[21]		
	% Yield Reduction Season 1	**% Yield Reduction Season 2**	**% Yield Reduction Season 3**	**% Annual Yield Reduction***	**% Yield Reduction Season 1**	**% Yield Reduction Season 2**	**% Annual Yield Reduction***
Reference	0.2	10	87.6	**97.8**	0.3	37.8	**38.1**
2030's	0.7	11.2	89.3	**101.2**	0.5	39.9	**40.4**

*Calculated by summing the percent yield reduction of in each growing season for each crop

Difference in Annual Yield Reduction of Beans (101.2% – 97.8%)	3.4%
Difference in Annual Yield Reduction of Maize (40.4% – 38.1%)	2.3%
SUE (3.4% + 2.3%)	**5.7%**

CropWat

CropWat uses climate, crop and soil data to calculate the crop water requirements of specific crops (Darshana, Pandey, Ostrowski, & Pandey, 2012). It has also been widely used to estimate yield reductions under water deficit conditions where relative yield reduction is related to the corresponding relative reduction in evapotranspiration (FAO).

[20] Growing season 1 for beans corresponds with the Primera growing season where planting is done in May, growing season 2 corresponds with Postrera where planting is done in September, growing season 3 corresponds with the Apante growing season where planting is done at the beginning of January.

[21] For maize, growing season 1 corresponds with planting in mid-April, and growing season 2 corresponds with planting at the beginning of October.

In this study CropWat 8.0 was used to calculate reference evapotranspiration (ET_o) for each municipio, a value that represents the evapotranspiration of a well-watered grass crop, using monthly air temperature, wind speed and humidity data for a particular municipio. CropWat utilizes the Penman-Monteith method (Smith, 1992), which is now recommended as the sole standard method for computation of reference evapotranspiration (ET_o) (FAO, 1998). The Penman-Monteith approach is a combination of aerodynamic and radiation terms, and the general equation is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + y\frac{900}{T+273}u_{2(e_s - e_a)}}{\Delta + y(1 + 0.34u_2)} \qquad (1)$$

where ET_o is the reference crop evapotranspiration (mm day−1); R_n is the net radiation at the crop surface (MJ m−2 day−1); G is the soil heat flux (MJ m−2 day−1); T is the mean daily air temperature (°C); u_2 is the wind speed (m s−1); e_s is the saturation vapour pressure (kPa); e_a is the actual vapour pressure (kPa) ; ($e_s - e_a$) is the saturation vapour pressure deficit (kPa); Δ is the slope vapour pressure curve (kPa °C); γ is the psychometric constant (kPa °C) and 900 is the conversion factor for daily basis calculation[22] (FAO, 1998).

CropWat determines water requirements (ET_c) over the growing season by using ET_o and estimates of crop evaporation rates expressed as a crop specific coefficient (Kc). Kc, which was determined experimentally by the FAO, integrates the following four primary characteristics that separate the specified crop from a well-watered grass crop: 1) crop height, 2) albedo of the crop-soil surface, 3) canopy resistance and 4) evaporation from soil (FAO).

ET_c is essentially the upper boundary of evapotranspiration which represents conditions where no limitations are placed on crop growth or evapotranspiration due to water shortage. ET_c is calculated using the following equation:

$$ET_c = K_c * ET_o \qquad (2)$$

[22] This was used to convert our monthly climate data input into daily values.

Using estimates of effective rainfall, CropWat calculates crop irrigation requirements assuming optimal water supply. CropWat uses soil water retention, infiltration characteristics and estimates of rooting depth as input data to calculate daily soil water balance and water content in the rooted soil by means of a water conservation equation, which accounts for the incoming and outgoing flow of water (Smith & Kivumbi, 2002). $ET_{C\ adjusted}$ is the evapotranspiration from crops grown under environmental conditions that differ from the standard optimal conditions. $ET_{C\ adjusted}$ is calculated using the following equation:

$$ET_{c\ adjusted} = ET_c * K_s \tag{3}$$

Where K_s is a water stress coefficient that describes the effect of soil water deficit on crop evapotranspiration, which is assumed to decrease linearly in proportion to the reduction of water available in the root zone (Smith & Kivumbi, 2002)[23]. From this CropWat is able to calculate the percent yield reduction that occurs over a growing season as a result of water stress.

Calculating Percent Yield Reduction

The seasonal yield reduction of beans and maize is expressed as a percentage of maximum production achievable in each municipio given optimal conditions (Smith & Kivumbi, 2002). CropWat uses the following equation to calculate percentage yield reduction (based on the assumption of no irrigation).

$$\mathbf{1 - \frac{Y_a}{Y_{max}} = K_y \left(1 - \frac{ET_{c\ adjusted}}{ET_c}\right)} \tag{4}$$

Where $1\text{-}Y_a/Y_{max}$ is the fractional yield reduction that is a result of the decrease in evaporation rate, K_y is a crop specific yield response factor, $ET_{c\ adjusted}$ is the crop evapotranspiration under non-standard conditions or stressed conditions, and ET_c is the crop evapotranspiration under standard conditions (FAO, 1998).

[23] For soil water limiting conditions KS<1, for conditions where there is no water stress, KS = 1 (Smith & Kivumbi, 2002)

CROPWAT Data Inputs

This section discusses the data and data processing used to get the necessary inputs for CropWat.

Climate

The climate data inputs to CROPWAT include: 1) minimum and maximum temperature, 2) sunshine hours, 3) wind speed, 4) relative humidity, and 5) precipitation. Monthly precipitation, monthly minimum temperature and monthly maximum temperature for each municipio in Nicaragua were calculated using zonal statistics from gridded data. Climate data from WorldClim – Global Climate Data[24] was used for reference period. Projected climate data for the 2030s, was taken from the Climate Change, Agriculture and Food Security – Downscaled GCM Data Portal[25] where we selected downscaled climate data from the ncar-ccsm3_0 climate model for SRES A1B.

Sunshine hours and wind speed were estimated by assuming CLIMWAT Data for a station in Managua were constant across the country. Relative humidity was calculated using dew point temperature as outlined in Chapter 3 of FAO Irrigation and Drainage Paper 56 (FAO, 1998).

