ASSESSING VULNERABILITY: A SYNTHESIS OF CLIMATE CHANGE IMPACTS TO AGRICULTURE

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DEDICATION

For Dollar Wilson (1998-2014), who saw me through the worst of it.

ABSTRACT OF THE THESIS

Assessing Vulnerability: A Synthesis of Climate Change Impacts
to Agriculture
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Over the next century, experts project a 2-5° C rise in global temperatures – a change that will result in significant and lasting impacts to agriculture. The impacts of global warming will affect more than commercial agriculture; in fact, some argue that impacts will be most acute in regions where a majority of the population survives through subsistence farming. This shift will have direct impacts on those who rely on agriculture for their livelihoods, such as fieldworkers and farmers, but will moreover impact the entire planet with effects to global food production and consumption. Because these impacts are urgent and wide-reaching, understanding and anticipating how agriculture will be affected by climate change is crucial for global adaptation efforts. Through a synthesis of 52 case studies conducted since 2001, this research examines patterns in agricultural vulnerability to climate change around the world. Vulnerability, a combination of exposures, sensitivities and adaptive capacity, is measured in myriad ways. A synthesis approach allows for the identification of common factors in sensitivity and adaptive capacity while respecting the heterogeneity of pressures and the diversity of studies. Despite a universal recognition in the literature that vulnerability is a combination of biophysical and socioeconomic factors, biophysical factors constitute the bulk of those identified in the case studies. In two thirds of the studies, variable precipitation and drought conditions are cited, and over half the studies cite temperature increase. Frequently cited factors that impact adaptive capacity include access to financial resources, credit and social networks. Important adaptive techniques to combat climate change impacts to agriculture are crop diversification, irrigation, and shifts to the timing of planting and harvesting. However, while these practices and many others identified in the case studies address the biophysical vulnerabilities of agriculture, fewer adaptive measures address the socioeconomic sensitivities that also comprise vulnerability. These findings suggest that addressing climate change vulnerability in policy and scholarship should go beyond the adaptive measures to improve farming systems and consider ways to expand access to financial, technical and social resources.

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INTRODUCTION

Over the next century, experts project a 2-5° F rise in global temperatures – a change that will result in significant and lasting impacts to agriculture (IPCC 2014b; Mechler et al. 2010). The impacts of global climate change will affect more than commercial agriculture; in fact, some argue that impacts will be most acute in regions where a majority of the population survives through subsistence farming (World Bank 2012). This shift will have direct impacts on those who rely on agriculture for their livelihoods, such as fieldworkers and farmers, and will impact food production and consumption globally. Because these impacts are likely to be large in magnitude and extent (P. Jones and Thornton 2003; David B Lobell and Field 2007; D. B. Lobell et al. 2008), understanding and anticipating how agriculture will be affected by climate change is crucial for global adaptation efforts. Changes associated with global climate change have the potential to create social conflicts that transcend farmers and farming communities who experience negative change (Ahmed et al. 2011; Hsiang, Burke, and Miguel 2013). Poverty rates for many non-agricultural households in Africa and Asia could rise by 20-50% by 2030, under low-productivity scenarios (Hertel, Burke, and Lobell 2010). While some climate change impacts are geographically specific (e.g., island-dwelling communities dealing with sea level rise), impacts to agriculture will be widespread.

Climate change impacts have been measured across a wide variety of disciplines since the middle of the last century, and especially over the last 15 years. Many of these case studies have assessed the vulnerability of agriculture to climate change. Documenting this vulnerability is critical in order to identify appropriate adaptive measures. For instance, crop sensitivity to unexpected changes in temperature, the abundance or lack of water, and degradation of soil, have been well documented and many studies have calculated estimates of climate change impacts to agriculture. Changes in temperature, annual precipitation rates, and erosion rates have been used to model staple crop yields globally and regionally (e.g., (David B Lobell and Field 2007; Parry et al. 2004). Additional studies have focused on

specific crops and regions, for example rice in India (Barnwal and Kotani 2013), maize yields in Africa and Latin America (P. Jones and Thornton 2003), and subsistence crops (maize, millet, sorghum, rice, and cassava) in Nigeria (Adejuwon 2005). Studies have also been conducted to estimate impacts of extreme events on agriculture, such as heatwave impacts to the local agrarian economy in Spain (e.g., Mechler, Hochrainer, Aaheim, Salen, & Wreford, 2010). While there are some studies that indicate that the effects of global climate change may increase yields in parts of the world in the near term, especially in the northern latitudes (Pittman et al. 2011), the majority of research overwhelmingly suggests that crop yields and food production will be negatively impacted (IPCC 2014a).

In many cases, these studies focus on measuring the *vulnerability* of individuals, communities, and regions. Vulnerability, broadly defined as a combination of exposures, sensitivities, and adaptive capacities (W. N. Adger 2006), provides a comprehensive framework for assessing impacts experienced in agriculture while simultaneously taking into account the ability for agricultural systems to adapt to those impacts. Despite disagreement in the past about the definition of vulnerability (Dow 1992), the above definition is now widely embraced in climate change scholarship (McCarthy, Intergovernmental Panel on Climate Change, and Working Group II 2001), even while the frameworks and methods employed to measure vulnerability remain disparate. The literature varies widely across disciplines and, consequently, no synthesis of these studies has been conducted to compare results across different climates and types of agriculture.

Synthesizing the results of vulnerability case studies is critical in order to help establish adaptation pathways, and to inform policy and provide promising practices for future case studies. Through a synthesis of 52 case studies conducted since 2001, this research examines patterns in case studies that assess agricultural vulnerability to climate change around the world. A synthesis approach allows for the identification of common factors in exposure, sensitivity and adaptive capacity, while respecting the heterogeneity of vulnerability factors experienced in different areas and by different farming communities. Scaling up the results of an individual vulnerability case study is likely to produce results that could fail to recognize important disparities from place to place (Rudel 2008). By contrast, this synthesis examines and compares unique elements from a breadth of studies, rather than attempting to apply findings from one case study across a broader region or community.

Specifically, I cataloged and analyzed the kinds of exposures or sensitivities to climate change identified in the case studies; the identified factors that affect adaptive capacity; and the factors that are identified most frequently in determining agricultural vulnerability to climate change. Additionally, I cataloged the adaptive measures that have been both observed and suggested in the studies. In identifying these details, I show where research currently stands and provide insight into promising practices for climate change vulnerability case studies, especially those focused on agriculture. Finally, I illuminate trends in the studies that are useful for communities (and the institutions that support those communities) as the world community addresses climatic change in the decades to come. The objective of this study is to guide future research and contribute to pathways to adaptation by asking:

1. How is vulnerability analyzed?
    a. What kinds of *exposure and sensitivity* factors are identified in the vulnerability case studies?
    b. What kinds of *adaptive capacity* factors are identified in the vulnerability case studies?
2. What adaptive measures are observed and suggested in the vulnerability case studies?
3. How does vulnerability analysis inform pathways to adaptation?

SECTION 2

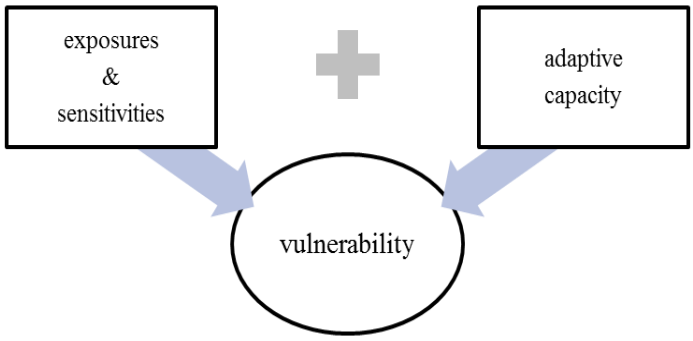
BACKGROUND

CLIMATE CHANGE VULNERABILITY

Since projections of crop yields and market impacts only tell a partial narrative, it is valuable to consider other aspects of vulnerability when discussing climate change impacts to agriculture. In addition to being a more robust account of the ways in which climate change will have impacts on households, communities, nations and regions, it has applications in proactive development work (Cannon, Twigg, and Rowell 2003; Downing et al. 2006). In the context of climate change, analyzing vulnerability can be a key aspect of informing policy and other pathways to adaptation, emphasizing a sustainable livelihoods approach rather than a reactionary one (Magombeyi and Taigbenu 2008).

The term ‘vulnerability’ in reference to climate change has been used in a wide range of disciplines and, accordingly, comes with a range of definitions. While there was little consensus before the turn of the century as to the definition of vulnerability (Dow 1992), interdisciplinary collaboration has finally led to one widely agreed-upon definition. The basic components of vulnerability are commonly recognized to be a combination of: a) the probability of experiencing adverse effects in the form of exposures and sensitivities, and b) the ability to adapt to those effects (Figure 1). As a combination of exposures and sensitivities and adaptive capacity, vulnerability varies spatially and temporally, and is shaped by social context.

