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Adjudication and the Adaptive Capacity of Pecan Farmers in the Lower Rio Grande

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THESIS

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ABSTRACT

Despite growing uncertainty of water availability in the future and popular understandings of water conservation in agriculture, a growing number of farmers in the Lower Rio Grande Basin are rapidly transitioning to pecan orchards, a long-term and highly water-dependent crop. Drivers of landscape change can be environmental, historic, socioeconomic, or institutional. Adaptation to change is understood as responses to external stimuli and is limited to a threshold by which an actor can meet their goals. Much of the current scholarship focuses on a given population's adaptive capacity toward global climate change, however, most water policy in the western United States is part and parcel a response to burgeoning climate crises. By framing agrarian change in terms of the capacity to adapt to water policy, adjudication, and litigation, I explore what externalities and mechanisms of uncertainty influence agricultural management decisions. I use multiple regression models to unpack some of the interplay between physical and institutional factors, spatial relationships, and cropping patterns. The analysis is evaluated based on qualitative surveys of farmers' perceptions of the drivers of change. I argue that the ability to acquire water rights to meet or exceed adjudicated irrigation amounts has disproportionately ensured the livelihood and environmental resilience of farmers with higher property value and larger farms in less rural areas. Current markets and ongoing adjudication has given advantage to pecan orchards over other crops.

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Acronyms and Abbreviations

Adjudication – LRG Adjudication

afay – acre feet per acre per year

AIC – Akaike Information Criterion

CDL – Cropland Data Layer

CIR – Consumptive Irrigation Requirement

Compact – Rio Grande Compact of 1938

EBID – Elephant Butte Irrigation District

EPCWID – El Paso County Water Improvement District

FDR – Farm Delivery Requirement

GWR – geographically weighted regression

LRG – Lower Rio Grande

NASS – National Agricultural Statistics Service

NHD – National Hydrography Dataset

NMPG – New Mexico Pecan Growers

NMSU – New Mexico State University

NRCS – Natural Resources Conservation Service

OA – 2008 Operating Agreement

OLS – ordinary least squares

OSE – New Mexico Office of the State Engineer

PCA – principal components analysis

Project – The Rio Grande Project

SES – social-ecological system

SRGDCFA – Southern Rio Grande Diversified Crop Farmers Association

SSURGO – Soil Survey Geographic Database

Texas v. NM – Texas v. New Mexico and Colorado, 2012

USDA – U.S. Department of Agriculture

VIF – variance inflation factor

WRRS – Water Rights Reporting System

1. Background

The story goes that nestled somewhere in a neat row of pecan trees on the outskirts of Las Cruces, New Mexico, there is a farm shed, and that in this shed there are old brass buttons stamped with the crest of the U.S. Army. These buttons are the only remaining parts of reins used to indenture the labor of the mules who hauled supplies in and rocks out during the construction of Elephant Butte Dam in the early part of the last century. This dam, of course, is the symbol of modern agriculture, human innovation, and significant homesteading in New Mexico. It also ushered in lasting and likely irreversible change to the landscape and economy of New Mexico. As the reservoir filled behind the dam, homesteaders stampeded the valleys below it and purchased federal land grants by hundreds or thousands of acres at a time (Schönfeld LaMar, 1984).

In 1926, the first crop that W. J. Stahmann planted on his new 1900 acres was presumably mostly cotton, and if the story is true, his ploughs were pulled by mules he bought from the Reclamation Service after their work was done in the containment of the river. Over the next decades, Stahmann and his sons transformed their operation into some of the most prolific pecan orchards in the world. Accounts vary as to what drove their decision to transition from cotton to pecans, one being that Stahmann took in some young saplings from a neighbor who didn't know what to do with them ("Get to Know Sally Stahmann," n.d.) and another that he was influenced by Fabian Garcia's test orchards at the agriculture college of New Mexico State University (NMSU) (Herrera, n.d.). What is known is that there is a long and intricate relationship between a government intent on managing water resources and the farmers it serves.

Despite the names and dates, this story is hardly unique to the Lower Rio Grande (LRG) Basin in New Mexico. Westward expansion around the turn of the twentieth century was facilitated largely by the regulation and management of rivers and the connected groundwater. Land is valued by the crops that grow on it. Crops are only attainable and solvent through the harnessing of what is popularly referred to as natural resources. As the relationship between natural resources and the governing bodies that assert dominion over them matures and is restructured, trends in agriculture emerge and others decline. Older farmers in the two valleys downstream from Elephant Butte Dam – the Rincon and Mesilla – will tell you about times when cotton was king, when an ocean of white stretched for miles along the river corridor. Today, pecans are king and dark green trees span for as far as the naked eye can see.

It's strange that pecans are king, though, because in this day and age the large amount of water required to sustain the orchards is threatened by climate change and intensifying fights between states, nations, and ideologies. Further complicating the puzzle is that pecan orchards are a long-term investment that don't respond quickly to sudden perturbations as readily as crops with a shorter lifespan, like cotton.

1.1 Drought and Climate

The dominant irrigation method in the LRG is to flood crops using a combination of surface water and groundwater (Figure 1). This flooding occurs many times throughout the irrigation season, which typically extends between late spring/early summer and late fall annually. The Southwest is entering its nineteenth year of significant drought (Meyer, 2018). Prolonged colder ocean conditions in the Eastern Pacific Ocean have pushed winter storms further north, reducing the amount of annual wet storms. Even when rain and snow storms do occur over the southwest, overall warmer temperatures still contribute to persistent drought conditions region wide (NASA Earth Observatory, 2018). Generally, as soils dry out, their ability to absorb water from rain events is diminished, meaning that soil and river health is dependent largely on slow and steady snowmelt (Holden, 2014), which is becoming less frequent. Climate projections in the Southwest are dire. Temperatures are expected to rise by up to 5.5° F by 2070, with the most pronounced impacts manifest as summer heatwaves and longer stretches between annual freezes, which will be detrimental to the yield and productivity of regional crops like established fruit and nut trees (Garfin et al., 2014).

At the end of 2018, Elephant Butte Dam was at three percent capacity. Smaller deliveries of irrigation water from the dam result in more intensive groundwater pumping, and as irrigators pull more from the shallow water table the river loses its ability to perform one of the most basic functions of a river, which is to flow above ground (Holden, 2014). Despite this, New Mexico is still liable for water deliveries downstream to Texas, and the United States to the Republic of Mexico.

Figure 1. Flood irrigation of a pecan orchard in the Lower Rio Grande (image courtesy of Lauren Sherson, USGS).

1.2 A Brief History of Water Litigation in the Lower Rio Grande

Around the turn of the 20th century, the Reclamation Service (now Bureau of Reclamation) initiated the Rio Grande Project (Project), which included the construction of Elephant Butte Dam and the irrigation infrastructure required to irrigate the farmland south of it down to Fort Quitman, Texas. Around the time the Project was completed, homesteaders were incentivized to settle and farm the region (Schönfeld LaMar, 1984). The influx of new irrigators along Rio Grande from its headwaters in Colorado, through New Mexico, and onward into Texas, presented a need to regulate water delivery between the three states. The Rio Grande Compact of 1938 (Compact) claims to "remove all causes of present and future controversy" (*Rio Grande Compact*, 1938) by appropriating water on a sliding scale per availability at the river's headwaters in the San Luis Valley. The formation of the Compact allows the three participating states to reap the benefits of surplus years and to equitably share the burden of dry ones.