Soil

The soil classification was completed by characterizing soil types using soil texture, which was calculated using area weighted grain size distributions within municipios. This simplified method was necessary due to the lack of widely available high resolution soil data for Nicaragua. We concluded that, although the physical properties of soil are not the only soil parameter that regulate crop growth, it was an adequate assessment for the scope of our research based on the fact that "soil texture is the most fundamental qualitative soil physical property in controlling water, nutrient and oxygen exchange, retention and uptake"(Schoenholtz, Miegroet, & Burger,

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[24] This data have a resolution of 30 arc-seconds, and were generated through the interpolation of average monthly climate data from weather stations. To read more about this source data see Hijmans, Cameron, Parra, Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

[25] http://www.ccafs-climate.org/data/

2000, p. 347) and "[soil texture] is the master soil property that influences most other properties and processes" (Schoenholtz et al., 2000, p. 347).

The soils classification for each municipio was done using data from the FAO-UNESCO Soil Map of the World. An area-weighted distribution of grain-size percentages was done for the topsoil (0-30cm) and subsoil (31-100 cm) within each municipio. Based upon the output of the area-weighted distribution of grain size, we were able to match the predominant top soil and sub soil type within a municipio. We assumed that the predominant soil type in each municipio would remain constant across the period 30 year period. Total available soil moisture values for each soil type were taken from FAO Paper 56 (FAO, 1998).

Cropping Parameters

For the bean crops we used each municipio's topsoil classification and for maize we used each municipio's subsoil classification in terms of soil type, since beans have a shallower rooting depth than maize (FAO, 1998). Over the stages of crop development the rooting depth for beans ranged from 0.15m to 0.90m and the rooting depth for maize ranged from 0.25m to 1.5m, both of which fall within the standard rooting depth ranges described by the FAO (FAO, 1998). The length of the crop development stages for each crop were also taken from the ranges provided in FAO Paper 56 and equated to 110 days per bean crop and 150 days per maize crop (FAO, 1998) The yield response factor (Kc) is a crop specific value that captures the complex linkages between production and water use by a crop (FAO). The Kc value for maize is 1.25 and the Kc value for beans is 1.15, which can be interpreted to mean that both crops are very sensitive to water deficits, with proportional larger yield reductions when water use is reduced because of stress (FAO).

We chose planting dates for beans and maize in accordance with actual reported planting dates in Nicaragua. There are three planting seasons for beans in Nicaragua: 1) the Primera which begins in May, 2) the Postrera, which begins in September, and 3) the Apante which begins in December (Michigan State University). The planting dates we used for maize were mid-April and the beginning of October which are substantiated by van Tienhoven and Lagemann (1981). The stage days, rooting depth, and critical depletion fraction used were all standard values published in FAO Paper 56 (FAO, 1998).

4.2.2. Municipio Adaptive Capacity Index

While adaptive capacity is most relevant as a local characteristic (Yohe & Tol, 2002), it is not always feasible to profile every household within a community, region or country. For the purposes of targeting interventions, an important first step can be identifying a geographic location where assistance may be needed most. The MAC index is derived from the Rural Farm Household Adaptive Capacity index (RFHACI) which is detailed in *Chapter Three - Adaptive Capacity of Rural Nicaraguan Farm Households*. The Rural Farm Household Adaptive Capacity Index (RFHACI) is formed from the sum scores of the following six composite sub-indices: presence of alternative economic activities; access to technologies; social capital; knowledge and skills; access to information; and access to infrastructure. The sub-indices each represent one theoretical determinant of adaptive capacity. Figure 1 outlines the structure of the RFHACI, showing the composite sub-indices and their component indicators.

Each of the sub-indices is made up of one to four variables that are representative of a respective theoretical determinant of adaptive capacity. Where the sub-index is comprised of more than one indicator, an average of those indicators was used so that each sub-index is scored between zero and one. The overall adaptive capacity score for a given household is calculated by summing that household's score for each of the sub-indices (see section *3.2.2 Calculating the RFHACI* for a more detailed explanation and an example of the calculations performed). The Municipio Adaptive Capacity (MAC) index was calculated by taking the average adaptive capacity scores of the surveyed households within each municipio, and assigning that mean score to the municipio.. Therefore, the potential maximum adaptive capacity score for any given municipio is 6, which would indicate that all households in that municipio tied for the highest adaptive capacity scores of all the households surveyed. An example of how this calculation was done for the municipio of Somoto, can be seen in the following table.

Table 4-2 MAC index calculation example

Household Survey Identifier	**RFHACI Score**
38311	2.03
38391	2.09
38321	1.95
38361	1.95
38401	1.28
46581	2.16
38411	2.67
38371	2.32
38491	2.1
MAC Index Score for Somoto	
Calculation	(2.03+2.09+1.95+1.95+1.28+2.16+2.67+2.32+2.10) / 9
MAC Index Score	2.06

We realize that scaling up our analysis in such a simple way may compound some uncertainty as there are elements missing from our analysis that would be relevant at the municipio level (such as local governance characteristics); however, indicators that captured some institutional characteristics exist in the social capital and infrastructure indices (see section *3.2.3 Indicator Selection* for more details). Local governance data at the municipio level were not available to us and since the central elements of adaptive capacity are common at different scales (Vincent, 2007), our methodology provides policy makers a place to begin a more thorough investigation and/or case study.

4.2.3. Sample Data

The sample data used to calculate the MAC index score for each municipio was 1212 rural Nicaraguan household surveys, where all of the households reported obtaining a share of their income from farming. This sub-set of household data was drawn from the 2001 National Household Living Standards Measurement Survey (LSMS) and represents 66% of the total rural surveys taken. The data set was provided to us by the Food and Agriculture Organization of the

United Nations (FAO UN)26. The LSMS data can be generalized to: 1) the national total, 2) urban and rural populations, and 3) the macro regions (Managua, Pacific, Central and Atlantic). Unfortunately, the results of the survey are not generalizable to the municipio level; however data availability is a common problem when working in developing countries. The results generated from this research provide a place from which further exploration can be done.