Figure 1: Components of vulnerability



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Exposure and Sensitivity

Exposure is described as stress, perturbation, or susceptibility; sensitivity refers to the degree of exposure that is experienced (Magombeyi and Taigbenu 2008). The scale of exposure and sensitivity varies (household, group, community, nation, region, etc.), as do their sources. Exposures and sensitivities are often associated with biophysical impacts, and are well represented in the studies that estimate the impacts of climatic change to crop yields and markets, including those focused on vulnerability. Most commonly, these studies focus on precipitation changes and extreme temperatures (IPCC 2014a). However, exposures and sensitivities can also be socioeconomic, and include economic, social, political, and cultural impacts, such as civil strife, political oppression, marginalization, and social stratification. 'Natural' disasters, hazards and risks, therefore, are "historical, political-economic, and cultural processes interacting with the dynamics of nature" (Eakin and Appendini 2008, 556).

Adaptive Capacity

Adaptive capacity is the ability of an individual, community or system to adjust to changes in their environment. In climate change vulnerability studies, adaptive capacity is commonly found to be influenced by non-climate factors (N. Adger, Khan, and Brooks 2003; as cited in L. Jones and Boyd 2011), such as social capital and access to credit. Jones and Boyd (2011) divide socioeconomic barriers to adaptation into two categories: social and informational, where social barriers include marginalization, discrimination and structural inequities that restrict access to key resources, and informational barriers refer to limits to

informational resources regarding change or potential change in environment. Adaptive capacity can also be influenced by biophysical factors, such as geographic configuration of land holding (e.g., low-lying farmland) and ecosystem thresholds (Jackson et al. 2011).

Adaptive Measures

Adaptations to climate change and adaptive decision making by individuals and communities address vulnerability impacts from climatic shifts, as well as social context (Pittman et al. 2011). Adaptive *capacity* differs from adaptive *measures* in that the latter refers to changes made to decrease vulnerability, while the former is a component of vulnerability (L. Jones and Boyd 2011). Adaptive measures are adopted and proposed to address exposures, sensitivities and/or barriers to adaptive capacity in order to reduce vulnerability. It can be helpful to differentiate between the different kinds of adaptation, in terms of public or institutional measures versus individual or household measures, and in terms of reactionary adaptation versus planned or anticipatory adaptation (Mechler et al. 2010). Reactionary adaptations could include shifted planting seasons as climatic factors dictate (e.g., Cuesta and Ranola 2009). Planned adaptations, by contrast, could include capacity building sessions in agricultural extension (e.g., Challinor et al. 2010).

Synthesis of case studies

While individual case studies vary in terms of their focus and scope, two cases illustrate how our understanding of vulnerability analysis can be enriched by comparing different sites. In a case study of dryland communities in the Elqui Valley of Chile using mixed-methods approach, Young et al. (2009) found that the inter-annual variability in precipitation and availability of water resources were the main biophysical challenges to agricultural stability and the most influential factors for adaptive capacity include infrastructure, economic wealth, and familial relationships. By contrast, a case in southeastern Arizona, a semi-arid region found that variable precipitation is a key factor in agricultural vulnerability (Vasquez-Leon 2009). Farming in this region occurs at a much larger scale than in Chile's Equi Valley, and the author shows that technological and infrastructure advances have protected some farmers from climatic variability. However, by exploring social capital, Vasquez-Leon (2009) shows that Hispanic farmers and farmworkers

are more vulnerable than Anglo-American farmers. With the availability of advanced farming techniques, the author shows that it is the socio-cultural fabric of southern Arizona that accounts for the variations of vulnerability. By comparing these two cases, we can better understand commonalities (e.g., the importance of infrastructure and institutional support for adapting to variable precipitation), as well as discrepancies (e.g., the role of social stratification and marginalization in reducing adaptive capacity). It is by synthesizing the findings of multiple case studies, rather than attempting to extrapolate findings from a few, that broader conclusions regarding vulnerability may be revealed (Rudel 2008).

CLIMATE CHANGE IMPACTS TO AGRICULTURE

The most recent report from the Intergovernmental Panel on Climate Change (IPCC) identifies 10 phenomena that are occurring or will occur from increased levels of greenhouse gas (GHG) emissions in the atmosphere and increased global temperatures: warming trends, extreme temperatures, drying trends, extreme precipitation, precipitation, snow cover, damaging cyclones, sea level rise, ocean acidification, and carbon dioxide fertilization (2014b). These changes have the potential to impact the lives of people around the world in many ways, including land loss, damaged and destroyed homes, and strained resources for basic necessities. Of the ten climate-related drivers of impacts identified by the IPCC in their most recent report, seven will directly impact farmers' ability to produce food for their families, communities, and the global marketplace.

SECTION 3

METHODS

CASE STUDY SELECTION CRITERIA

In order to refine the collection of case studies for the synthesis, a rigorous set of criteria were used to select relevant studies, including: those focused on climate change, agriculture and vulnerability; published after 2001; and peer-reviewed. First, case studies were required to focus on climate change explicitly, rather than tangentially. Second, the case studies all addressed different kinds of terrestrial agricultural production (for a list of agriculture types, see Appendix). Third, case studies addressed vulnerability, defined as a combination of sensitivities, exposures and adaptive capacity. Many studies examined biophysical and socioeconomic sensitivities related to climate change; in order for them to be included in the synthesis, they were also required to address adaptation or adaptive capacity in some form. In addition to the thematic criteria, only case studies published in 2001 and thereafter were included. In 2001, the IPCC in their third Assessment Report changed their Working Group II title to include vulnerability ("*Vulnerability, consequences, and options*") – a shift that reflects the emergence of vulnerability as a crucial component of climate change assessment. Finally, case studies were retrieved through a Web of Science search in order to limit the collection to peer-reviewed articles. The studies were retrieved from the online Thomson Reuters Web of Science Core Collection during June and July of 2014, using the following search terms: "climate change AND agriculture AND vulnerability AND case study" and further refined using the above mentioned criteria. While there is ample information in unpublished studies, grey literature, and studies published outside of peer-reviewed journals, these sources were not included in the synthesis in order to maintain the highest level of confidence in the analysis. This set of criteria yielded 45 journal articles with a total of 52 individual case studies. The collection of case studies had some limitations: it was limited to peer-reviewed journal articles and only included English language

publications. Moreover, books and book chapters were not included as they are not part of the Web of Science database. Future syntheses could provide a more comprehensive picture by including some of these sources (Janssen et al. 2006).

DATA COLLECTION AND ANALYSIS

Each article was evaluated, coded, and documented in a database. First, the following basic information was recorded for each study (for examples, see Table 1):

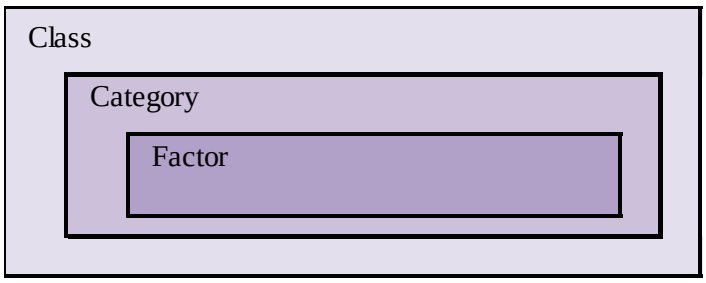
- Article title
- Author
- Date of publication
- Location/region of study
- Type of agriculture
- Climate (as identified by authors)
- Key words
- Methods (quantitative, qualitative, or mixed)

For articles that included more than one case study location, each site was counted separately. For example, in Campos et al. (2013), the authors compared perceptions and adaptations to climate change in rural communities in both Mexico and Spain. In this scenario, Ichamio, Mexico and Montlús, Spain were considered separate records.

Recording factors that influence variability: exposure and sensitivity & adaptive capacity

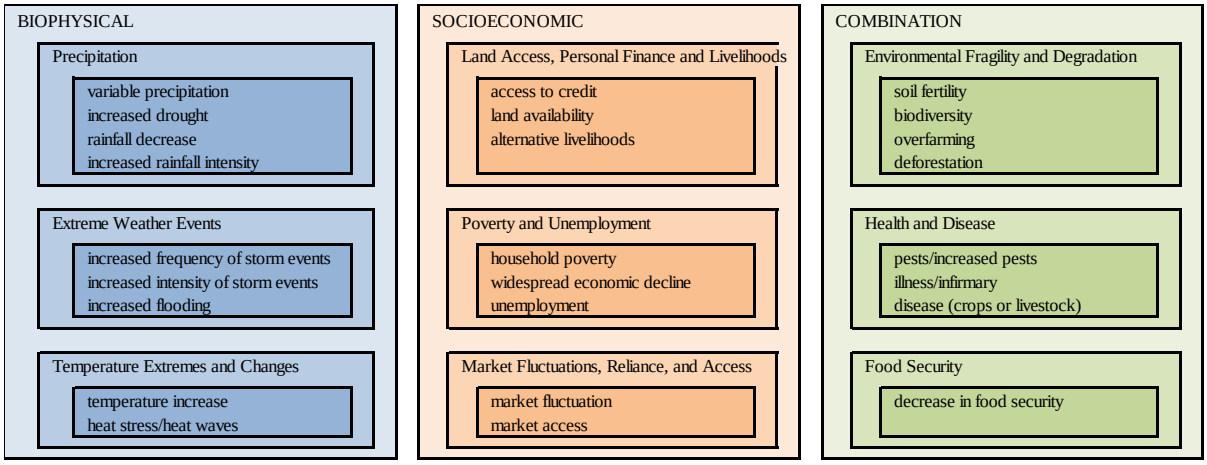
Vulnerability factors for each case study were categorized according to whether their focus was on biophysical, socioeconomic, or a combination of factors (referred to as class), then further sub-divided into categories (Figure 2).

