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Author
ERVIN, DANIEL

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by

Daniel Chaney Ervin

Committee in charge:

Professor David López-Carr, Chair

Professor Michael Gurven

Professor Pascale Joassart-Marcelli

Professor Christopher Still

Professor John Weeks

December 2017

The dissertation of Daniel Chaney Ervin is approved.

David López-Carr, Committee Chair

Michael Gurven

Pascale Joassart-Marcelli

Christopher Still

John Weeks

December 2017

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VITA OF DANIEL CHANEY ERVIN

September 2017

EDUCATION

2017 Ph.D., Department of Geography, University of California, Santa Barbara. Dissertation: *Migration, Human, and Environmental Health*. Committee Chair: Dr. David López-Carr.

2012 M.A., Department of Geography, University of Wyoming. Thesis: *Business Distribution in the Tourism Zone of Oaxaca, Mexico*. Committee Chair: Dr. William J. Gribb.

2002 B.A., Department of Psychology, George Washington University.

PUBLICATIONS

Peer Reviewed Publications

2017 in press Lopez-Carr, David and Daniel **Ervin**. "Population-Health-Environment (PHE) Synergies? Evidence from Africa and Asia." *The European Journal of Geography*.

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PRESENTATIONS AND CONFERENCES

Invited Presentations

2015 **Ervin**, Daniel “Applications of Stable Isotope Ratio Analysis for Social Science Research.” Paper presented at the Montana Tech of the University of Montana Public Lecture Series, Butte, MT, March 12, 2015.

2012 **Ervin**, Daniel. “Disciplinary and Interdisciplinary Science and Their Broader Applications to Society.” Paper presented at the Central Fellowship Awards Reception: Mathematical, Life, and Physical Sciences, Santa Barbara, CA, October 7, 2012.

Panels Organized

2016 **Ervin**, Daniel, Kevin M. Mwenda, and David Lopez-Carr. “Space and place in Population, Health, and Environment Research.” The Association of American Geographers Annual Meeting, San Francisco, CA, March 29 – April 2, 2016.

2015 **Ervin**, Daniel. “Interactions between Human Processes, Population Changes, and the Environment”. The International Geographic Union Regional Geographic Conference, Moscow, Russia, August 18-22, 2015.

2015 **Ervin**, Daniel. “Developing Cultural Competency in Healthcare: An Interactive Session” The University of California Global Health Day, Los Angeles, CA, April 18, 2015.

2014 **Ervin**, Daniel. “An Introduction to Migration Streams and their Effects on Health”. The University of California Global Health Day, Davis, CA, April 26, 2014.

Papers Presented

2016 **Ervin**, Daniel. “Twin Gods: A Mixed-Method Investigation of Diet Change in Latino Immigrants.” The Association of Pacific Coast Geographers Annual Meeting, Portland, OR, October 6-7, 2016.

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ABSTRACT

The Effect of Time-Variant Acoustical Properties on Orchestral Instrument Timbres

by

Daniel Chaney Ervin

This dissertation is an examination of the environmental and health impacts of the migration process at multiple scales: individual, *muncipio*, biome, national, and regional/continental. It seeks to address the questions: Whose health benefits or worsens when people migrate? Under what conditions? Through this, I hope to further the understanding of the complex effects of migration upon the places and people who participate in this process.

Migration affects the natural environment directly through the changes produced in sending communities: Rural depopulation occurs as people migrate to seek wage labor in urban and international destinations. This can lead to a diverse set of outcomes: forest cover returning on abandoned small farms, or forest cover declining as remissions allow for investment in agriculture or as empty smallholdings are replaced with large industrial farms. Migration also contributes to changes in the natural environment indirectly: Most migration occurs up the development continuum from rural to urban, and/or developing to the developed world. As people move up the development continuum they almost invariably consume more resources, including high-resource food in the form of meat, animal products, and prepared and processed foods. Migration also directly affects the

health of the individual. In addition to the stresses and dangers of the migration process itself, changes in location result in changes in access to health related resources, changes in health behaviors, and health-related acculturation. As Mexican migrants move from rural to urban places, and to the U.S., they often move to less stable or less family based living environments, and they commonly eat in a less healthy manner, resulting in higher risk for nutrition-related chronic diseases such as obesity, diabetes, cardiovascular disease, and cancer.

This dissertation consists of four chapters that seek to explore this complex relationship. A ‘theoretical’ or ‘literature’ chapter, three ‘empirical’ chapters, and a conclusion. Each chapter has been formatted as stand-alone, publication-ready manuscripts, and each contain their own literature sections. The first chapter makes two principal arguments: first, that research on migration should be included in the emerging academic topic of “Planetary Health”, and second, that this dissertation is part of an emerging theme within the subfield of nutritional geography, “the geography of malnutrition”. Chapter 2 is an examination of the relationship between population trends (including migration), agricultural land use, and food at multiple scales, using data from the Food and Agriculture Organization (FAO). The chapter examines trends from recent decades in population change and distribution, as well as patterns of agricultural expansion and intensification at the global region scale and the national scale for Latin America. We also examine agricultural intensification vs production in Latin America, and discuss three case studies to highlight how space and place context are critical in understanding the population-food-environment nexus. Chapter 3 is an examination of the relationships between migration, population, and economic processes, and forest

cover change in Mexico from 2000 to 2010. Using multiple regression analyses with remotely-sensed, significant ($p > 0.10$) change in woody vegetation from 2000 to 2010 as our dependent variable, we explore the effects of a suite of environmental, demographic, and economic indicators at the national and regional biome scales. Results highlight the importance of international migration on forest change across various scales, and that internal migration and other demographic and economic variables contribute at particular scales and regions. Chapter 4 examines how migration history influences diet and diet-related health among recent internal migrants to Tijuana, Mexico. We investigate how characteristics of migrants' origin influence their health and diet, finding that migrants from rural places and of indigenous status have better diet-related health, but have undergone more diet change than other groups. These results indicate the importance of migration history and geographic variables in health related research with migrants.

TABLE OF CONTENTS

I. LITERATURE

In this chapter, we seek to place this dissertation and the following three empirical chapters within the existing academic literature. We advance two arguments, first that research on migration should be included in the emerging academic field of "Planetary Health", and second, that this dissertation is part of a theme within the subfield of nutritional geography, "the Geography of Malnutrition". We will begin with the discussion of Planetary Health, providing a review of the current definitions of the the topic, developing our argument as to how human migration is an important contributor to the processes and outcomes associated with Planetary Health, and where the research in this topic is lacking. In the second part of the chapter we will review and define a subfield of the literature that we call the Geography of Malnutrition and explain why Chapter 3 of this dissertation belongs in that grouping as well.

A. Planetary Health

"Planetary Health" is a recent and still emerging interdisciplinary framework, which attempts to integrate the disparate research on human, animal, and environmental health, as parts of one complete system. This framework has been advanced by the private philanthropic organization The Rockefeller Foundation, which describes Planetary Health as "a new, multi-disciplinary approach to health and well-being that brings together scientific knowledge of both human and ecosystem health with what we know about economic trends, market behavior, and policy making"[1] The Foundation, working with the Lancet organization, which is responsible for the long-running, high impact medical journal *The Lancet*, as well as over a dozen other topic-specific health-related academic journals, created the Rockefeller Foundation-Lancet Commission on Planetary Health to produce data, research, and policy material[2]. This included a special issue in the popular

[1] https://www.rockefellerfoundation.org/about-us/news-media/rockefeller-foundation-launches-economic-council-focused-planetary-health

[2] https://www.rockefellerfoundation.org/our-work/initiatives/planetary-health

news magazine *The Economist*, a special issue in *The Lancet* journal, and launching of a dedicated new journal *The Lancet Planetary* Health, in 2017.

The purpose of these efforts is to spur action on improving the health of coupled human-natural systems, through increased attention, research, and policy[3]. Part of this work has been to define and bound the topic, the issues of particular interest, and potential areas for future work. We argue that the full effects of human migration on planetary health have yet to be considered in this literature. We examined the published literature concerning the subject of human migration, reviewing publications using the keyword Planetary Health, containing the phrase Planetary Health in the text, published as part of special issues or journals dedicated to Planetary Health, and literature commonly cited literature in the above. These publications have included discussion on the impacts of environmental health on human migration, animal migration, and human health, and some discussion of the impacts of human migration on environmental health. We found the discussion of climate change and other negative environmental outcomes *caused by* human migration to be less than thorough, especially as it relates to indirect and long-term outcomes. To that end, we will review how the topic is discussed currently, and why we think it deserves further consideration.

1. Current Migration Related Research in Planetary Health

Human migration as an outcome of environmental health, or 'climate refugees', is a common topic in this literature (e.g. Hartmann 2010). This research has discussed short-term migration outcomes from extreme weather events and well as longer-term implications of rising mean temperatures, sea level rise, drought, desertification, and land degradation (Tacoli 2009). The initial research was concerned with forecasting the numbers and locations of potential short-term or disaster driven climate migrants, and tended to be alarmist (e.g. Baird et al. 2007). Further work has focused on the longer-term effects of climate-change on migration, and has concluded that much of it will be subtle and difficult to assess, as loss of resources or productivity lead to increases in already established migration patterns, many of which are internal (McMichael, Barnett,

[3] https://www.rockefellerfoundation.org/our-work/initiatives/planetary-health

and McMichael 2012; Tacoli 2009). This is in line with research on general migration motivation, which notes the numerous potential and often multiple components of a migration decision (Massey 1999; Samers 2010). We note here that these increases in established migration patterns forecasted as part of climate-driven migration include rural-to-urban migration.

McMicheal, Barnett, and McMicheal's (2012) widely-cited summary of the connections between climate-driven migration and health outlines the current thinking. They note that commonly assumed outcomes of climate-driven migration are often political: migration-related border problems, and perhaps political unrest, state instability, and armed conflict (e.g. Morisetti and Blackstock 2017). They note that climate change's long-term negative effects on food security, clean drinking water, and therefore health, may also increase migration. They, and others, highlight the potential for increased movement of humans and attendant fauna to increase infectious disease outbreaks (e.g. Warner et al. 2009; Liang and Gong 2017). Less directly, migration can also lead to infectious disease outbreaks in refugee settlements, or in migrants in general due to weakened immune systems caused by stresses leading to, or because of, migration. Much of the non-immediate negative health outcomes that McMicheal, Barnett, and McMicheal discuss in their review are caused by the poor circumstances that caused the migration or the negative circumstances that refugees and recent migrants often find themselves in. This can cause less commonly discussed health outcomes, including poor reproductive health outcomes during and after migration. They also discuss the potential for medium term food shortages, micronutrient deficiencies, and longer-term reduced food yield in already marginal places.

Other recent work has begun to explore the circular linkages between food security and rural-to-urban migration in the developing world (Crush 2013; Nickanor, Crush and Pendleton, 2016). Some research has also noted the connection between *animal* migration and human health, in particular as it pertains to infectious disease (Fritzsche-McKay and Hoye 2016; Plowright et al. 2011; Prosser, Nagel, and Takekawa 2013). Absent from all of the literature that we surveyed is written work connecting this circle and fully examining the short and long-term effects of human migration on environmental health.

2. Direct Impacts of Human Migration on Environmental Health[4]

Human migration concerns the movement of people from one place to another and often from one *type* of place to another. This movement has consequences for the migrant, the origin, destination (and intermediate) places, as well as the people and environments in all of the above. The direct impacts of this migration are perhaps the easiest to recognize: migrants come to a new place, and effect change. Migration across international borders is perhaps the most easily recognizable form of this movement, but internal migration, the migration within a country or other political unit is very common, although harder to track. For example, somewhere between 200 and 400 million people have migrated within China in the last 40 years (Chan and Bellwood 2011).

We will begin examining these indirect linkages with rural-to-rural migrants. Despite being less common, they can have a disproportionately large effect on the *destination* environment due to their agricultural activities. These migrants are often the first agricultural users in 'virgin' or 'old-growth' environments, and have been noted as key factors in the conversion of rainforests to farmland (Carr 2009; Lambin and Meyfroidt 2011; Levy et al. 2011; López-Carr and Burgdorfer 2013). The direct effects of outmigration (and resultant depopulation) from rural *origin* locations is complex, scale and local context dependent, and can commonly result in forest cover loss, forest cover regrowth, agricultural or pasture expansion or decline (e.g. Aide and Grau 2004; Rudel, Schneider, and Uriarte 2010).

Much of the internal migration in developing nations is rural-to-urban and most international migrants move 'up' the development continuum of nations from less to more developed (Abel and Sander 2014). The *direct* impacts of this movement on the environment are incremental increases to the existing impacts of urban systems such as housing, water, and sewage (e.g. Seto et al. 2011). Examinations of rural vs. urban resident contributions to greenhouse gas (GHG) emissions have noted that contrary to

[4]This portion of this chapter has been partially adapted from: Ervin, Daniel and David López-Carr. "Agricultural Inputs, Outputs, and Population Density at the Country-Level in Latin America: Decadal Changes Augur Challenges for Sustained Food Production and Forest Conservation." 2015. *Interdisciplinary Environmental Review (IER)*, 16(1): 63-76.

perception, urban residents may be more efficient on a per capita basis in regards to emissions related to transportation, or heating and cooling of living spaces (Dodman 2009); the dominant driver of GHG appears to be consumption patterns (Satterthwaite 2008). Therefore, the changes in consumption and behavior patterns of migrants that result from migration are more important. Rural-to-urban and international migration tends to move people to places where higher consumption of commercial products, and especially higher consumption of resource intensive food, occurs. Residents of the developed world are responsible for far more per capita consumption of food and agricultural resources, as they eat more total food and, importantly, more red meat, animal products, and processed food, all of which are more resource-intensive to produce (Gerber et al. 2013; Heller, Keoleian, and Willett 2013; Hallström et al. 2015; Tukker and Jansen 2006; Machovina et al. 2015). Tilman et al. (2011) compared groups of the richest and poorest nations and found that per capita consumption of calories was more than 250% higher in the richer nations, and protein consumption was 430% higher. The direction of this relationship is the same when one compares urban residents with rural residents in the developing world. Urban residents consume more in the absolute sense as well as more resource intensive food products. As migrants acculturate to these environments, they adopt the higher-consumption lifestyles (Handley et al. 2013; Levitt 1998) resulting in much higher indirect effects upon the environment.

One of the common consequences of rural-to-urban and international migration is migrants sending money back to their origin location (remittances). Remittances can make up a large portion of the income in developing countries and produce substantial change in origin area behavior (Levitt 1998). The relationship between remittances, resource consumption, and the environment are complex and not unidirectional. In some cases, these remittances allow household members to abandon agriculture, meaning less direct environmental impact. In other cases, remittances can allow households to invest in agriculture, leading to intensification and/or extensification, increasing the direct environmental impact (Davis and Lopez-Carr 2010; Lambin and Meyfroidt 2011; Levy et al. 2011). In either case, this process should be included in conceptualized migrations impact.

The indirect results of migration and acculturation upon migrants' health are again complex. McMicheal, Barnett, and McMicheal (2012) overviewed the direct interactions, but again failed to consider the longer-term effects as migrants acculturate to the health behaviors of their new location. These can be mixed, and are very dependent on the particular migration stream, but to generalize: rural-to-urban movement can lead to increased negative health behaviors such as tobacco use and alcohol consumption, direct exposure to pollution, and decreased exercise. On the positive side, migrants often have increased access to health services and a larger range of available health services, increased income and time, which they can use to improve their health, and increased potential for exposure to health knowledge (Abraído et al. 2006; Martínez 2013; Rechel 2011; Wiking, Johansson, and Sundquist 2004)

The connection between urban living's effects on resource use and greenhouse gas emissions is well covered in the Planetary Health literature, as is the connection between the consumption of meat and animal products and numerous negative environmental impacts (e.g. Tilman and Clark 2014; Hallström et al. 2015). However, work to this point has failed to complete the circle and fully connect migration to urban environments, acculturation to high resource life-styles, and increased consumption[5]. We argue that moving forward this should be taken into full consideration in Planetary Health research.

B. The Geography of Malnutrition[6]

Chapter three of this dissertation examines how migration history influences diet and diet related health in recent internal migrants to Tijuana, Mexico. This project fits most firmly into the sub- discipline of Medical and Health Geography, as defined by Gaile and Willmott's 2006 survey of this discipline, as well as its sub-discipline Nutritional Geography. We argue here that there is a body of work specifically relating to geographic approaches to malnutrition that deserves examination as its own subfield, which we have

[5]We note one possible exception in the 2017 editorial by Dangour, Mace, and Shankar.

[6]This portion of this chapter has been partially adapted from: Beal, Ty, and Daniel Ervin. "The Geography of Malnutrition." The Professional Geographer (2017): 1-13.

called the Geography of Malnutrition. In this portion of the chapter, we will quickly review the topics of Health and Medical Geography and Nutritional Geography, before discussing in more detail the Geography of Malnutrition. We will close with a brief discussion of why Chapter three of this dissertation belongs to this subfield.

3. Health and Medical Geography

Research into Medical and Health Geography has a long, if interrupted history. Like Geography itself, it began in ancient Greece. The linkages between climate, the environment, and health were an important topic in western medicine for thousands of years (and remain so in some non-western medicine traditions) (Barrett 2000; Koch 2005; Meade and Emch 2010). However, changes in the study of health and the practices of medicine that began in the 19th century excluded Geography from their purview. With a growing understanding of diseases, and as germ theory became the dominant paradigm, the focus of medicine was no longer the environment, or the community, or even the individual. Diagnosis and treatment occurred at the sub-individual scale: specific diseases or specific organs within a person (Barrett 2000; Meade and Emch 2010). In the U.S., the study of medicine within Geography focused primarily on cartography and description until the 1970's (Barrett 2000). At that time Medical Geography, along with the rest of the discipline, underwent a 'revolution' in quantitative methods; analysis and the use of statistics became almost a requirement (Barrett 2000; Mayer 2010; Meade 2010).

In the 1980's Medical Geography experienced an epistemological and methodological debate which led to the addition of health geography to the subfield (or a division into two subfields, depending on one's viewpoint) (Andrews and Evans 2008; Dorn, Keirns, and Del Casino Jr. 2010; Meade and Emch 2010). Currently, medical geography is primarily focused on the mapping of disease, disease ecology, health services, disease diffusion, and spatial epidemiology. The methods used are generally cartography, locational analysis, spatial analysis, and spatial statistics (Barrett 2000; Gesler 2006). Health Geography is focused on the interactions between health and place. Its methods and philosophies are diverse, but they are usually qualitative or critical (Andrews and Moon 2005; Anthamatten and Hazen 2011; Gesler 2006; Kearns 1993; Kearns and Collins 2010; Kearns and Moon 2002; Rosenberg 1998). Another way to differentiate the two is to categorize Medical Geography as studying health and space interactions, while Health Geography studies health and place interactions.

4. Nutritional Geography

Others have argued for the existence of a sub-field of Medical and Health Geography focusing on nutrition. Wade Edmundson was the first mention of the term “nutritional geographer” that we could find, in his 1972 doctoral dissertation (Edmundson 1972) but it was not until 1991 in Dunbar’s Modern Geography: An Encyclopedic Survey that the subdiscipline of nutritional geography was formally acknowledged, and it was still not recognized in the American Association of Geographers sponsored Geography in America at the Dawn of the 21st Century (Gaile and Willmott 2005).

Nutritional geography is described by Louis Grivetti in his 2000 review of the topic *Nutritional Geography: History and Trends.* The subfield, though not completely bounded itself, is defined as research using geographic frameworks or methods to examine issues of nutrition. In this article he provides both narrow and broad definitions of nutritional geography, with the narrow containing research that integrates distinct nutritional and geographic components, such as “deficiency diseases, famine, malnutrition, and other nutrition— or physiological—related topics set within geographic concepts of area, distribution, space, pattern, and time” (Ibid. 2). His broad definition includes topics without distinct nutritional and geographic components, such as agricultural geography, food access and distribution, cultural aspects of food patterns, and health consequences of diet choices. Researchers whose work falls under his narrow definition, such as Grivetti himself or Wade Edmundson, refer to themselves as nutritional geographers, but they are few. In contrast, literature that could be classified under the broader definition of nutritional geography is common, but normally not labeled as nutritional geography due to a lack of cohesion and awareness of the field itself.

Using this broader definition we will quickly note some past notable practitioners. These include Maximilien Sorre (1947) who was among the earliest geographers to develop field methods for studying food and diet patterns. Josué de Castro, Brazilian geographer, nutritionist, physician, and early chairman of the Food and Agriculture

Organization (FAO), who earned the international peace prize in 1952 for his influential writings about the geography and geopolitics of hunger (De Castro 1952). Others notable practitioners include Jacques May, Frederick Simoons, Wade Edmundson, and Louis Grivetti: May studied what he referred to as the ecology of human disease (May 1959), the ecology of malnutrition (May 1961), and the geography of nutrition (May 1974). He addressed the etiology of malnutrition from medical, ecological, and cultural perspectives in dozens of low-income countries in Africa, Asia, and Latin America. In the 1970s and 1980s Simoons studied lactose malabsorption and celiac disease from a geographical perspective (Simoons 1978, 1981). In the early 1980s and 1990s, Edmundson assessed the role of biological and cultural factors in contributing to nutritional deficiencies (Edmundson 1980), while Edmundson and Sukhatme (1990) attempted to establish the relationship between malnutrition and productivity and explain cycles of poverty. During the 1980s, 1990s, and 2000s, among other topics, Grivetti spent much time studying the nutritional properties and cultural importance of wild plants (e.g. Ogle and Grivetti 1985).

5. The Geography of Malnutrition

The work defined as nutritional geography has a major focus on the negative outcomes and causes of poor nutrition, although not entirely. We consider the geography of malnutrition one of many themes within the subfield of nutritional geography and we argue it has come more into focus with the worldwide decreases in famine and hunger, increased awareness of micronutrient deficiencies, rapid growth of overweight and obesity, and the accompanying critiques of diet and nutrition knowledge by political ecologists and others. The major foci of the geography of malnutrition that we identified are undernutrition, diseases that cause malnutrition, the nutrition transition, and critical and feminist approaches to malnutrition. We will review these foci, provide examples of prominent work, and identify areas of research concerning malnutrition that are highly spatial, but have yet to be effectively studied using geographic techniques.