The Compact has been tested numerous times since its inception (Utton Center, 2013), and in modern times, calls for formalization of the extent and scope of water rights in the LRG led to the Lower Rio Grande Adjudication (hereinafter Adjudication), an ongoing case that essentially defines exactly who owns rights to exactly how much water in the LRG Basin. Based on the understanding that irrigators on the New Mexico side of the Project need groundwater to operate and that those on the Texas side need what they refer to as "sweet water" from Rio Grande surface deliveries to dilute the saline groundwater from the Ogallala Aquifer for the same purpose, both states entered into the 2008 Operating Agreement (OA) as brokered by Reclamation to ensure that both parties remain legally whole under the Compact.

The agreement was generally popular among farmers in both districts. During an interview, one farmer told me, "We had finally gotten into an Operating Agreement that both sides were [satisfied]. You could drive across the state line and, you know, smile and wave at a ditch rider in [the El Paso irrigation district] and vice versa." Popular though it may have been, the longevity of the agreement wasn't afforded the opportunity to withstand the test of time. Rather, in what has been called "politicized hydrology," (Esslinger, 2011) and a "sinister motive," (Haussamen, 2012) then New Mexico Attorney General, Gary King, sued Reclamation for giving away New Mexico water to Texas at a moment that happened to align with the run up to the 2012 gubernatorial race. King lost that race, nevertheless leaving behind a lasting legacy: Texas's response.

At its most basic level, the argument that Texas has presented to the Supreme Court of the United States is that groundwater pumping between Elephant Butte Dam and the Texas state line is in direct violation of New Mexico's responsibility to deliver water as decreed by the Compact. Political aspirations and certain livelihoods have thrust the river and its dependents into a bitter altercation.

1.3 Economics of Pecan Farming in New Mexico

Agriculture in the LRG, much like the rest of the world, experiences trends that ebb and flow according to a number of environmental, institutional, and economic factors (Lybbert & Sumner, 2012; Smith, 2016). While row crops are still an important and robust source of productive food production in the region, establishment of pecan orchards is steadily increasing. To date, New Mexico is the second largest pecan producer in the nation after Georgia and before Texas (Bustillos & Bautista, 2018). Moreover, hurricanes in 2018 severely impacted the future of pecans in Georgia (Haire, 2018). And still, pecans are expected to retain a high and likely increasing market value for the next few years ("Pecan Market - Global Trends, Growth, & Forecast to 2026," n.d.). Two salient distinctions between annual seed crops and pecans are that pecan orchards provide a relatively steadier financial and economic projection, and the labor associated with pecan harvesting is highly mechanized and predictable (Herrera, 2000).

1.4 Research Question

In the study of agrarian change, researchers focus on the myriad drivers that may influence trends, like the observed increase of pecan orchards in the LRG. The main question I will investigate is this: what mechanisms and processes allow pecan farmers to comfortably operate in the Mesilla and Rincon Valleys despite growing uncertainty surrounding the future of water?

In the Adjudication, Stream System Issue 97-101 (SS-97-101) defined how much water it takes to irrigate every crop basin wide, the consumptive irrigation requirement (CIR), and how much surface water is to be delivered to each crop, the farm delivery requirement (FDR). The CIR of every crop, regardless of type, is 4.5 acre feet per acre per year (afay). This CIR is only for irrigators with conjunctive groundwater/surface water rights – surface water-only irrigators only get what EBID can deliver during a given irrigation season, and groundwater-only irrigators are only allocated 3.024 afay. Pecan farmers with conjunctive use rights whose orchards were planted before March 31, 2009, were given the opportunity to "prove up" to 5.5 afay. Most, if not all, did. The FDR from Elephant Butte Irrigation District (EBID) is 1.476 afay. Conjunctive-use irrigators may exceed 3.024 afay in years when the FDR is small – which has been the case every year since the decision (see Table 7). Another crucial provision in SS-97-101 is the ability of farmers to accumulate, or "stack" leased water rights to exceed their crop's CIR (*SS-97-101*, 2011). This new arrangement restructures the traditional motion of water leases beyond gravity-fed systems and it broadly allows farmers to stack the water rights necessary to irrigate their crops from multiple sources and leasing agreements.

I argue that local laws and policies like SS-97-101 have equipped these irrigators with the ability to work around uncertainties of water availability and to instead respond to other drivers of agrarian change, such as national and global markets, labor availability, and overall financial stability. The normalization of water rights in the SS-97-101 agreement has exacerbated inequality of water rights administration while simultaneously leading farmers to respond to uncertainties of water availability by doubling down on water-intensive crops rather than initiating more conservative irrigation techniques. To support this claim, I rely on theories that balance resilience and adaptation literature with political ecology to support the development of a multivariate statistical model of agrarian change. I then evaluate the results based on semi-structured interviews with Mesilla and Rincon Valley farmers in an attempt to gain a more nuanced and deeper understanding of the underlying drivers of change.

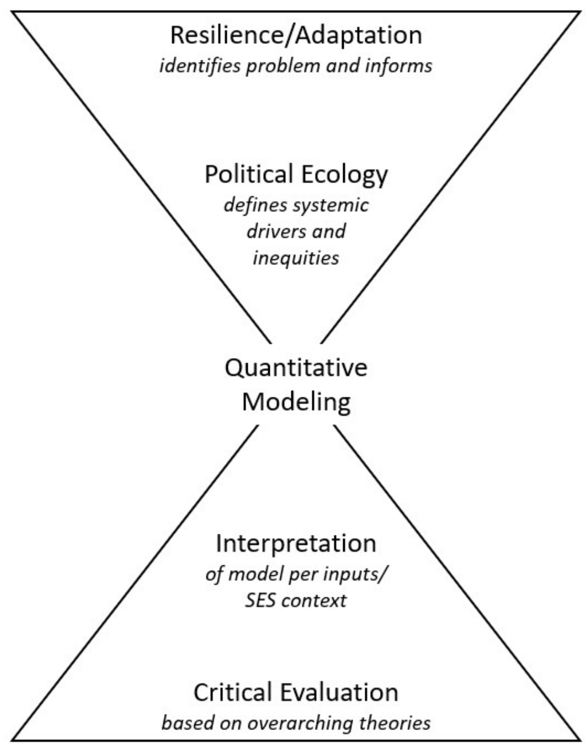
2. Literature Review

What then, are the mechanisms and processes that allow pecan farmers to comfortably operate in the Mesilla and Rincon Valleys despite growing uncertainty surrounding the future of water? Moreover, how can researchers understand these mechanisms and processes? Agrarian change scholarship has roots in political economics and economic history (Boserup, 2003), and contemporary literature of agrarian change is highly interdisciplinary, as shown in the inaugural essay of *Journal of Agrarian Change* by Bernstein and Byres (2001). The complexity of agrarian change drivers is a field continually ripe for investigation that is informed by new concerns and novel or otherwise maturing epistemologies. The theoretical foundation I use to explain the drivers of change in EBID is based on straddling the divide between resilience/adaptation literature and political ecology. Within this divide, debates remain as to the effectiveness, accuracy, and overall appropriateness of modeling human behaviors that relate to social-ecological systems (SES) – networks where societies rely on the extraction of so-called natural resources to exist (Kull & Rangan, 2016).