Figure 2: Diagram of relationships between class, category, and factor



Each study was first evaluated for information related to the first sub-question: *What kinds of exposures or sensitivities to climate change are identified in the vulnerability case studies?* Exposure and sensitivity factors were recorded for presence in the study, grouped into categories, and assigned a class – biophysical, socioeconomic, or combination (Figure 3). Exposures or sensitivities that had both biophysical and socioeconomic elements were categorized as combination in order to account for factors such as food insecurity, declining soil fertility, and reduced biodiversity where the biophysical aspects are inextricable from the socioeconomic components. For example, Esham & Garforth (2013) identified sensitivities, including lack of irrigation water and rainfall variability, as well as cost of production, fertilizer prices, and market access. In this example, water scarcity and rainfall variability were recorded as biophysical factors (water and precipitation); lack of irrigation, cost of production, fertilizer prices, and market access were recorded as socioeconomic factors. Similarly, each study was evaluated for information related to the second sub-question: *What factors that impact adaptive capacity are identified in the vulnerability case studies?* Again, these data were recorded for presence in the study, grouped into categories, and codified by class: biophysical, socioeconomic, or combination. Factors that influence adaptive capacity included those related to individuals (e.g., social class/caste, gender, education levels) and systems (e.g., regional conflicts, government incentives). Together, exposure and sensitivity factors and adaptive capacity factors were aggregated to quantify which factors were identified most frequently in determining agricultural vulnerability to climate change.

Figure 3: Examples of Classes, Categories, and Factors



Recording responses to vulnerability: adaptive measures

Additionally, I identified and recorded any adaptation measures that were mentioned in the case studies. Each adaptive measure was divided into groups based on purpose, scale and degree of planning. Some examples of adaptation measures include crop management, such as shifted or shortened growing seasons or species; varietal substitution, such as changing the type of crop or changing to resilient crop varieties; income diversification, such as ecotourism; or internal or transnational migration.

CHARACTERISTICS OF THE CASE STUDIES

The case studies included in the study draw from across the globe. Notably, there were clusters in Central America (Guatemala and Honduras) and South Asia (especially Nepal, India and Bangladesh). Mexico boasted the highest number of cases, with six studies. The 52 cases include 15 quantitative studies, 18 qualitative studies, and 19 mixed methods studies.

Table 1: Number of Case Studies per Region of Study

Region	Studies
Africa	11
Asia	12
Europe	5
Latin America	15
North America	6
Oceania	3
Total	52

Figure 4: Case Study Locations

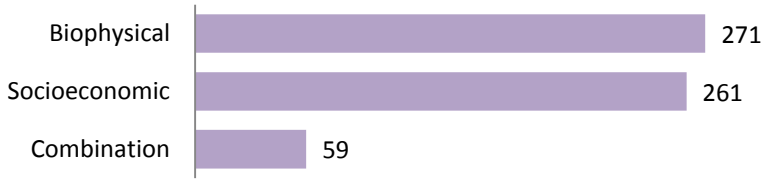
SECTION 4

SYNTHESIS RESULTS

VULNERABILITY ASSESSMENT

In order to assess vulnerability factors that affect farmers, communities and agricultural systems holistically, all of the identified factors were aggregated. Since the case studies were often imprecise in categorizing vulnerability factors into the main components of vulnerability (exposure and sensitivity and adaptive capacity), a combination of all identified vulnerability factors were assessed to compare them by class before separating them out into the vulnerability components. Biophysical factors and socioeconomic factors were cited in the case studies with nearly equivalent frequency (44.2% for socioeconomic factors compared to 45.9% for biophysical factors; Figure 5).

Figure 5: Vulnerability by Class (Biophysical, Socioeconomic or Combination)



When all vulnerability factors were aggregated, the most common category was Precipitation – identified in the case studies on 117 occasions. Precipitation was identified over twice as many times as each of the next most common categories: Extreme Weather Events (56) and Land Access, Personal Finance and Livelihoods (52). Water quality and availability are clearly important limiting factors for agriculture, and together, Precipitation and Water Stress and Scarcity account for 27% of all factors identified in the 52 studies. The Precipitation category included factors such as rainfall increase, decrease and variability, while Water Stress and Scarcity included general water stress, surface and groundwater scarcity, salinity,

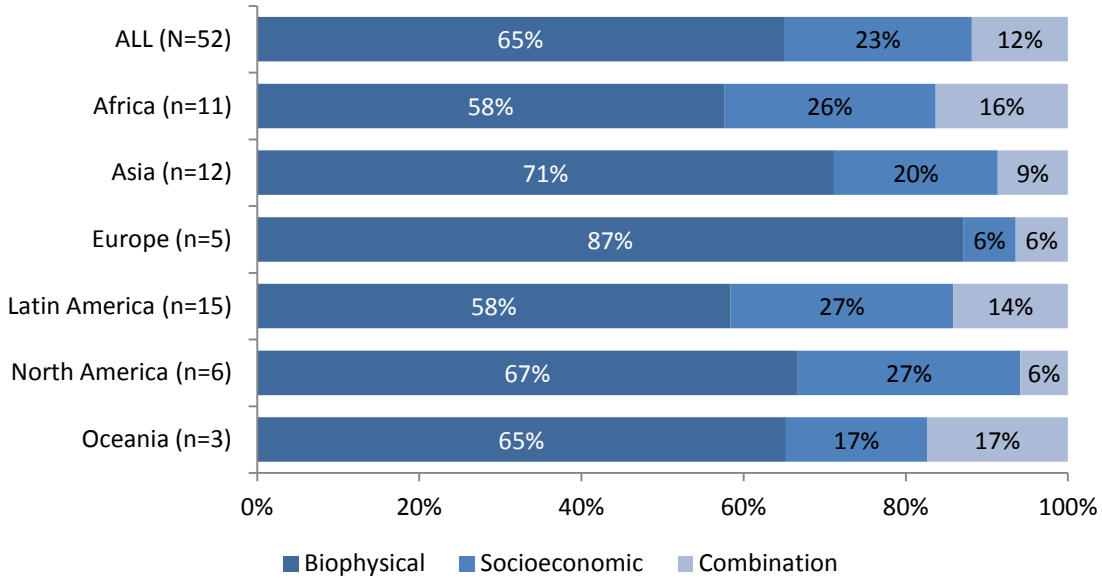
and water pollution. By comparison, Agriculture Policy, Governmental Support and Stability; Social Status and Social Networks; Education Levels and Technical Knowledge; Infrastructure Access, Availability and Quality; Health and Disease; Food Security; and Geographic Land Constraints *combined* account for the same percentage (27%) of factors identified in the studies. Across the 52 case studies, the ten most frequently identified factors associated with vulnerability in agriculture were:

1. Variable Precipitation
2. Drought Conditions/Increased Drought
3. Temperature Increase
4. Rainfall Decrease
5. Poverty/Financial Resources
6. Increased Rainfall Intensity
7. Access To Credit
8. Increased Frequency Storm Events
9. Market Fluctuations/Low Prices
10. Acute/Household Poverty

Exposure and Sensitivity

Although biophysical and socioeconomic factors were identified with equal frequency when all vulnerability factors were combined, when vulnerability is separated into its two component parts – exposure/sensitivity and adaptive capacity – the pattern is different. The majority of agricultural exposures and sensitivities identified in the studies were biophysical (65.0%; Figure 6). This pattern was consistent across all of the study regions, with only 6-27% of identified factors being categorized as socioeconomic factors (Figure 6).

Figure 6: Exposure and Sensitivity by Class (Biophysical, Socioeconomic or Combination) by Region



When the broad classes of exposures and sensitivities were broken down into categories, the most commonly identified categories were Precipitation; Extreme Weather Events; and Temperature Extremes and Changes (Table 2). Precipitation factors included: variable precipitation, drought conditions or increased drought, increase in rainfall intensity, rainfall decrease, low average rainfall, and hail storms. Overall, Precipitation factors appeared over twice as many times as the next category (Table 2). Variable precipitation alone—included in the Precipitation category—was identified in nearly two thirds of the case studies.