4.3. Vulnerability

Finally, to calculate a vulnerability score for each municipio we used the following equation:

$$Vulnerability = (Z_{SUE} * 0.6667) + (Z_{MAC} * -1 * 0.3333) \qquad (5)$$

Where Z_{SUE} is the standard normal score of the SUE index and Z_{MAC} is the standard normal score of the MAC index, and 0.6667 and 0.3333 represent the weighting of each index. As per common practice in the vulnerability literature, weights were assigned equally to each of the three components that make up the vulnerability framework (Hinkel, 2011)[27]. Multiplying Z_{MAC} by -1 was done for ease of interpretation of the vulnerability index, where positive vulnerability scores are associated with higher than average vulnerability and negative vulnerability scores are associated with lower than average vulnerability, and scores of zero exhibit average vulnerability. We standardized the scores of both SUE and MAC to ensure that that the value and range of scores did not influence our results in an unintended manner.

The following table provides an example of how the vulnerability calculation was done for the municipio of Somoto.

Table 4-3 Vulnerability score calculation example

SUE	Standardized SUE	MAC	Standardized MAC	Calculation	Vulnerability Score
5.7	0.55	2.06	0.12	(0.55*0.6667) + (0.12*-1*0.3333)	0.32

[26] The Living Standards Measurement Survey (LSMS) was undertaken in 2001 by the Nicaraguan National Institute of Statistics and Census with technical and financial support from the world Bank, United nations Development Program, the Swedish international l Development Agency and the Social Emergency Investment Fund

[27] The SUE index encompasses two components of vulnerability.

4.4. Results

The results of this research can be best communicated in a series of maps that depict the spatial distribution of vulnerability, adaptive capacity (MAC index) and sensitivity under exposure (SUE index) across the 93 Nicaraguan municipios included in the study[28]. For the MAC and SUE index maps (see Figure 3 and Figure 4) the standard deviation classification method was used to show how much a given municipio varies from the mean vulnerability score for all municipios in the country, and is a method that is consistent with the idea of assessing the municipios relative to one another. Using the same method of classification and interval colors for both maps, where green represents a favorable condition and brown represents a non-favorable condition, also helps make the maps more comparable.

A Pearson r correlation was applied to examine the relationship between the MAC Index ($M = 2.01$, $SD = 0.43$) and the SUE Index ($M = 4.08$, $SD = 2.97$). A significant positive correlation was obtained, $r = 0.42$, $p < .01$ (2-tailed).

The overall Vulnerability map (Figure 5) was classified according to manual interval because the MAC and SUE indices were standardized in the vulnerability calculation. It is important to keep in mind that it is optimal for a municipio to have below average sensitivity and above average adaptive capacity.

[28] Municipios where there were less than four rural household surveys completed were not included in the sample.