Within EBID, it could be argued that farmers who respond to drivers of agrarian change are behaving rationally in the absence of water as a confounding factor. Water availability should always be a consideration in crop selection, but it is not always so in the New Mexico because conjunctive use has allowed a full water supply, even in years in which minimal water is released from upstream reservoirs. However, between the neoclassical economic concerns of externalities and the political ecology of agrarian change lies this middle ground of understanding how, when the lack of water is a confounding factor, farmers are folding in capital accumulation (Moore, 2015) by increased water rights appropriation in the stacking of water rights. So, it follows that not all water rights, and certainly not access to them, are created equally. Structural investigation of agrarian change in EBID ought to be informed by a look at the power differentials and structural mechanisms that influence or enable such inequality.

In this section I will explore the theoretical structure that an effective paring of political ecology and resilience/adaptation may take in the modeling and understanding of SES. I liken the structure to an hourglass shape, where at the top, wide-ranging theory identifies problems at the social/ecological interface. Scaling down closer to the middle of the hourglass, that theory informs examples and operational definitions of behaviors or phenomena as a result of the identified problem. In the middle of the hourglass, pointed or direct quantitative analyses are used to investigate the relationship between observed behaviors and their results. Moving back outward, resilience scholars and political ecologists alike can begin to interpret the results of such analyses by using critical scrutiny and current theories. The benefit, therefore, of this kind of interdisciplinary work is that it does not terminate at the operationalized research stage, nor are the resulting interpretations devoid of critical thought used to inform the entire study.

Figure 2. General structure of theoretical union between resilience and political ecology to model social-ecological systems.



2.1 Resilience versus Political Ecology?

The concept of SES is predicated on the assumption that both social and ecological systems are given equal weight in resilience frameworks, and further that both act as parts of an integrated whole (Widgren, 2012). Conversely, political ecology frames society as a function of biophysical and ecological processes (Zimmerer & Bassett, 2003). To that end, social systems may outweigh ecological ones in terms of their historical context and the residues of power that shape them (Widgren, 2012).

Resilience and political ecology are both interdisciplinary in their own right, but they are often used as critiques of the other. Broadly, political ecologists argue that resilience scholarship necessarily lacks critical examination of lived experiences and power structures within the SES it observes. Meanwhile, the resilience school of thought argues that political ecology has abandoned ecology, becoming instead something more representative of the political economy of natural resource extraction. A growing body of literature has emerged in the last decade and a half that seeks to reconcile these differences. Within contemporary social disciplines, calls for interdisciplinary approaches are the norm (Kinzig, 2001; Kull & Rangan, 2016; Miller et al., 2008; Schoolman, Guest, Bush, & Bell, 2012). Kull and Rangan (2016) use the metaphor of a sieve to discuss the interdisciplinarity between resilience-adaptation scholarship and political ecology, arguing that the mesh of the sieve is the function by which definitions and approaches are either explored or discounted. In this metaphor, resilience has a finer epistemological mesh, allowing the discipline to adhere to more specific methods and professional or scholastic associations while permitting a broader range of sciences to participate. The political ecology mesh, on the other hand, is much coarser, which, while it may not lend itself to the development of a new or rigidly-defined discipline, can provide useful penetration into the array of concerns associated with socioenvironmental relationships.

Critiques of political ecology are rooted in its systemic rigidity that can be contrary to interdisciplinarity. Political ecology, it is argued, does not provide much of an integrative framework when researching socioenvironmental processes, instead “self-professed practitioners” (Kull & Rangan, 2016) will thinly apply a political ecological veil on their varied analysis (Kull & Rangan, 2016; Robbins, 2011). This veil has also led to an abandonment of the more anthropologic roots of political ecology and, in geography, has resulted in new epistemological directions which branch out into other disciplines, qualifying political ecology to become, as Blaikie (1999) puts it, “all things to all people”.

Similarly, several limitations of resilience theory have been tossed around. While resilience claims to be broadly transdisciplinary (Folke et al., 2002; Gunderson & Holling, 2002) and a better epistemological fit for understanding ecological transformations than other dominant narratives (Benson & Craig, 2017), it is not necessarily a novel approach. Rather, resilience scholarship has firm roots in political ecology, environmental ethics and history, traditional ecological knowledge, and more (Kull & Rangan, 2016).

Furthermore, the use of normativity in resilience thinking is more of a conclusion than a guiding theoretical structure. The aim of much of the resilience scholarship is for actors within a network to see the links between ecology and society and then to make informed decisions armed with that knowledge (e.g. Folke et al., 2010; Walker & Salt, 2012). Many calls for "resilience thinking" are made by what Kull and Rangan (2016) refer to as "self-appointed stewards of the resilience approach".

2.2 Bridging the Gap

Despite these cross-disciplinary critiques and the epistemological divide, there exists a growing body of studies that explicitly attempt to reconcile the two approaches. My investigation of the landscape and livelihood transition in the Mesilla and Rincon Valleys will utilize the theories posited in these literatures to include both perspectives as a way to sufficiently understand the changing relationship at the social-ecological interface. The following studies serve as evaluations from within by practitioners who seek to bridge the divergence. Folke and colleagues (2010) present a theoretical framework for understanding SES that incorporates concepts of resilience, adaptation, and transformation. Given that Holling's (1973) original definition of resilience, a "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables," has since been expanded into two main typologies (Brand & Jax, 2007), SES are best understood by the dynamics that are present beyond an equilibrium steady state. Resilience in this purview is defined by the sheer amount of disturbance that a system can endure and absorb before changing to another regime – a definition termed ecosystem resilience (Brand & Jax, 2007; Gunderson & Holling, 2002). In terms of my research, I want to uncover the capacity farmers have to absorb changes in water policy and climate-driven availability of water.

In his essay, *Resilience thinking versus political ecology*, Mats Widgren (2012) expertly summarizes the differences between the two epistemologies as a function of different world views. While political ecology derives meaning by exploring the past, resilience exists in the "ethnographic present". The nature of societies, conceptualization of space, and the flow of behavior within society across space and time are also salient points of divergence between the two camps. These differentials are determined largely by exploring who controls labor and access to resources, a chief tenet of political ecology, or how learning, growth, or the adaptive capacity of actors in a network is dependent on the systems in which they exist. I seek to understand the problems of resource abstraction and over-extraction by uncovering the adaptive capacity of farmers as a response to adjudication, which is ostensibly a method of controlling access to water resources. This distinction in world views, he argues, is an effect of scalar models of change. Whereas local views position individual livelihoods and lived experiences at the forefront, global, and indeed resilient, referential frames view landscape change as both a direct result and driver of those changes. Resilience thinking is spurred by an appreciation of how change is driven by broad and far-reaching factors (Walker & Salt, 2006), while resilience practice (Walker & Salt, 2012) emphasizes more multi-scalar understandings of system thresholds and points of transition. Indeed, as resilience scholarship has matured, it has taken on more diverse worldviews that incorporate modes of production and capital as they relate to individualistic values and responses (Moore, 2015; Peet, Robbins, & Watts, 2011) and large-scale implications of land use and landscape change vis-à-vis development in the modern world (Zimmerer & Bassett, 2003).