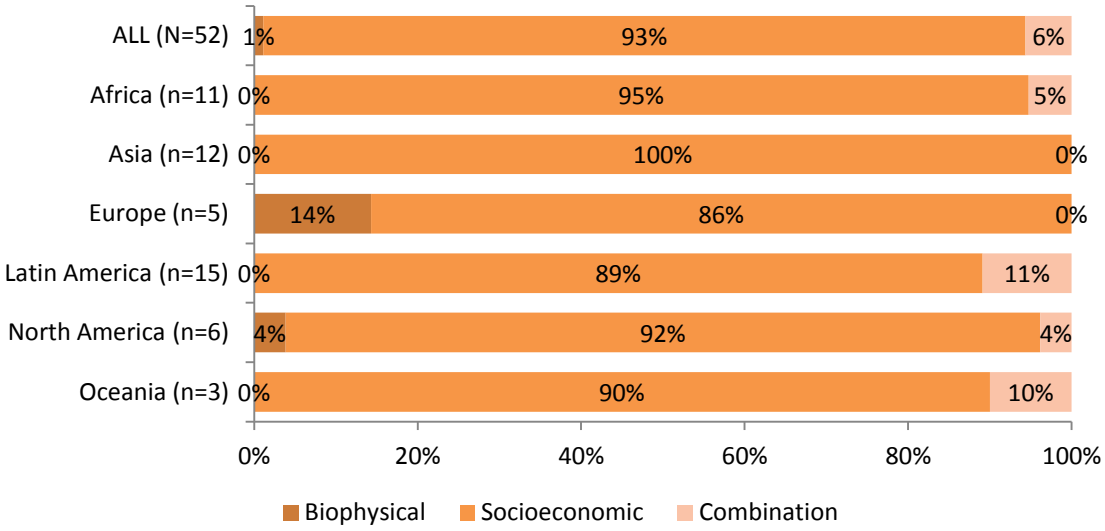
Table 2: Categories of Exposure and Sensitivity Identified in the Case Studies

Categories of Exposure & Sensitivity	Count
Precipitation	117
Extreme weather events	56
Temperature extremes and changes	51
Water stress and scarcity	41
Environmental fragility and degradation	28
Market fluctuations, reliance and access	25
Poverty and unemployment	24
Health and disease	16
Population change and demographics	16
Agriculture policy, governmental support, and stability	9
Land access, personal finance, and livelihoods	9
Infrastructure access, availability and quality	8
Food security	6
Education levels and technical knowledge	4
Geographic land constraints	2
Social status and social networks	2

Adaptive Capacity

While most of the agricultural exposures and sensitivities identified were biophysical, the opposite was true for factors influencing adaptive capacity, where there was an overwhelming emphasis on socioeconomic factors. In fact, 93.2% of the factors identified were socioeconomic (Figure 7), and this was consistent across regions. In case studies from the Asia region, there were no biophysical or combined adaptive capacity factors identified at all, while in other regions such as Latin America and Africa there were no biophysical factors identified and 5-11% of factors were combined socioeconomic and biophysical. The one exception to this pattern was Europe, where 14% of the factors identified as influencing adaptive capacity in agriculture were biophysical.

Figure 7: Adaptive Capacity by Class (Biophysical, Socioeconomic or Combination) by Region



Note: For a complete list of Adaptive Capacity factors, see Table 3.

When the three broad classes of adaptive capacity (biophysical, socioeconomic, and combination) were broken down into categories, the most commonly identified categories affecting adaptive capacity were Land Access, Personal Finance and Livelihoods; Social Status and Social Networks; and Agriculture Policy, Government Support and Stability (Table 3). Land Access, Personal Finance and Livelihoods included factors such as access to credit, farm holding size and land availability, and alternative livelihoods. For many factors, access was the key aspect; for example, access to capital, markets, credit, irrigation, and social networks were all recognized as influencing adaptive capacity.

Table 3: Adaptive Capacity Factors Identified in the Case Studies

Land Access, Personal Finance and Livelihoods	**43**
access to credit	16
access to land/farm holding size	9
access to financial insurance	5
alternative livelihoods	5
high input costs (to diversify)	3
debt/indebtedness	2
delayed return on investment	2
land tenure	1
Ag Policy, Governmental Support and Stability	**25**
government safety nets/institutional support	9
local/regional government collaboration or support	5
government incentivized monoculture	2
government policy interventions against trade adaptation	2
inappropriate adaptations promoted by local gov't	2
institutional barriers to alternative crops	2
adaptation tradeoffs	1
financial incentives	1
regional/civil conflicts	1
Social Status and Social Networks	**25**
lack of access to social networks/capital	13
resistance to change/"tradition"	4
discrimination	3
being "marginalized"	2
caste/class (lower)	2
low perception of adaptation effectiveness	1

Education levels and technical knowledge	**19**
lack of public awareness/perception of cc	10
high illiteracy rates/lack of education	6
lack of technical knowledge	3
Population Change and Demographics	**19**
gender (woman)	8
age of farmers (advanced)	5
high dependency ratio	3
household size (small)	1
labor-intensive adaptation methods (advanced age)	1
small town/village	1
Poverty and Unemployment	**18**
poverty/access to capital	18
Infrastructure Access, Availability and Quality	**11**
lack of access to irrigation	7
lack of roads/transportation infrastructure	4
Environmental fragility and degradation	**8**
poor soil/soil degradation	4
diversity in agro-ecosystem	2
reliance on rainwater	2
Market fluctuations, reliance and access	**5**
market access/reliance on intermediaries to sell crop	3
market fluctuations/low prices	2
Health and disease	**2**
malnutrition	1
poor health	1
Geographic land constraints	**2**
fields in flood basins	1
steep slope of arable land	1

ADAPTIVE MEASURES

While the studies evaluated identified 44 factors that influence the ability to adapt to climate change, they also identified specific measures that could be implemented to mitigate or respond to climate change effects on agriculture. For farmers, farming communities and agriculture systems, adaptive measures are adopted to address and combat the many aspects of vulnerability. The measures identified across the studies were wide ranging, differing in purpose, scale (individual/household or institutional/public), and degree of planning (planned/anticipatory or reactionary). Adaptive measures were categorized as primarily addressing vulnerabilities that were biophysical, socioeconomic, or both. When divided this way, 42% of adaptive measures focused on tools and techniques to help farmers mitigate for biophysical factors such as a variable and changing climate; 33% explicitly addressed underlying socioeconomic factors that increase vulnerability, and 26% of the adaptive measures addressed factors that could be categorized as both biophysical and socioeconomic. In the case studies, the most frequently cited category of adaptive measure was Crop Management, followed by Varietal Substitution and Institutional Support. Crop Management included techniques such as changing planting and harvesting times; crop rotations and cropping pattern migration; and agroforestry. Varietal Substitution included diversifying crop varieties; adopting heat or drought resistant varieties; and planting different crops. The case studies also identified various types of Institutional Support, including outreach programs and research; poverty alleviation programs; and subsidized fertilizer.

When separated by scale, institutional or public adaptations (such as poverty alleviation programs or information dissemination to farmers) comprised 35 of the different individual adaptive measures identified and 36% of all adaptive measures suggested or observed in the studies. By contrast, individual or household-level adaptations (such as reducing household expenditures or increasing fertilizer use) comprised 39 of the 74 kinds of measures identified and over 64% of all the measures suggested or observed in the studies. Divided into planned or reactionary, the majority of the adaptive measures identified in the case studies were planned adaptations (57 out of 74), such as capacity building and shifted harvesting times. Among those planned adaptations, the percentage that focused on addressing biophysical impacts increased to 53%, compared to just 22% that focused on addressing socioeconomic impacts. Across all 52 case studies, the most frequently observed

or suggested adaptation measures largely addressed biophysical vulnerability factors (Table 4).

Table 4: Most Frequently Identified Adaptation Measures

Adaptation Measure	Count	Class of Vulnerability Addressed
Diversify Crop Variety (Same Crops)	17	Biophysical
Irrigation	15	Biophysical
Change Planting/Harvest Dates/Times	12	Both
Internal Migration	11	Socioeconomic
Heat/Drought Resistant Crops/Varieties	11	Biophysical
Different Types of Farming (e.g., livestock, cash crops)	10	Both
Migration Of Cropping Patterns/Crop Rotations	9	Biophysical
Agrobiodiversity/Diversify Crop Type (different crops)	9	Biophysical
Water Conservation Measures	8	Biophysical
Agroforestry	8	Biophysical

SECTION 5

DISCUSSION

Returning to the final research question: *How does vulnerability analysis inform pathways to adaptation?*, this synthesis shows that the factors identified as contributing to vulnerability in the case studies influence the types of adaptation measures proposed and adopted by affected communities. Determining what class of vulnerability (biophysical, socioeconomic or combination) an adaptation measure was designed to address was complicated, as measures often addressed multiple vulnerabilities. Furthermore, reinforcing an artificial demarcation between biological and economic, social or cultural factors can be problematic as it obscures their interconnectedness (Speed Rossiter et al. 2015). However, many case studies included in this synthesis reinforced these norms in the way that factors were addressed, and in observed and suggested adaptation measures.