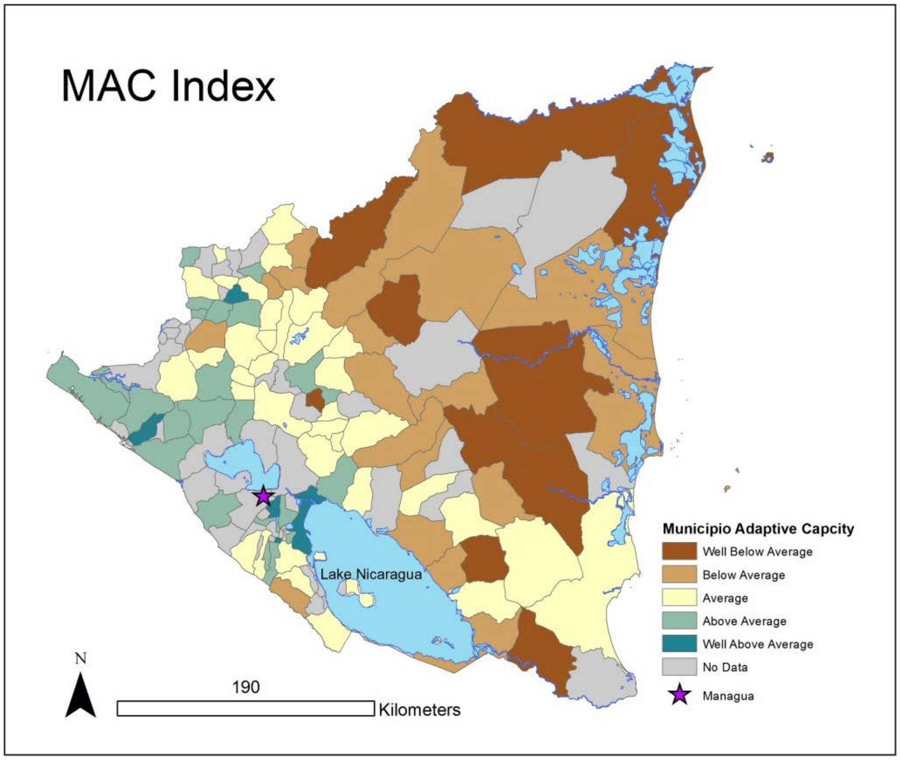

Figure 3 Map depicting spatial variation of MAC index

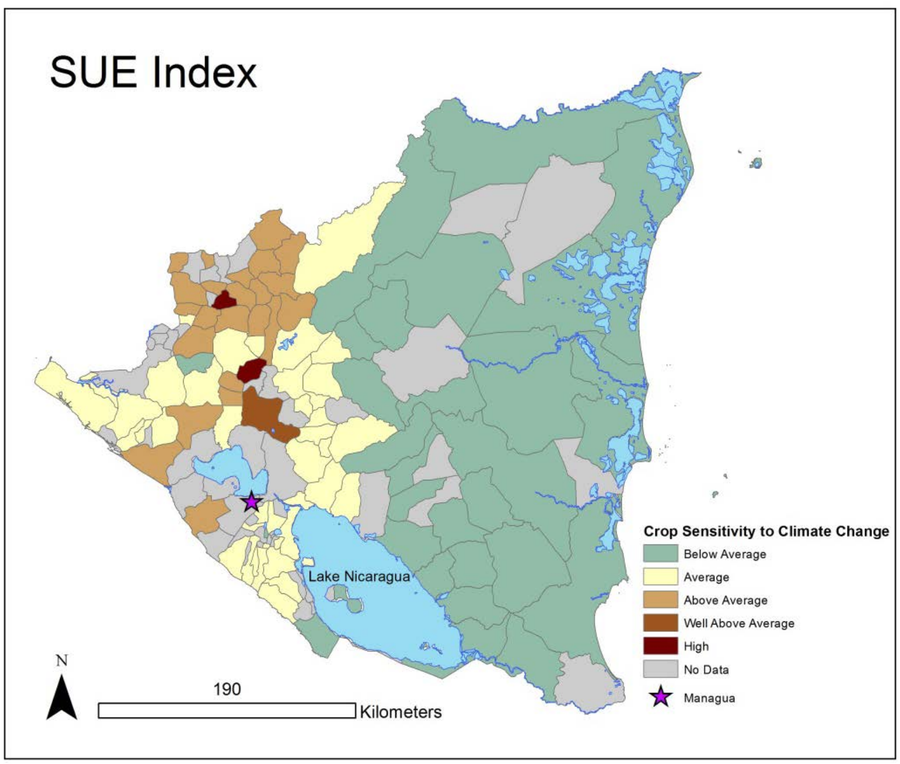

Figure 4 Map depicting spatial variation of SUE index

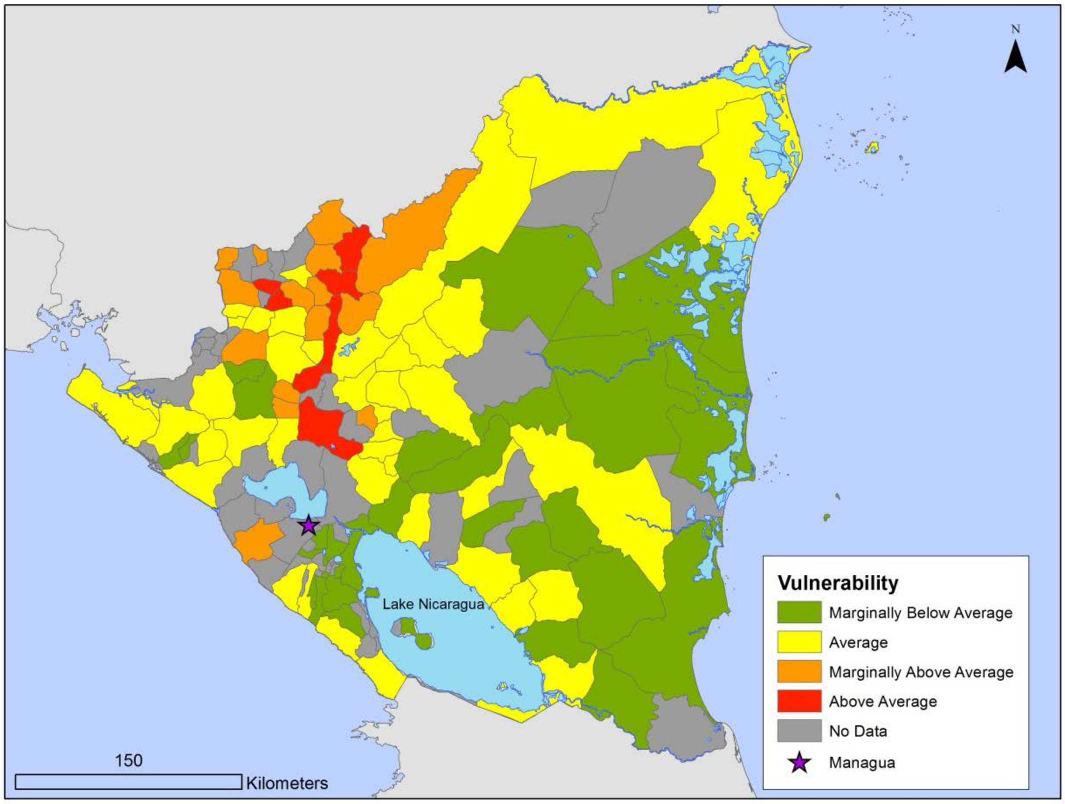

Figure 5 Current vulnerability to future climate change in rural Nicaragua

4.5. Analysis

If a population is exposed to significant changes in climate but is not negatively affected by those changes, they are not vulnerable to climate change (Smith et al., 2003). In contrast, even small changes in climate can have significant negative effects on populations where the capacity to adapt to those changes is low or non-existent. Thus it is critical to assess all three components of vulnerability to differentiate relative vulnerabilities to climate change (O'Brien et al., 2004).

The results show that the municipios in Nicaragua demonstrate diversity in terms of agricultural response to projected climate change and current adaptive capacity conditions. The differences in vulnerability between municipios suggest that policy makers need to develop specifically targeted intervention polices to address climate change at the local level.

From an agricultural perspective, the municipios that are the most vulnerable to climate change in Nicaragua, are located in the northern and northern-western part of the central highlands. The municipios that demonstrate “above average” vulnerability to climate change are (in order of decreasing vulnerability):

1. Palacagüina, Madriz,
2. La Trinidad, Estelí
3. Ciudad Darío
4. Totogalpa, Madri
5. Central Highlands
6. Murra, Nevuo Segovia
7. San Rafael del Norte, Jinotega