6. *Undernutrition*

For this chapter, we will consider hunger and micronutrient deficiencies as forms of undernutrition. Whereas hunger can be defined as the inability to consume adequate energy to meet expenditure, micronutrient deficiencies occur when individuals fail to consume adequate micronutrients to meet requirements or have biological conditions that prevent absorption or utilization of exogenous nutrients (Ervin, Tuholske, and López-Carr 2017). Micronutrient deficiencies are more common in hungry individuals but are also prevalent in people who consume adequate or excess energy. Geographers studying how the food supply (including production, distribution, and access) affects malnutrition were initially concerned with addressing hunger, and later began to also address micronutrient deficiencies.

Josué de Castro’s 1946 seminal work, which was published in the United States in 1952 under the title *The Geography of Hunger*, gave a passionate overview of global hunger and called for its eradication (De Castro 1952). His perspective largely was in opposition to the prevailing (neo-Malthusian) view, which predicted population growth would inevitably outpace food production due to exhaustion of available resources. De Castro considered hunger largely a social problem and theorized that eliminating world hunger would naturally reduce fertitlity (De Castro 1952). De Castro supported his theory by referencing country-level data that showed as animal protein consumption increased, birth rates decreased.

Conway (1998) argued that the Green Revolution—the advancement in farming techniques and plant breeding beginning in the 1940s that led to a rapid increase in crop productivity and yields—may be largely responsible for the reduction in global hunger since the 1970s. One’s interpretation of this varies depending on their subscribed theoretical framework, be it neo-Malthusian, Boserupian, or more recent Political Ecology theories (Jolly 1994; Turner and Ali 1996; de Sherbinin et al. 2007). The development of higher yielding cereal varieties through plant breeding, as well as agronomic practices such as mechanization, irrigation, and increased pesticide and fertilizer use helped increase cereal production in Asia more than twofold from 1970 to 1995, defying (at least a simplistic view of) Malthusian theory (Ervin and López-Carr 2017; Hazell 2003). Even with 60 percent population growth, food energy supplies increased by almost 30 percent per person, and rice and wheat became more affordable

(Rosegrant and Hazell 2000). Agricultural production and the food supply also increased in Latin America, but much less so in sub-Saharan Africa, probably because of a relative lack of infrastructure and resources necessary to make significant gains (Ervin and López-Carr 2015; Evenson and Gollin 2003).

The health, nutritional, and environmental impacts of the Green Revolution have remained contentious topics. There is little debate that the Green Revolution helped increase the availability of and lowered the price of food worldwide. However, Kerr (2012) notes that this likely reduced the cost of less nutritious staples such as corn and rice, at the expense of increasing the cost of more nutritious fruits and vegetables. Lakshman Yapa similarly examined the paradox of how the improved seeds of the Green Revolution produced higher yields but at the same time created poverty and hunger through social scarcity and environmental degradation (Yapa 1993). Political ecologists also emphasize how the green revolution was part of a political-economic shift in food regimes, which redistributed power towards large corporate and export-oriented farms. This contributed to poverty and hunger (as well as migration) among landless peasants, including many indigenous groups.

Production of enough food is a necessary but not sufficient condition to end hunger; Inadequate access to or ownership of food also causes food insecurity (Sen 1981). Geographers have participated in demonstrating that issues of access and inequality are important when discussing undernutrition, with scale being of particular importance (Ervin, Tuholske, and López-Carr 2017; Smith, El Obeid, and Jensen 2000; Weber and Kwan 2003). Just because food is produced or available at some scale (e.g. national, city-wide) does not mean that inhabitants of that place will have the resources necessary to access this food, be these resources income, knowledge, transit, or other (Lindley, Van Crowder, and Doron 1996; Vagneron 2007). This inequality and lack of access may result in undernourishment in both the developed and developing world (Ervin, Tuholske, and López-Carr 2017; Haddad, Ruel, and Garrett 1999; Beaulac, Kristjansson, and Cummins 2009).

Diseases that Cause Malnutrition

While an inappropriate diet is one cause of malnutrition, various diseases or genetic characteristics that prevent absorption or retention of nutrients also contribute.

For example, diarrhea reduces absorption of nutrients and is one of the leading causes of death in low-income countries. Although most infectious diseases do impact nutrition in the short term, our focus here is those conditions where the primary consequence is nutritional. These diseases or genetic characteristics, such as lactose malabsorption, celiac disease, and stomach parasites, are often spatially determined by social and ecological environments and have all been studied from a geographical perspective.

Most humans stop producing the enzyme lactase sometime after weaning, preventing them from being able to digest the milk-sugar lactose in adulthood. This natural phenomenon, referred to as lactose malabsorption, does not occur in high proportions across all population groups. A low prevalence of lactose malabsorption exists in Northern and Western Europeans, a few groups in the Mediterranean and Near East, many regions in the Indian subcontinent, and several African pastoralists societies, all of which share a long history of cattle milking (Simoons 1978; Harcourt 2012). Simoons (1978) formed a geographical hypothesis that ecological conditions created selective genetic pressure on lactase persistence over a long historical period of animal domestication and milk consumption. His findings have been supported by recent genetic studies (Tishkoff et al. 2007). Simoons' discovery has significant implications for the study of malnutrition, since milk is widely consumed globally. Lactose malabsorption increases the likelihood of lactose intolerance, which causes diarrhea and can reduce absorption of nutrients.

Simoons (1981) later explored the relationship between the origins of the domestication of wheat and celiac disease. He discovered an increasing gradient of celiac disease incidence from the Middle East to Northern Europe, which corresponded with the adoption of agriculture (and thus consumption of gluten) 10,000 years ago. His findings suggest that Middle Eastern populations have experienced greater selective pressure against the HLA-B8 gene (which is indicative of celiac disease) than Northern European populations because they have had a longer history of wheat and barley consumption. Simoons' geographic research on lactose malabsorption and celiac disease is still relevant today to evolutionary perspectives on diet and nutrition (Cordain 1999) and in showing how culture influences genetics (Laland, Odling-Smee, and Myles 2010).

Flukes, worms, and other parasites can cause reduced absorption of nutrients. This topic is particularly geographic, as it is dependent upon ecologically and geographically sensitive small organisms. Helminthiases (stomach parasites) are by far the most prevalent soil-transmitted diseases and well suited to study by geographers. The first highly detailed global maps of Helminthiases were created in the early 1950s by May (1952). Since then, geographers have contributed to the study of these diseases by applying spatial principles and analysis to more established public health methods, integrating remotely sensed data, and mapping and describing infection hotspots for outbreaks or efficient interventions (Brooker et al. 2009; Koroma et al. 2010; Magalhães et al. 2011; Menzies et al. 1999; Vounatsou et al. 2009; Yang et al. 2005).

7. *The Nutrition Transition*

Great progress has been made in reducing hunger and micronutrient deficiencies in low-income countries, yet all countries experience high and/or rising rates of overweight and obesity. Recent estimates suggest approximately 2 billion people are overweight or obese worldwide (Popkin, Adair, and Ng 2012), and nearly two thirds of obese people now live in developing countries (Ng et al. 2014). Moreover, while the acceleration of obesity in developed countries has slowed, rates continue to increase in developing countries, which can lead to a dual burden of coexistent overnutrition and undernutrition (Doak et al. 2004; Kennedy, Nantel, and Shetty 2006). Barry Popkin (1993) has lead the research on how this “nutrition transition” (a term he coined) has evolved over space and time. He defines the nutrition transition as consisting of five five phases of nutrition patterns: (1) Collecting food; (2) Famine; (3) Receding famine; (4) Degenerative diseases; and (5) Behavioral change.

The nutrition transition is occurring in a spatially heterogeneous manner; the nature and especially the pace of this transition varies geographically. At the global scale, the developed world (excluding East Asia) began the transition to phase 4 earlier and proceeded slowly. For a large portion of the population it began at the turn of the 20^{th} century in North America, by the end of World War II in Western Europe and Australia, and accelerated rapidly for all regions in the 1980s. In the developing world the transition began much later, beginning in earnest in the 1980s, and has since accelerated rapidly

(Ng et al. 2014). Mexico, a middle-income country, now has the same adult obesity prevalence as Canada and Australia (Figure 1).

There is strong evidence that spatial connectivity and globalization are correlated with phase 4 malnutrition for countries at all levels of development. Primary mechanisms of this association are the lowering prices of food staples and the opening (or easing) of access for the sale of processed and prepared foods (Baker and Friel 2014; Clark et al. 2012; Popkin 2006). The importance of globalization in this process can be seen clearly in the cases of China and the Soviet Union, which transitioned rapidly along with the opening of markets (Du et al. 2014; Huffman and Rizov 2007).

Within countries this transition is also spatially uneven, usually expressed through a rural/urban divide (López-Carr and Ervin 2012; Mendez and Popkin 2004; Neuman et al. 2013). In developed countries phase 4 tends to be most common among rural residents and the urban poor, while in developing countries phase 3 is often more common in rural areas and phase 4 in urban areas. Local context is important, but this transition seems to be correlated with development and global access (Goryakin and Suhrcke 2014; Jaacks, Slining, and Popkin 2015; Song et al. 2015). This spatial heterogeneity occurs at even finer scales; throughout the world various populations are observed within cities in different phases of this transition. This pattern even extends to the household level, with rapid behavior change and rural-to-urban migration engendering undernutrition and overnutrition within the same family (Galal 2002).

Like other social processes, this transition is affected and mediated by factors such as socioeconomic status, race, gender, and other context-specific constructs and structures, including the local environment (McLaren 2007; Sánchez-Vaznaugh et al. 2009; Townshend and Lake 2009). The concept of "food deserts," which is the lack of healthy food options, has become a topic of much interest in geography. It has also been seized upon by the public and politicians, especially in the United States and Britain (Wrigley 2002; Ver Ploeg 2010). Food deserts appear to be particularly prevalent in the United States, perhaps due to its unique patterns of landscape development (Shaw 2006; Beaulac, Kristjansson, and Cummins 2009). Research on food deserts is primarily geographic, examining access and barriers to acquiring healthy foods. As this research has progressed, what was once regarded as a simple spatial issue is now seen to be part of complex and place-based issues of access and availability (Gordon et al. 2011; Morland and Evenson 2009; Walker, Keane, and Burke 2010).

Geographic research on food deserts ties into the larger topic of "obesogenic environments," which explores the effects of the entire landscape on malnutrition. In addition to food deserts, researchers have also paid particular attention to the overabundance of unhealthy food options (especially fast food) and environments that promote or restrict physical activity (especially walking) (Fraser and Edwards 2010; Townshend and Lake 2009). Research in this area has been particularly challenged, since there are an abundance of potential contributing factors to obesogenic environments, as well as a lack of consistent definitions of such (Guthman 2013). However, characteristics of local environments seem to be strongly associated with obesity outcomes (Boehmer et al. 2006; Fraser and Edwards 2010; Kirk, Penney, and McHugh 2010; Lebel et al. 2012; Townshend and Lake 2009).

8. Critical and Feminist Approaches to Malnutrition

Research in this area views food not merely as a source of nutrients, but also as an economic, cultural, and political construct (Kimura et al. 2014). Production or even availability of nutritious foods does not always guarantee increased consumption of those foods, as preferences and norms may vary. Moreover, there is little consensus on the makeup of an ideal diet, and this likely varies between individuals (Freidberg 2016; Hayes-Conroy et al. 2014). Merely improving access to food that is considered healthy according to conventional dietary guidance or even alternative nutrition guidance, fails to address the cultural politics of how the definition of a healthy diet was formed (Hayes-Conroy et al. 2014; Kimura et al. 2014).

This critique has led to what Hayes-Conroy and Hayes-Conroy (2016) call "hegemonic nutrition," which assumes (1) the relationship between food and body can be standardized; (2) nutrition can be reduced to its constituent macronutrients and micronutrients; and (3) that this attempt at objectivity decontextualizes nourishment from the social, cultural, and political contexts where it takes place, creating a pretense of objectivity. Instead, critical and feminist geographers argue, the relationship between food and malnutrition can be better understood through consideration of the spatial variation in agriculture, nutrition, economics, power, justice, and history (Del Casino Jr. 2015).

Del Casino Jr. (2015) provides a detailed overview of critical and feminist work, wherein geographers have challenged top-down, hegemonic, positivist, and reductionist views of food, nutrition, and the obesogenic environment and the problematizing of certain bodies. Hayes-Conroy et al. (2014) criticize dietary recommendations and policies for promoting messages that imply a healthy diet can prevent numerous diseases with multifactorial causes, particularly chronic diseases. Such approaches to dietary guidance attribute the causes of chronic diseases to an individual's inability to adhere to dietary recommendations, which are often based on low-quality evidence with limited scientific consensus.

Geographers have also criticized work attributing the causes of obesity to inert environments or poor individual behaviors, thereby blaming the victim while ignoring the societal structures and the role of powerful actors in agricultural and food industries (Evans 2006; Fazzino II and Loring 2016; Guthman 2012) . Evans (2006, 260) outlines the problems with viewing bodies in a mechanical way, noting how terms like "gluttony" and "sloth" have been inappropriately used in United Kingdom policy formation that attempts to solve the problem of obesity. Guthman (2012) draws from political ecology to provide evidence of new discoveries in environmental epigenetics—alterations in gene expression that are environmentally caused but may still be heritable—that demonstrate how ecological factors, not just individual behaviors, cause obesity.

While some researchers view the study of obesogenic environments as a move away from blaming individuals for obesity, this has also been challenged by critical geographers. Colls and Evans (2014) categorize the critiques of current work as such: the measurement of obesity, especially BMI, is problematic; moral judgments of obesity and racial and class discrimination persist; and most research lacks qualitative techniques. Other geographers have pointed out that the discourse about obesity, food deserts, and the obesogenic environment within geography follows traditional power structures, often problematizing women, low socioeconomic status individuals, non-whites, rural residents, or the disabled (Alkon et al. 2013; Kirkland 2011; Kurtz 2013; McPhail, Chapman, and Beagan 2013; Slocum and Saldanha 2016). Critical and feminist examinations of research on malnutrition are particularly relevant due to the uniquely gendered nature of food, cooking, and bodies (Neuhaus 2003).

BMI has received criticism from multiple circles (e.g. Nuttall 2015); In addition to the 'critical' objections (see Colls and Evans 2009 for a thorough review), some scholars within the public health sphere argue that it is a less-than optimal indicator of adiposity, that its relationship to mortality and obesity related conditions such as cardio-vascular disease and diabetes is worse than other measures, as well as issues with the categorization and discussion of BMI values. Despite this, we have included BMI as one of multiple dependent variables in Chapter Four. We include this measure for a number of reasons: it very efficient to collect, and participants typically consent to this procedure even if they are wary of more invasive ones; BMI is still almost universally collected in research related to health and allows for easy cross-study comparison; The number is well established and easily understood and remembered by participants. To mitigate some of its disadvantages we have included other measures of adiposity and diet-related health, and we do not organize results by category.

9. Chapter Four and the Geography of Malnutrition

In Chapter Four of this dissertation we test the relationship between migration path, origin, and destination place upon diet and diet-related health outcomes in internal migrants to Tijuana, Mexico. This work meets Grivetti's 'narrow' definition for Nutritional Geography, being that it "integrates distinct nutritional and geographic components" (2000). It also meets our proposed definition for the Geography of Malnutrition, in that it meets all of the above criteria, and focuses on geographic impacts on *poor* nutrition. In particular, this chapter belongs to the work examining the *Nutrition Transition*, large-scale changes in diet that, in this case, are affected in part by migration processes and mitigated by space and place.

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II. CHAPTER 2 - POPULATION, FOOD PRODUCTION, AND THE ENVIRONMENT[7]

A. Introduction

Delivering sufficient caloric quantity and a balanced diet for a world soon to eclipse 8 billion humans is among the most pressing human and environmental concerns of our era. How can we fairly, efficiently, and sustainably provide adequate nutrition to more people consuming more resources per capita? As population, health, and land transitions' progress at unprecedented speed through divergent trajectories, understanding these pathways is critical to informing how we will reconcile growing demands for food, fuel, and feed competing for space on dwindling available farmland. In this chapter we overview population and its relationship to land and food. We open by discussing common conceptual frameworks through which to approach this issue, then examine trends from recent decades in population change and distribution, as well as patterns of agricultural expansion and intensification at the global region scale and the national scale for Latin America, a continent that in recent decades has undergone transitions reflective of both developed and developing regions. Within Latin America we discuss three interrelated topics: the exponentially increasing intensification inputs as contrasted with stagnant or arithmetically increasing outputs; a contrast of Mexico and Brazil with the remainder of Latin America, demonstrating the important effect these two countries exert on Latin America's agricultural resource use and production; finally, three examples of how space and place context are critical in understanding the population-food-environment nexus. We conclude with some predictions on the future of this complicated relationship.

D. Population-Food-Environment Theory – Boserup, Malthus and Multiphasic

[7]This chapter has been adapted from:
Ervin, Daniel and David López-Carr. 2015. "Agricultural Inputs, Outputs, and Population Density at the Country-Level in Latin America: Decadal Changes Augur Challenges for Sustained Food Production and Forest Conservation." *Interdisciplinary Environmental Review (IER*), 16(1): 63-76.
Ervin, Daniel and David López-Carr. (Submitted). "Linkages among Population, Food Production, and the Environment at Multiple Scales" *The Journal for International and Global Studies*.

The most widely known theories concerning the relationship between population and agriculture have not changed notably over last two centuries. Still the go-to reference on population impacts on the environment today, Thomas Malthus posited at the end of the 18th century that increasing population would inevitably lead to famine and population loss. He argued that unchecked population grows 'geometrically' while food production can only increase arithmetically by adding to the amount of land that is used to grow food. He also presciently noted that the most productive land tends to be exploited first, and therefore as agricultural land expands the average production will fall (Bilsborrow and Carr 2001; Malthus 1803). Malthusian and neo-Malthusian thinking call for population growth to be checked. Malthusian theories also predict that population increase leads to an increase in land devoted to agriculture, referred to here as (agricultural) extensification.

The mass famine predicted by Malthus never happened, at least not on a continental scale. Technological advances in agriculture, a 20th century grouping of which is often termed the 'green revolution', allowed for exponential increase in agricultural productivity (the yield that can be achieved on a per area, such as per hectare, basis). At the tail end of this remarkable change in agricultural productivity Ester Boserup, an economist, advanced the theory that population pressure drives agricultural innovation. Increased population will therefore lead to more intensive cultivation of land (intensification).

In practice, increasing population can lead to a number of human responses, including extensification, intensification, changes in fertility related practices such as postponing marriage, and migration to less pressured areas (Carr and Bilsborrow 2001; Davis 1963). Bilsborrow (1987) synthesized these various, or "multiphasic", responses to increased population pressure and categorized them as economic (extensification and intensification), demographic (fertility), and economic-demography (migration) (Bilsborrow and Carr 2001). Bilsborrow further posits that people respond to population pressure first through their potential economic responses usually by extensifying and then intensifying. This is followed by temporary or seasonal outmigration, then full migration, and active fertility reduction as the final option. Malthus and Boserup's ideas have become so entrenched as to be considered near ontologies or philosophies as much as theories, with more complex contemporary theories often characterized as 'neo-Malthusian', or 'Boserupian'. Although the Malthus, Boserup and Multiphasic population environment theories specifically arose from population-agricultural relationships, many later theories include a broader range of environmental impacts, such as greenhouse gas emissions. However, as agriculture is the most impactful of human activities on the environment, all population-environment theories encompass and highlight the role of agriculture.

To recap many years of theoretical development in a limited space, early theories posited (or assumed) a direct and/or linear relationship between population, agriculture, and the environment. As research has progressed, some broad conclusions have been drawn: the scale of analysis for population-agriculture-environment is critical and with some frequency can change dramatically the nature and direction of key population-environment interactions (Carr, Suter, and Barbieri, 2005; Hazell and Wood 2008) and the population-agriculture-environment nexus is usually complex and non-linear (Hummel et al. 2014). These two conclusions are intimately related. At a village scale, for example, population decline could be associated with reforestation as farms are abandoned, or associated with deforestation as farms are consolidated to livestock ranches or larger farms. Meanwhile, at the national level population decline is often associated with reforestation and agricultural intensification (and/or the exportation of extensification) (Carr 2002; Meyfroidt et al. 2010). Factors such as export agriculture, globalization, diet choices, and transnational agro-businesses complicate this relationship. Despite all of this, increased population means increased food consumption and environmental degradation to some degree, and the same holds true at most scales of analysis (Schneider et al. 2011).

E. Agricultural Intensification and Extensification

Agricultural development in the developing world has proceeded at a rapid pace since the middle of the 20th century. Growing populations, a purposeful focus on export agriculture, and the adoption of Green Revolution agricultural techniques has accompanied the transformation of subsistence economies. Concomitantly, agricultural development in the form of extensification has converted forests and other natural landscapes into pasture land, farmland, and mechanically irrigated fields (Carr et al. 2009; Chen et al. 1998; Southgate 1998). Intensification of agriculture, whether it is developed land converting from pasture to cropland, increased use of fertilizers or pesticides, irrigation, or active production time by not permitting fields to lie fallow, has occurred simultaneously.

Agricultural extensification has obvious natural limits, and much of the world’s remaining undeveloped arable land is limited in its production capacity because of soil, slope, water access or other natural suitability factors (Aide et al. 2013; Futemma and Brondizio 2003; Hecht 2005; Hecht et al. 2006). As extensification becomes more difficult, the most viable option for food production increase becomes agricultural intensification. In practice the dual processes remain imperfectly tied in space and time and both extensification and intensification occur simultaneously (and sequentially) at various spatial scales. A causal relationship is also insufficiently complex, with some researchers claiming that the percentage of forest versus agricultural land held depends largely upon economic development (e.g. Mather et al., 1999), rather than need.