Socioeconomic Vulnerability Factors and Biophysical Adaptive Measures

There is widespread recognition in climate change literature that vulnerability is a combination of exposures, sensitivities and adaptive capacity (W. N. Adger 2006; W. N. Adger and Kelly 1999; Smit and Wandel 2006). In this synthesis, the studies used similar definitions, but in practice, exposures and sensitivities dominated, both in terms of the total number of factors identified and, more importantly, the frequency with which they were identified. Furthermore, while vulnerability has been adopted widely as a measure of climate change impacts (McCarthy, Intergovernmental Panel on Climate Change, and Working Group II 2001) and it is defined as a combination of physical, geographic, economic, social, political and cultural factors (Alwang, Siegel, and Jorgensen 2001; Blaikie et al. 1994)—or more broadly, biophysical and socioeconomic factors—this analysis illustrates that the case

studies focus much more heavily on the biophysical factors, leaving understandings of the socioeconomic aspects of vulnerability less well documented.

These findings support similar ideas put forth in several articles that highlight the prevalence of biophysical impact-based studies in the climate change literature. Despite long-held recognition of the importance of social structures in the analysis of vulnerability (Dreze and Sen 1991; Watts 1983), the focus on biophysical factors persists. O'Brien et al. (2007) characterize the division in vulnerability frameworks in context of outcome vulnerability and contextual vulnerability, where the former refers to a 'scientific framing' and the later 'human-security framing'. They argue that the human-security framing has been underrepresented in scholarship and policy and that additional attention to contextual vulnerability would "broaden the scope of adaptation policies" (O'Brien et al. 2007, 73). Through a content analysis of four major climate change journals, Bassett and Fogelman (2013) found that a mere 3% of climate change adaptation articles focus on the underlying socioeconomic factors of vulnerability. Sugden et al. (2014) initiated their agricultural vulnerability case study[1] on the premise that the political economic approach to vulnerability has been sidelined in favor of biophysical impacts. In their analysis, they consider climatic changes alongside other stresses to agriculture, including political-economic processes and the intersections between gender, caste and socio-economic status, concluding that adaptive measures proposed in both international and national levels focus on "technocratic interventions to respond to the proximate causes of vulnerability" (Sugden et al. 2014, 268). The findings from this synthesis support these works, and suggest that addressing climate change vulnerability in policy and scholarship should go beyond adaptive measures intended to address only biophysical impacts, to also consider ways to expand access to financial, technical and social resources.

Focus on Easily Measurable Variables and Poverty

Of the 116 vulnerability factors identified in this synthesis, easily measureable variables were among the most frequent. In fact, six out of the top ten related to precipitation and temperature. This finding is unsurprising, as a) precipitation and temperature are limiting

[1] The Sugden et al. article was published after the data collection period and therefore was not included in the synthesis results.

factors in most types of agricultural yield and, b) there is ample evidence that global climate change is leading to changes for both (IPCC 2014b; World Bank 2012). As much as 30% of year-to-year variations in global average crop yields can be attributed to precipitation and growing season temperatures (David B Lobell and Field 2007). Poverty, income levels and market fluctuations also featured prominently in the synthesis. This finding is also unsurprising, given that across disciplines—such as economics, environmental science, risk/disaster management, public health, and others—poverty is considered a major source of vulnerability (Alwang, Siegel, and Jorgensen 2001). These factors additionally work synergistically because of the large role agriculture plays in low-income countries, where fluctuations in both the climate and market contribute to income variations and poverty (Morduch 1994). All other things being equal, in regions and countries where agriculture is central to GDP, the impacts of climate change will be more acute (Füssel 2012).

While some climate data may be readily available, data on social variables can remain more elusive. For instance, data on social networks and perceptions of climate change require qualitative data collection, which can prove logistically difficult or beyond the scope of many studies. In this synthesis, there were several factors that occurred less frequently, but were pivotal to the studies that included them. For example, in 13 out of the 52 studies, social capital, or access to social networks, was identified as influencing adaptive capacity. The majority of case studies that identified social capital and access to social networks acknowledged these factors as being *crucial* in determining vulnerability (Gilbert and McLeman 2010; Jones and Boyd 2011; Westerhoff and Smit 2009). Metrics and data collection methods for measuring social capital have been developed and used in environmental management, but were largely missing from this collection of studies (Carpenter, Daniere, and Takahashi 2004a; Carpenter, Daniere, and Takahashi 2004b). Similarly, perceptions of risk and awareness of climate change appeared in only 10 of the 52 case studies, but in over half of those cases, it was considered to be the most important factor (Kerry et al. 2012; Li et al. 2013; Mallick et al. 2005; Tucker, Eakin, and Castellanos 2010). Given the importance of social networks and perceptions of risk in these studies, it is possible that they were similarly important in other places, but neglected in the analysis. Likewise, Pittman et al. (2011) suggest that despite findings that technical adoptions are constrained by social context, many impact-based studies continue to emphasize technical adaptations. In

efforts to inform pathways to adaptation, neglecting to include vital factors in vulnerability analysis can lead to adaptation suggestions that only address vulnerability factors that are easily measured.

Consistent Patterns Across Regions

Literature on global climate change frequently points to variability across regions and locations, as stressors and change are geographically disparate (IPCC 2014a; P. Jones and Thornton 2003; Schaap et al. 2011). However, this analysis suggests that the literature may not be capturing these differences, as the case studies are relatively consistent across regions, with regards to the emphasis on biophysical exposure, sensitivity, and socioeconomic adaptive capacity. For both exposure and sensitivity factors and adaptive capacity factors, European case studies in this synthesis identified only a slightly higher percentage of biophysical factors than the rest of the world. This indicates the relatively higher importance of biophysical factors over socioeconomic factors for European agricultural systems, but the pattern is not significantly different than other regions. Research suggests, however, that Europe is not as vulnerable to climate change, especially compared to Asia, Africa and Latin America (P. Jones and Thornton 2003). Studies suggest European agricultural yield will continue to exceed demand for food, largely due to anticipated technological advancements (e.g., Ewert et al. 2005). The relatively consistent findings indicate vulnerability studies may be underreporting socioeconomic factors.

SECTION 6

CONCLUSION

Since increases in agricultural vulnerability to climate change are imminent and the consequences are significant, there is an urgent need to consider the many ways that climatic change could impact communities and to share effective strategies for adapting to those changes. Vulnerability provides an ideal framework with which to assess impacts to agriculture by considering a combination of exposures, sensitivities and adaptive capacity. Case studies that focus on both experienced and anticipated climatic change, as well as adaptive measures and factors that influence adaptive capacity, are useful for communities and institutions as they develop pathways to adaptation.

This synthesis of the vulnerability factors identified in 52 case studies considered a wide variety of studies and a breadth of study types, identifying patterns that were consistent across regions. Notably, exposure and sensitivity factors made up the bulk of factors identified in the case studies, a finding that is likely linked to how factors are expressed and described semantically. However, the overemphasis on exposure and sensitivity factors could be problematic when looked at concurrently with the distribution of classes of vulnerability (biophysical, socioeconomic and combination) as they were overwhelmingly biophysical. The emphasis on exposures and sensitivities, especially easily quantifiable variables, leads to a possible overemphasis on adaptation measures that address biophysical impacts rather than socioeconomic ones.

Recommendations for Policy and Scholarship

Identifying pathways to adaptation is an increasingly important objective in policy and scholarship. Vulnerability analyses shape pathways to adaptation by identifying exposure, sensitivity and adaptive capacity factors, as well as adaptive measures. Moving forward, however, additional steps can be taken to support further vulnerability studies that

explicitly include socioeconomic aspects, in addition to the many that focus on biophysical impact factors. For findings from these kinds of studies to be useful for society, in policy and otherwise, taking societal situations into account is crucial ("Time for the Social Sciences" 2014). While biophysical impact-based case studies are essential, considering socioeconomic aspects of vulnerability is equally vital in order to fully inform pathways to adaptation.

REFERENCES

Adejuwon, James. 2005. "Assessing the Suitability of the EPIC Crop Model for Use in the Study of Impacts of Climate Variability and Climate Change in West Africa." *Singapore Journal of Tropical Geography* 26 (1): 44–60.

Adger, N., S. Khan, and N. Brooks. 2003. *Measuring and Enhancing Adaptive Capacity*. UNDP. http://www.undp.org/cc/apf-outline.htm.

Adger, W. Neil. 2006. "Vulnerability." *Global Environmental Change* 16 (3): 268–81. doi:10.1016/j.gloenvcha.2006.02.006.