Two nested concepts support the concept of ecosystem resilience – first, transformability, or the ability of a system to cross defined thresholds, and second, adaptability, or the overall capacity of any given system to withstand internal and external perturbations up to the point of transition (Folke et al., 2010). Equipped with these prescribed concepts, researchers make normative claims about the ideal functioning of a system based on more rigid structural observations that tacitly or explicitly acknowledge that human management has the potential to either destroy or create resilience in SES (Folke et al., 2002, 2010; Walker, Holling, Carpenter, & Kinzig, 2004).

2.3 Normativity as a Theoretical Tool

Political ecologists argue that by defining the idea functioning of SES, resilience thinking can tend to make more normative claims about what functions a system *ought* to maintain or how people *ought* to work to maintain it. For example, if societal dependence on any given ecosystem for wellbeing or industry makes that society less resilient (Adger, 2000), particularly when faced with environmental perturbations, then normative claims must be sensitive to the situational relationship between people and nature. In a meta-analysis of resilience, Brown (2014) sought to determine if there is a significant social turn in resilience scholarship. The general finding is that there is little social focus in resilience literature and that there exists an ontological tension between normative and analytic approaches to framing the concept of resilience broadly (Brown, 2014). A salient critique of modeling SES is that the removal of normative analysis in predictive models tend to dilute social diversity (Turner, 2014). Moreover, the positioning of normativity in resilience as a conclusion or way to explain what *ought* to be is an inherently moral or ethical stance to take (Cote & Nightingale, 2012) – a stance that allows the resilience thinker (Walker & Salt, 2006) to wield certain power. Situating empirical studies of SES allows researchers to ask questions of power, both of the actor and the observer. By asking how a system is resilient and for whom, empirical observation may be situated, because resilience cannot be "seen from nowhere" (Cote & Nightingale, 2012; Haraway, 1991). Certainly, critical analysis of power dynamics cannot be unwed from any system where society is a key component.

Similar to the way that abstract definitions of resilience and associated concepts necessitate normative questions (Cote & Nightingale, 2012), these abstractions allow and even call for the treatment of resilience as a boundary object to promote cross-disciplinary collaboration and debate (Kull et al., 2018; Kull & Rangan, 2016). Boundary objects are concepts that may be interpreted differently across disciplines or situated among communities, but that still have the ability to maintain integrity – making resilience as a boundary object in and of itself an object of resilience. The resilience of a "regime shift", for example, has metaphorical power when used to define multiple diverse systems in alternating ways (Kull et al., 2018). This is despite a call for just the opposite from Brand and Jax (2007). The malleability of resilience as a concept is a specific result of more normative claims, and while the plasticity of resilience as a boundary object leaves it open for interpretation, which is not objectively bad, it may lead to the co-opting of resilience for different or competing interests (Brown, 2014). MacKinnon and Derickson (2012) frame this ability to be co-opted as a “dark side to resilience” and “deeply problematic”. Conversely, Shaw (2012) argues that resilience at a local government level supports the growth of sustainable development, which is otherwise marginalized among local authorities. So, the interpretability of resilience may serve great benefit, the risks of which can be mitigated by critical normative interpretations.

This criticality provides the basis for more sensitive critiques of resilience studies. Turner (2014) explores the relationship between political ecology and resilience in terms of common features, histories, and points of divergence between the two. Citing a broad trend away from truly ecological inquiry in political ecology, he proposes that the study of land use ecology will help engage both epistemologies. Gallardo and colleagues (2017) conducted an illuminating study to systematically identify this epistemological break in praxis. A team of six researchers – three who align with resilience scholarship and three political ecologists – explored the impacts of environmental change on the livelihood strategies of reindeer herders in Subarctic Sweden. From the same empirical data, notably different conclusions were reached by the teams. The political ecologists focused on the dialectical relationships between past and present and between local or global markets to inform the ways that claims to and assertions of power were framed by study subjects. The SES approach was more systemic, and by observing the behavior of and interplay between key parts within the observed system the team was able to identify problems with trust and communication across actors (Gallardo et al., 2017).

In modeling any observable phenomena, it follows, the modeler must be sensitive to how normativity informs their research. While the action of making didactic claims about a system can exert unintended power upon that system and the actors within, the way in which a researcher utilizes normative claims can produce radically different results in the practice of modeling reality.

2.4 Incorporating Epistemologies to Explain Complex Phenomena

Other researchers, like Neil Adger, are able to move between each approach comfortably (Kull & Rangan, 2016). For example, in order to define cultural change and responses to climate change, Adger and colleagues (2013) seamlessly integrated critical historical analysis of power relationships and structural impacts of social and environmental change. To do so, they defined climate change as a direct result of modes of production in modern society and used current social research to explore how culture and adaptation are interrelated. Furthermore, they argue that perception of environmental risks can be unique to distinct cultures at varying scales. This research is built on earlier work that seeks to define resilience from a social lens (Adger, 2000), arguing that a dependence on ecosystem services may inherently make a given society less resilient. Similarly, Peterson (2000) uses resilience and political ecology concepts to examine salmon in the Columbia River Basin, showing that human behavior and political institutions exert power on each other and on ecosystems.

More recently, a growing body of work that attempts to explain observed processes using the theoretical underpinnings bridging resilience and political ecology. Contemporary research is working to test the limits of combining these epistemologies. From situated analysis within the social, economic, and discursive mechanisms associated with climate change and coffee production in Ethopia (Hirons, Mehrabi, et al., 2018), to a "biocultural" framework that relates resilience to the underlying political, social, and psychological apparatuses of resilience and adaptation in Ghanaian cocoa communities (Hirons, Boyd, et al., 2018). Research into the perceptions of environmental impacts and vulnerability of rural smallholder farmers in Madagascar suggests that their livelihoods are related to access to an array of assets and the utilization thereof (Stoudmann, Waeber, Randriamalala, & Garcia, 2017). Stoudmann and colleagues' contribution highlights an important research gap in political ecology/resilience literature in that experiences of change and its impact on asset bases is left broadly untouched.

These two approaches to understanding SES have generated some useful insight into the drivers of changes to human behavior in response to internal or external disturbances. System resilience is scalar, meaning that different and often nested systems will demonstrate independent degrees of resilience based on inputs and requirements. To that end, it has been shown that agricultural conversion and privatization presents negative impacts on small-scale social resilience by acting in opposition to local property institutions (Adger, 2000). This finding is rooted in the theoretical notion that culture is dynamic and reflexive and it thereby directly influences the concept of climate change (Adger et al., 2013). In the LRG, and indeed much of the American west, water and other environmental governance policies are a response to cultural perceptions of climate change.