Each form of agricultural intensification also contains environmental costs, including loss of bio-matter and natural capital, aquifer depletion, and chemical contamination. The net environmental impact of using land more intensely is open to debate, but the increase in intensive agricultural by-products of practices appears unavoidable (Godfray et al. 2010; Green et al. 2005).

F. Population-Food-Environment Interactions

10. Total Population

Prima facie the most important driver in the population-food-environment nexus should be total population. Unassailably, *ceteris paribus*, more population means more demand for resources. However, the type or location of population has important consequences for their demand for food and other agricultural resources, and therefore their ultimate environmental impact. When conceptualizing the population-food-environment nexus it is critical to consider a population’s direct effects (e.g., clearing land and planting crops) and their indirect effects (e.g., consuming high-resource products such as red meat). Usually direct actions have local ramifications, while indirect actions have distant ramifications. The ultimate impact may vary widely (DeFries et al. 2010): a momentary choice to redecorate a house in teak may have more indirect effect, though distant in origin, on Indonesian rainforests than a lifetime of the direct, local actions of an Indonesian subsistence farmer.

11. Urban/Developed vs. Rural/Developing Population

Residents of the developed world are responsible for far more per capita consumption of food and agricultural resources, as they eat more total food and, very importantly, more red meat, animal products, and processed food, all of which are more resource-intensive to produce (e.g. Tilman et al. 2011). Tilman et al. (2011) compared groups of the richest and poorest nations and found that per capita consumption of calories was more than 250% higher in the richer nations, and protein consumption was 430% higher. The direction of this relationship is the same when one compares urban residents with rural residents in the developing world. Urban residents consume more in the absolute sense as well as more resource intensive food products. The impacts of developed and urban populations are more likely to be indirect and distant, whereas developing/rural impacts tend to be more direct and local.

12. Fertility

Fertility rate is the number of children per population group and is highly related to population growth, in any setting. Outside of the impact on total population, fertility rate and the consequent number of children per household also influences the population-food-environment nexus. First, households in developed countries and urban areas tend to have significantly lower fertility than their developing and rural counterparts. Second, the effects of fertility differ by region. High fertility in developed countries and urban areas causes higher population in these high food consumption areas, leading to indirect effects via greater food imports. In contrast, high fertility in developing and rural areas can cause increased direct, local, agricultural need (Bilsborrow and Stupp 1997; Carr 2009). High rural fertility can also lead to migration to developed or urban areas or migration to other rural areas.

13. Migration

Migration directly and indirectly impacts the food-environment relationship. Migration across international borders is perhaps the most easily recognizable form of this movement, but internal migration - the migration within a country or other political unit - is very common, although harder to track. For example, somewhere between 200 and 400 million people have migrated within China in the last 40 years (Chan and Bellwood 2011). Various types of migration interact with the food-environment nexus differently, but changing one's type of location tends to change one's behavior. Much of the internal migration in developing nations is rural-to-urban and most international migrants move 'up' the development continuum of nations from less to more developed (as well as also often moving from rural to urban places) (Carr 2009; Lambin and Meyfroidt 2011; Levy et al. 2011). Therefore, migration tends to move people to places where higher consumption of food and higher consumption of resource intensive food occurs. Rural-to-rural migrants, despite being less common, can have a disproportionately large effect on the environment due to their direct agricultural activities. These migrants are often the first agricultural users in 'virgin' or 'old-growth' environments, and have been noted as key actors in the conversion of rainforests to farmland (Carr 2009; Davis and Lopez-Carr 2010; Geist and Lambin 2002).

14. Remittances

One of the consequences of migration is remittances: money transferred by migrants from their current location to their origin location. Remittances can make up a large portion of the income in developing countries and produce substantial change in origin area behavior (Levitt 1998). The relationship between remittances and food and environment are complex and not uni-directional. In some cases, these remittances allow household members to abandon agriculture, meaning less direct environmental impact. In other cases, remittances can allow households to invest in agriculture, leading to intensification and/or extensification, increasing the direct environmental impact (Davis and Lopez-Carr 2010; Lambin and Meyfroidt 2011; Levy et al. 2011). Remittances and other aspects of cross-cultural contact create cultural change on both sides of the migration process (Levitt 1998). Relevant to our discussion, migration can cause the adoption of urban or developed world diets in origin places, with the resultant indirect environmental impacts (Handley et al. 2013, Levy et al. 2011).

G. Data and Methods

We analyze data gathered from the United Nations Food and Agriculture Organization (FAO) Agricultural Yearbooks, as well as FAO online statistical resources (www.faostat.org and http://faostat3.fao.org). We acknowledge that this country-level data is both broad in area and in to varying degrees estimated or imprecise, but the purpose here is to examine these factors at general level and these data are adequate for that task. The data we present can be categorized as population measures, input measures, and output measures. Inputs can be further categorized as extensification indicators or intensification indicators. The variables examined are summarized in Table 1.

15. Population:

- Total population.
- Percentage of total population that is rural.
- The average number of rural persons per 1000 hectares of arable and permanently cropped land (rural population density).

16. Input

- Total Ha of arable and permanently cropped land.
- Total Ha of land equipped for irrigation.
- The percentage of total land area that is arable and permanently cropped.
- The percentage of total land area that is in permanent meadows or pasture.
- The percentage of total land area that is in ‘agricultural use’ (created by adding the previous two statistics).
- The percentage of arable and permanently cropped land that is equipped for irrigation
- Total fertilizer use (in metric tons).

- Engine-driven agricultural machine (tractor) use presented as tractor per 1000 Ha of arable and permanently cropped land.
- Metric ton (Mt) of fertilizer used per Ha of arable and permanently cropped land,
- Tractor per Ha of arable and permanently cropped land.
- Fertilizer use, expressed as Kilogram (Kg) per Hectare (Ha) of cropped land.

17. Output

Agricultural output is presented for two groups of crops: cereals, which include wheat, maize, and rice, and oil cakes (equivalent), which includes all edible oils, notably soybeans, rapeseed, and sunflower seeds. We chose these groups because they contain the most common agricultural commodities worldwide and are cultivated to some degree throughout Latin America. We present total output in Mt over Ha of arable and permanently cropped land (yield).

These indicators were chosen as they are mostly universally available across the space and time periods encompassing this study and their use in examining associations among processes of population, agricultural extensification and intensification is established in prior literature. A number of statistical indices changed or were no longer reliably collected by the FAO after 2002, in which case comparison with pre-2002 numbers is inappropriate or unavailable. We present the 2011 statistics where possible to demonstrate continuing trends. We compare groupings of country results using a two-tail, two-sample unequal variance T-test conducted in Microsoft Excel. The formula for this statistic is described by the following equation: $t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$ where x bar 1 and x bar 2 are the sample means, s^2 is the pooled sample variance, n1 and n2 are the sample sizes and t is a Student t quantile with n1 + n2 -2 degrees of freedom.

Table 1 - Data

Statistic	Raw or Calculated	Measure of	Expressed in	Source
Total population	Raw	Population	Number	UNPOP
% of rural population	Calculated	Rural population	%	UNPOP
Rural population per Ha of arable and permanently cropped land	Calculated	Rural population density	Person per Ha	FAO & UNPOP, our calculation
Total population growth - rural population growth	Calculated	Rural vs. Urban pop	%	UNPOP, our calculation
Arable and permanently cropped land	Raw	Extensification, input	1000 Ha	FAO
Total land equipped for irrigation	Raw	Intensification, input	1000 Ha	FAO
% of total land that is arable or permanently cropped	Calculated	Extensification, input	%	FAO, our calculation
% of total land that is pasture	Calculated	Extensification, input	%	FAO, our calculation
% of land in permanent use	Calculated	Extensification, input		
% of arable and permanently cropped land equipped for irrigation	Calculated	Extensification, input	%	FAO, our calculation
Total Fertilizer use	Raw	Intensification, input	Metric ton	FAO
Total number of tractors	Raw	Intensification, input	Number	FAO
Fertilizer used per arable and permanently cropped land	Calculated	Intensification, input	Kg/Ha	FAO, our calculation
Tractor per arable and permanently cropped land	Calculated	Intensification, input	Number	FAO, our calculation
Total cereal production	Raw	Output	Metric ton	FAO
Total oilcake equivalent production	Raw	Output	Metric ton	FAO
Cereal yield	Calculated	Hg per Ha	Number	FAO
Oilcake yield	Calculated	Hg per Ha	Number	FAO

H. Global Region Scale Trends in Population and Agriculture over Time

We now present an analysis of the relationship between population, agricultural extensification, and intensification at the global region scale, with a closer examination of Latin America (Table 2). Our analysis is at the decadal scale from 1970 to 2010 (when available). We highlight Latin America, as it has rapidly moved through the demographic transition[8] during this period. Central America and South America also hold a large portion of the world's remaining high-biomass forests, both of which have been heavily exploited for agricultural production during this time period, raising significant concern about global environmental impacts.

Table 2 - Global Region Population Statistics

	Population		**% Rural Pop**		**Rural Persons / Ag Land**	
Global Region	2010	1970- 2010	2010	1970-2010	2010	1970-2010
Africa	1,022,234	177.67%	60.8%	-15.7%	2.42	56.2%
Asia	4,164,252	95.05%	55.6%	-20.7%	4.19	15.5%
Europe	738,199	12.55%	27.3%	-9.8%	0.69	7.8%
Latin America and the Caribbean	590,082	106.05%	21.2%	-21.8%	0.68	-31.0%
Northern America	344,529	48.96%	18.0%	-8.2%	0.29	18.2%
Oceania	36,593	87.60%	29.3%	0.6%	0.24	93.9%
Sub-Saharan Africa	822,724	188.61%	63.7%	-16.8%	2.26	62.8%
World	6,895,889	86.57%	48.4%	-15.0%	2.17	31.6%

Since 1970, population has increased globally by 86% and has increased more dramatically in Latin America (106%) and Africa (176%). The percentage of this population that is rural has decreased, globally dropping from 63% to 48%, even though rural population density has increased by 32 %, a function of total population growth outstripping rural population growth vis-á-vis urbanization. Latin America is the only region where rural population density has declined, and it has increased dramatically in Africa, especially in sub-Saharan Africa (SSA). Rural population density shows similar trends globally, with the number of rural people per arable land area increasing, except in Latin America, which is now equal to that of Europe. Meanwhile, African and Asian rural population density continues to increase, despite already high levels. The increase in rural population is far less than the increase in overall population for these regions.

[8] Wikipedia contributors, "Demographic transition," *Wikipedia, The Free Encyclopedia,* https://en.wikipedia.org/w/index.php?title=Demographic_transition&oldid=795697323

Table 3 contains extensification and intensification statistics at the global region level.

Table 3 - Global Region Agricultural Extensification and Intensification Statistics

	Global Region Extensification Statistics						Global Region Intensification Statistics					
	% of Land Arable or Cropped		% Land in Pasture		% of Land in Agricultural Use		% of Arable or Cropped Land Irrigated		Fertilizer Use	Tractor use		
Country	2010	1970-2010	2010	1970-2010	2010	1970-2010	2010	1970-2010	2000	1970-2000%	2000	1970-2000 %
Africa	8.6	2.5	30.7	0.8	39.4	3.4	5.4	0.8	17.41	8.50	2.42	31.4
Asia	17.9	3.4	34.9	13.7	52.8	17.0	40.8	14.3	132.51	106.20	14.48	731.6
Europe	13.2	-4.0	8.1	-10.2	21.3	-14.2	8.7	2.7	72.55	-20.35	35.90	68.8
Latin America and the Caribbean	9.1	2.9	27.3	3.5	36.4	6.4	12.0	3.9	15.68	9.52	10.93	115.7
Northern America	11.3	-1.7	14.1	0.2	25.4	-1.6	13.0	3.9	92.25	25.14	23.47	-2.6
Oceania	5.3	-0.1	43.3	-10.1	48.6	-10.2	60.7	12.5	61.50	30.36	7.92	-15.1
Sub-Saharan Africa	10.0	2.9	33.2	1.7	43.2	4.6	8.3	1.3	29.43	16.15	3.59	60.9
World	11.9	0.9	25.8	1.6	37.6	2.5	20.6	7.7	89.09	40.43	17.79	57.4

Concerning the extensification of agriculture, since 1970 the global percentage of agricultural land has mostly held steady at around 11 percent for cropped and arable land and 25 percent for meadow and pasturelands. Percentage of arable and cropped land in the developed regions has dropped towards this mean of 11% over time, while the percentages in Latin America and Africa have risen to meet it. The exception here is Asia, which was at about 15 percent in 1970 and has risen since. The global percentage of land that is permanent meadows or pasture has held mostly steady over the study period from 24.2% to 25.8%. Similar to arable and cropped land, this steady trend hides regional differences. The numerator in these two statistics is total land, whose large size perhaps hides the dramatic changes these percentages indicate. For example, Africa increased its percentage of total land area in agricultural use by 3.4 percent. This means that there are 100,802,064 more hectares of arable and cropped land in 2010 than there was in 1970, an area of land roughly equivalent in size to the nation of Egypt. Previous work has noted that during the 20th century global cropland has more than halved from .075 ha to 0.35

per person, even though cropland extent has increased dramatically (Ramankutty, Foley, and Olejniczak 2002).

Intensification statistics indicate that the percentage of arable and cropped land irrigated has increased across all global regions, especially in Asia where the percentage of irrigation is very high at 40.8 percent, much of this due to rice cultivation. Fertilizer use from 1970 to 2000 (country-level numbers are not available after 2002) has doubled globally from 48.6 to 89.1 kg per ha in 30 years. All regions increased their fertilizer use, save Europe. Latin America and Asia increased dramatically both in percentage and absolute use of fertilizer, while Africa has tripled its percentage of use but remains low in absolute terms. Regarding the use of tractors, from 1970 to 2000 there was an almost 60 percent global increase, and an increase in most global regions. However, there remain stark differences in the absolute use of mechanical machines for agriculture between continents, despite the major increases in Latin America, Asia and Europe.

At this crude scale, is it possible to observe any connection between population change and agricultural practices? Increases in population and increases in rural population density were accompanied by increases in both extensification and intensification, although each occurred at different rates in different places. In the case of Latin America, increases in total population and decreasing rural population density have been accompanied by increases in both extensification and intensification. We discuss how these overall trends occurred distinctly at national and regional scales in the following section.

I. Trends in Latin America

18. Central America

Table 4 contains statistics about population change in Central America from 1970 to 2010, while Table 5 contains extensification and intensification statistics for these nations.

Table 4 - Central America Population Statistics

	Population		% Rural Pop		Rural Pop Density	
Country	2010	1970- 2010 %	2010	1970-2010 %	2010	1970-2010 %
Belize	312	154.7%	55.0%	6.0%	1.60	20.2%
Costa Rica	4,659	155.9%	35.8%	-25.4%	2.88	27.4%
El Salvador	6,193	65.8%	35.7%	-24.9%	2.48	-31.6%
Guatemala	14,389	164.1%	50.7%	-13.8%	2.98	32.1%
Honduras	7,601	182.7%	48.4%	-22.7%	2.52	103.1%
Mexico	113,423	118.7%	22.2%	-18.8%	0.90	-2.2%
Nicaragua	5,788	141.4%	42.7%	-10.2%	1.16	10.2%
Panama	3,517	132.9%	25.4%	-27.0%	1.23	-15.4%
Central America	**155,881**	**124.0%**	**27.9%**	**-18.3%**	**1.20**	**8.6%**

The total population of Central America increased by almost 125% between 1970 and 2010. Only El Salvador's growth was below 100%, much of which is explained by an outmigration caused by civil war and demographic pressure (Gammage 2007). Despite this population increase, rural population density for the region increased by only 8.6%, although Mexico's large size tends to lower this number, obscuring rural population increases in most Central American countries. Major drivers of this population change are a steep decline in mortality in the 20th century because of improved health conditions and concurrent economic development (Carr, Lopez, and Bilsborrow 2009). Fertility began to fall across the region in the 1960s for a few select countries, in the 1970s for the majority of countries, while a few more rural Central American countries lagged behind (Ibid). The process of population momentum[9] explains the continuing population growth despite this fertility decline (Keyfitz 1971; Carr 2004). During the study period there has been much rural-to-urban migration within countries and the region, as well as a large international migration movement, almost exclusively to the United States (Carr 2004). This population growth and migration have left Central America highly urbanized, despite low economic development in many nations.

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[9] Wikipedia contributors, "Population momentum," *Wikipedia, The Free Encyclopedia*, https://en.wikipedia.org/w/index.php?title=Population_momentum&oldid=776508182

Table 5 Central America Extensification and Intensification Statistics

	Extensification Statistics				Intensification							
	% of Land Arable or Cropped		**% Land in Pasture**		**% of Land in Agricultural Use**		**% of Arable or Cropped Land Irrigated**		**Fertilizer Use**		**Tractor use**	
Country	2010	1970-2010	2010	1970-2010	2010	1970-2010	2010	1970-2010	2000	1970-2000 %	2000	1970-2000 %
Belize	4.7	2.7	2.2	0.6	6.9	3.3	3.7	1.5	62.02	-15.4	11.62	-8.8
Costa Rica	11.4	1.7	25.5	-1.2	36.8	0.5	18.6	13.3	340.82	240.4	14.29	38.1
El Salvador	43.1	12.9	30.7	1.3	73.8	14.2	5.0	1.8	86.42	-16.9	3.81	-4.7
Guatemala	22.8	8.3	18.2	7.0	41.0	15.3	12.9	9.3	107.68	261.6	2.19	8.0
Honduras	13.0	-0.7	15.7	2.3	28.8	1.6	6.0	1.7	126.49	711.6	3.64	230.1
Mexico	14.4	2.5	38.6	0.3	53.0	2.7	23.2	7.7	66.86	187.7	11.86	200.3
Nicaragua	17.7	7.7	25.1	5.3	42.8	13.0	2.9	-0.5	13.44	-37.4	1.32	219.3
Panama	9.8	2.4	20.6	5.3	30.4	7.7	5.9	2.2	44.87	16.0	11.15	152.3
Central America	**14.8**	**2.9**	**34.8**	**1.0**	**49.6**	**4.0**	**19.7**	**6.6**	**72.17**	**172.3**	**10.15**	**175.8**

Concerning extensification, the percentage of land in agricultural use increased for the region as a whole to almost 50 percent, which is the highest for any global region except Asia (Table 3). This increase in cropped and pastureland has come at the expense of forest (Houghton, Lefkowitz, and Skole 1991). Guatemala and Nicaragua, both with the highest remaining amount of rainforest in Central America, increased their land in agricultural use dramatically. Intensification statistics indicate that irrigation has increased significantly (again the land area numerator hides a large area of land affected). Fertilizer use from 1970 to 2000 has increased dramatically on a per area basis, as well as in total (not shown). Tractor use increased for the region as a whole, but this hides much variability, wherein the more developed nations of Costa Rica, Mexico and Panama increased their already high use, and the less developed nations remained quite low or even decreased in use. In sum, extensification and intensification occurred simultaneously in Central America, accompanied by growing total population but despite rural population density decreases (see Ervin and Carr 2015 for further discussion). Agricultural intensification increased dramatically along with GDP, as rural-urban migration shifted labor from farms to wage labor and intensive farming operations consolidated land in rural areas.

19. South America

Data for South America indicate that the population for the region as a whole grew over 100%, although a few countries such as highly urbanized Uruguay and highly rural French Guiana and Suriname grew far less than that. Rural population density fell by more than 40% for the region, although the three countries of Chile, Colombia, and Ecuador all increased their rural population density. Similar to Central America, South American demographic changes during the study period were driven by fertility decline, high rates of internal rural to urban migration, and some international migration. However, South America experienced fertility decline earlier, had higher rates of rural to urban migration, and less international migration, which was largely to Europe (Carr, Bilsborrow and Barbieri 2003).