Adger, W. Neil, and P. Mick Kelly. 1999. "Social Vulnerability to Climate Change and the Architecture of Entitlements." *Mitigation and Adaptation Strategies for Global Change* 4 (3-4): 253–66.

Ahmed, Syud Amer, Noah S. Diffenbaugh, Thomas W. Hertel, David B. Lobell, Navin Ramankutty, Ana R. Rios, and Pedram Rowhani. 2011. "Climate Volatility and Poverty Vulnerability in Tanzania." *Global Environmental Change* 21 (1): 46–55. doi:10.1016/j.gloenvcha.2010.10.003.

Alwang, Jeffrey, Paul B. Siegel, and Steen L. Jorgensen. 2001. *Vulnerability: A View from Different Disciplines*. Social protection discussion paper series.

Barnwal, Prabhat, and Koji Kotani. 2013. "Climatic Impacts across Agricultural Crop Yield Distributions: An Application of Quantile Regression on Rice Crops in Andhra Pradesh, India." *Ecological Economics* 87 (March): 95–109. doi:10.1016/j.ecolecon.2012.11.024.

Bassett, Thomas J., and Charles Fogelman. 2013. "Déjà vu or Something New? The Adaptation Concept in the Climate Change Literature." *Geoforum* 48 (August): 42–53. doi:10.1016/j.geoforum.2013.04.010.

Blaikie, P., Terry Cannon, I. Davis, and B. Winser. 1994. *At Risk: Natural Hazards, People's Vulnerability and Disasters*. London: Routledge.

Campos, Minerva, Doribel Herrador, Carlos Manuel, and Michael K. McCall. 2013. "Adaptation Strategies to Climate Change in Two Rural Communities in Mexico and El Salvador." *Boletín De La Asociación De Geógrafos Españoles* 61: 433–36.

Cannon, Terry, John Twigg, and Jennifer Rowell. 2003. *Social Vulnerability, Sustainable Livelihoods and Disasters*. University of Greenwich, Chatham: DFID Conflict and Humanitarian Assistance Department (CHAD) and Sustainable Livelihoods Support Office, Natural Resources Institute.

Carpenter, Jeffrey P., Amrita G. Daniere, and Lois M. Takahashi. 2004a. "Cooperation, Trust, and Social Capital in Southeast Asian Urban Slums." *Journal of Economic Behavior & Organization* 55 (4): 533–51.

———. 2004b. "Social Capital and Trust in South-East Asian Cities." *Urban Studies* 41 (4): 853–74.

Challinor, Andrew J, Elisabeth S Simelton, Evan D G Fraser, Debbie Hemming, and Mathew Collins. 2010. "Increased Crop Failure due to Climate Change: Assessing Adaptation Options Using Models and Socio-Economic Data for Wheat in China." *Environmental Research Letters* 5 (3): 034012. doi:10.1088/1748-9326/5/3/034012.

Cuesta, Michael A., and Roberto F. Ranola Jr. 2009. "Adaptive Capacity of Rice Farmers to Rainfall Variability and Extremes in the Province of Camarines Sur, Philippines." *PHILIPPINE AGRICULTURAL SCIENTIST* 92 (4): 419–30.

Dow, Kristin. 1992. “Exploring Differences in Our Common Future(s): The Meaning of Vulnerability to Global Environmental Change.” *Geoforum* 23 (3): 417–36.

Downing, Thomas E., J. Aerts, J. Soussan, O. Barthelemy, S. Bharwani, C. Ionescu, J. Hinkle, et al. 2006. *Integrating Social Vulnerability into Water Management*. SEI Working Paper and Newater Working Paper No. 4. Oxford: Stockholm Environment Institute.

Dreze, Jean, and Amartya K. Sen. 1991. *Hunger and Public Action*. Oxford Clarendon.

Eakin, Hallie, and Kirsten Appendini. 2008. “Livelihood Change, Farming, and Managing Flood Risk in the Lerma Valley, Mexico.” *Agriculture and Human Values* 25 (4): 555–66. doi:10.1007/s10460-008-9140-2.

Esham, Mohamed, and Chris Garforth. 2013. “Agricultural Adaptation to Climate Change: Insights from a Farming Community in Sri Lanka.” *Mitigation and Adaptation Strategies for Global Change* 18 (5): 535–49. doi:10.1007/s11027-012-9374-6.

Ewert, F., M.D.A. Rounsevell, I. Reginster, M.J. Metzger, and R. Leemans. 2005. “Future Scenarios of European Agricultural Land Use.” *Agriculture, Ecosystems & Environment* 107 (2-3): 101–16. doi:10.1016/j.agee.2004.12.003.

Füssel, Hans-Martin. 2012. “Vulnerability to Climate Change and Poverty.” In *Climate Change, Justice and Sustainability*, edited by Ottmar Edenhofer, Johannes Wallacher, Hermann Lotze-Campen, Michael Reder, Brigitte Knopf, and Johannes Müller, 9–17. Dordrecht: Springer Netherlands. http://www.springerlink.com/index/10.1007/978-94-007-4540-7_2.

Hertel, Thomas W., Marshall B. Burke, and David B. Lobell. 2010. “The Poverty Implications of Climate-Induced Crop Yield Changes by 2030.” *Global Environmental Change* 20 (4): 577–85. doi:10.1016/j.gloenvcha.2010.07.001.

Hsiang, S. M., M. Burke, and E. Miguel. 2013. “Quantifying the Influence of Climate on Human Conflict.” *Science* 341 (6151): 1235367–1235367. doi:10.1126/science.1235367.

IPCC. 2014a. *Climate Change 2014: Impacts, Adaptation, and Vulnerability - SUMMARY FOR POLICYMAKERS*. http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf.

———. 2014b. *IPCC Fifth Assessment Synthesis Report*. V. http://ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_LONGERREPORT.pdf.

Jackson, L. E., S. M. Wheeler, A. D. Hollander, A. T. O’Geen, B. S. Orlove, J. Six, D. A. Sumner, et al. 2011. “Case Study on Potential Agricultural Responses to Climate Change in a California Landscape.” *Climatic Change* 109 (S1): 407–27. doi:10.1007/s10584-011-0306-3.

Janssen, Marco A., Michael L. Schoon, Weimao Ke, and Katy Börner. 2006. “Scholarly Networks on Resilience, Vulnerability and Adaptation within the Human Dimensions of Global Environmental Change.” *Global Environmental Change* 16 (3): 240–52. doi:10.1016/j.gloenvcha.2006.04.001.

Jones, Lindsey, and Emily Boyd. 2011. “Exploring Social Barriers to Adaptation: Insights from Western Nepal.” *Global Environmental Change* 21 (4): 1262–74. doi:10.1016/j.gloenvcha.2011.06.002.

Jones, P, and P Thornton. 2003. “The Potential Impacts of Climate Change on Maize Production in Africa and Latin America in 2055.” *Global Environmental Change* 13 (1): 51–59. doi:10.1016/S0959-3780(02)00090-0.

Lobell, David B, and Christopher B Field. 2007. “Global Scale Climate–crop Yield Relationships and the Impacts of Recent Warming.” *Environmental Research Letters* 2 (1): 014002. doi:10.1088/1748-9326/2/1/014002.

Lobell, D. B., M. B. Burke, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon, and R. L. Naylor. 2008. “Prioritizing Climate Change Adaptation Needs for Food Security in 2030.” *Science* 319 (5863): 607–10. doi:10.1126/science.1152339.

Magombeyi, Manuel S., and Akpofure E. Taigbenu. 2008. “Crop Yield Risk Analysis and Mitigation of Smallholder Farmers at Quaternary Catchment Level: Case Study of B72A in Olifants River Basin, South Africa.” *Physics and Chemistry of the Earth, Parts A/B/C* 33 (8-13): 744–56. doi:10.1016/j.pce.2008.06.050.

McCarthy, James J, Intergovernmental Panel on Climate Change, and Working Group II. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge, U.K.; New York: Cambridge University Press for the Intergovernmental Panel on Climate Change.

Mechler, Reinhard, Stefan Hochrainer, Asbjørn Aaheim, Håkon Salen, and Anita Wreford. 2010. “Modelling Economic Impacts and Adaptation to Extreme Events: Insights from European Case Studies.” *Mitigation and Adaptation Strategies for Global Change* 15 (7): 737–62. doi:10.1007/s11027-010-9249-7.

Morduch, Jonathan. 1994. “Poverty and Vulnerability.” In *Papers and Proceedings of the Hundred and Sixth Annual Meeting of the American Economic Association*, 84:221–25. 2. American Economic Association.

O’Brien, Karen, Siri Eriksen, Lynn P. Nygaard, and Ane Schjolden. 2007. “Why Different Interpretations of Vulnerability Matter in Climate Change Discourses.” *Climate Policy* 7 (1): 73–88. doi:10.1080/14693062.2007.9685639.