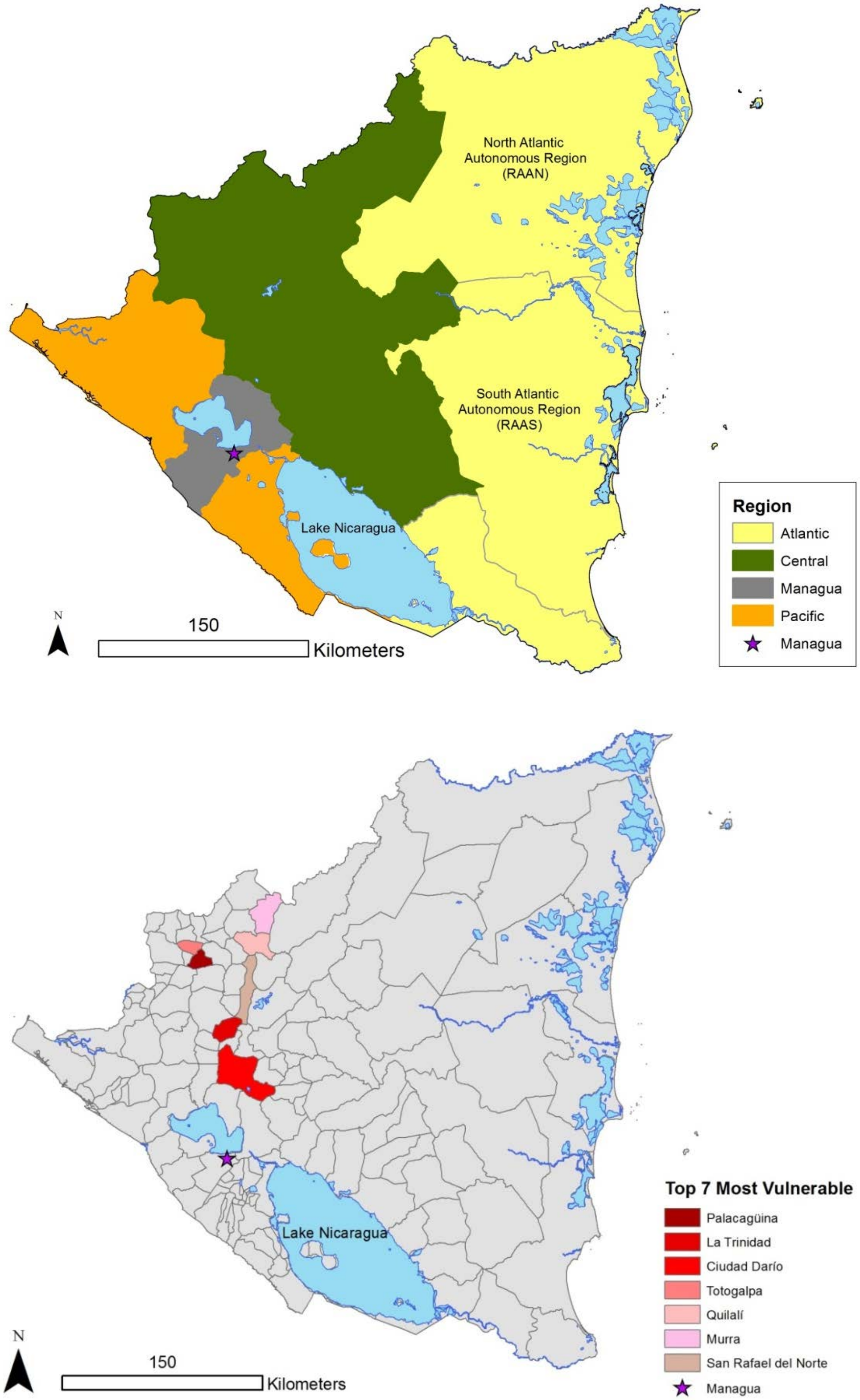

Figure 6 Location of top seven most vulnerable municipios

The seven most vulnerable municipios listed above may be a place where intervention could be targeted first since these are the municipios where the impacts of climate change are likely to be felt most adversely. This may be because of increasing yield reductions through the 2030s, because of their current low levels of adaptive capacity, or as a result of both. There is no single policy intervention that would suit all the municipios listed here, since the vulnerability of each municipio is a function of sensitivity to climate change and adaptive capacity. For example Palacagüina, Madriz, which ranked as the most vulnerable municipio in the country, had the 5th highest adaptive capacity ranking, but ranked as "above average" vulnerability because of yield reduction increasing by an additional 19.3% by 2030. On the other hand, Murra and Quilalí both scored very low in terms of adaptive capacity, ranking 10th and 11th lowest in the country. Therefore, policy makers should consider the needs of each community, when tailoring their intervention approach.

By contrast, there are 31 municipios that fall into the category of having "marginally below average" vulnerability. While it is harder to distinguish any spatial pattern between municipios with "marginally below average" vulnerability, when we look at the seven municipios with the lowest vulnerability scores, there are some geographic similarities (see Figure 7). The seven municipios that are the least vulnerable are all located in the southern half country, and are either on, or close to, the north-western edge of Lake Nicaragua; in the southern part of the Atlantic Region; or in the very southern part of the Central highlands. The seven municipios that are currently the least vulnerable to climate change (in order of increasing vulnerability) are:

1. La Paz de Carazo, Carazo, (not on Lago Nicaragua, but close to edge of Lake Nicaragua)
2. Villa Sandino, Chontales,
3. Nindirí, Masaya, (not on Lago Nicaragua, but close to edge of Lake Nicaragua)
4. Nandasmo, Masaya, (not on Lago Nicaragua, but close to edge of Lake Nicaragua)
5. Grandada, Granada
6. Bluefields, Atlantico Sur