Table 6 - South America Population Statistics

	Population		**% Rural Pop**		**Rural Pop Density**	
Country	2010	1970- 2010 %	2010	1970-2010 %	2010	1970-2010 %
Argentina	40,412	68.5%	7.7%	-13.5%	0.08	-57.0%
Bolivia	9,930	135.5%	33.6%	-26.6%	0.84	-43.8%
Brazil	194,946	102.9%	15.7%	-28.4%	0.39	-61.6%
Chile	17,114	78.7%	11.1%	-13.7%	1.10	89.3%
Colombia	46,295	117.0%	25.0%	-20.2%	3.45	80.0%
Ecuador	14,465	142.2%	33.1%	-27.6%	1.86	31.0%
French Guiana	231	376.0%	23.8%	-8.8%	3.55	-77.6%
Guyana	754	4.7%	71.7%	1.1%	1.21	-11.5%
Paraguay	6,455	160.0%	38.6%	-24.3%	0.62	-63.3%
Peru	29,077	120.5%	23.1%	-19.5%	1.50	-24.8%
Suriname	525	40.9%	30.7%	-23.4%	2.64	-50.2%
Uruguay	3,369	19.9%	7.5%	-10.1%	0.15	-57.7%
Venezuela	28,980	171.3%	6.7%	-21.5%	0.60	-30.5%
South America	**392,555**	**105.0%**	**17.2%**	**-23.1%**	**0.48**	**-43.9%**

Table 7 South America Extensification and Intensification Statistics

	Extensification				Intensification							
	% of Land Arable or Cropped		% Land in Pasture		% of Land in Agricultural Use		% of Arable or Cropped Land Irrigated		Fertilizer Use		Tractor use	
Country	2010	1970-2010	2010	1970-2010	2010	1970-2010	2010	1970-2010	2000	1970-2000 %	2000	1970-2000 %
Argentina	14.0	4.1	39.6	2.2	53.6	6.4	4.3	-0.4	30.1	832.2	10.5	67.1
Bolivia	3.7	2.1	30.5	4.1	34.1	6.2	4.4	-0.3	2.4	160.1	1.9	46.1
Brazil	9.2	4.3	23.2	4.9	32.3	9.2	6.7	4.8	100.7	314.8	12.4	207.5
Chile	2.3	-3.2	18.8	4.1	21.2	0.9	110.0	81.2	228.4	623.3	25.6	208.6
Colombia	3.0	-1.5	35.3	1.0	38.3	-0.5	31.3	26.3	144.8	404.5	4.6	2.3
Ecuador	10.4	0.1	19.8	10.5	30.2	10.6	38.0	19.6	55.2	313.5	4.9	305.4
French Guiana	0.2	0.2	0.1	0.1	0.3	0.2	38.7	-61.3	75.0	NA	26.2	-31.1
Guyana	2.3	0.4	6.2	1.2	8.5	1.6	33.6	2.6	26.3	-2.6	7.6	-15.2
Paraguay	10.0	7.7	42.8	16.4	52.8	24.1	1.7	-2.7	21.0	113.6	5.3	1.4
Peru	3.5	1.3	13.3	1.5	16.8	2.8	26.8	-12.6	59.3	98.0	3.1	-21.1
Suriname	0.4	0.1	0.1	0.0	0.5	0.2	93.4	19.8	86.6	53.7	19.9	-18.0
Uruguay	9.9	1.7	72.2	-5.7	82.1	-4.0	12.6	8.9	73.6	51.7	23.2	11.8
Venezuela	3.7	-0.3	20.4	1.8	24.1	1.5	32.5	24.6	83.1	389.3	14.4	163.3
South America	**8.0**	**2.9**	**26.3**	**3.9**	**34.4**	**6.8**	**9.7**	**3.4**	**79.3**	**340.2**	**11.0**	**115.1**

South America as a whole increased its percentage of land in agricultural use, although again country rates vary widely. Brazil's massive land area pulls the continents average towards its value, obscuring lower rates of agricultural extensification in almost all other countries. The total amount of land converted to agricultural use in the period was approximately 120 million Ha, roughly the size of the nation of Columbia. Much of this extensification came at the expense of tropical forest. Intensification statistics indicate large increases in the amount of land irrigated, large increases in the amount of agricultural machines and a notable increase in the use of fertilizer.

Trends for South America largely mirrored Central America. Urbanization and international migration became increasingly important demographic processes (Carr et al 2009). Fertility declined notably, particularly in urban areas. However, rural areas lagged in the demographic transition with continued high infant mortality and fertility, with the southern cone nations of South America, Chile, Argentina, and Uruguay notable counter-examples (Carr, Pan and Irvani 2006; Pan and Lopez-Carr 2016). Elsewhere, remote rural areas in both regions were associated with continued high though declining numbers of small farm (semi) subsistence agriculture, particularly in less desirable lands. Meanwhile, pastureland and intensive export agriculture surged, largely to meet demand from higher earning urban populations both within Latin America and also abroad. These exports are primarily destined for the rapidly growing urban populations of China and Southern Asia. Already complex relationships between population size, structure, and distribution have been rendered yet more complex by increasing demand for food, especially meat and dairy products from populations outside of Latin America.

Does this mean that demography has become a less predictive factor of land change in the region? Perhaps demography, rather than losing importance in relation to land change, has qualitatively changed as a driver (Aide et al 2013). Local population size, growth, and structure driving demand for food and thus local land conversion are less important. More important is the demand coming from an urbanizing developing world both in Latin American and elsewhere, particularly Asia. Where rural-rural migration of farm households has for decades been a major driver of forest clearing in Latin America, increasingly rural-urban and international migration both within the region and elsewhere is shifting labor from agricultural to urban service applications, accompanied by rising wages and increased adoption of western diets characterized by more processed and animal based products with relatively higher energy and land conversion impact when compared to the grains and legumes that have been the staple of rural populations (Ervin and Lopez-Carr 2015)**.**

20. Inputs and Outputs

Table 8 presents statistics on the use of fertilizers and machine inputs in Latin American countries. For all of the nations in Central America, fertilizer per hectare of cropland has steadily and dramatically increased since 1961. The least dramatic increase was in El Salvador where they used 142% more fertilizer per hectare than in 1961; conversely Honduras increased its fertilizer inputs by nearly 30-fold during the time period. Results for South American nations are similar, with large increases in per hectare use of fertilizer consistently observed. In most nations, the increase in fertilizer use per area has been accompanied by an expansion of cropland, leading to a large increase in total fertilizer used (not shown). Table 8 also contains the total, displaying steady increases in nearly all countries.

Table 8 - Intensification measures 1961-2001

Central America and Mexico	Fertilizer Use (Kg/Ha. of Cropland) 1961	1971	1981	1991	2001	% Change 1961-2001
Belize	8.6	22.9	27.3	64.2	47.5	454%
Costa Rica	38.9	115.2	142.2	226.0	239.1	514%
El Salvador	31.8	121.0	116.3	93.6	77.0	142%
Guatemala	9.8	15.9	50.8	80.2	102.7	946%
Honduras	3.8	17.8	16.1	19.3	106.1	2701%
Mexico	8.0	26.4	63.1	61.1	67.8	743%
Nicaragua	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Panama	7.2	48.0	107.3	52.6	27.8	286%
Average	**15.5**	**52.5**	**74.7**	**85.3**	**95.4**	**518%**
Unweighted Average						**827%**
South America	**1961**	**1971**	**1981**	**1991**	**2001**	
Argentina	0.8	2.9	3.6	6.1	29.7	3464%
Bolivia	0.6	2.4	3.3	3.4	3.6	555%
Brazil	9.5	25.9	51.8	57.4	102.9	982%
Chile	12.1	30.9	29.0	104.1	223.7	1756%
Colombia	14.3	36.5	53.8	125.2	149.9	949%
Ecuador	4.4	7.2	27.7	27.6	124.9	2750%
French Guiana	*NA*	*NA*	150.5	108.3	75.0	*NA*
Guyana	24.0	32.6	28.7	31.0	27.2	13%
Paraguay	6.2	25.6	16.3	11.5	9.1	48%
Peru	0.3	1.6	2.6	5.2	15.7	5024%
Suriname	31.7	63.4	75.0	33.8	60.0	89%
Uruguay	16.4	61.8	44.6	60.4	82.3	401%
Venezuela	5.5	19.1	41.1	109.8	88.3	1518%
Average	**10.5**	**25.8**	**44.0**	**57.0**	**82.7**	**689%**
Unweighted Average						**1462%**

Central America and Mexico	Tractors (Number) 1961	1971	1981	1991	2001	% Change 1961-2001
Belize	211	596	825	1100	1150	445%
Costa Rica	3800	5200	6000	6500	7000	84%
El Salvador	1600	2642	3320	3420	3430	114%
Guatemala	1950	3250	4020	4220	4300	121%
Honduras	304	1950	3440	4650	5200	1611%
Mexico	56000	92800	143078	317313	324890	480%
Nicaragua	130	550	2250	2650	2900	2131%
Panama	347	2693	5420	5047	8066	2224%
Total	**64342**	**109681**	**168353**	**344900**	**356936**	**455%**
Unweighted Average						**901%**
South America	**1961**	**1971**	**1981**	**1991**	**2001**	
Argentina	120000	171000	213000	274034	299608	150%
Bolivia	1300	2300	4200	5300	6000	362%
Brazil	72000	183500	569000	730000	806000	1019%
Chile	33550	34050	34370	37570	54000	61%
Colombia	18241	23469	29500	31000	21000	15%
Ecuador	1558	3400	6844	10919	14680	842%
French Guiana	20	39	106	303	419	1995%
Guyana	3240	3340	3480	3620	3630	12%
Paraguay	3900	4900	8035	15878	16500	323%
Peru	6950	11100	11900	12750	13191	90%
Suriname	580	940	1120	1300	1330	129%
Uruguay	24695	29910	33160	32800	33000	34%
Venezuela	11400	20700	39000	48500	49000	330%
Total	**297484**	**488748**	**953832**	**1204101**	**1318475**	**343%**
Unweighted Average						**412%**

Table 9 - Agricultural Production Measures 1961-2011

Central America and Mexico	Cereals Yield (Hg/Ha) 1961	1971	1981	1991	2001	2011	% Change 1961-2011
Belize	5963	15290	20714	22761	31012	28172	420%
Costa Rica	11535	18378	22763	32989	35496	33762	208%
El Salvador	9378	16771	16913	16335	19096	24920	104%
Guatemala	8221	11422	15240	18100	18254	19874	122%
Honduras	10511	12095	13769	13170	14469	12326	38%
Mexico	11049	15299	22925	24269	28556	32406	158%
Nicaragua	9397	10826	14712	14171	16928	21430	80%
Panama	9515	11988	16255	18829	18315	25685	92%
Unweighted Average	**9446**	**14009**	**17911**	**20078**	**22766**	**24822**	**141%**
Weighted Average							**153%**
South America	**1961**	**1971**	**1981**	**1991**	**2001**	**2011**	
Argentina	14106	17835	24249	26661	32068	46723	127%
Bolivia	9543	11031	13005	13580	17849	23654	87%
Brazil	13463	12908	16110	18506	31485	40377	134%
Chile	14413	19944	21204	40508	49356	69339	242%
Colombia	12752	19045	24797	24507	35483	40329	178%
Ecuador	10106	9619	17679	16739	18994	26044	88%
French Guiana	23877	37142	10784	42722	37870	24539	59%
Guyana	20137	18210	31163	31422	39478	47408	96%
Paraguay	12517	12574	15277	17684	21602	34800	73%
Peru	14877	17501	21349	22926	32413	38988	118%
Suriname	27633	33915	39581	38134	37673	41327	36%
Uruguay	8597	10349	18041	24188	33381	45874	288%
Venezuela	11155	12348	18853	26214	33033	36014	196%
Unweighted Average	**14860**	**17879**	**20930**	**26445**	**32360**	**39647**	**118%**
Weighted Average							**133%**

Central America and Mexico	Oilcakes yield HG/HA 1961	1971	1981	1991	2001	2011	% Change 1961-2011
Belize	ND	ND	ND	3612	8354	10364	ND
Costa Rica	4546	4305	4685	3591	3490	3479	-23%
El Salvador	6837	7808	6014	4393	6397	8707	-6%
Guatemala	4074	6519	8328	8506	6957	12058	71%
Honduras	4335	4209	3038	2581	4018	4033	-7%
Mexico	5206	7207	7836	9077	6761	8212	30%
Nicaragua	5121	6430	5623	4172	12728	13259	149%
Panama	NA	ND	ND	3732	2083	2038	ND
Unweighted Average	**5020**	**6080**	**5921**	**5150**	**6062**	**7398**	**21%**
Weighted Average							**35%**
South America	**1961**	**1971**	**1981**	**1991**	**2001**	**2011**	
Argentina	3624	4247	9408	13237	17694	19027	388%
Bolivia	4809	5364	9114	14038	12001	14816	150%
Brazil	3426	4029	10208	10693	20864	23591	509%
Chile	5933	9010	6762	11355	16113	17852	172%
Colombia	4850	5921	6195	6483	6778	7661	40%
Ecuador	2354	2457	6103	8096	5690	5941	142%
French Guiana	ND	ND	NA	ND	2920	4263	ND
Guyana	ND	ND	ND	3457	3642	3625	ND
Paraguay	3068	6177	10619	12705	16743	21790	446%
Peru	4708	5385	6178	4803	5782	6729	23%
Suriname	3119	3139	2419	1914	4232	2960	36%
Uruguay	2705	3047	5677	6111	7848	13999	190%
Venezuela	2416	3079	3883	3675	3087	5070	28%
Unweighted Average	**3728**	**4714**	**6961**	**8047**	**9492**	**11333**	**155%**
Weighted Average							**193%**

Table 9 displays per-area production measures for Latin America. The intensification trends observed in Table 8 should, if intensification is working as intended

–namely producing more food per hectare, evince a positive relationship with per-area agricultural production in Table 3[10]. As contrasting intensification and production is our main purpose here, we calculate change between 1961 and 2001, the same periods that data is available for inputs. We only display 2011 data. The results of these tables indicate that output per acre has indeed increased throughout Latin America. However, outputs have increased at a notably lower rate than inputs.

Simple arithmetic comparison of the intensification and production figures for each country points to the lack of a linear relationship between agricultural input and output. For example, from 1961 to 2001 Honduras increased its fertilizer use per hectare by 2701% and its number of tractors by 1611%, yet its gains in yield are low or non-existent. Argentina, a large developed country and by all accounts an agricultural export success story, increased its fertilizer use by almost 3500% per Ha in the study period, yet its per hectare outputs for cereals and oilcakes increased by only 127% and 388%. While most countries have experienced increases in production along with increases in intensification, in a worrisome echo of Malthusian theory, the results point to inputs increasing exponentially, while outputs at best increase arithmetically.

J. Rural Population

We now present an examination of the relationship between rural population, other demographic factors, and agricultural extensification and intensification. Rural population density varies considerably by county in Latin America, as displayed in Table 10. Mexico is the sole nation in Central and Meso-America with rural population densities below one person per hectare, along with several South American countries.

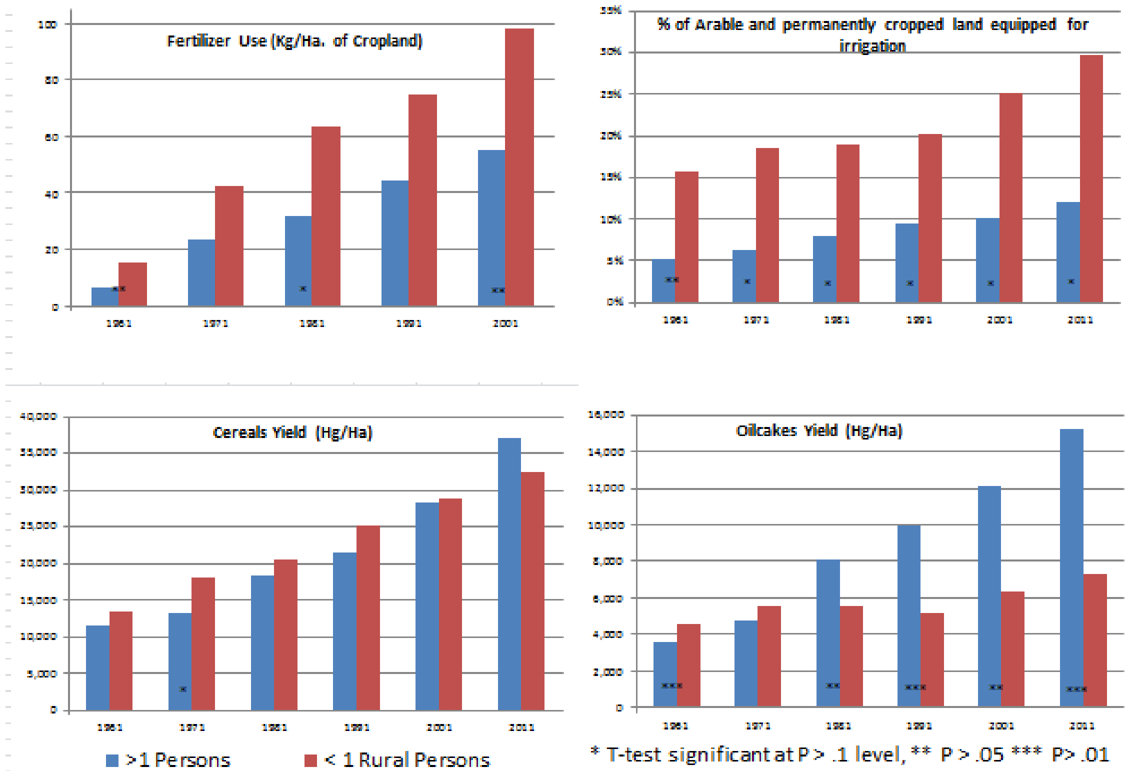
[10] As contrasting intensification and production is our main purpose here, we calculate change between 1961 and 2001, the same periods that data is available for inputs. We only display 2011 data.

Table 10 - Latin American countries by 2010 rural population density

Country	Person per Ha
Argentina	0.08
Uruguay	0.15
Brazil	0.39
Venezuela	0.6
Paraguay	0.62
Bolivia	0.84
Mexico	0.9
Chile	1.1
Nicaragua	1.16
Guyana	1.21
Panama	1.23
Peru	1.5
Belize	1.6
Ecuador	1.86
El Salvador	2.48
Honduras	2.52
Suriname	2.64
Costa Rica	2.88
Guatemala	2.98
Colombia	3.45
French Guiana	3.55

We observe that countries with a mean of fewer than one rural person per Ha of cultivated land and countries with a mean of more than one rural person per Ha of cultivated land varied considerably in land use outcomes. We present these differences graphically in Figure 1. Each graph in the figure compares that year's results for the statistic between country groupings. T-test significance results are indicated with asterisks in the figures.

Figure 1 - Agricultural Inputs and Outputs by Rural Population Density



These graphs point to several conclusions. First, there are noticeable differences between the two country groupings for the input measure: fertilizer use (Kg/Ha. of land), and for two of the three output measures: percentage of arable and permanently cropped land equipped for irrigation, and oilcakes yield (Hg/Ha). Despite a modest number of data points in the two country groupings, grouping of countries with more than one person per rural hectare use far less inputs per agricultural unit and yet have roughly the same output than the higher population density group with cereals and out performed with oilcake production. This is despite their significant lower use of inputs, all of which is contrary to Boserupian expectations of increased population density leading to increased agricultural intensification and performance. Cereals are more likely to be consumed for subsistence than are oilcakes and yield increased similarly among the two population density groupings during the time period, but, in support of Boserup, with a notable change over time of the higher density nations out-producing the lower density nations. Conversely, oilcakes are more likely to be used for animal feed and for export and yet, counter to Malthusian notions, increased most dramatically among nations of higher population density. We find these results to be interesting, but difficult to draw meaningful conclusions from.

21. Brazil and Mexico

The comparisons of per unit input and output measures by country groups produce intriguing results, but they are ultimately difficult to frame as a coherent theory. It is quite possible that the most important factor in agricultural inputs and outputs is the policies and behaviour of specific countries. In support of this notion, we present some total agricultural inputs and outputs for the two dominant countries in Latin America: Brazil and Mexico, as compared to the remaining countries in the region. While the economic importance of Brazil and Mexico may be widely known, this particular analysis of country-wide agricultural inputs and outputs suggests the impact of the two nations in Latin America remains striking.

Figure 2 - Agricultural Resource Use and Total Production of Brazil and Mexico Vs. the Rest of Latin America

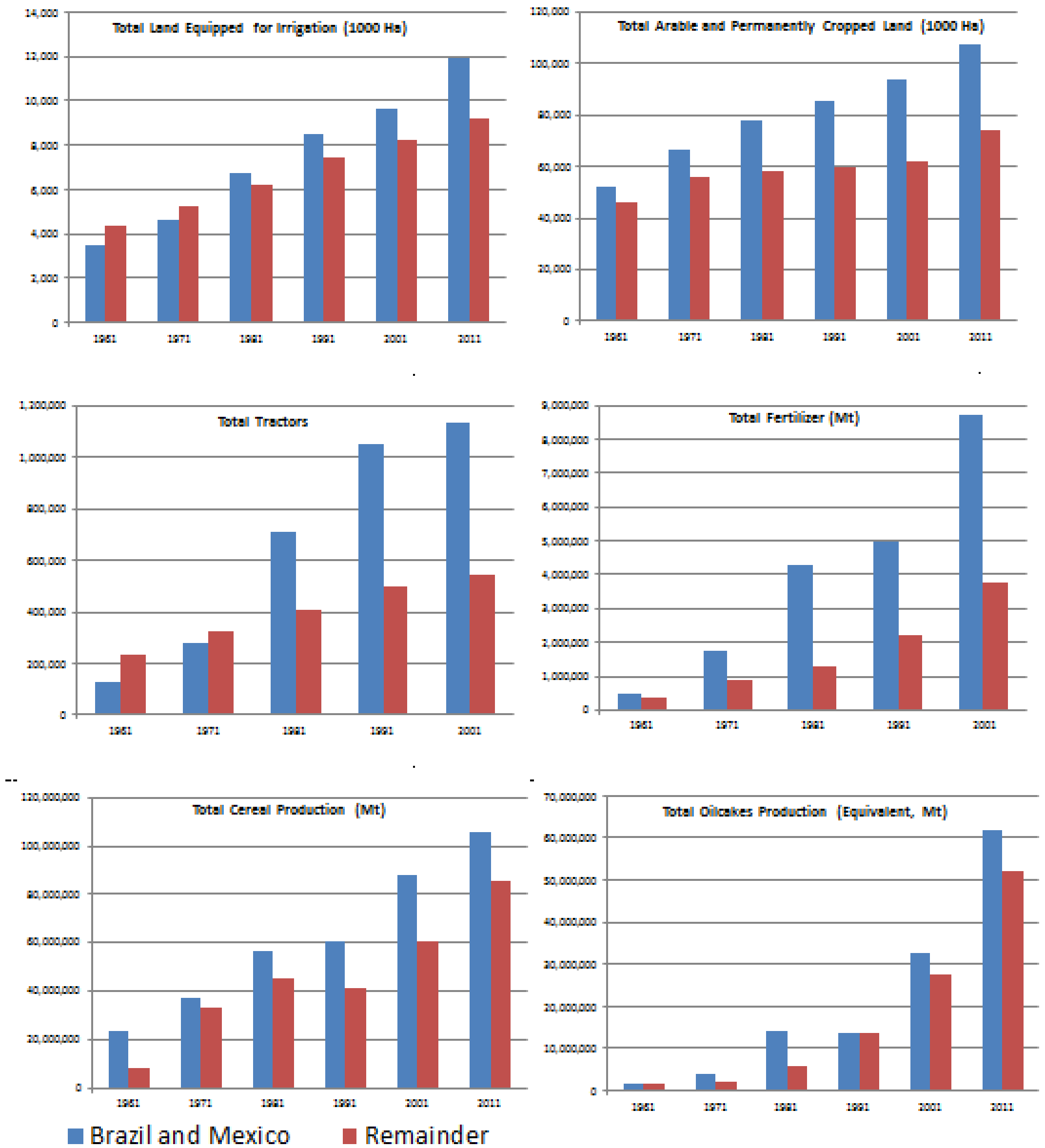


Figure 2 demonstrates that, in terms of agricultural resource use and output, Brazil and Mexico together exceed the rest of Central and South America combined. In some cases, such as with fertilizer use and tractors, Brazil and Mexico are using more than double the amount of resources per unit area than the rest of their Latin American neighbours combined. These results have implications for addressing resource use at a scale-appropriate scope. For example, at least in some cases, perhaps it is more strategic to effect land use policy by targeting these two countries. However, we acknowledge that examining data at the country level may exaggerate the importance of countries or the differences.