Because transformability and adaptability are core components of resilience (Brown, 2014; Folke et al., 2010; Gunderson & Holling, 2002; Walker et al., 2004), it is imperative to understand the ability of an actor to respond and transform to externalities, thereby maintaining resilience. Research into drivers of change, particularly agrarian change, places a resilience-oriented importance in understanding barriers to adaptation among marginalized groups. Perspectives and values regarding livelihood goals and hence adaptive capability (Campos, Velázquez, & McCall, 2014; Dow, Berkhout, & Preston, 2013; Dow, Berkhout, Preston, et al., 2013; Stoudmann et al., 2017; Warner, 2016) are affected by governmental structure. To illustrate this, Ghanian cocoa farmers have resorted to fatalism as a coping strategy, placing the ability to change and respond to governance or climactic disturbances beyond their control (Hirons, Boyd, et al., 2018). Fatalism is but one manifestation of complacency as a barrier to adaptation. Complacency can also stem from maladaptive perceptions of resilience already present in a given system (Adger et al., 2013; Amundsen, 2012). Moreover, seemingly apolitical institutions assert control over access to and flow of resources (Gallardo et al., 2017; Heynen, McCarthy, Prudham, & Robbins, 2007), and these institutions lock stakeholders into political or economic marginalization traps (Gallardo et al., 2017; Hall et al., 2015) – a situation that is observed through banks and other lending control of capital assets (Brunt, 1992; Petit, Kuper, & Ameur, 2018; Warner, 2016). While a resilience approach uses explanations to insist that political and apolitical bodies will seek a desirable state of policy-making (Kull

& Rangan, 2016), political ecology argues that these mechanisms limit the ability of marginalized people to redistribute or dissent effectively (Gallardo et al., 2017; Mouffe, 2005).

Other barriers to adaptation are manifested through perceptions of risk beyond livelihood alone. Dow, Berkhout, and Preston (2013) suggest that climactic risks impose pressures on the health, safety, and security of stakeholders. Beyond immediate risks, perceived threats to cultural values of objectives include impacts on food production (Adger, 2000), food security (Turral, Burke, & Faurès, 2011; Warner, 2016), lifestyles and aesthetic or spiritual values (O'Brien, 2009; O'Brien & Wolf, 2010; Warner, 2016), social justice and security (Albizua & Zografos, 2014), capital (Turral et al., 2011) and others. The value-based approach in the above articles holds individualized experiences and perceptions of risk as a key component in the likelihood that a stakeholder will choose to adapt to externalities, and the ways in which they will frame their responses.

The theoretical drivers of change proposed through a union of political ecology and resilience studies have been used to produce some interesting findings in the realm of agrarian change and SES modeling. Adger and colleagues (2013) argue that cultural geography and human ecology of SES differ based on conflicting ontologies of culture. Quantitative studies have attempted to reconcile the political ecology/resilience divide through careful modeling. Chowdhury and Turner (2006) sought to broadly understand land use patterns of smallholder farmers in the Southern Yucatan by incorporating agent and structure models of that SES. In that context, agency is defined by variables relating to individual people, like ethnicity, demography, quality of life, and economic strategy, and structural variables are those that relate to institutions like crop or land subsidies, credit, and access to employment or information. The underlying principle is that people and the systems in which they reside, be it institutional or ecologic, exert influence on one another (Zimmerer & Bassett, 2003).

2.5 Geospatial Modeling of Agrarian Change

GIS modeling and remote sensing have been used to model observed processes of landscape change for decades (Jensen, 2006). Taking the step from modeling the presence of change to explaining the drivers of that observed change is difficult. Population data have been used to reveal correlations to landscape transition (Van Eetvelde & Antrop, 2004), and Campbell and colleagues (2005) used complimentary remotely-sensed and field survey data to uncover the drivers of land use and land cover change in Kenya. However, the field surveys were used for their explanatory power only after data were collected and analyzed (Campbell et al., 2005). Another relatively early attempt to model drivers of landscape change analyzed four methods of conceptualizing the relationship between driving forces, actors, and change (Hersperger, Gennaio, Verburg, & Bürgi, 2010). While these studies paved a way for modeling and interpreting drivers of change, they do not fully grasp the values, perceptions, and individual behaviors of the humans represented.

Citing resilience-leaning studies (e.g. Below et al., 2012; Cutter et al., 2008; Eakin, Benessaiah, Barrera, Cruz-Bello, & Morales, 2012), that nevertheless incorporate proxies for structural power such as socioeconomic influence on adaptability, Minerva Campos and her colleagues (2014) propose that the drivers of landscape change can be grouped into four categories – environmental, historic, socioeconomic, and institutional. The researchers used mixed methods to demonstrate that adaptive capacity to climate change in rural agriculture is influenced by political, cultural, social, and environmental pressures. Their work builds on an earlier study (Campos et al., 2012) that models landscape change by interpreting the proximate and underlying driving forces between land use change and the social perceptions of farmers.

Most of the spatiotemporal modeling of land use change still broadly does not incorporate qualitative assessment of the drivers. However, the use of powerful geospatial and statistical techniques can inform or corroborate more normative conclusions. Wagner and colleagues (2017) tested both static and dynamic models of land use change for their ability to explain complex hydrologic processes – processes that are likely undergoing radical transformation from climate change. Building on this, it has been demonstrated that there is statistical complementarity between biophysical and socioeconomic variables and observed land use change in western India (Wagner & Waske, 2016). Using similar methods, Kang and colleagues (2018) conducted a logistic regression to uncover trends and periods of agricultural land use change, focusing primarily on environmental drivers, such as soil suitability and climate, and the environmental/socioeconomic factor of distance and thereby access to markets. The utility of logistic regression modeling to evaluate proximal variables related to agrarian change and expansion was demonstrated by Xiao and colleagues (2015). Cutting-edge remotely-sensed satellite based land cover classification has also been used to correlate landscape change to socioeconomic and climate drivers in India (Wilken, Wagner, Narasimhan, & Fiener, 2017).

Despite the promise in the above geospatial models, factors relating to perceptions and values of the people being modeled are essentially absent. Other statistical models seek to incorporate just that. For example, an assessment of vulnerability to climate change as it relates to food security in subsistence agriculture in the Bay of Bengal (Mandal, Satpati, Choudhury, & Sadhu, 2018), generates a more granular assessment of SES in terms of impacts of change on a marginalized population. In their study, the researchers utilized multivariate and principal components analysis (PCA) to develop a more reliable vulnerability map. However important this and similar research may be, it still falls short of addressing a primary critique of SES literature, that normativity is essentially absent until conclusions are reached. Rather than discounting models of agrarian or broad land use change, though, geospatial data and analysis can be used to provide quantitative support for thoughtful and more normative approaches. To wit: Ojha and colleagues “transcend” linear models of agrarian change to dive into the problem of land abandonment during times of environmental insecurity. Using extensive qualitative surveys and focus group interviews, the researchers developed a spatial classification system of socio-environmental pathways, which explain agrarian and other land use change by observing multiple social and ecological interactions at diverse scales. Theirs and work by Khanal (2018) attempt to relate observable land use change to critical study that challenges dominant discourses and assumptions of human behavior in SES.