7. San Miguelito, Rio San Juan

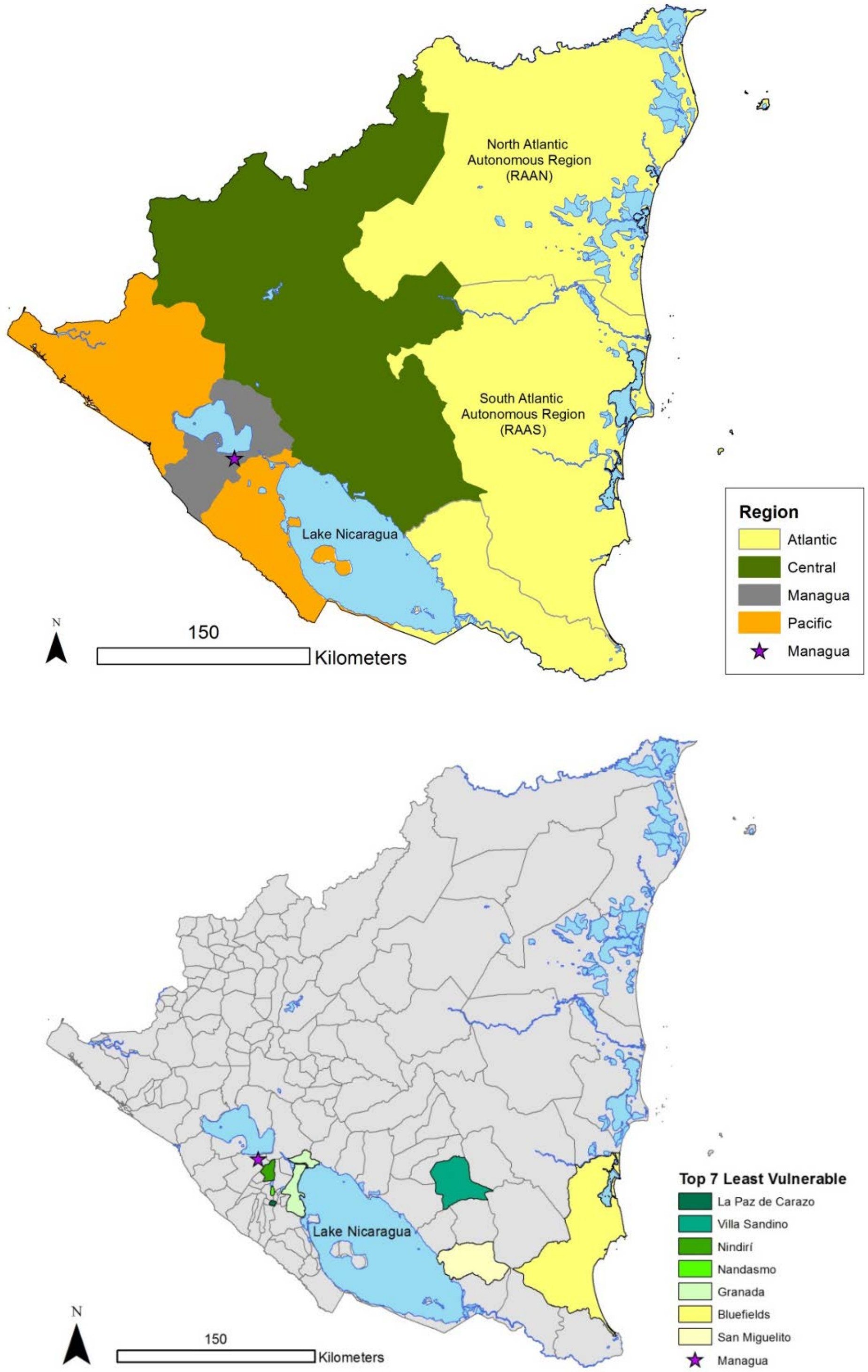

Figure 7 Location of top seven least vulnerable municipios

The vulnerability scores that result in the above rankings are not absolute; they just show that relative to the average level of vulnerability in Nicaragua, these are the municipios that are the most and least vulnerable to gradual climate change. The spatial relationships discussed in this analysis allow us to see visual correlations, but are not meant to imply causal linkages. Overall, our results show that farmers in the northern and north-western part of the central highlands as the most vulnerable to future climate change. This particular part of Nicaragua not only demonstrates a high level of sensitivity to projected climate change, it is also an area that is considered one of the poorest parts of the country (USAID, 2011); however our seven most vulnerable municipios demonstrated diversity in terms of their levels of adaptive capacity.

4.5.1. MAC Index Map

The MAC index map shows a clear spatial pattern where current adaptive capacity increases as we move from east to west across the country. Municipios located in the Atlantic region[29] of the country have average to below average adaptive capacity, while in the Central highland region of the country, many of the municipios are within half a standard deviation of the mean adaptive capacity score. A few notable exceptions in the Central region are the municipios of Palacagüina, located in the deparatamento of Madriz, which ranks among the municipios with the highest adaptive capacity in the country, and San Dionisio, in Matagalpa, and Wiwilí, in Jinotega, which rank among the municipios with the lowest adaptive capacity in the country.

[29] which encompasses the Deparatmentos of the North Atlantic Autonomous Region (RAAN), the South Atlantic Autonomous Region (RAAS) and Rio San Juan

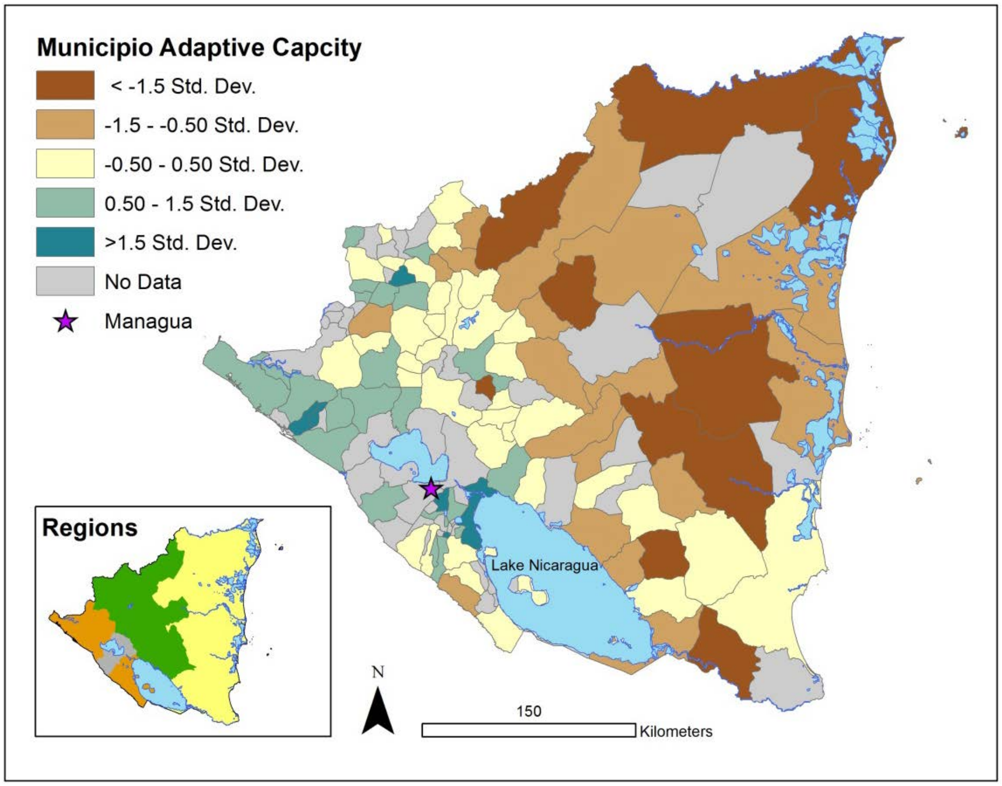

Figure 8 Regions of Nicaragua and Municipio Adaptive Capacity (MAC) index results