K. Case Studies

We have examined population, agricultural extensification and intensification at the global scale, the global region scale, and the country scale. We now present three case studies at three different scales: country-regional, municipal, and 'county', where population changes were associated with different outcomes for agricultural and the environment.

22. Population Decline and Extensification: Amazonian Brazil

From 1970 to 2010 Brazil's absolute rural population declined from around 42 million to 32 million, while the nation doubled in total population (UNPOP). During this period, the Brazilian government encouraged the conversion of the Amazon to agricultural use through the construction of roads and cities in the region, as well as making land, credit, and even food available for settlers (Carr 2002; Hecht and Cockburn, 1990; Stewart, 1994). Small-scale agriculture proved to not be viable for many of the initial settlers, who then out migrated to cities or to other rural frontiers. The initial farmland was consolidated and converted into pastureland for cattle ranching, and the conversion of forestland to ranchland continued despite a declining rural population. Although high fertility and other contributors to land scarcity in outmigration areas led to initial conversion of much of this area, environmental degradation for agriculture continued despite declining local rural population (Ibid.). Similar trends have been observed recently in the Ecuadorian Amazon (Barbieri and Carr 2005; Carr 2002; Pan et al. 2007).

23. Population Growth and Extensification: Petén, Guatemala

Petén is the largest department of Guatemala, and at 12,960 square miles accounts for about one third of its total area[11]. Historically, Petén was densely forested, almost inaccessible, and had a very low population. Two actions by the Guatemalan government

][11] Wikipedia contributors, "Petén Department," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Pet%C3%A9n_Department&oldid=635190972.

caused population to increase rapidly: offering land at very cheap rates to Guatemalans who were willing to cultivate it in the 1960s, and building functional roads to connect it to the rest of Guatemala in the 1970s. The result of this was large in-migration to the area. Driving this was a lack of agricultural land in the remainder of Guatemala, itself caused by high rural fertility, rural poverty, and concentration of agricultural land (Carr 2002; Schwartz 1990). In Petén this in-migration, and to a lesser extent high fertility of the existing population, resulted in incredible population growth in the region, and extensive conversion of forest to agricultural land (Carr 2002; Grandia and Schwartz 1999, Schwartz 1990). This conversion of forest to cropland, and then grazing land, persisted from the 1960s to the current day, despite the creation of vast reserves and parks in 1989 (Carr 2002; Carr 2005). This is a clear example of rural population growth driving extensification (Carr 2002; Grandia and Schwartz 1999; Schwartz 1990).

24. Population Growth and Intensification: Sarapiquí, Costa Rica

Sarapiquí, a canton (equivalent to a county) of the Costa Rican province of Heredia, experienced intense population growth beginning in the 1960s. In-migration beginning in 1967, spurred by a banana plantation, led initially to extensive conversion of forest land to agricultural land (Carr 2002; Schelhas 1996). High fertility led to increased population density and declining land available for households. In this case, these conditions did not primarily lead to further land conversion or migration to other rural frontier areas. Instead, the main response was off-farm employment and agricultural intensification on existing plots where small scale farmers raised the market products of dairy cattle, coffee or black pepper (Ibid.).

These case studies at three different scales demonstrate that population growth or decline can be associated with the primary response of extensification, intensification, and in or out migration. There are multiple factors contributing to these outcomes besides local population change, including population processes occurring in other areas, land availability, quality, and distribution, political systems, and agricultural market influences, global or otherwise. However, these case studies suggest that population growth, population density, and scale remain important and sometimes misunderstood when examining the population-food-environment nexus.

L. Conclusions

Our analysis indicates that agricultural inputs and outputs have increased over the prior several decades across Latin America. While output per acre has increased continuously throughout the region, what may be alarming in its support of Neo-Malthusianism, is the observation that output growth consistently failed to keep pace with the dramatic increase in inputs during the period. We observed significant differences between nations of higher versus lower rural population density. But contrary to Boserupian (and Malthusian) expectations, nations of lower population density invested more in agricultural intensification. An understanding of empirical processes corroborates this apparent contradiction to theory. As local population plays an increasingly reduced role in consumption and production trends, and as global demand for animal products surge, the more developed and urban nations, largely of South America, have placed a greater portion of their rural land in highly mechanized, low labor-intensity agriculture for large-scale output, increasingly for export production (Carr et al. 2009). These land transitions in Latin America are thus intimately related to the nutrition transition globally (Ervin 2014; Popkin 2009), with much of Latin America now following a forest transition observed historically in Europe and North America (Rudel and Coomes 2005). As a result, some places, especially mountainous areas, are reforesting while the major arc of deforestation is concentrated in large-scale soy and beef production in large swaths of southern and central South America, particularly Brazil (Aide et al. 2013; Morton et al. 2006).

Population drivers are related to a host of factors (e.g., Bremner et al. 2010; Lambin et al. 2001) and are increasingly distanced in space and time from land change impacts (Aide et al. 2013; Grau and Aide 2008; Lambin and Meyerfroidt 2011). The timing, spatial pattern, and magnitude of rural farm abandonment, land consolidation by large holders, and urban and international migration will have a large impact on predicting future land cover change patterns in the region and globally (López-Carr and Burgdorfer 2013; López-Carr and López-Carr 2014; Rudel et al. 2002; Schmook and Radel 2006). Fewer rural households devoting their lives to farming leading to labor being replaced by financial and technological capital in rural areas is clearly a major factor. However, among rural dwellers who remain, remittances sent from household members in the city or abroad will also play an increasingly important role in rural agricultural production and land change (Davis and López-Carr 2010; Grau and Aide 2008). From a political-economic view, the potentially displacing effect on rural populations of the unprecedented expansion of agricultural exports may challenge neoliberal modernization policies (Altieri and Toledo 2011). Climate change, and with it, changing geographies of water availability, will further texture implications for both land change and food security (Bradley 2006; Buytaert 2012; Murtinho et al. 2013).

Regardless of the underlying drivers, be they population-based, economic, or political, this analysis demonstrates that the resources being devoted to agricultural production, be it in the form of land, water, or chemicals, have increased rapidly. The smaller increase in output, especially per area output, raises concerns about the ability of these countries to sustain food production while conserving their remaining forests. There are seemingly unavoidable limits on the gains that can be realized through intensification, perhaps demonstrated by this analysis. Therefore, the exploitation of remaining land seems inevitable.

Much of the food produced in the developing world is no longer produced to meet the needs of local or regional populations, but to feed swelling middle class urban populations in the developing world and the relatively wealthy in the developed nations. How does this change relate to Boserupian or Malthusian theory? Are we now facing purely economic pressure to innovate or do demographic drivers remain but in a changed guise? It is clear that population processes are just one of several important drivers of agricultural development and food consumption, and the relationship between population and land use change is difficult to predict, especially without a strong understanding of local context. However, it also remains seemingly unavoidable in the short to middle term that global food demand will rise due to increased population and increased meat and dairy consumption. One recent estimate expected a doubling of crop production by 2050 would be needed to meet current consumption habits (Tilman et al. 2011). The best arable land is already in production and remaining available arable land not currently in production is a rare and dwindling commodity. In order to meet this demand, where will there be extensification, where will there be intensification, where will both occur? Will there be new intensification technologies? What will be the implications of these shifting inputs to food production? Foley et al. (2011), predict that doubling food production could be achieved without agricultural expansion, using intensification methods and reducing animal product consumption and waste. Godfray et al. (2010), among others, discuss the potential of increased aquaculture to meet future food demand.

Evidence suggests that without major behavioral changes or technological breakthroughs, more people eating more food, especially more meat and dairy products, will continue to threaten the sustainability of food systems and natural habitats. What can we do? International coordination in *where* agriculture is produced may be a proverbial ''low hanging fruit'' towards increased food production efficiency with mitigated environmental impact. Each unit of land cleared in the tropics vs. temperate zones causes twice the carbon stock loss, while producing less than half of the agricultural yield (West et al. 2010). While we anticipate continued technological innovation, the pace and magnitude of future advances cannot be predicted. Yet we have the ability through political will to make meaningful changes now. Behavioral changes away from red meat consumption and towards plant-based protein among inhabitants of developed countries and the rising middle class in the developing world would have an immediate impact, freeing up most of the world's agricultural land for conversion to more efficient crops or wildland regeneration.

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III. EXAMINING THE RELATIONSHIP BETWEEN MIGRATION AND FOREST COVER CHANGE IN MEXICO FROM 2001 TO 2010[12]

- Introduction

Mexico is an environmentally diverse nation featuring some of the greatest reserves of forests (~70 million Ha) in Latin America[13]. However, forest change has been dramatic in recent decades. The nation has experienced smallholder settlement and deforestation in southern tropical biomes, more modest forest loss accompanying urbanization and agricultural land consolidation in the central valleys, and land abandonment and reforestation in more arid and mountainous regions (Aide et al. 2013; Bray and Klepeis 2005; Carr, Lopez, and Bilsborrow 2009; García-Barrios et al. 2009). There have been numerous studies examining drivers of Land use and land cover (LU/CC) change, especially forest cover change at regional, watershed, community, or regional scales in Mexico (e.g. Barsimantov and Antezana 2012; García-Barrios et al. 2009; Radel and Schmook 2008). These prior studies have documented a number of different drivers, mostly using case studies, but have yet to address internal and international migration's relationship with land change at the national scale. These forms of mobility are relevant because they can drive forest change in dramatically different ways. Outmigration can lower labor supply that can potentially slow down primary sector activity (e.g., increasing the amount of land lying fallow) and slow down the rate of deforestation (in the extreme, leading to reforestation). Financial flows to or from migrants, commonly known as remittances, can also be used to invest in non-primary economic activities which, in turn, could have a similar effect on the rate of deforestation/reforestation. Further, remittances invested in primary sector activities could lead to increased intensification and reduced extensification (thus reducing/increasing the rate of deforestation/reforestation), or simply promote

[12] This chapter has been adapted from: Ervin, Daniel, David López-Carr, Fernando Ríosmena, and Sadie J. Ryan. "Examining the Relationship between Migration and Forest Cover Change in Mexico from 2001 to 2010." *Regional Environmental Change*.

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extensification (e.g., via increased cattle ranching activities), increasing deforestation or stalling reforestation.

In this paper we examine the relationship between forest-cover change, migration, and other demographic, and economic indicators in Mexico from 2001 to 2010, concluding that international and internal migration are important in forest cover change in Mexico at national and sub-national (biome) scales. We begin with a discussion of the recent academic literature on migration and forest cover change in general, as well as research specific to Mexico, arguing that an examination of this relationship at the national scale is needed. We then advance our hypotheses, discuss our data and statistical methods, which consist primarily of a series of multiple regression analyses. We follow with the results of our study, presenting and discussing the national and biome-scale trends in forest cover change, and then displaying the results of our regression analyses. We close with a discussion of these results, their support of our hypotheses, and their broader implications.

25. Migration and Forest Transition

There is ample literature on the relationship between internal migration and forest cover change in developing nations: numerous studies demonstrate the significance on forest cover change of rural-to-rural migration and rural-to-urban migration (e.g., Barbieri and Carr 2005; Lambin et al. 2001; Rudel, Bates, and Machinguiashi 2002). Less work has explicitly linked international migration, or the role of remittances on forest cover change (Lopez et al. 2006). With the increasing importance of financial and social exchanges associated with international migration –including that in nations with significant remaining forest cover, the association between international mobility and forest cover changes has a large potential impact on the future of forests (Hecht 2010). According to Forest Transition Theory, as populations migrate to seek wage labor in urban and international destinations, forest cover returns on abandoned small farms, usually located on suboptimal farmland, while it declines in areas with large industrial farms, typically located on preferable agricultural conditions (Rudel, Schneider, and Uriarte 2010). Aide and Grau (2004) theorize that ecosystems will tend towards recovery from rural land abandonment associated with agricultural intensification and followed by rural out-migration to urban areas. Perfecto and Vandermeer 2010 take a different tack, arguing that conservationists need to consider a landscape scale approach, the “matrix quality” model, rather than anticipating that forest transitions will stem forest loss. Several authors, including Redo et al. 2012 and Aide et al. 2013, argue that finer-scaled analyses and data are needed to definitively link observed changes in forest cover in Latin America to help explain forest transition theory.

Research in Latin America has revealed connections among population dynamics, migration, agricultural expansion, and forest cover. These links are particularly dynamic in frontier regions. For example, Carr 2008 and Ludewigs et al. 2009 demonstrate rapid population and agricultural change in newly settled forested regions, while Perz 2004 illustrates variation in forest cover outcomes according to farming strategies. The magnitude and direction of the relations is scale and context specific, however. For example, Carr, Lopez, and Bilsborrow 2009 find inconclusive evidence as to whether agricultural extensification or intensification accompanies population growth. While Zak et al. 2008 show how global commodity demands drive deforestation in areas of high export agriculture growth, such as the southern cone of South America and Argentina, even as rural populations contract.

26. Migration and Forest Cover Change in Mexico

Mexico has a long history of international population mobility, the vast majority of which is directed to the U.S, in addition to the high levels of internal rural-to-urban migration typical of most of Latin America during the second half of the 20^{th} Century (Arizpe 1981; Massey 2008). Because of its historical and persistent links to agricultural labor in the United States, international migration remains deeply entrenched in rural sending areas (Durand et al. 2001) and thus represents an interesting case study on how international mobility can affect forest cover change. During the study period, migration from Mexico to the United States underwent drastic changes. After reaching a historic peak in the early 2000s, the economic recession in the U.S. and an increasingly hostile climate resulted in declining rates of emigration (Hanson and McIntosh 2010; Passel et al. 2012). Currently, Mexico is probably a net receiver of migrants from the U.S., a drastic swing that began during our study period (Gonzalez-Barrera 2015). The full ramifications of this national change are certain to be significant, although beyond the scope of this article. Long-term migration patterns in Mexico have also contributed to halving the share of the Mexican population living in rural areas since the 1970s; however, as of 2010 nearly a quarter of the population –or 25 million people –remain rural inhabitants (Ervin and López-Carr 2015). This fuels a large level of agricultural production containing both significant labor-scant, capital and technology intense, industrial large-scale agriculture and ranching, and labor intense, family-based, small-scale agriculture and livestock rearing (Ervin and López-Carr 2015; Gomez et al. 2005; Taylor et al. 2005).

Past research on forest cover change in Mexico has identified diverse drivers, which is no surprise, given the environmental, social, and economic diversity of Mexico, as well as the variety and complexity of potential drivers of forest conversion. García-Barrios et al. (2009) conducted a review and meta-analysis of the literature on this topic in Mexico, and found that first: different drivers, or groups of drivers, were important in different types of forest. Of those that they were able to untangle, drivers of forest *loss* included expanded crop areas and (often illegal) logging in temperate forests, and expansion of cultivation and cattle ranching in tropical dry and rainforests. Forest *regrowth*, or lower-than-average forest loss, was associated with land abandonment and the creation of protected areas (PAs) in temperate and tropical dry forests, while tropical dry forests also experienced agricultural intensification and the growth of (non-PA) forest management systems. In all but one study, this research began during the 1980s and ended in 2000 at the latest. Since that time, a number of new trends have been noted in the literature. There have been important changes to policies concerning agriculture, land development, and market access, which have been associated with forest cover-change (Galvan-Miyoshi, Walker, and Warf 2015; Schmook and Vance 2009). Notably, seemingly minor changes in regulations in the 1990s led to extensive highland pine-oak forests being converted to avocado orchards in e.g., the highlands of Michoacán in the Central West (Barsimantov and Antezana 2012). In addition, the expansion of cattle ranching continues to drive forest loss, especially in the south (Busch and Vance 2011; Kolb and Galicia 2011).

The process of migration and its resultant effects of depopulation and increasing capital in sending communities is a common theme for many of the proposed explanations of forest loss *and* forest regrowth in Mexico (e.g. Lopez et al. 2006; Mendoza et al. 2011). However, this trend can be quite context specific, resulting in wholly different outcomes under seemingly similar conditions: withdrawal from agriculture; extensification of land use to previously fallow or abandoned land, often for cattle pasture; intensification on existing land in production, by replacing labor with technology (Busch and Vance 2011; Ervin and López-Carr 2015; Schmook and Radel 2008). Further, local or temporary ecological, political, and economic conditions may influence forest cover change. Different outcomes from the same drivers have been observed simultaneously even within the same small village (e.g. Radel, Schmook, Chowdhury 2010). We would note that the forest-cover outcomes for internal rural-to-urban migration appear to be very similar to international migration (e.g. Schmook, Radel, and Méndez-Medina 2014).

Using very similar outcomes as the current study, Bonilla-Moheno et al. (2012 & 2013) examine land cover change in Mexico from 2001 to 2010 as a function of: environmental processes, land-tenure system, economic marginalization, type of income, general population change (presumably, mainly driven by migration), and population density. While Bonilla-Moheno and colleagues conclude that environmental factors are the primary cause of forest cover change during the period, they do find some evidence supporting the importance of land tenure systems. More importantly perhaps, they also find that forest cover change has different drivers operating in different ecoregions, or biomes. They hypothesize that "forest recovery in municipalities that lost population is an expected effect of land abandonment, the increase in woody cover in municipalities that gained population might be the result of urbanization, changes in rural productivity, or new economic activities that intensify land use in one area, yet allow woody recovery in other areas" (Bonilla-Moheno et al. 2012, 552). Following this literature, we tested an expanded set of variables, more directly linked to specific components of population change and of different types and aspects of population mobility more specifically, hoping to account for possible major inputs to forest cover change from a number of directions.

Our analysis uses Moderate Resolution Imaging Spectroradiometer data, processed and aggregated into municipality boundaries. This data set was created for all of Latin America and has been used for numerous peer-review publications since, including those previously discussed by Bonilla-Moheno et al. (2012 & 2013) to examine Mexico. Some authors have criticized this dataset (Skutsch et al. 2014) for its large pixel size and choice of classification techniques. However, for the purpose of our research question we believe that its high temporal resolution makes it the most suitable data for our analysis, and that its flaws are well mitigated (see Bonilla-Moheno et al.'s 2014 response to Skutsch et al. for a detailed response to criticism). In addition, the use of this data has resulted in articles that were "critically reviewed and accepted in a wide array of peer-reviewed journals, including those in high-impact remote sensing journals." (Ibid. pg. 388).

N. Hypotheses & Methods

We proceeded with the assumption that forest cover change would be heavily driven by environmental factors, as it is a natural, environmental process. We also assumed that drivers of forest cover change would be different in different biomes (as demonstrated by Ibid. and given that historical political-economic processes have led to different regional development and land use patterns across Mexico). We retested both of these assumptions during our analysis and found them to be supported.

In addition, we hypothesize that:

1. International *and* internal migration will be an important driver of land cover changes in Mexico.
2. Variables from the population and economic suites will also impact forest-cover change.

To test these hypotheses, we assembled data on the environment, migration, population, and the economy, from diverse sources and used multiple regression analyses to explore their relationships with forest cover change. Our measure of forest cover change is derived from 250-m pixel MODIS satellite data that was classified, aggregated to fit boundaries of Mexico's 2,438 *municipios*, and split into yearly results, as described in Aide et al. (2013). Municipalities were assigned to the biome with the greatest area, and those biome polygons were assigned to the largest surrounding biome (Clarke et al. 2012). These biomes were derived from Olson et al. 2001. We would note that the Desert and Xeric Shrubland (DES) is in arid and semi-arid regions and not strictly a forest biome, but rather a natural vegetation/ shrubland biome and includes shrubland in large portions of arid and semi-arid regions. Our dependent variable is the slope of the regression ($p > 0.10$) indicating the km^2 of yearly woody cover gain or loss at the municipal level from 2001 to 2010. Linear regressions were fit to the resulting pixel-wise cover type data, and regression slopes were filtered for significance and explained variance, to describe cover gain/loss (see Aide et al. 2013 and Clark, Aide and Riner 2012).

Our independent variables were drawn from a number of sources and assembled into 'suites' of potential contributors to forest-cover change (details in Table 1):

- Environmental: measures of area of each *municipio*[14], precipitation, temperature, elevation, and terrain variability.
- Migration: measures of international out-migration, international return migration, international circular migration, and of internal migration, as well as international remittances, to capture different types and aspects of mobility (see detailed description in Table).
- Population: measures of total population, population growth, and fertility, to control for other forms of population change not related to mobility.
- Economic: measures of economic marginalization, unemployment, primary sector employment, cattle, and education.

The 'environmental' variables were constructed with a synthesis of variables described in Aide et al., (2013). We then include additional *municipio*-scale variables described below, to explore the relative influence of international versus internal migration, shifting demographic pressures, socioeconomic and labor sector changes within major ecological biomes. All variables were collected at the *municipio* scale,

[14] Area of *municipio* is included in all models to serve as a control variable, such that we are effectively modeling the rate of forest change as opposed to the amount, thus standardizing for municipality size.

which is the smallest scale at which consistent data is available for the nation. All variables are centered, and where available, presented as proportional change both for scale issues, and ease of interpretation in the model.