Parry, M.L, C Rosenzweig, A Iglesias, M Livermore, and G Fischer. 2004. “Effects of Climate Change on Global Food Production under SRES Emissions and Socio-Economic Scenarios.” *Global Environmental Change* 14 (1): 53–67. doi:10.1016/j.gloenvcha.2003.10.008.

Pittman, Jeremy, Virginia Wittrock, Surendra Kulshreshtha, and Elaine Wheaton. 2011. “Vulnerability to Climate Change in Rural Saskatchewan: Case Study of the Rural Municipality of Rudy No. 284.” *Journal of Rural Studies* 27 (1): 83–94. doi:10.1016/j.jrurstud.2010.07.004.

Rudel, Thomas K. 2008. “Meta-Analyses of Case Studies: A Method for Studying Regional and Global Environmental Change.” *Global Environmental Change* 18 (1): 18–25. doi:10.1016/j.gloenvcha.2007.06.001.

Schaap, Ben F., Margaretha Blom-Zandstra, Christiane M. L. Hermans, Bastiaan G. Meerburg, and Jan Verhagen. 2011. “Impact Changes of Climatic Extremes on Arable Farming in the North of the Netherlands.” *Regional Environmental Change* 11 (3): 731–41. doi:10.1007/s10113-011-0205-1.

Smit, Barry, and Johanna Wandel. 2006. “Adaptation, Adaptive Capacity and Vulnerability.” *Global Environmental Change* 16 (3): 282–92. doi:10.1016/j.gloenvcha.2006.03.008.

Speed Rossiter, Jaime, Giorgio Hadi Curti, Christopher M. Moreno, and David Lopéz-Carr. 2015. “Marine-Space Assemblages: Towards a Different Praxis of Fisheries Policy and Management.” *Applied Geography*, January. doi:10.1016/j.apgeog.2014.12.015.

Sugden, Fraser, Niki Maskey, Floriane Clement, Vidya Ramesh, Anil Philip, and Ashok Rai. 2014. “Agrarian Stress and Climate Change in the Eastern Gangetic Plains: Gendered

Vulnerability in a Stratified Social Formation." *Global Environmental Change* 29 (November): 258–69. doi:10.1016/j.gloenvcha.2014.10.008.

"Time for the Social Sciences." 2014. *Nature* 517 (7532): 5–5. doi:10.1038/517005a.

Vasquez-Leon, Marcela. 2009. "Hispanic Farmers and Farmworkers: Social Networks, Institutional Exclusion, and Climate Vulnerability in Southeastern Arizona." *American Anthropologist* 111 (3): 289–301.

Watts, Michael J. 1983. *Silent Violence: Food, Famine, and Peasantry in Northern Nigeria*. University of Georgia Press.

World Bank. 2012. "Turn Down the Heat: Why a 4 Degree Centrigrade Warmer World Must Be Avoided." http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf.

Young, Gwendolynne, Humberto Zavala, Johanna Wandel, Barry Smit, Sonia Salas, Elizabeth Jimenez, Melitta Fiebig, Roxana Espinoza, Harry Diaz, and Jorge Cepeda. 2009. "Vulnerability and Adaptation in a Dryland Community of the Elqui Valley, Chile." *Climatic Change* 98 (1-2): 245–76. doi:10.1007/s10584-009-9665-4.

APPENDIX

SYNTHESIS CASE STUDIES

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
1	Developing sustainable practices to adapt to the impacts of climate change: a case study of agricultural systems in eastern England (UK)	Lorenzoni, I.; Jordan, A.; Favis-Mortlock, D. T.; Viner, D.; Hall, J.	REGIONAL ENVIRONMENTAL CHANGE	2001	Eastern England	Europe	arable croping (winter wheat, sugar beet, oilseed rape, potatoes, barley)	mix
2	Sustainable agriculture in the semi-arid agro-pastoral interweaving belt of northern China - A case-study of west Jilin province	Pan, XL; Deng, W; Zhang, DY; Li, F; Wang, YJ	OUTLOOK ON AGRICULTURE	2003	N. China	Asia	agro-pastoral	quant
3	Mapping vulnerability to multiple stressors: climate change and globalization in India	O'Brien, K; Leichenko, R; Kelkar, U; Venema, H; Aandahl, G; Tompkins, H; Javed, A; Bhadwal, S; Barg, S; Nygaard, L; West, J	GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS	2004	India	Asia	various	quant

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
4	Case study 3: Bangladesh floods in Bangladesh: A shift from disaster management towards disaster preparedness	Mallick, DL; Rahman, A; Alam, M; Juel, ASM; Ahmad, AN; Alam, SS	IDS BULLETIN-INSTITUTE OF DEVELOPMENT STUDIES	2005	Bangladesh	Asia	unclear	quant
5	Case study 6: Zimbabwe - Climate proofing infrastructure and diversifying livelihoods in Zimbabwe	Chigwada, J	IDS BULLETIN-INSTITUTE OF DEVELOPMENT STUDIES	2005	Zimbabwe	Africa	subsistence; maize, sorghum	quant
6	Policies for reducing agricultural sector vulnerability to climate change in Mali	Butt, TA; McCarl, BA; Kergna, AO	CLIMATE POLICY	2006	Mali	Africa	various	quant
7	Responding to the coffee crisis: a pilot study of farmers' adaptations in Mexico, Guatemala and Honduras	Eakin, H; Tucker, C; Castellanos, E	GEOGRAPHICAL JOURNAL	2006	Veracruz, Mexico	Latin America	coffee	qual
8	.	.	.	.	San Pedro la Laguna, Guatemala	Latin America	coffee	qual
9	.	.	.	.	La Campa, Honduras	Latin America	coffee	qual

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
10	Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study	Conde, C.; Ferrer, F.; Orozco, S.	ATMOSFERA	2006	Mexico	Latin America	maize	qual
11	Potential impacts of climate change on agriculture: A case of study of coffee production in Veracruz, Mexico	Gay, C.; Estrada, F.; Conde, C.; Eakin, H.; Villers, L.	CLIMATIC CHANGE	2006	Veracruz, Mexico	Latin America	coffee	quant
12	Travelling in antique lands: using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change	Fraser, Evan D. G.	CLIMATIC CHANGE	2007	Ethiopia	Africa	various	mix
13	Crop yield risk analysis and mitigation of smallholder farmers at quaternary catchment level: Case study of B72A in Olifants river basin, South Africa	Magombeyi, Manuel S.; Taigbenu, Akpofure E.	PHYSICS AND CHEMISTRY OF THE EARTH	2008	South Africa	Africa	maize	quant

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
14	Farmers' coping response to the low flows in the lower Yellow River: A case study of temporal dimensions of vulnerability	Liu, Chunling; Golding, Dominic; Gong, Gang	GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS	2008	China	Asia	various	quant
15	The rains are disappointing us: dynamic vulnerability and adaptation to multiple stressors in the Afram Plains, Ghana	Westerhoff, Lisa; Smit, Barry	MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE	2009	Ghana	Africa	subsistence agriculture	mix
16	Adaptive Capacity of Rice Farmers to Rainfall Variability and Extremes in the Province of Camarines Sur, Philippines	Cuesta, Michael A.; Ranola, Roberto F., Jr.	PHILIPPINE AGRICULTURAL SCIENTIST	2009	Camarines Sur, Philippines	Oceania	rice	mix
17	Climate Change and Tropical Andean Glacier Recession: Evaluating Hydrologic Changes and Livelihood Vulnerability in the Cordillera Blanca, Peru	Mark, Bryan G.; Bury, Jeffrey; McKenzie, Jeffrey M.; French, Adam; Baraer, Michel	ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS	2010	Cordillera Blanca, Peru	Latin America	subsistence ag and livestock	mix
18	Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico	Tucker, Catherine M.; Eakin, Hallie; Castellanos, Edwin J.	GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS	2010	Atitlan, Guatemala	Latin America	coffee	qual

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
19	.	.	.	.	La Campa, Honduras	Latin America	coffee	qual
20	.	.	.	.	Veracruz, Mexico	Latin America	coffee	qual
21	Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China	Challinor, Andrew J.; Simelton, Elisabeth S.; Fraser, Evan D. G.; Hemming, Debbie; Collins, Mathew	ENVIRONMENTAL RESEARCH LETTERS	2010	China	Asia	wheat	quant
22	Household access to capital and its effects on drought adaptation and migration: a case study of rural Alberta in the 1930s	Gilbert, Genevieve; McLeman, Robert	POPULATION AND ENVIRONMENT	2010	Alberta, Canada	North America	wheat	qual
23	Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa	Mertz, Ole; Mbow, Cheikh; Reenberg, Anette; Genesio, Lorenzo; Lambin, Eric F.; D'haen, Sarah; Zorom, Malicki; Rasmussen, Kjeld; Diallo, Drissa; Barbier,	ATMOSPHERIC SCIENCE LETTERS	2011	Sudano-Sahelian	Africa	various/subsitence ag	qual