Municipios in the Pacific region of Nicaragua generally have higher adaptive capacity than municipios in other regions of the country. This finding is not surprising as municipios located in the Pacific region are generally closer in proximity to the country's urban capital and political and economic heartland of Managua. Poverty rates in the Atlantic region are among the highest in the country (USAID, 2011) and given that adaptive capacity was measured primarily based on access to resources (social, human capital, economic, institutional) it is not surprising that the Atlantic region ranks below average in adaptive capacity. Although poverty is an important aspect of adaptive capacity because of its direct association with access to resources, (Adger, 1999) poverty does not measure important components of adaptive capacity such a social and human capital. There are also some exceptions to the general statement that adaptive capacity is above average in the Pacific region and it appears that as we move farther south from capital, adaptive capacity in the Pacific region decreases, with the municipio of Tola (in Rivas) having below average adaptive capacity and the municipio with the lowest level of adaptive capacity in the Pacific region.

The low adaptive capacity of municipios in the Atlantic region is likely linked to historical events and the current legal and political framework that has excluded the less populated, and primarily indigenous, Atlantic region from the national political agenda. Since 1987 the majority of the Atlantic region (the North Atlantic Autonomous Region (RAAN) and the South Atlantic Autonomous Region (RAAS), but not Rio San Juan) has been under the autonomous model of governance which in theory, allows RAAN and RAAS to be self-governing collective entities that act within the national political sphere (Cott, 2001). The Autonomy Law, which was established in 1987 and enacted in 1990, has never been enabled to function properly (Feiring, 2003), and the central government has been reluctant to transfer power and resources to the Atlantic region (Cott, 2001). Considering the tumultuous political history of the relationship of the autonomous regions with the centralized government , that good governance is key in adaptive capacity at the national level (Brooks et al., 2005) and that governance connects individuals and households with organizations, agencies and institutions (Folke et al., 2005), it is not surprising that there is adaptive capacity seems to be lower in the Atlantic regions.

4.5.2. SUE Index Map

The SUE index map demonstrates a different spatial gradient than the MAC index map, where sensitivity to climate change is generally much higher on the Pacific side than on the Atlantic side of the country. SUE values ranged from 0%, indicating no change in yield reduction between the reference period and 2030, to approximately 19% indicating that in certain areas climate change has the potential to greatly impact the yield of bean and maize. Looking at the SUE index Map (Figure 3), a spatial gradient can be distinguished with agricultural sensitivity to climate change increasing as we move from east to west, and south to north across the country.

This spatial gradient is not surprising given that climate, which is spatially distributed, is a driving factor in agricultural yield (Challinor et al., 2007), and Atlantic region experiences significantly higher annual precipitation, as well as more precipitation during the dry season, than either the Pacific or Central regions[30]. While municipios in the Atlantic region of Nicaragua are not expected to experience a change in the yield reduction of beans and maize, their low adaptive capacity levels put them at serious risk if climate shocks, such as hurricanes, do occur.

The results of our SUE index show that under the SRES A1B scenario for the 2030's the yield reduction of beans and maize in northern part of the central highlands will increase significantly - more than anywhere else in the country, putting beans and maize farmers in this area at great risk unless they are able to adapt. The majority of the municipios in RAAN and several of the municipios in RAAS showed no change in yield reduction for beans and maize between 2030 and the reference period.

It is important to keep in mind that the greatest increase in yield reduction (as captured by the SUE index) does not directly equate to low overall agricultural productivity, but simply measures which municipios may have to deal with the largest changes local food supply and negatively affect rural incomes.

4.5.3. Putting the Results in Context

This research focuses on agricultural vulnerability to *gradual* climate change for rural areas. Extreme weather events such as hurricanes and cyclones may be a more immediate threat to agriculture and should be considered for future study. However, our measure of sensitivity under exposure and adaptive capacity can also represent vulnerability to climate variability as farmers will be adapting to changes in temperature extremes and precipitation patterns as much as changes in mean climate conditions (O'Brien et al., 2004). Our climate data does not capture local

[30] The Pacific region of the country is known to have annual precipitation ranging from 1250-2500 mm and 1500 mm along the coast and approximately 1500 mm annual inland, while the RAAN and RAAS in the Atlantic Region average 2000-3000 mm and 3000-6000 mm of annual rainfall, respectively (USAID, 2011)

extremes, as we used monthly data averaged over numerous years as inputs to CropWat. Given the scope of our analysis and the uncertainty associated with extreme weather events, we focused on how gradual changes in climate will affect small-holder agriculturists.

These findings also need to be put into the context of the SRES A1B scenario that was utilized in this research. SRES A1B is characterized by an integrated world in which there is rapid economic growth, efficient diffusion of new and innovative technologies, and a population that peaks at 9 billion in the 2050s at which point it begins to slowly decline. This scenario assumes a balanced emphasis between fossil fuels and other non-fossil fuel energy sources (Nakicenovic et al., 2000). Often SRES A1B is considered a "middle of the road" scenario; therefore, if we had used climate data from other scenarios actual yield reductions could be considerably higher or considerably lower, depending on the chosen scenario.