Table 1. Variables.			
Variable name	**Time Scale***	**Variable Description**	**Source**
Environmental Variables			
Area_km2	2010	Area (km$^{2)}$	Aide et al. 2013
DEM_Mean	2010	Mean elevation	Aide et al. 2013
DEM_Std	2010	SD of elevation	Aide et al. 2013
PrecipMA	2000-2010	Annual mean precipitation (mm)	Aide et al. 2013
PrecipSDA	2000-2010	Annual SD of precipitation (mm)	Aide et al. 2013
PrecipSDM	2000-2010	Monthly SD of precipitation (mm)	Aide et al. 2013
TempM	2000-2010	Annual mean temperature (C)	Aide et al. 2013
TempSDA	2000-2010	Annual SD of precipitation (mm)	Aide et al. 2013
TempSDM	2000-2010	Monthly SD of precipitation (mm)	Aide et al. 2013
Migration Variables			
PEMIG	2000, 2010	International outmigration rate-ratio = proportional change in the percent of households in municipality with at least one international out-migrant in 2005-2009 relative to same percentage in 1995-1999.	CONAPO
PCIRC	2000, 2010	International circular migration rate-ratio = proportional change in percent of households in municipality with at least one circular migrant (i.e., leaving to and returning from the US in the five-year period prior to interview) in 2005-2009 relative to the same percentage in 1995-1999.	CONAPO
PRETR	2000, 2010	International return migration rate-ratio = proportional change in the share of municipal households with at least one member moving back from the US in the five-year period prior to interview) in 2005-2009 relative to the same percentage in 1995-1999.	CONAPO
PA25	2000, 2010	Change in population, age 25-29 (Age structure proxy for internal migration)	INEGI
PREM	2000, 2010	Proportional change in in share of municipality's households receiving international remittances	CONAPO
Economic Variables			
MARG00	2000	An index statistic representing economic marginalization	CONAPO
PMARG	2000-2010	Proportional change in marginalization index (MARG00)	CONAPO
PRIMSECT00	2000	Percent of working people in primary sector activities	INEGI
PUNEMP	2000-2010	Proportional change in unemployment	INEGI
TOTALHEADS	2007	Count of heads of beef cattle	INEGI
ED00	2000	Percentage of complete secondary level education	INEGI

PED	2000-2010	Proportional change in education level (ED00)	INEGI
Population Variables			
CPOP00	2000	Population	INEGI
PCPOP	2000-2010	Mean annualized growth rate in population	INEGI
PA4	2000, 2010	Ratio of population under 5 in 2010 by ratio of population under 5 in 2000 (Age structure proxy for fertility)	INEGI
CONAPO = National Population Council INEGI = National Institute for Statistics and Geography All estimates come from 2000 and 2010 Census short-form enumeration available via INEGI or CONAPO			

We began by conducting a number of multiple regression analyses, including a regression analysis using biomes as a categorical variable to validate our assumptions about biomes and support continued analysis at the biome scale. We then created separate models for: *municipios* with significant forest cover change in either direction; *municipios* with significant positive change; *municipios* with significant negative change; and the significant *municipios* for the majority direction of change in each of the four biomes[15]. For each we began with a regression using only the environmental variables, following our prediction that environmental factors will explain the plurality of model residuals. Then, following an information-theoretic approach to model selection (Burnham and Anderson 2003) we used the multi-model selection R package 'glmulti' (Calcagno & de Mazancourt, 2010) to step through each variable in the suites in the order listed above. Using this method we created all possible unique models with our suites of variables, and ranked them based on Akaike's Information Criterion modified for small sample sizes (AICc), finally selecting the 'best' model (minimum criteria of AICc ≤ 2).

AICc is a measure of the relative goodness-of-fit of the model (Equation 1), where k is the number of variables in the model, L is the maximum value of the likelihood function of the estimated model, and n is the sample size (Ibarra et al. 2013). AICc modifies AIC to include a greater penalty for extra parameters. When comparing a set of candidate models, smaller values of AICc indicate a model that best fits the data.

[15] The minority direction of change for all biomes was in total only 67 *municipios,* or ~12% of the significant results, and therefore too few to extract meaningful results from when further segmented.

$$AIC = 2k - 2\ln(L)$$
$$AICc = AIC + \frac{2k(k+1)}{n-k-1}$$

Equation 1.

The advantages of the glmulti model selection process over more 'traditional' step-wise processes is that all potential models are evaluated, resulting in the same model being selected as the 'best', regardless of direction or order of variables, unlike other methods (Calcagno & de Mazancourt, 2010). We believe that this method allowed us to identify important non-environmental contributors to forest cover change, despite the environmental suite's high level of variance described (Table 3) and the large number of variables examined.

O. Results

We anticipated large-scale differences in forest cover change at the level of biome, based on previous work, and our initial regression analysis using the biomes as a categorical variable confirms this. Using tropical and subtropical coniferous forests (CON) as the reference category we found that biome category explained a considerable amount of the variance in land cover change (R^2=0.202, p< 0.001), with the Desert and Xeric Shrubland (DES) biome the most important predictor. This was *not* significant among municipalities experiencing woody cover loss (negative slopes), but *was* significant (R^2=0.215, p<0.001) for those experiencing woody cover gain (positive slopes). Therefore, we subset the data into the 4 majors biomes in Mexico, namely (1) Desert and Xeric Shrubland (DES); (2) tropical and subtropical coniferous forests (CON); (3) tropical and subtropical dry broadleaf forests (TSB); and tropical and subtropical moist broadleaf forests (TSMB) (Figure 1, Table 1)[16].

Mexico has 2,438 *municipios*; of these, 22% (i.e., 538 municipalities) experienced a significant (*p* > 0.10) slope of change in their woody vegetation, with 17% (422 *municipios*) exhibiting significant positive change and 116 significant negative change

[16] These four biomes represent more than 99% of *municipios* in Mexico. There was one *municipio* classified as 'Mediterranean Forests, Woodlands and Scrub' that had significant woody vegetation change which we excluded from our analysis for simplicity.

(Table 2 & Figure 1). The total area seeing significant positive change was about 500,000 SQ KM, or around 25% of Mexico's total land area. The total area seeing significant negative change is around 120,000 SQ KM (around 6% the total land area). Note that these total areas are based on 250m pixel size data, which has also been aggregated up to match the *municipios*. Therefore, these results should not be considered accurate at a fine scale or as a reliable counting statistic, but indicative of the trend at the *municipio* and larger scales.

Examining positive change in vegetation by biome land area, changes in Desert and Xeric Shrubland (DES) overwhelmingly located in the borderlands and the Central Northern plateau between the Western and Eastern Sierras Madre, account for almost four times the significantly positively changed land area than the other three biomes combined, and more than a fifth of Mexico's total land area. *Municipios* classified as tropical and subtropical dry broadleaf forests (TSB) and tropical and subtropical coniferous forests (CON), mostly located in the foothills of the Western Sierra Madre along the Pacific Coast and in the Central part of the country, both exhibit significant positive change in approximately 50,000 km^2 (about 3% of Mexico's total land area). Significant negatively changed areas are much smaller in total, with *municipios* in the Eastern and Southeastern portions of the country classified as tropical and subtropical moist broadleaf forests (TSMB) containing about half of this (~65,000 km^2). Examining the biomes, we can see that each follows an obvious trend with the strong majority of significantly changed land area in all four biomes in the same direction, positive for DES, TSB, and CON, and negative for TSMB.

Figure 1. Terrestrial Biomes and Significant Woody Vegetation Change at the *Municipio* level 2000-2010, Mexico.

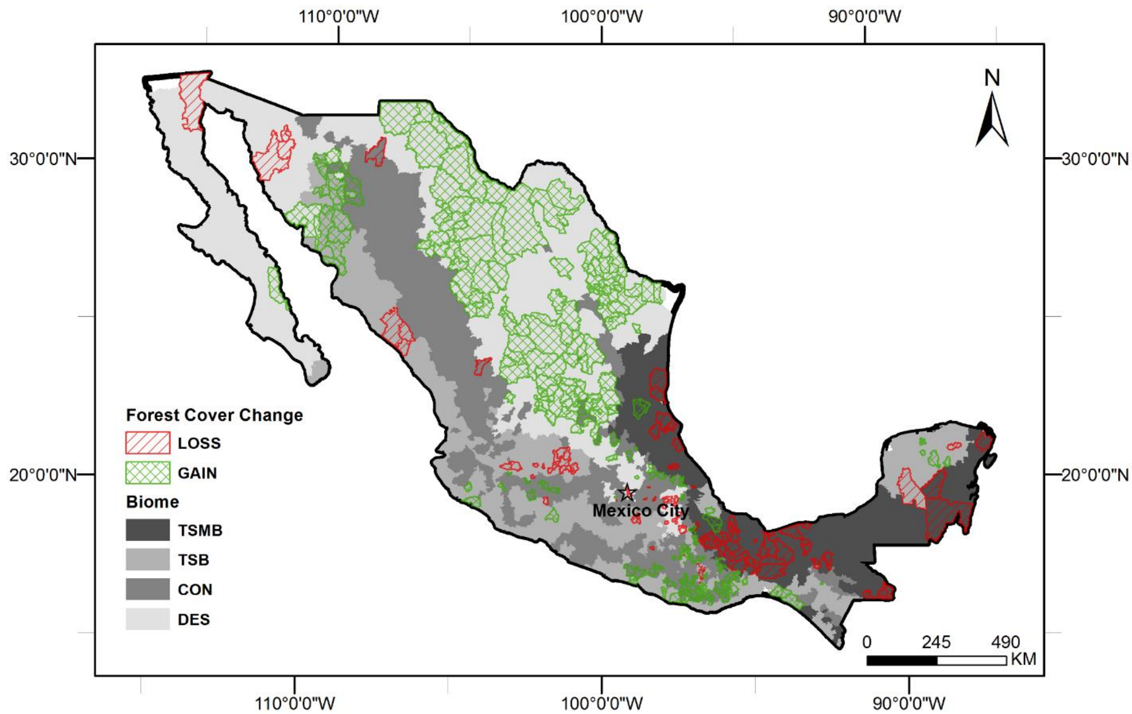

Table 2. Biomes and Significant Woody Cover Change.				
Biome	Tropical and subtropical moist broadleaf forest (TSMB)	Tropical and subtropical dry broadleaf forest (TSB)	Tropical and subtropical coniferous forest (CON)	Desert and Xeric Shrubland (DES)
# of Municipios	432	701	829	474
# of Municipios, + Change	8	109	165	140
# of Municipios, - Change	57	30	10	19
% Munis Positive	2%	16%	20%	30%
% Munis Negative	13%	4%	1%	4%
Land Area (SQ KM)	293,002	382,262	429,743	862,085
Positive Change (SQ KM)	4,641	57,690	45,152	393,781
Negative Change (SQ KM)	66,878	20,000	3,249	29,164
% SQ KM Positive	2%	15%	11%	46%
% SQ KM Negative	23%	5%	1%	3%

27. Environmental Suites Results

The resulting selected models are displayed in Table 3 and 4, all results are significant at $p > .05$ r lower. For all *municipios* with significant results, the top selected model using the environmental suite of variables captures 47% of model variance, as conveyed by the adjusted R^2 statistic (Table 3, model 'MexE1'), while the top selected model for *positive slopes* captures 68% of the variance (model 'MexE1pos') and for *negative slopes* captures 74% of the variance (model 'MexE1neg'). These environmental variables also capture similar or greater amounts of variance in each of the individual directional biome models. These very high adjusted R^2 results support our prediction of environmental drivers being important, and our proposed method of using these as 'base models' to add our subsequent variables suites to improve model fit.

Table 3. Environmental Suite Models.

Model Name	Model Description	Adjusted R^2	AICC	Variables
MexE1	All significant slopes	0.47	5232.68	+Area_km2 +DEM_Mean -PrecipMA -DEM_Std -PrecipSDA +PrecipSDM+TempSDA
MexE1neg	All significant **negative** slopes	0.74	834.18	-Area_km2 -DEM_Mean -TempM +DEM_Std
MexE1pos	All significant **positive** slopes	0.68	3936.68	+Area_km2 -PrecipMA -DEM_Std
MexE1despos	Significant **positive** slopes in **DES** biome	0.64	1449.22	+Area_km2 -DEM_Std +PrecipSDA -PrecipSDM -TempSDM
MexE1conpos	Significant **positive** slopes in **CON** biome	0.78	873.75	+Area_km2, -DEM_mean, +TempSDM
MexE1tsmbneg	Significant **negative** slopes in **TSMB** biome	0.80	415.41	-Area_km2
MexE1tsbpos	Significant **positive** slopes in **TSB** biome	0.63	674.67	+Area_km2 +DEM_Mean +PrecipMA +TempM +TempSDM

+ and - indicate direction of the coefficients

28. All Variable Suites Results

Table 4 displays the results of adding our additional variable suites using our model selection process. Each ‘improved’ model’s change in AICc from the ‘environmental suite only’ version of the model is displayed in the column “dAICc”. We have listed the additional variables selected, but do not re-list the environmental variables from Table 3 for brevity's sake.

Table 4. All Variable Suite Models.

Model Name	Model Description	dAICc	Variables
MexB1	All significant slopes	1069.55	+PEMIG +PCIRC -PRETR +PREM -CPOP00 -pa +PUNEMP +PED
MexB1neg	Significant **negative** slopes	74.63	-PCIRC +PRETR –PREM +TOTALHEADS
MexB1pos	Significant **positive** slopes	964.15	+PEMIG -PCIRC -PRETR +PA25 +PRIMSECT00 –PUNEMP
MexB1despos	Significant **positive** slopes in **DES** biome	496.07	-PEMIG -PCIRC -PA25 +PRIMSECT00
MexB1conpos	Significant **positive** slopes in **CON** biome	124.71	+PEMIG -PCIRC +prert +PREM +PRIMSECT00 -ED00
MexB1TSMBneg	Significant **negative** slopes in **TSMB** biome	38.10	-PCIRC +prert +PA4
MexB1TSBpos	Significant **positive** slopes in **TSB** biome	110.22	+PEMIG +PCIRC +PRETR

+ and - indicate direction of the coefficients

29. Individual Model Results

Before presenting the results of the individual models, we would note that these variables represent all directions of migration simultaneously, and therefore must be co-variate to some degree. Places with high rates of emigration almost always have high rates of return or circular migration as well. At a basic level, you must have out-migration first to have return or circular migration. Additionally, the same processes that cause high outmigration also often causes to have high return or circular migration. Therefore, although we have separated these in our analysis to allow for more information to be gathered, they would not necessarily be identified as individually significant in a linear regression, as they capture much of the variance of the other. In this way, our use of AICc is superior to R^2, in that it allows us to identify these variables' role in explaining forest cover change despite their co-varying nature. However, it does mean that these variables may be selected by the model because international migration is important as a whole, but because of the covariation, the inclusion or omission of one in a model is not particularly meaningful, nor is whether the international migration variables have positive or negative signs in the models.

For all *municipios* in Mexico in which significant forest cover change occurred (n=538), the 'best' model (Table 4, 'MexB1') all three international migration variables were selected (PEMIG, PCIRC, PRETR), along with remittances (PREM), total population in 2000 (CPOP00), our fertility proxy variable (pa), proportional change in unemployment from 2000 to 2010 (PUNEMP), and proportional change in education levels from 2000 to 2010 (PED). For all *municipios* in which significant forest cover *loss* occurred (n= 116), our second 'best' model (MexB1neg), selected change in circular and return migration, as well as negative remittances and positive total heads of cattle (in 2007, TOTALHEADS). For all *municipios* in which significant forest cover *gain* occurred (n= 422) our third model (MexB1pos) selected all three measures of international migration, our proxy measure of *internal* migration (PA25), which was positive, percentage of working people in the primary sector in 2000 (PRIMSECT00), which was positive, and change in unemployment (PUNEMP), which was negative.

Regarding our results at the sub-national level, we will discuss them by majority direction of change in each biome. In the Desert biome the net **forest cover gain** (model MexE1despos) was best described by international and internal migration and increased primary sector employment. In the tropical and subtropical coniferous forest biome (model MexE1conpos) the net **forest cover gain** was best described by international migration, an increase in remittances, an increase in primary sector employment, and a decrease in the percentage of population with complete secondary level education from 2000 to 2010 (ED00). In tropical and subtropical moist broadleaf forests (model MexE1tsmbneg) the net **forest cover loss** was best described by measures of international migration and our (proxy) measure of fertility (PA4). In our final biome model (MexB1tsbpos), the net **forest cover gain** in the tropical and subtropical dry broadleaf biome, international migration variables alone were chosen for the best model.

P. Discussion

30. Hypothesis Support

First, we would like to note again that our two assumptions were supported: environmental variables being of primary importance in predicting forest cover change was demonstrated by the high adjusted R^2 results for all environmental suite models. Likewise, using biomes as a unit of analysis was also clearly supported by the significant results of our regression analysis using biomes as a categorical variable (see section “Results”, paragraph 1).

Hypothesis 1, that international and internal migration will be important drivers of forest cover change was also supported, as variables from the migration suite were selected in all improved models at the national level for both positive and negative change, as well as for biome-specific analyses (Table 4). Stated another way, for each model tested: (significant) forest cover change for the entire nation, positive and negative change for the entire nation, and the majority direction of significant change in each biome; adding migration variables to the models improved the model fit (dAICc) significantly, with no exceptions. We interpret this as a clear indication of support for this hypothesis, indicating that migration-related processes are also drivers of forest cover change in Mexico behind environmental variables. Hypothesis 2 was also supported, as non-migration variables were selected into the ‘best’ models in all cases, save significant positive slopes in the TSB biome, which only included physiographic/environmental and migration variables.

The larger implications of these results are multiple. First, we repeat our call for full inclusion of migration and migration linked processes in any analysis of land use and land cover (LU/CC) or forest-cover change, regardless of discipline. These variables’ universal inclusion in the models demonstrates their impact, even in relationships where environmental factors account for almost all of the observed variance. Second, the models for each biome differ, which further supports the decision to conduct research at this scale, as well as the variability in forest cover outcomes.

For all *municipios* in Mexico in which significant forest cover change occurred (MexB1), the results highlight the complexity and diversity of drivers of deforestation. Most of the major theorized drivers of forest change are included: migration, remittances, total population and population growth, labor supply (in the form of unemployment), and changes in the make-up labor force (indicated by education levels). As this represents all significant forest cover change across the nation, we hesitate to make sweeping generalizations. However, we are encouraged by this result as it is consistent with past research around the globe and the sub-national work done in Mexico. We take this to mean that forest cover change processes in Mexico follow observed patterns and that future research at a minimum should include migration, population, labor and other economic considerations.

When we examine model results individually, we see two different stories emerging for regrowth and loss areas. For all *municipios* in which significant forest cover loss occurred (MexB1neg), the model selected international migration variables, indicating a positive association between deforestation and higher return/lower circulation of international migrants. These findings suggest that the increased return of migrants from the US, much of it potentially due to the ramp-up in deportations taking place since 2006, as well as the lower short-term circulation of migrants during the period likely as a result of the economic crisis spawned by the US housing bust (Villarreal 2014) could be contributing to increased deforestation by increasing the local labor supply and higher total land use in primary sector activities (especially cattle ranching). Our findings also suggest that a lack of capital (via lower remittances) either allows for land use intensification, or diversification of the household's portfolio into non-primary activities, increasing deforestation, through land use extensification. Finally, our findings of a positive relationship with total heads of cattle in 2007 reinforce the historical importance of cattle ranching in driving land use change and deforestation in Southern Mexico in particular: indeed, the undersupply of labor and the presence of inexpensive or un-used land leading to the expansion of cattle ranching was a common outcome in our review of the literature. Given available land, cattle ranching requires little investment and much lower labor than many other agricultural endeavors. In the moist coastal forests (TSMB) predominant in the Eastern and Southeastern regions of the country, our sole biome in which forest cover loss represented the majority of forest cover changes, the variables selected were international migration and fertility, again established drivers of deforestation. It may be a worrying outcome, given how much of the Amazon's forests were reduced through similar drivers, but perhaps offers a place to begin researching preventative measures.

For forest cover regrowth, international migration and increased primary sector employment are consistent components of the models across scales. In the model examining all *municipios* in which significant forest cover gain occurred (MexB1pos), international migration variables, and positive relationships with *internal* migration, primary sector employment, and employment percentage were selected, suggesting population mobility reduces deforestation pressures (by lowering the supply of labor, but not necessarily by improving capital investments in primary activities given that the remittance variable was not selected) and that primary sector activities led to intensification and not extensification. When we examine results by biome, however, our conclusions may vary slightly. T. When we examine results by biome, the model for desert regrowth (MexB1despos) selects international migration variables along with a *negative* relationship with internal migration and a positive relationship with primary sector employment. Coniferous forest regrowth (MexB1conpos) was best explained by international migration, and increased remittances and primary sector employment. The regrowth in the dry broadleaf forests (TSB) is best explained by international migration alone. We interpret the increase in agricultural employment and migration paired with forest regrowth to mean that intensive agricultural practices are being favored over extensive ones, leading to higher employment in the sector even as cultivated land decreases, allowing for regrowth on fallow land. This would be consistent with the increased capital captured by the remittances in the CON biomes. Concerning the different directions of internal migration in the models, we note that internal migration is a zero-sum variable.

Q. Conclusion

We set out to explore the relationship between international migration processes, and forest cover change. Our results demonstrate that these processes have a significant relationship with each other. While the environmental suite of variables is by far the most important set, unsurprisingly as we are predicting an environmental outcome, migration, demographic, and economic factors add important information. Of these, international migration has a particularly important role, suggesting accelerated forest cover change may occur along with international migration more profoundly relative to internal mobility processes or other drivers of population change (at least in Mexico, which has a long and storied history of international movement). We observed heterogeneity across models examining forest cover gain and loss nationally and by biome, suggesting an opportunity for future research to examine separately the different drivers for each of these subsets. This association between international migration processes and forest cover change is one that should be more fully explored, suggesting that migration processes might fruitfully inform forest cover change processes, be integrated into forest cover change research agendas. Conversely, more research might reveal under what forest cover change processes are an important outcome (and possibly driver in some instances) of international migration flows.