Using extant literature to define historically important livelihoods stemming from agriculture and aquaculture cultivation in Central Asian river delta regions, Hoque, Quinn, and Sallu (2018) developed a survey to determine the assigned values of those factors by stakeholders. The results were used to stratify households according to wealth and livelihood opportunities as a measure of socioeconomic vulnerability to external changes.

2.6 Moving Forward

A salient connection between geospatial analyses of observed change, the adaptability of people in changing environments, and the association of values, livelihoods, and power dynamics among people is largely missing. I seek to fill this gap by exploring the utility of contemporary geospatial technologies to uncover the role of perception and structures of systemic power to explain observable land use change.

Importantly, neither epistemology is superior. Rather, by recognizing the shortcomings of each one and employing their relative strengths, a more holistic and comprehensive understanding of complex systems may be achieved. By fitting methods to the proposed hourglass figure (Figure 2), resilience thinking can be credited with the identification of the problem of monocropping long-term and water-intensive orchards in the face of dwindling water availability and external legal pressures. Rather than proceeding directly to modeling the relationship between irrigation and the river system, a political ecology lens can inject a much-needed historic framework to uncover power differentials among irrigators in the basin. How do these historic relationships inform and impact interpersonal dynamics, and how do these altered dynamics relate to the SES of water resource management for agriculture? And finally, how can interpretation and evaluation of reported values and perceptions of resource extraction illuminate the complex legal, political, and ecological realities of the past, present, and future in the Lower Rio Grande?

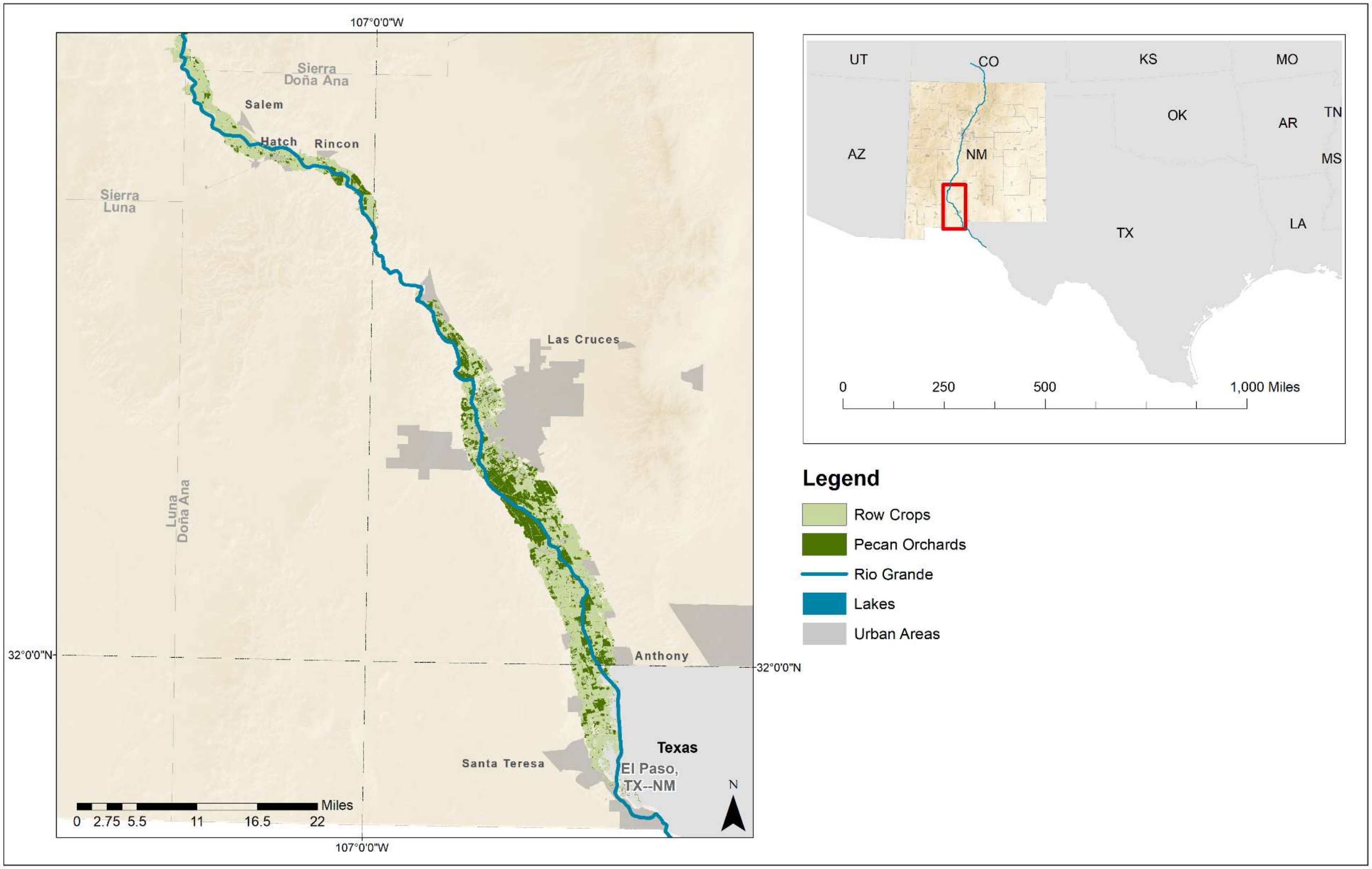
3. Materials and Methods

3.1 Study Area

The study area encompasses agricultural land south of Elephant Butte Dam across the Rincon Valley to the north and to the south the Mesilla Valley, separated by Seldon Canyon. There are a number of diversion dams south of Elephant Butte Dam to redirect water from the river to irrigation channels. Caballo Reservoir, immediately south of Elephant Butte Dam, is used as Project storage. Two miles south of Caballo Dam, Percha Dam diverts water into the Rincon Valley. The Leasburg and Mesilla Dams divert water across the Mesilla Valley. Three other diversions south of the study area, the American, Riverside, and International Dams, regulate irrigation water in Texas and for delivery to Mexico (Schönfeld LaMar, 1984). There are more than 90,000 acres of irrigated farmland within EBID (DeMouche, 2004) spanning the Rincon and Mesilla Valleys south of Elephant Butte Dam and the Texas state line. The northernmost portion of the Rincon Valley is in Sierra County, and the rest of the irrigation district is south in Doña Ana County. The model of sample parcels, discussed below, includes only farmland in Doña Ana, which is primarily due to data availability and justified by the fact that only a small portion of farmland irrigated by surface water deliveries from EBID is in Sierra. All irrigable farmland within the purview of EBID is centered along the Rio Grande, where a series of gravity-fed ditches and canals can transport surface water to farms. Approximately 33,000 acres of farmland in the study area in 2018 are pecan orchards, roughly 6000 of which were transitioned from row crops or other land uses since 2008.