4.6. Limitations, Strengths & Future Works

The research presented in this paper has both limitations and strengths. Mapping vulnerability by municipio may lead to a false sense of precision. Our vulnerability maps imply abrupt changes in vulnerability status at municipio borders, whereas more realistic "fuzzy" or transitional boundaries of vulnerability are likely to exist (Eakin & Luers, 2006). Our map is representative of current vulnerability to future climate change for rural communities where agriculture is important; however we did not account: 1) the proportion of the population that is rural vs urban in each municipio, nor 2) the importance of beans and maize within each municipio. Therefore, some municipios may actually be more or less vulnerable overall, but the ranking should be relatively accurate in the context of their rural population. Since beans and maize are grown widely across the country and are primarily grown for domestic consumption, we believe that if local food supply was to be altered, it would have impacts to both the rural and urban population (IICA, 2007). Lastly, it is likely that there is heterogeneity in terms of adaptive capacity within municipios and in some cases the households surveyed in a municipio may not be representative of the entire municipio; however, data availability is a common challenge in developing countries, and to our knowledge, there is only limited data available on a municipio by municipio basis.

Perhaps the most critical strength of this study is that it provides a way to measure the phenomenon of vulnerability, which is not tangible nor easily quantifiable (Vincent, 2007). By focusing on differentiating 'relative vulnerability' over the entire country, this research will be useful to NGOs, local and national governments. Another advantage of our approach is the transparency of our indices and indicator framework which allow us to trace the vulnerable regions back to their underlying determinants (Gbetibouo & Ringler, 2009). The vulnerability calculation also provides a transparent way to change indicator weighting.

Future research in this area should incorporate projections from increased number of climate modules, and higher resolution daily climate data. Also, using panel data as an input to the MAC index analysis would provide a more realistic view of adaptive capacity in the country since point in time indicators are not able to capture trends. We would recommend continuing with the approach of measuring *current* adaptive capacity in the context of future climate change as projecting adaptive capacity into the future would only compound the uncertainty that already exists in climate models and emissions scenarios.

4.7. Conclusion

This research operationalized the IPCC's definition of vulnerability to climate change to examine how current vulnerability to future climate change varies by municipio across rural Nicaragua. Our framework allows us to quantify agricultural sensitivity to climate change and current adaptive capacity to see the relative distribution of vulnerability across the country. We chose to focus on vulnerability impacts in the 2030s, as this is a time period most relevant to agricultural investment (Lobell et al., 2008), and is a time period that is also critical to development in Nicaragua.

The differences in vulnerability between municipios suggest that policy makers need to develop specifically targeted intervention polices to address climate change at the local level. Our results demonstrate a strong need for policy intervention in the northern part of the central highlands, where there is projected to be a higher sensitivity to climate change, than anywhere else in the country. This is one of the poorest areas in the country (USAID, 2011); however in general, this area shows relatively average adaptive capacity. Policy makers could focus on building adaptive capacity in the Atlantic region – an area that is lacking adequate infrastructure and has been plagued by political and legal battles. Our maps provide policy makers with place to begin further investigation of how to mitigate potential harm against the imminent threat of climate change.

Chapter 5: Conclusion

This research set out to explore the concept of vulnerability to climate change and has identified, from an agricultural perspective, the spatial distribution of current vulnerability to future climate change on a municipio by municipio basis across Nicaragua. The study has also sought to determine whether adaptive capacity varied significantly when rural farm households were located in different geographic regions of Nicaragua, or when they exhibited certain demographic characteristics. The general literature on vulnerability and adaptive capacity, and specifically in the context of Nicaragua, is lacking in practical applications that are relevant and useful to policy makers. This research sought to help fill the gap by answering the following two questions:

1. Are there significant differences in rural farm households' adaptive capacity based on their geographic location, or when households exhibit certain demographic characteristics?
2. How does current vulnerability to future climate change vary spatially across rural Nicaragua?

The RFHACI presented in Chapter 3 provides a methodology for using household survey data to assess the relative adaptive capacity of rural farm households. In keeping with a growing body of literature on adaptive capacity, we contribute to the research gap that exists in sub-national assessments of Nicaragua, as well as the need for practical measures of adaptive capacity that support policy targeting and design. Our findings show that household adaptive capacity varies significantly across regions in Nicaragua, and also when households display certain demographic characteristics. Statistical tests showed significant differences in household adaptive capacity when households were grouped by climatic region, household size, indigenous status, and age of the head of household. More specifically, the findings revealed that households located in the Atlantic region, small households, households with a young head of household, and indigenous households, all had significantly lower adaptive capacity than their counterparts. While some of our findings provide support for what has been established in the literature, other findings challenge previous research. One key finding of interest is the that medium sized households had significantly higher adaptive capacity than ‘small’ households, contradicting a finding published in an FAO working paper by Davis and Stampini (2002), which found that smaller household size was a characteristic of rural Nicaraguan households exiting poverty. Our finding potentially helps delineate low adaptive capacity from lack of financial resources, and emphasizes the importance of non-economic indicators such as social capital.

The results on current vulnerability to future climate change demonstrate how relative vulnerability of municipios varies spatially across Nicaragua. The vulnerability map in this thesis highlights the fact that municipios in Nicaragua demonstrate diversity in terms of agricultural response to projected climate change and current adaptive capacity conditions, and challenges the notion that a “one size fits all” policy solution will prevent negative outcomes. The finding that farmers in the Atlantic region may fare better in the context of gradual climate change is surprising, given that the Atlantic region is known to be disadvantaged when compared to the rest of Nicaragua. Although farmers living in municipios located in the Atlantic region had the lowest adaptive capacity in the country, the sensitivity under exposure analysis predicts that they will experience little to no yield reduction for beans and maize through the 2030’s, under SRES A1B. Alternatively, the northern part of the central highlands where some of the most vulnerable municipios are located, may be a good place to target policy intervention. It is important to note that the results of this research do not capture which municipios will have the highest or lowest yields of beans and maize in the 2030’s, but instead highlights which municipios are projected to experience the greatest changes in agricultural yield, and whether or not they currently have the resources to adapt.

The people who are likely to be impacted most by climate change are unfortunately, those who also have the least resources from which they can adapt or respond to this global problem (Smit & Pilifosova, 2003). In contrast to research that contributes to the vulnerability discourse from a theoretical perspective only, we have provided assessments that policy makers can use to implement practical measures and reduce the negative impact of gradual climate change.

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