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IV. CHAPTER 4 - RURAL AND INDIGENOUS ORIGIN PREDICTS DIET AND DIET RELATED HEALTH OUTCOMES IN RECENT MIGRANTS TO TIJUANA, MEXICO

S. Introduction

International migration is a powerful force in current society which has numerous and far-reaching effects, including on health. As individuals migrate they enter new health and food environments, encounter, and acculturate to new health behaviors. This study examines migrants' diet and diet related health to determine how migration impacts an individuals' dietary patterns and health outcomes. There is a growing field of literature concerning this subject; much of it sparked by the increased incidence of diet related disease in Mexico, the United States of America's (U.S.) Latino population, and the persistence of the 'the Latino paradox' phenomenon.

We argue here that *internal* migration, migration *within* national borders is an understudied and under-discussed part of international migration. Almost all international migrations begin with one or a series of internal migrations, particularly with lower-resource migrants (Massey 1998). These same migrants are more likely to be vulnerable to the health effects of changing environments (Bojorquez et al. 2015). Internal migration is much more difficult to track, categorize, and study, but its size is thought to be many times that of international migration (Nam 1990; Smith 2016). Despite this, there is a lack of research focusing on the connections between internal migration and health (Martinez 2013). Our study, in part, seeks to address this lack of information.

We collected information from recently arrived migrants to Tijuana, Mexico (*n*=93) using a modified snowball method. Study participants were residents of two *colonias* (small neighborhoods) that were known to have a high concentration of immigrants and indigenous residents. Participants answered a survey concerning their demographics, education, employment and income, personal and family health history, access to health care, their current diet and exercise, current household (HH) makeup and living situation, migration history, including diet and health behavior at migration 'stops' that lasted over three months, their origin household information, and comparisons of their current, origin, and intervention stops' diet and health behaviors. In addition, we collected information on common diet related health measures: body mass index (BMI), waist circumference (WC), and glycated hemoglobin (HbA1c). Participants' responses were examined using several statistical methods to determine possible associations between their current situation, their origin and migration history, changes in their diet, and measurements of their health. Results indicate that participants of indigenous origin and participants who were from *municipios (*equivalent to U.S. counties) with a high percentage of very small and rural *localidades* (the administrative level below *municipios*) had significantly more diet change, but better current health. These results demonstrate that more detailed information about migration path and origin is important in diet and health related research. It also points to recent rural and indigenous migrants as a high value population for diet and health related interventions.

Our study also sheds light on a rarely studied and difficult to encounter population. Migrants within Mexico and Latino migrants in or on their way towards the United States are a difficult population to encounter for logical reasons. They often have low levels of resources, some do not have official documentation or permissions, and they can be subject to harassment or arrest by officials in either Mexico or the United States. The recent political situation in the U.S. has served to heighten what was already an increasingly fraught position for these migrants, which became increasingly strict under the administration of Barack Obama in 2008.

Another missing piece of the literature that we seek to explore further is that of richness in migration history. In public health, even in studies that purposefully include migrants, their history is often simply a ‘yes-or-no’ field, or at best one measured by ‘time since migration’. These studies make a number of assumptions which are often untrue; the main assumption being that time since migration to a new country serves as a proxy for changing health behaviors, acculturation, and exposure to the new culture (Hunt, Schneider, and Comer 2004; Schwartz et al. 2010; Viruell-Fuentes 2007). This approach ignores return migrants, circular migrants, the impact of the migration process, the similarities and differences between origin and destination, and the realities in between. Furthermore, much of the health research, and indeed much migration research, simply ignores internal migrants. This occurs not because of a lack of evidence that internal migration has important effects, including on health behaviors and outcomes, but simply because tracking (and classifying) internal migration is difficult (Nam 1990; Smith 2016). Migrants' paths to international destinations are often lengthy, complex, and circular (Massey 1998). We argue that more richness is needed in exploring migrants' histories in health research.

T. Literature

The incidence of nutrition related non-communicable diseases (NR-NCDs), such as obesity and diabetes, has reached pandemic proportions in the United States and Mexico. However, these diseases do not strike uniformly. Ethnicity, poverty, socio-economic status (SES), education, access to healthy food, and access to health care all affect their manifestation in the population (Caballero and Popkin 2002). When migrants enter the U.S., they have better health than their U.S.-born counterparts, including rates of diabetes and obesity (Franzini, Ribble, and Keddie 2001; Palloni and Arias 2004; Palloni and Morenoff 2006). This outcome is observed despite lower incomes, lower SES, and lower access to health services than the U.S.-born Latino population (Perez-Escamilla et al. 2010; Viruell-Fuentes 2007). As immigrants adopt to urban U.S. lifestyles, their BMIs rise and the presence of NR-NCDs increases, despite increases in wealth, SES, and access to health services (Perez-Escamilla et al. 2010; Roshania et al.2008). Latinos within the United States, as a whole, currently have much higher levels of obesity and diabetes than non-Hispanic whites (CDC 2011). A part of this acculturation process includes a change in health behaviors, of which diet is a critical component (Franzini, Ribble, and Keddie 2001; Palloni and Arias 2004; Satia 2010; Satia-Abouta et al. 2002). Recent Latino immigrants are therefore a population that could benefit from early diet and nutrition interventions and one where unhealthy behaviors and subsequent NR-NCDs could be prevented.

31. Acculturation and Health

All immigrants undergo acculturation to their new location to some degree (e.g. Berry 1997). Dietary change is just one part of this larger process wherein immigrants' behaviors adapt to their new surroundings (Akresh 2007; Ayala et al. 2007; Lara et al.

2005; Satia-abouta et al. 2002). There has been much work on the associations between acculturation and health, as well as the subtopic of acculturation and diet (Lara et al. 2005). Studies of health and acculturation have come under criticism from researchers, who have challenged the basic assumptions of this work (Hunt, Schneider, and Comer 2004; Satiaa- Abouta 2003). Past research often assumed that the effects of acculturation towards the 'host' culture was positive and should be the goal of interventions. Researchers now acknowledge that the effects of acculturation on health may not be uniformly positive or negative (Lara et al. 2004). Individual change in behaviors associated with acculturation may include those classified as 'unhealthy', like increased smoking, as well as those classified as 'healthy', like increased recreational exercise (Gordon-Larsen et al. 2003; Lara et al. 2004; Martínez 2013). Many of the problems in the study of acculturation and health could be categorized as a lack of attention to differences in place, for example Mexico or Latin America being treated as one homogeneous area. There has been some work about dietary acculturation among Mexican or Latino immigrants to the U.S. (e.g., Gordon-Larsen et al. 2003; Martinez 2013; Sanchez-Vaznaugh et al. 2008: Satia 2010). However, we believe that in light of the obesity epidemic among the U.S.-Latino population that this is an area that deserves more research.

32. Nutrition Transition

Much of the internal migration in Mexico is rural-to-urban, or to increasingly urban areas (i.e., urban-to-urban). In addition, most international migrants move 'up' the development continuum of nations from less to more developed countries (Abel and Sander 2014).Therefore migrants often pass through locations at different stages of the "Nutrition Transition". The nutrition transition is a conceptual framework used to describe the drastic changes in human diet that have occurred over time and space, particularly in recent years. It proposes five categories: food gathering, famine, receding famine, chronic diseases, and behavior change (toward a healthy, balanced diet) (Popkin 2002). To roughly characterize the current state of the world, the overwhelming majority of the population in developed nations is in the chronic disease stage, with some transitioning to behavior change. For developing nations, most of the population can be characterized by either receding famine or chronic disease. Recently, the developing world has undergone the transition at an alarming rate. Many areas are characterized by the 'dual burden': high levels of both the diseases of undernutrition and NR-NCDs (Popkin 2002a). This divergence between stages can be seen in the same nation, the same city, the same neighborhood, and even the same household (Doak et al. 2005). Most migrants, as they move from rural to urban, and from developing towards developed, move 'up' the nutrition transition continuum and adopt a less healthy 'Western' diet, with a marked increase in meat and dairy, sugars and sweeteners, edible oils, and prepared and processed foods, accompanied by a decrease in fruits, vegetables, and legumes, all of which are risk factors for NR-NCDs (Satia-Abouta et al., 2002). However, this transition does not happen evenly; some migrants preserve their healthier habits, although the predictors for such have yet to be fully explained (Ayala et al., 2008; Espinosa de Los Monteros et al. 2008). Part of our goal with this study is to explore whether geographic, migration history, or household characteristics of migrants can explain these different outcomes.

33. Indigenous and Dietary Health

In our research, we attempted to capture migrants of indigenous populations. Indigenous migrants make up an increasing percentage of internal migrants within Mexico as well as migrants to the U.S. (Holmes 2014; Velasco Ortiz et al. 2010). They are more vulnerable than non-indigenous migrants, usually having less resources, less schooling, do not speak Spanish as their first language, let alone English, and are usually found at the bottom of the totem pole in the migration and post-migration life, the negative health effects of such which were so vividly captured by Seth Holmes (2014) and others (Duncan et al. 2009). This group of migrants are, if possible, even more reluctant study participants than most recent migrants. This is in part due to their lack of capital and resources, which makes them even more vulnerable, combined with a history of poor treatment by the Mexican state, as well as an often-present common cultural trait of 'shyness' which can make them even less likely to speak with strangers, especially about themselves. However, they are important, as their health outcomes can be significantly different than the rest of the population (e.g. Rodríguez-Morán et al. 2008).

Our study was not entirely successful in this endeavor as we managed to speak with only 15 migrants who self-identified as indigenous or of an indigenous household, yet we did see some difference in their outcomes as compared to the rest of the study population.

34. The Latino Paradox

Many of the migrants who participated in our study have lived in the U.S. at some point during their migration history, or firmly intend to. One of the aims of this study is to shed light on a still-unsolved health effect, often called the Latino or Migrant Paradox. More than three decades of research in the United States has consistently found lower levels of chronic disease and adult mortality risks among Latino immigrants than among U.S.-born Latinos, and non-Latino whites. This is despite Latino immigrants' lower levels of SES, income, access to health care, and utilization of healthcare, all characteristics commonly associated with better health (Elo et al. 2004; Ruiz et al. 2013). This advantage tends to decline with greater duration of residence and disappear over an immigrant generation (Abraido-Lanza et al. 2006; Cho et al. 2004; Kaplan et al. 2004; Lara et al. 2005). These patterns appear to be mirrored for internal (and especially) indigenous migrants in Mexico (Bojorquez, Rentería, and Unikel 2014; Neufeld et al. 2008; Stoddard et al. 2011), although there has been far less attention paid to this topic. We will therefore summarize the research on the Latino Paradox, both to outline the current thinking and to aid our current goal of attempting to study eventual predictors of NR-NCDs for Latino migrants to the United States.

There have been a number of studies conducted on the question of whether the Latino paradox can be explained through selective immigration of healthier individuals, or selective emigration of the unhealthy or those close to death (a phenomenon known as salmon migration). These articles find some evidence for these migration effects, but not enough to account for the entire phenomenon. In a widely cited 1999 study using the National Longitudinal Mortality Study, Abraido-Lanza et al. ruled out immigration effects. In another widely cited 2004 study, Palloni and Arias used some complex indirect estimation methods and found support for selective migration as a factor, for the Mexican population only. Using social security data, Turra and Elo in 2005 found that selective emigration was a contributor, although partially counter-balanced by salmon migrants returning home from the U.S., and altogether too small to be an explanation for the Latino Paradox. They estimated that 15-20% of excess mortality was explained by migration processes, not including return salmon migration. Rubaclava et al. in 2008, using the Mexican Family Life Survey, found mostly weak and non-significant effects of selective migration on health. In 2011, Van Hook and Zhang used age and self-rated health as measured in the U.S. Community Population Survey, and found some evidence for health selective emigration among non-Mexicans. Riosmena and Massey in 2012, using National Health Interview Survey (NHIS) in the United States and the Mexican Health and Aging Study (MHAS) for men ages 50+ found that there was support for, and association between, migration processes and health outcomes, especially hypertension. Kaestner and Malamud (2013) using the Mexican Family Life Survey and using self-rated health found no support for immigration selection.

The contribution of cultural and behavioral factors to the Latino Paradox emerged from research during the 1990s and 2000s that identified healthier lifestyles among Latino communities in the United States (Abraido-Lanza et al. 2005; Singh & Siahpush 2002). For instance, Mexican immigrants in California eat more fruits and vegetables and drink less soda than whites (Allen et al. 2007). And there is evidence that Latino immigrants import social and behavioral characteristics that are beneficial to health (Buttenheim et al. 2010). Perhaps the single most important contributing factor to differences in mortality among U.S.-born Latinos is cigarette smoking (Blue and Fenelon 2011; Fenelon & Blue 2015). Smoking is particularly important in explaining mortality differences for Mexican and other Latino immigrants, because they have especially low rates of cigarette use in their home countries (Fenelon 2013; Singh & Siahpush 2002). Mexican immigrants smoke at rates similar to those in sending regions of Mexico, indicating that the orientation towards low smoking is not a result of selective migration (Fenelon 2013).

Research on the relationship between migration, acculturation and diet, and diet related health among Latinos in the U.S. has produced some clear findings: Latino migrants to the U.S. have lower levels of obesity and other diet related chronic disease indicators than U.S. born Latinos and non-Latino whites. These converge to the (relatively high) levels of these indicators found in the U.S.-born Latino population over time and generation, with acculturation to U.S. behavioral norms is an important factor in explaining this change (Antecol and Bedard 2006; Akresh 2007; Ayala et al. 2008; Barcenas et al. 2007; Creighton et al. 2012; Liu et al 2012; Misra and Ganda 2007).

35. Study Area

Our study was limited to residents and acquaintances of two neighboring *colonias* in the city of Tijuana, Mexico. Tijuana is a city of a million and a half people, the third largest (by *municipio*) in the nation. It has been called the "busiest border crossing in the world" and has long been a center of immigration and emigration, as people originating in Mexico, Central America (and increasingly Asia and Africa) migrate here before moving on to the U.S.. We focused on the *colonias* of Pedregal de Santa Julia and Obrera, building off previous research which had identified them as having a high concentration of internal migrants and a large indigenous population (Velasco Ortiz et al. 2010). Although official statistics are not kept at the *colonia* level, making it difficult to compare these *colonias* to the rest of the city, they are described as having high levels of indigenous residents, and comparatively low socio-economic indicators (Ibid). Figure 1 displays a map of Tijuana with our two study areas among those highlighted, along with a picture of Colonia Obrera.

Figure 1. Tijuana and Indigenous *Colonias*.

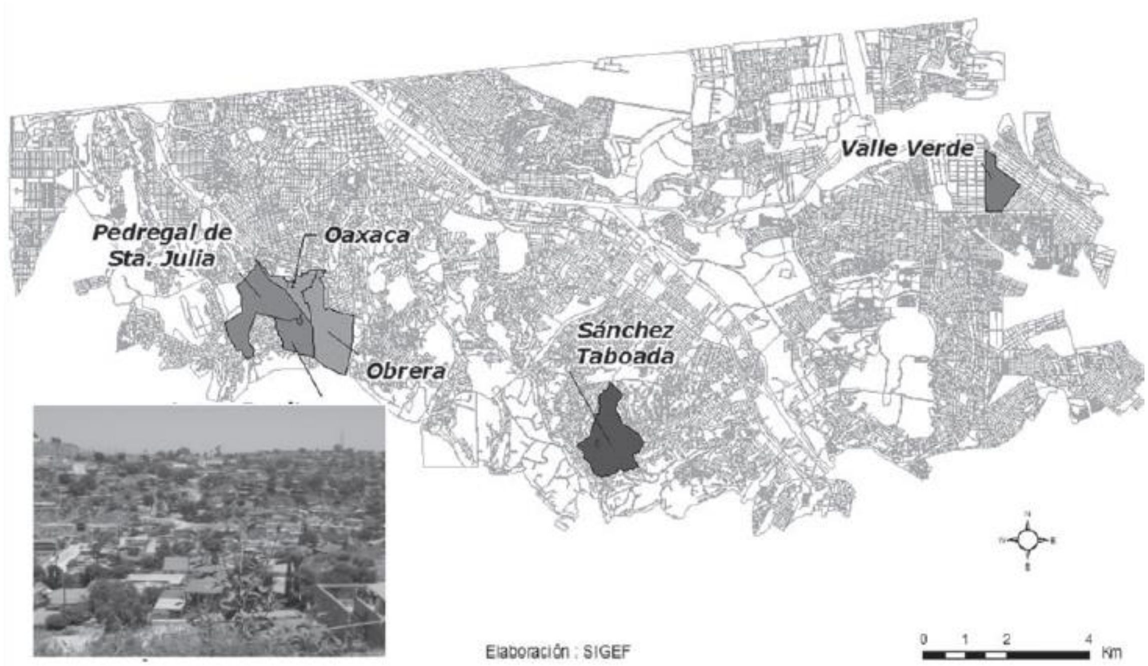

Image courtesy of Velasco Ortiz et al. 2010.

U. Hypotheses

Our fundamental research question is, how do migration, geography, and indigenous heritage influence diet and diet related health among internal migrants within Mexico? To address this broad question, we pose the following hypotheses:

Hypothesis 1. Diet change.

1. Self-reported diet change will be significantly associated with characteristics of a study participant's origin or migration history.
2. Self-reported diet change will be significantly associated with study participant's indigenous status.

Hypothesis 2. Body mass index.

1. Body mass index above 24 will be significantly associated with characteristics of a study participant's origin or migration history place.
2. Body mass index above 24 will be significantly associated with study participant's indigenous status.

Hypothesis 3. Waist circumference.

- Waist circumference above 80 cm will be significantly associated with characteristics of a study participant's origin or migration history place.
- Waist circumference above 80 cm will be significantly associated with study participant's indigenous status.

Hypothesis 4. HbA1c.

- HbA1c above 5.5 will be significantly associated with characteristics of a study participant's origin or migration history place.
- HbA1c above 5.5 will be significantly associated with study participant's indigenous status.

V. Methods

36. Data Collection Procedures

We collected data in Tijuana, Mexico from March through August of 2016. All subjects were residents of two neighboring *Colonias*: Colonia Pedregal de Santa Julia and Colonia Obrera. We chose these areas to maximize our chances of contacting this difficult-to-access population, as well as to control for current sociodemographic factors, geographic access to resources and other issues by using residents of the same colonias. Attempts to contact study participants and conduct interviews initially took place at the colonia's bilingual indigenous elementary school *Ve e tu un xavi*. Initial participants, staff at the school, staff at churches and other community organizations, and other community gatekeepers were asked to refer potential participants to the study. Because initial contact took place through schools, and most interviews took place in schools or at people's homes, our sample was about 60 percent female (Table 1). We argue that the snowball method, although not a statistical or representative method, is necessary due to the scarcity and reluctance of the study population.

Interviews and measurements took place at the elementary school in the nurse's office, or much more frequently, during scheduled appointments at participants' homes. The data collection team consisted of a (female) nurse and a (male) interviewer. Data collection began with an introduction of the team, and a reading of the consent form (many subjects were of low literacy). Potential participants completed a pre-screening questionnaire to determine their eligibility for the study (Appendix 1). If the participants qualified, the subjects answered questions from the interviewer or completed the questionnaire themselves under the instruction of the interviewer. After the interview, the nurse took height, weight, and waist circumference measurements, and had their finger pricked to provide blood for the HbA1C portable instrument. Participants were provided written record of their measurements, were given information about their measurements in context (i.e. if their measurements indicated their membership in a high-risk group) and were provided referrals to local and appropriate health services if desired. Study participants were reimbursed with a non-cash equivalent of 100 pesos (~$8 U.S. dollars) upon completion of the study. Participants were not required to complete the study in its entirety in order to receive the compensation.

37. Anthropometrics

Obesity or adiposity is highly related to overall health, nutritional health, and NR-NCDs. We evaluated two measures of obesity: BMI and waist circumference. Body mass index is perhaps the widest collected anthropometric concerning obesity and diet, although it has acknowledged limitations (e.g. Gallagher et al. 1996). Waist circumference is thought to be a more accurate and responsive measure of obesity related health (e.g. Sánchez-Castillo et al. 2003). We also collected blood from subjects to conduct onsite HbA1c testing. HbA1c is a chronic measure of glycemic levels that correlates with the risk of diabetes complications, and cardiovascular risk (Gillett 2009; Gomez-Perez et al. 2010; Khaw et al. 2004). This measure has several advantages over other blood glucose measures: in that it provides a long-term record of glucose, which is less subject to short-term variation, and does not require the subject to be fasting. We utilized a portable Hemoglobin A1c instrument which has a high level of validity when compared to laboratory tests (Arrendale et al. 2008).

Our study focused entirely on migrants who had arrived in Tijuana within the last five years. Research in the United States has shown that health behaviors tend to change significantly after five years of residence (Barcenas et al. 2007; Sanchez-Vaznaugh et al. 2008). As the focus of our study was the effects of origin places and migration history, and not necessarily the effects of the current location, we chose to select only the more recent migrants. An additional consideration is that we are also interested in the effects of internal migration upon eventual migrants to the United States, and our anecdotal encounters led us to believe that migrants who will eventually migrate to the United States often do so before five years of residence in Tijuana.

38. Questionnaire

A condensed list of the data examined is displayed in Table 1, which consists of two parts. All subjects were asked to complete a questionnaire (Appendix 1). This questionnaire was adapted almost entirely from existing, validated instruments, mostly the 2012 *Encuesta Nacional de Salud y Nutrición* (ENSANUT), and the 2011 California Health Interview Survey (CHIS). Current diet and diet change questions were adapted from a study by Dr. Laura Velasco Ortiz and others concerning diet change in migrants in Baja California (unpublished). The SF-12 Health Survey (Version 2), a well-established instrument in public health (e.g. Jenkinson et al. 2001) was used to assess physical and mental health. Respondents are asked a series of questions, both self-rated and based on daily activities, which we then scored and converted into separate physical and mental health composite scores (Ware, Keller, and Kosinski 1998).