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
		Bruno; Moussa, Ibrahim Bouzou; Diouf, Awa; Nielsen, Jonas O.; Sandholt, Inge						
24	Vulnerability to climate change in rural Saskatchewan: Case study of the Rural Municipality of Rudy No. 284	Pittman, Jeremy; Wittrock, Virginia; Kulshreshtha, Surendra; Wheaton, Elaine	JOURNAL OF RURAL STUDIES	2011	Canada	North America	cereal, oilseed, cattle	mix
25	Climate change and agricultural vulnerability: a case study of rain-fed wheat in Kairouan, Central Tunisia	Mougou, Raoudha; Mansour, Mohsen; Iglesias, Ana; Chebbi, Rim Zitouna; Battaglini, Antonella	REGIONAL ENVIRONMENTAL CHANGE	2011	Tunisia	Africa	wheat	quant
26	A Modelling Framework for Optimisation of Commodity Production by Minimising the Impact of Climate Change	Pelizaro, Claudia; Benke, Kurt; Sposito, Victor	APPLIED SPATIAL ANALYSIS AND POLICY	2011	South West Region of Victoria, Australia	Oceania	various - grains, pasture, forest	mix

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
27	Impact changes of climatic extremes on arable farming in the north of the Netherlands	Schaap, Ben F.; Blom-Zandstra, Margaretha; Hermans, Christiane M. L.; Meerburg, Bastiaan G.; Verhagen, Jan	REGIONAL ENVIRONMENTAL CHANGE	2011	Netherlands	Europe	seed potato & winter wheat	quant
28	Exploring social barriers to adaptation: Insights from Western Nepal	Jones, Lindsey; Boyd, Emily	GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS	2011	Western Nepal	Asia	subsistence - wheat, barley	qual
29	Case study on potential agricultural responses to climate change in a California landscape	Jackson, L. E.; Wheeler, S. M.; Hollander, A. D.; O'Geen, A. T.; Orlove, B. S.; Six, J.; Sumner, D. A.; Santos-Martin, F.; Kramer, J. B.; Horwath, W. R.; Howitt, R. E.; Tomich, T. P.	CLIMATIC CHANGE	2011	California	North America	alfalfa, maize, rice, sunflower, tomato, and wheat	mix

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
30	Quantifying human vulnerability in rural areas: case study of Tutova Hills (Eastern Romania)	Stanga, I. C.; Grozavu, A.	NATURAL HAZARDS AND EARTH SYSTEM SCIENCES	2012	Eastern Romania	Europe	small plot crop production	quant
31	Human competences that facilitate adaptation to climate change: a research in progress	Kerry, Jackie; Pruneau, Diane; Blain, Sylvie; Langis, Joanne; Barbier, Pierre-Yves; Mallet, Marie-Andree; Vichnevetski, Evgueni; Therrien, Jimmy; Deguire, Paul; Freiman, Viktor; Lang, Mathieu; Laroche, Anne-Marie	INTERNATIONAL JOURNAL OF CLIMATE CHANGE STRATEGIES AND MANAGEMENT	2012	New Brunswick, Canada	North America	various	qual
32	Defining Spaces of Resilience within the Neoliberal Paradigm: Could French Land Use Classifications Guide Support for Risk Management Within an Oceanian Regional Context?	Bardsley, Douglas K.; Pech, Pierre	HUMAN ECOLOGY	2012	South Australia	Oceania	various-orchards, horticulture, vinyards, dairy	mix

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
33	Projecting the effects of climate change on the distribution of maize races and their wild relatives in Mexico	Ureta, Carolina; Martinez-Meyer, Enrique; Perales, Hugo R.; Alvarez-Buylla, Elena R.	GLOBAL CHANGE BIOLOGY	2012	Mexico	Latin America	maize	quant
34	Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate	McDowell, Julia Z.; Hess, Jeremy J.	GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS	2011	Bolivia	Latin America	various, subsistence	qual
35	Rural Nevada and Climate Change: Vulnerability, Beliefs, and Risk Perception	Safi, Ahmad Saleh; Smith, William James, Jr.; Liu, Zhnongwei	RISK ANALYSIS	2012	US-Nevada	North America	various, esp. ranching	mix
36	Typical patterns of smallholder vulnerability to weather extremes with regard to food security in the Peruvian Altiplano	Sietz, Diana; Mamani Choque, Sabino Edgar; Luedeke, Matthias K. B.	REGIONAL ENVIRONMENTAL CHANGE	2012	Altiplano-Peru	Latin America	various; small-holder farming	mix
37	Climate change adaptation and sustainable regional development: a case study for the Federal State of Brandenburg, Germany	Reyer, Christopher; Bachinger, Johann; Bloch, Ralf; Hattermann, Fred F.; Ibisch,	REGIONAL ENVIRONMENTAL CHANGE	2012	Germany	Europe	various; organic farming	mix

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
		Pierre L.; Kreft, Stefan; Lasch, Petra; Lucht, Wolfgang; Nowicki, Christoph; Spathelf, Peter; Stock, Manfred; Welp, Martin						
38	Challenges of agricultural adaptation to climate change: The case of cassava post-harvest in Southeast Nigeria	Enete, Anselm Anibueze	INTERNATIONAL JOURNAL OF CLIMATE CHANGE STRATEGIES AND MANAGEMENT	2013	Southeast Nigeria	Africa	casava	quant
39	Climate Change in the Wine Sector of an Ultra-Peripheral European Region: A Case Study	Alonso, Abel Duarte; Liu, Yi	AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS	2013	Canary Islands	Africa	wine	qual
40	Agricultural adaptation to climate change: observations from the Mid-Hills of Nepal	Biggs, E. M.; Tompkins, E. L.; Allen, J.; Moon, C.; Allen, R.	CLIMATE AND DEVELOPMENT	2013	Nepal	Asia	various; subsistence	qual
41	Agricultural adaptation to climate change: insights from a farming community in Sri Lanka	Esham, Mohamed; Garforth, Chris	MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE	2013	Sri Lanka	Asia	small-holder	mix

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42	Buffer capacity: capturing a dimension of resilience to climate change in African smallholder agriculture	Speranza, Chinwe Ifejika	REGIONAL ENVIRONMENTAL CHANGE	2013	Kenya	Africa	pastoral smallholder conservation agriculture	mix
43	Reconciling approaches to climate change adaptation for Colombian agriculture	Ramirez-Villegas, Julian; Khoury, Colin K.	CLIMATIC CHANGE	2013	Colombia	Latin America	various;	qual
44	How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops	Evangelista, Paul; Young, Nicholas; Burnett, Jonathan	CLIMATIC CHANGE	2013	Ethiopia	Africa	subsistence ag; cereal crops	quant
45	Local Farmers' Perceptions of Climate Change and Local Adaptive Strategies: A Case Study from the Middle Yarlung Zangbo River Valley, Tibet, China	Li, Chunyan; Tang, Ya; Luo, Han; Di, Baofeng; Zhang, Liyun	ENVIRONMENTAL MANAGEMENT	2013	Tibet	Asia	traditional; barley, wheat, rapeseed	mix
46	Social capital and drought-migrant integration in 1930s Saskatchewan	Laforge, Julia M. L.; McLeman, Robert	CANADIAN GEOGRAPHER-GEOGRAPHE CANADIEN	2013	Saskatchewan	North America	various	qual

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
47	Land-users' perceptions and adaptations to climate change in Mexico and Spain: commonalities across cultural and geographical contexts	Campos, Minerva; McCall, Michael K.; Gonzalez-Puente, Marc	REGIONAL ENVIRONMENTAL CHANGE	2014	Ichamio, Mexico	Latin America	various; corn, sorghum	qual
48	.	.	.	.	Fogars de Montlu´s, Spain	Europe	various; traditional agriculture and livestock	qual
49	Adaptation strategies to climatic variability: A case study of small-scale farmers in rural Mexico	Campos, Minerva; Velazquez, Alejandro; McCall, Michael	LAND USE POLICY	2014	Ticuiz, Mexico	Latin America	various; livestock, fishing, fruit, small-scale	mix
50	Is South Asian Agriculture Adapting to Climate Change? Evidence from the Indo-Gangetic Plains	Ojha, Hemant R.; Sulaiman, Rasheed; Sultana, Parvin; Dahal, Khemraj; Thapa, Dhanej; Mittal, Nimisha; Thompson, Paul; Bhatta, Gopal Dutt; Ghimire, Laxman; Aggarwal, Pramod	AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS	2014	Patuakhali, Bangladesh	Asia	rainfed rice, limited winter cropping	mix

	Title	Author(s)	Source Title	Year	Location (exact)	Location (Regional)	Type of ag	Methods
51	.	.	.	.	Punjab, India	Asia	rice-wheat system, intensive	mix
52	.	.	.	.	Rupandehi, Nepal	Asia	rice-wheat system, cash crops, integrated farming system	mix