This project utilizes a sequential exploratory design, and as such was designed in three phases. Sequential exploratory mixed methodology draws quantitative information from qualitative sources, such as interviews, and can be used to the development or modification of new ideas and concepts (Flynn & Kramer, 2019; Greene, Caracelli, & Graham, 1989). First, I used semi-structured interviews with farm managers (n=15) who operate within EBID to identify data relating to factors that are perceived as important when making farm management decisions (see Appendix 2). Second, I collected those data for a random sample of farms (n=1430, approximately 8000 acres) and analyzed them using binary logistic regressions, geographically weighted regressions (GWR), and ordinary least squares (OLS) linear regressions to explain transition to pecan orchards. Finally, I revisited the interview data to critically evaluate the statistical models.

Figure 3. Study area map showing crop distribution in 2018.



3.2 Interview

The interview script is designed to account for environmental, socioeconomic, historic, and institutional drivers of change, following the conclusions from Campos and colleagues (2014). While no single question strictly adheres to any one category presented in that study, all questions and responses could defensibly be grouped into at least one of those categories. This reflexivity in questioning and potential discussions allows the subsequent analysis to remain sensitive to the differing or even opposing viewpoints of participants – essentially seeking to uncover how and for whom current water administration is important (Cote & Nightingale, 2012).

The interview is divided into three parts. In the first part, I ask questions about the participant, their land, and their general irrigation techniques to establish discrete variables of each participant from which important distinctions in later analysis may be drawn. Participants are asked their age, education level, how many years they had farmed personally, and how many generations their family has farmed in the study area. I also asked participants the acreage of their farm, how many wells they use to irrigate that acreage, and the range of depth of their wells.

Moving from the short answers, I asked a series of open-ended questions about the factors that influence the participant's farm management decisions. Throughout the interviews, I posed topical follow-up questions to help shed light on the underlying values and beliefs that informed those decisions. In the third and last section of the interview, I asked participants to assign a number to the following eight statements on a Likert-style scale, ranging from one (strongly disagree) to five (strongly agree). The interview script is provided in Appendix 2.

I conducted the interviews over the course of four trips to the study area between September and December 2018. Most of the participants were recruited at three EBID board meetings and one New Mexico Farm and Livestock Bureau meeting, both of which are available to the public as part of the New Mexico Open Meetings Act. I contacted others through word of mouth between farmers in the region.

Prior to any questions, I asked participants if they were willing to be recorded and provided a consent form approved by the UNM Office of the Internal Review Board. In total, eight participants agreed to be recorded. Seven others declined, citing the ongoing Supreme Court lawsuit, but nevertheless agreed to speak with me under the promise of anonymity. Because one of the most important uses of the interview is to inform data to be collected in the second phase, I considered this concession to still be useful and appropriate.

3.3 Geospatial Modeling

Initial analysis of the interviews allowed me to identify general trends in responses relating to factors that influence management decisions and that can effectively be represented in a geospatial model with available data. The template to which data were related is an ArcGIS shapefile of parcels within Doña Ana County in 2018 provided by the Doña Ana County Office of the Assessor. Of the 87,646 parcels represented in the county shapefile, I extracted farmland by relating it to other data sources described below.

The study area is delineated by a polygon drawn around agricultural land in 2018 as classified by the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) CropScape Cropland Data Layer (CDL), a crop-specific land cover dataset generated using moderate-scale satellite imagery and ground truthing. According to the metadata, classification accuracy of the CDL is generally 85% to 95% accurate for major crop types. The overall accuracy for New Mexico between 2008 and 2018 is rather low, in the high 70% range with a Kappa coefficient between .70 and .80, but the accuracy of classified pecan pixels is considerably higher, in the .90 range with a Kappa coefficient above .91 for all 11 years, so the dataset is sufficient for all subsequent analysis.

After selecting and extracting only parcels from the initial shapefile that are within or intersect the farmland boundary, I further subset it by performing a spatial join to urban land use classes in the CDL and removing those polygons, essentially leaving only agricultural or otherwise non-developed parcels.

These preliminary analyses subset the parcel shapefile to 17,797 polygons representing 131,663 acres. The additional 40,000 acres represented in the subset shapefile is likely mostly open space, pasture, or non-developed land. Moreover, misclassification in the input raster has probably led to errors of commission. A shapefile of the ongoing hydrographic survey conducted by the OSE provided by the Reclamation office in New Mexico was used to further subset the shapefile to established agricultural land. I extracted polygons in the hydrographic survey representing irrigation water rights and converted them to points, which were used to perform a spatial join to the parcel shapefile from which I produced a final subset of predominantly agricultural parcels. This final selection covers 91,948 acres of land and is therefore deemed suitable for analysis. I took a random sample of 8500 acres, comprising 1430 parcels in total, and built an attribute table based on information gleaned in the interview process.

3.4 Variable Selection

1.1.1 Dependent Variables

The dependent variables used in the statistical analyses relate to transition from row crops or some other land use to pecan orchard over ten discrete temporal windows divided annually from 2008 to 2018. To understand the transition to pecan orchards in the region as a dependent variable, I have conceptualized it in two ways. First, if a pixel value in CDL transitioned to pecan during the target temporal window, it is related to the intersecting farm polygon. In this binary association, each polygon is given either a value of 1 for having demonstrated some level of transition or 0 for no change. The second conceptualization of transition to pecan is a scalar value of acres transitioned within each parcel over the target temporal observation window. This variation is necessary to control the statistical association of the relationship between transition to pecans and dependent variables that only have values greater than zero after transition, such as the crop type present before orchards were established. I developed a thematic raster change analysis tool that identifies transition to a target pixel value and the value transitioned from between sequential years in the set. The resulting raster datasets displays only pixels that are, for example, pecan land cover in the more recent scene, but the values are those of the former scene. So, a pixel value may be 2, representing cotton, but in the latter year the pixel at that location is 74, representing pecans. See Appendix xx for a detailed description of the tool.

1.1.2 Independent Variables

In this section I will describe each explanatory variable used in the geospatial model of randomly selected farm polygons. I will justify each selection with concepts in theoretical literature, established science of geophysical properties where applicable, and salient quotes from the interview process. Each interviewee is given a pseudonym to protect their anonymity.

The Euclidean distance from farm centroids to the banks of the Rio Grande is a scalar distance measurement for each parcel that is used to understand both the relationship between well depth and the physical location of any farm, and the degree of biodiversity in and around that farm. It was calculated using ArcMap (Version 10.4). The centerline of the Rio Grande is modeled with data from the National Hydrography Dataset (NHD). The concept of well depth is a relative term that is dependent on the depth to water at any given location (Arizona Cooperative Extension, 2011). It is commonly understood that the water table gets shallower closer to the Rio Grande. Peter, a recently retired small-tract organic farmer put it simply when asked how deep his deepest well is, saying, "[my well is] seventy feet, right near the river though. It was the property right near the river." He and other farmers also spoke about the biodiversity near their land. Peter recalls that the location of his farm is an important characteristic when managing his use of pesticides. "First off," he said, "where the farm is located, we have a lot of wildlife, so I knew that. I minimized the use of poisons, if you will." In order to capture the relationship between distance to the river and well depth, I collected well drill data from the OSE Water Rights Reporting System (WRRS) online, which catalogs every well and point of diversion from the river associated with every conjunctive groundwater/surface water right or groundwater-only water right. Often, water rights and farms are serviced by multiple wells, so only information relating to the deepest well is recorded in the attribute table. Most of the well depth data also include depth to water measurements in feet from the ground level.