Most of the "Geography & Migration" section was compiled after the collection of questionnaire data, and all data are at the *municipio* scale. This information was collected for migrants' origin and intervening stops of greater than six months. The regions of Mexico were based on Batalla (1983), a well-established grouping (Liverman and Cravey, 1992). The statistics were sourced from the Mexican statistical agencies *Instituto Nacional de Estadística y Geografía* (INEGI) or *Consejo Nacional de Población* (CONAPO). These data were from 2010. The index of marginalization is a statistic calculated by CONAPO, and consists of a principal component analysis (PCA) created variable using the following information: the proportion of households in the municipality (1) with dirt floors, (2) without indoor plumbing or a toilet, (3) without electricity, (4) without access to piped water, and (5) with more than two people per room, as well as the proportion of adults in the municipality (6) who are illiterate, (7) who have not completed primary education, and (8) who earn less than twice the minimum wage. The Index of migration is another CONAPO variable created through

PCA of the percentage of households in the municipality (1) receiving remittances, (2) with at least one member emigrating to the United States between 1995 and 1999, (3) with at least one member returning from the United States between 1995 and 1999, and (4) with at least one member emigrating to and returning from the United States between 1995 and 1999.

Table 1 -Variables Collected (part 1)

Variable	Data Source	Data Scale	Data Type
Demographics & Socioeconomics			
Age	Survey	Individual	Continuous
Sex	Survey	Individual	Categorical
Marital Status	Survey	Individual	Categorical
Literacy (Spanish)	Survey	Individual	Categorical
Education (years)	Survey	Individual	Continuous
Education (category)	Survey	Individual	Continuous
Indigenous language speaker	Survey	Individual	Categorical
Indigenous language HH	Survey	Individual	Categorical
Employment status	Survey	Individual	Categorical
Salary	Survey	Individual	Continuous
Household Composition			
Age, Sex, Relationship of Current HH Members	Survey	Household	Mixed
Age, Sex, Relationship of Origin HH Members	Survey	Household	Mixed
Count of HH members (origin, current)	Survey	Household	Continuous
Age mean of HH members (origin, current)	Calculated	Household	Continuous
Age variance of HH members (origin, current)	Calculated	Household	Continuous
Change in age mean between Origin and Current HH	Calculated	Household	Continuous
Change in age variance between Origin and Current HH	Calculated	Household	Continuous
Change in count between origin and current HH	Calculated	Household	Continuous
Health & Health History			
Personal or family history of diabetes	Survey	Individual	Categorical
Personal or family history of Cardiovascular Disease	Survey	Individual	Categorical
Personal or family history of hypertension	Survey	Individual	Categorical
Personal or family history of cancer	Survey	Individual	Categorical
Food frequency questionnaire	Survey	Individual	Categorical
Health insurance (status and type)	Survey	Individual	Categorical
SF-12 Health Survey	Survey	Individual	Continuous
Current physical activity, work & leisure	Survey	Individual	Continuous
Cigarette consumption	Survey	Individual	Mixed
Alcohol consumption	Survey	Individual	Mixed

Table 1 -Variables Collected (part 2)

Variable	Data Source	Data Scale	Data Type
Diet			
7 day dietary recall	Survey	Individual	Continuous
Eating habits	Survey	Individual	Mixed
Self-rated silhouette	Survey	Individual	Categorical
'Unhealthy' eating, origin, current, and intervening	Survey	Individual	Continuous
Alcohol consumption, origin, current, and intervening	Survey	Individual	Continuous
Exercise, origin, current, and intervening	Survey	Individual	Continuous
Interview regarding diet differences, current	Survey	Individual	Text
Geography & Migration			
Estado, municipio, localidad.	Survey	Individual	Nominal
Region	Survey	Individual	Nominal
Previous international migration	Survey	Individual	Binary
Number of stops in migration history	Survey	Individual	Continuous
Total population	INEGI	Municipio	Continuous
Population category	INEGI	Municipio	Categorical
% of population - urban	INEGI	Municipio	Continuous
% of population - indigenous	INEGI	Municipio	Continuous
% of unemployment	INEGI	Municipio	Continuous
% of employment in the primary sector	INEGI	Municipio	Continuous
% of population in localidades with less than 5,000 residents	INEGI	Municipio	Continuous
Index of marginalization	CONAPO	Municipio	Continuous
Index of migration intensity	CONAPO	Municipio	Continuous
Diet & Health Outcomes			
BMI (body mass index)	Survey	Individual	Continuous
Waist circumference	Survey	Individual	Continuous
Diastolic blood pressure	Survey	Individual	Continuous
Systolic blood pressure	Survey	Individual	Continuous
HbA1c	Survey	Individual	Continuous

39. Outcomes

Our outcomes (as detailed in the hypotheses) were a self-reported measure of diet change, as well as our three anthropometrics. The self-reported diet change outcome was created by combining items a-d on Question 52.1 (Appendix 1). This question was a five-point likert scale, ranging from "much less" to "much more" with a neutral option. Respondents compared their food and eating habits in their original home to their current location on the questions of whether they ate outside the home (*comer fuera)*, ate "fast food" (*comida rapida),* drank sodas or *refrescos* (common sugar-sweetened beverages) or ate more (*más*). These responses were entered as numbers from negative two to two with "about the same" as zero. Then the four questions were totaled, giving maximum and minimum values ranging from negative eight to eight, with zeros indicating no change and negative values indicating that the participant ate a 'healthier diet' at their origin then their current location. Looking for significant associations with our study questions was limited to associations with 'poor health' outcomes. Therefore, when testing associations with BMI, only subjects with a value equal or greater than 24 were tested (n=75), waist circumference values equal or greater than 80 (n=72), and HbA1c values equal or greater than 5.4 (n=72). These cutoff points were drawn from the literature as indicating higher-risk groups, specific to the Mexican population where possible (Ginde et al. 2008; Gomez-Perez et al 2010; Sánchez-Castillo et al. 2003)

40. Data Analysis Methods

After all the data variables were created, cleaned, and prepared for analysis, we tested these groups of variables (as indicated in Table 1) for significant associations with each of our outputs: Demographics & Socioeconomics, Household Composition, Health and Health History, Diet, and Geographic & Migration Path Characteristics. Although there were numerous small but significant relationships with our outcomes, as is statically inevitable when testing so many dependent and independent variables, the variable that continued to emerge from these relationships concerned the nature of participant's origin *municipio*: the percentage of *localidades* in the municipio which contained less than 5000 people. This outcome is not surprising nor divergent from the established literature.

Categorizing locations as ‘rural’ using *localidades* under 2,500 (official ‘rural’ destination by INEGI) or 5,000 residents is a common one in social science work concerning Mexico and in literature examining migration (e.g. Nawrotzki et al. 2015; Riosmena and Massey 2012). Although there are few statistics collected at the *localidad* scale, *municipios* with high concentrations of such (in essence, rural counties) have different outlooks than others: they tend to be poorer, less educated, more indigenous, more dependent on agriculture, with less resources, and located in ‘southern’ Mexico (including the south east and the Yucatán). In addition, we also observed outcome differences among those participants of indigenous heritage (n=15), almost all of whom were from the most rural counties. Following these observed relationships, we separated our participants into two sets (non-exclusive): those who were from *municipios* with greater than 25% of the population living in *localidades* with less than 5,000 residents (rural-not rural) and those who spoke an indigenous language or whose parents spoke an indigenous language (indigenous-not indigenous). We conducted independent sample t-tests for each of our four outcomes for these two sets of groups (further limiting membership to higher-risk groups for the anthropometric outcomes as detailed above) and results indicate that being of rural origin or indigenous heritage is significantly associated ($p > .20$[17]) with outcomes of higher BMI, waist circumference, and HbA1c, supporting most of our hypotheses. In the following section, we present results for all subjects, and broken out by membership in four groups. We then present the results of our analysis.

W. Results

41. Study Participant Characteristics

Table 2 contains counts and descriptive statistics concerning individual and household level characteristics for our study participants, while Table 3 contains the same for their migration path, and characteristics of their origin location. Each table contains information for all participants, and for our two sets of (non-exclusive) study groups.

[17] We chose this high level of significance due to the small sample size of most of our outcome groups.

Table 2 - Individual & Household Characteristics

Study Group Characteristics	**All**	**Rural**	**Not-Rural**	**Indig.**	**Not Indig.**
Male	38%	43%	32%	33%	39%
Female	62%	57%	68%	67%	62%
Age (mean)	35.2	35.3	35.0	28.1	36.6
Age (median)	33	32.5	33.0	28.0	34.0
Age (SD)	11.4	11.6	11.6	4.7	11.8
Indigenous	15	28%	0%		
Rural	54			100%	54%
Education Level					
No Schooling	6%	9%	5%	13%	5%
Primary School (grade 1-6)	26%	39%	18%	27%	31%
Secondary School (7-9)	37%	43%	44%	47%	37%
Preparatoria (10-12	15%	9%	28%	13%	19%
Additional	6%	4%	8%	0%	0%
Employed					
Yes	62%	62%	62%	67%	61%
No	38%	62%	62%	33%	39%
Health Insurance					
Seguro Social (IMSS)	34%	35%	32%	40%	33%
Seguro Popular	38%	35%	43%	47%	36%
None	28%	30%	24%	13%	31%
Current HH count	5.0	4.9	5.2	5.7	4.9
Origin HH count	5.8	6.0	5.5	6.0	5.8
Current HH Age Mean	26.5	26.9	26.4	18.9	27.9
Origin HH Age Mean	25.5	25.3	26.4	22.8	26.0
Region					
Noroeste	18%	20%	16%	7%	21%
Norte	1%	2%	0%	0%	1%
Noreste	1%	0%	3%	0%	1%
Centro-Occidente	17%	7%	32%	7%	20%
Centro-Este	19%	15%	27%	7%	22%
Sur	32%	50%	8%	73%	25%
Oriente	8%	6%	11%	7%	8%
Peninsula	1%	0%	3%	0%	1%

Table 3 - Geographic & Migration Characteristics

Study Group	**All**	**Rural**	**Not-Rural**	**Indig.**	**Not Indig.**
Number of Stops					
1	57%	56%	57%	47%	58%
2	24%	24%	22%	20%	24%
3	10%	13%	5%	20%	8%
4+	11%	7%	16%	13%	10%
International					
Yes	16%	9%	24%	20%	15%
No	84%	91%	76%	80%	85%
Years since left origin					
0-4	62%	48%	61%	40%	55%
5+	38%	52%	39%	60%	45%
Origin Population (*Municipio*)					
1-2500	28%	44%	0%	33%	27%
2500-15,000	8%	13%	5%	27%	4%
15,000-100,000	23%	32%	11%	13%	24%
100,000-500,000	23%	9%	43%	13%	24%
500,000+	18%	2%	40%	13%	19%
Origin Grade of Marginalization					
Very Low	31%	26%	78%	20%	33%
Low	20%	43%	14%	13%	22%
Medium	28%	13%	8%	0%	33%
High	8%	19%	0%	27%	4%
Very High	11%	0%	0%	40%	5%
Origin Grade of Migration Intensity					
Very Low	5%	4%	8%	13%	4%
Low	38%	32%	49%	53%	35%
Medium	44%	48%	41%	13%	50%
High	11%	17%	3%	20%	9%
Origin Employment in Primary Sector	27.4%	41.8%	6.5%	39.9%	25.0%
Origin Unemployment	4.3%	4.4%	4.2%	5.2%	4.1%
Origin Indigenous	16.8%	24.0%	6.2%	55.0%	9.3%

These tables highlight the similarities and differences between these groups, and indicate that the indigenous group (all of which are also in the rural group) in many ways are ‘extreme’ representatives of the rural group. Both rural and the indigenous group have less schooling than the comparative groups and lower rates of literacy (not shown), and the majority of both groups are from the southern region. The indigenous group in addition is younger, originated and currently live in larger and younger households. When we examine Table 2 we again see the differences between the rural and non-rural groups and how the indigenous group is an extreme version of the rural group. Unsurprisingly both rural and indigenous participants come from smaller *municipios*, that are more marginalized, with more employment in the primary sector, more unemployment, and with a higher percentage of indigenous population.

42. Analysis Results

We conducted independent sample T-Test's for each hypothesis for each group. Table 3 presents the results of these analyses. Subject groups were evaluated based on Levene's test for equality of variance and the appropriate results are displayed. Significant (p < .20) results are **bolded**.

Table 3 - T-Test Results

		N	Mean	SD	SE	T	df	Sig. (2-tailed)	Avg Diff	SE Diff	95% CI Lower	95% CI Upper
Diet Change Score	**Rural**	54	1.48	2.80	0.38	2.18	57.4	**.034**	1.73	0.79	0.14	3.31
	Not Rural	37	-0.24	4.23	0.70							
	Indig	15	1.80	3.05	0.79	-1.35	91.0	**0.180**	-1.38	1.02	-3.40	0.65
	Not Indig	78	0.42	3.71	0.42							
BMI	**Rural**	45	29.02	3.76	0.56	-2.22	45.1	**0.032**	-2.66	1.20	-5.08	-0.24
	Not Rural	30	31.68	5.81	1.06							
	Indig	13	30.04	3.41	0.95	0.28	75.0	0.781	0.45	1.61	-2.76	3.66
	Not Indig	64	30.49	5.58	0.70							
WC	**Rural**	48	95.75	10.09	1.46	-1.36	78.0	**0.177**	-4.01	2.94	-9.86	1.84
	Not Rural	32	99.76	16.21	2.87							
	Indig	14	92.68	8.42	2.25	2.20	29.3	**0.036**	6.15	2.80	0.44	11.87
	Not Indig	68	98.83	13.69	1.66							
HbA1c	Rural	46	6.62	1.77	0.26	0.82	68.0	0.416	0.32	0.39	-0.46	1.09
	Not Rural	24	6.30	0.93	0.19							
	Indig	12	5.96	0.33	0.09	2.88	70.0	**0.005**	0.67	0.23	0.20	1.13
	Not Indig	60	6.62	1.63	0.21							

There were significant (p> .20) difference between one set of our two groups for each outcome variable tested.

X. Analysis

First, we present the formal results of our hypotheses:

Hypothesis 1. Diet change.

A Self-reported diet change will be significantly associated with characteristics of a study participant's origin or migration history place **was supported**.

B Self-reported diet change will be significantly associated with study participant's indigenous status **was supported**.

Hypothesis 2. Body mass index.

A Body mass index above 25 will be significantly associated with characteristics of a study participant's origin or migration history place **was supported**.

B Body mass index above 25 will be significantly associated with study participant's indigenous status **was *not* supported**.

Hypothesis 3. Waist circumference.

A. Waist circumference above 80 cm will be significantly associated with characteristics of a study participant's origin or migration history place **was supported**.

B. Waist circumference above 80 cm will be significantly associated with study participant's indigenous status **was supported**.

Hypothesis 4. HbA1c.

A HbA1c above 5.5 will be significantly associated with characteristics of a study participant's origin or migration history place **was *not* supported**.

B HbA1c above 5.5 will be significantly associated with study participant's indigenous status **was supported**.

In summary, membership in the rural or indigenous groups was associated with the tested outcomes for all four of our hypotheses. Rural or indigenous groups had more diet change towards our definition of 'unhealthy' eating practices, lower BMI and waist circumferences. In addition, rural and indigenous status effects all moved in the same direction (excepting HbA1c), which we take as a positive sign, given our assertion that indigenous participants were 'extreme' rural inhabitants in many ways.

Higher values and membership in high-risk groups for the anthropometric outcomes we used all increased with increased age. To control for this, we tested the relationship between these outcomes and age, and found no significant relationships, except in the case of HbA1c. The indigenous group was younger than participants in the non-indigenous group (Table 1). We conducted a linear regression on HbA1c values (high-risk group only) using age of the subjects and indigenous status as a 'dummy' variable. Age did have a significant ($p > .001$) relationship with HbA1c of the participants, with an adjusted r square value of 0.228. The addition of indigenous status did not improve the model significantly and we therefore conclude that indigenous status was acting a proxy for age, and therefore indigenous nor rural status is an important predictor of HbA1c. Therefore, hypotheses 4a and 4b are **not supported**.

Despite this, we find the results of our study to be meaningful. Migrants from rural places and of indigenous status had significantly different diet change and health outcomes than those of the other groups. Past research has demonstrated that those from more rural and more indigenous places have generally better diet related health, which was consistent with our study: these recent migrants still maintained their health advantages, despite their common food and health environments with migrants from other groups. However, these same groups saw the highest level of negative diet change, again a previously observed pattern. Despite length of time since migration and intervening stops, migrants' origin locations had significant relationships with their diet and their diet related health.

Y. Conclusion

We began this paper with three large goals: to add to the literature concerning internal migrants, to test whether geographic and migration history was important in diet and diet related health outcomes, and to determine if there were opportunities in the above for health interventions. We feel that these goals have been met, despite the small sample size of our study. We conclude that indigenous heritage migrants and those from rural places represent a prime opportunity to stop negative dietary acculturation and slow the advancement of NR-NCDs in Mexico and the United States. In addition, the significance of origin characteristics supports our call for greater geographic history in public health work with migrants.

In addition, we call for further research on migrants' intervening paths and the effects of circular and other migration histories, as our study was unable to address these questions, but feel it is one that continues to deserve attention. Acculturation and diet is a topic that deserves more study, and offers opportunities to stop negative health acculturation and could potentially allow migrants to retain their health advantages.

These results also have implications for the Latino paradox: internal migration patterns before the cross-border trip may be an important factor, as negative health acculturation (here in the form of diet) appears to begin before arrival in the U.S.. The initial promise of this study prompts us to call for future work in this area. In addition to a larger or more scientific study, work could be done comparing, short and long-term migrants, to better identify when this acculturation translates into poor health outcomes. We still feel that the migration history between origin and final destination of migrants may play a role, although our study's small sample size did not allow for meaningful comparisons.

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V. CONCLUSION

This dissertation has sought to address a large, complex, and important process: migration and its effects on human and environmental health. Rather than attempt to describe or categorize this entire process, we mirrored the analysis methods for many geographers: we began at the crudest scale and focused in tighter at each step, following our theme through time, place, space, and even academic discipline. First, we examined the relevant theory and literature to ground us in our search. We then used publicly available data to examine this process at the crude scales of globe and global region, over a 50-year period. Following this relationship ever tighter, we looked at a manifestation of the relationship between migration and environmental health for the nation of Mexico at a ten-year scale, and then ended with a detailed examination of the short-term impacts of migration on health for a selected population of Mexican migrants in one city. Throughout we kept our eye on how place, space, and scale impacted this relationship, as we feel that in some ways geography is overlooked in the research surrounding this topic. As the dissertation changed the scale of its focus, some aspects of the relationship between migration and health remained constant, while others changed or disappeared. In this way, the structure of this dissertation itself allows for a reflection on how geographic factors affect migration and health. We hope to avoid making pat or self-serving conclusions about this broad topic based solely on our research. However, we feel confident in the importance of future work on migration and health, the need to consider geographic factors in such, and the vital role that geographers can play in the trans-disciplinary efforts that will be needed.

This project had a number of limitations. Although we have argued for the advantages of examining this large process at multiple scales and through multiple methods, there are clear disadvantages to doing so; we are unable to address each topic with the breadth that it deserves. Regarding the specific literature this dissertation addresses, Chapter 1 makes two distinct arguments. In the first part, we conducted a limited review of the Planetary Health literature for discussion of human migration, and concluded that it is not being fully considered. We find that there is adequate discussion on the impacts of environmental health on human migration, animal migration, and human health, and limited discussion of the impacts of human migration on environmental health. We argue the need for increased discussion of negative environmental outcomes because of human migration. In addition, this chapter reviews literature concerning geographic approaches to malnutrition and argues that it deserves its own subfield, which we labeled the Geography of Malnutrition. Both parts of this chapter are limited in that they use less than formal methods for their literature review, necessitated by the undefined boundaries of the subfields that they are examining. However, we believe that it makes a positive contribution to Planetary Health literature concerning human migration and Geography literature concerning nutrition. We hope to expand upon this research in future work by empirically examining some of the linkages between environmental health and human migration.

Chapter Two examines population and food production statistics at several (crude) scales over 50 years. The chapter examines demographic trends, agricultural production, and related resource use, and attempts to draw broad lessons from their association. We find that within Latin America there are exponentially increasing inputs as contrasted with stagnant or arithmetically increasing outputs; the outsize impact that Mexico and Brazil have on this nexus, as well as examine some case studies, all of which leads us to some predictions on the future of this relationship. We believe that this chapter, although limited by being broad in scope and crude in scale, adds to the literature surrounding this topic.

Chapter 3 is nation-wide examination of forest-cover change from 2000 to 2010 and economic, demographic, and migration processes during the same period. We find that forest cover change is driven by environmental processes, along with diverse predictors from other groups, but that migration processes are of universal importance at the national and biome scale, for both forest cover loss and growth. This paper is limited in the variables it was able to consider in the analysis and by the large amount of variance that environmental factors accounted for. Despite this, this paper makes a positive contribution to the discussion of the drivers of forest cover change in Mexico.

Our final chapter investigates dietary change and health in recent internal migrants to Tijuana, Mexico. This chapter finds that migrants from rural places and of indigenous status have better diet-related health, but have undergone more negative diet change than the rest of the population. This study is one of a very few that examines the diet and health internal migrants in Mexico, let alone focusing on recent migrants. The results demonstrate the importance of detailed information on migrant's origin and indigenous status. This study was limited by the unscientific sampling method and small number of subjects contacted, all functions of studying this relatively rare and reluctant population. In future work we hope to expand this research, allowing us to explore in more detail the drivers of health and diet change in recent migrants, perhaps by focusing on subject's full migration history. Despite the limited number of subjects, we feel the study has important ramifications for research on health and diet and migration, and may indicate a population for health intervention research.