I used data from every well – regardless of use – in Lower Rio Grande Basin with reported depth to water to interpolate a continuous surface of the water table across both valleys. I co-kriged wells within the boundary of the study area with all wells basin-wide to ensure that no inaccurate results would be interpolated at the edge of the study area polygon as a result of boundary limitations in the form of sudden drop-offs or spikes in the interpolated water table limit (Reilly & Harbaugh, 2004). The reported root-mean-square error of semivariogram fitting in the interpolation is 7.806 feet.

The assumption when collecting well and water depth data and calculating the distance to the river is that they would be statistically correlated. However, because wells are expensive to drill, I was interested to see the relationship between farm size, farm value, and well depth. This assumption is predicated on the notion that socioeconomic power differentials may enable farmers with higher overall capital to ensure access to groundwater. According to both political ecology and resilience, rural livelihoods are directly related to access to natural, physical, human, and social resources, and the utilization thereof (Stoudmann et al., 2017). Farms closer to the river may have the ability to be shallower, potentially equalizing access to water as a natural and physical asset for those farmers who cannot afford to drill deeper or more wells.

In order for groundwater to effectively offset surface water deliveries, farmers must have access to groundwater. So, beyond only drilling deeper, most farms are irrigated with more than one well. The number of wells per parcel is spatially joined and used as another attribute in the model of sample farms. Put simply, James, a large-scale pecan farmer in the Mesilla Valley told me:

> We believe in redundancy. If you get in the middle of the season and you have a well go down you can lose a crop. We'd rather have – the way the State Engineer's told me they look at it – you can irrigate with x amount of water and we don't care if you pump it out of one well or five wells; it makes to us no difference but that's all the water you're gonna get. And so, we've invested in and we have more wells that we need – there's no question about it. We do not want to get out on land and lose a valuable crop because all of a sudden we had not enough water, and we couldn't get across it.

Furthermore, older farms tend to be closer to the river, as early irrigation in the valley was primarily irrigated by surface water deliveries through canal or acequia systems (Schönfeld LaMar, 1984). The modernization of irrigation technology following the Rio Grande Project increased the distance between irrigable acreage and the river, Data pertaining to well drill date is also available through the WRRS. This situational assessment of well depth, drill date, and distance to river, then, can be used to justifiably sort those variables into either environmental, socioeconomic, or historic groups.

Another pair of important environmental factors commonly referenced during the interview process was soil type and quality, and if the farm is located in the Mesilla or Rincon Valley, where soil types are generally different. The ability of soil to promote effective irrigation is a primary concern that is affected by, among other things, the proclivity of a soil to taint the water supply. For example, Peter tells me:

> "My farm had heavier soil so I didn't need that much water...if you go, leave Las Cruces and look up to your left and see way up on desert soils up on the bench, well…those are very porous soils up there, but somebody made the decision [that] as long as you have the water, you can do anything as long as you have the water."

Soil data were collected using the USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) Web Soil Survey online tool, which provides interpretation ratings for each mapped soil type in terms of its irrigation suitability. These ratings are based on a number of factors including environmental characteristics, water requirements, crop yield, energy use and conservation, water quality, and others (Natural Resources Conservation Service, 1997). These ordinal data were reassigned discrete numeric values in the attribute table.

Given that farmers understand the soils and related irrigation capabilities to vary across the Rincon and Mesilla Valleys, farms in each respective valley were assigned either a value of 0 for Rincon or 1 for Mesilla. Each valley also comes with associated perceptions on water availability. Joseph, a vegetable farmer in the Rincon Valley states, "It's not really an aquifer, it's like an underground river here in the Hatch (Rincon) Valley." And Gary, a large-scale pecan farmer south of Las Cruces in the Mesilla Valley, says:

> There can be [many] definitions for water being 'tight'. In the Hatch Valley more so than in the Mesilla Valley extended low surface water allotments will lead to short term issues in their aquifer, so water can be tight because their aquifer has been under stress four or five years in a row. In the Mesilla Valley our aquifer doesn't see the same types of stress,

but we do have increased costs of pumping it because as the water table drops the energy needed to lift that water is greater.

Beyond the environmental differences between these valleys highlighted by farmers, each one has its own historic and socioeconomic associations with types of crops and neighboring farms or communities. In Hatch, the primary community of the Rincon Valley, there is a strong association with green chile that dates back to Hispanic agriculture prior to the construction of Elephant Butte Dam (Urig, 2015). While much of the green chile produced in the region bears the Hatch name, it is not unique to that place alone. However, larger portions of irrigable land in the Mesilla Valley to the south may have enabled more diverse crops (Schönfeld LaMar, 1984), including the first pecan orchards.

And while farming traditions such as these can certainly influence patterns over time, farm conversion over a short scale can be understood as a diffusion of sociotechnical innovation (Lybbert & Sumner, 2012; Padel, 2001; Rogers, 2003). This potential for diffusion is represented by modeling observed trends of transition to pecan orchards across the study area represented as statistical hot spots. Using the thematic raster change analysis tool described above, I generated a combined raster of transition over the last decade and recalculated all nonzero values to one. With this I made a binary map of every pixel transitioned yearly from some land cover type to pecan. Next, I calculated a vector fishnet over the entire study area in which I counted all corresponding transitioned pixels. The appropriate length for a fishnet in geostatistical analysis is determined according to the following equation (Mitchell, 2005):

$$l = \sqrt{2\left(\frac{A}{n}\right)} \tag{1}$$

Where l is the leg length of a fishnet cell in meters, A is the area of the surface being analyzed in square meters, and n is the total number of observations. In this case, the study area is approximately 5.8B square meters and there are 131,513 pixels that demonstrate a transition, so the length of each leg is 298.6 meters. Next, I related each transitioned pixel to the containing cell of the fishnet using zonal statistics and performed the Getis-Ord Gi* hot spot analysis. The Getis-Ord Gi* statistic calculates where values spatially cluster in relation to neighboring features. The output z-scores are normally distributed, and a probability ranking is assigned to each feature where higher z-scores indicate a high probability of clustering and conversely, a low group of z-scores indicates a low probability (Mitchell, 2005). ArcGIS groups these probability rankings into seven classes that indicate either a high or low probability, 99% or -99%, respectively, and a distribution of probabilities between. Features with values of 0 are considered to be statistically insignificant and thereby carry no statistical probability in terms of clustering. I reclassified the seven probability rankings to a nominal scale from 0 to 6 and then spatially associated the distribution of hot spot transition zones to the 1430 sample parcels in the attribute table.

On the surface, this trend of transition has an interesting relationship with the perceptions of farmers and how they behave based on the actions of their peers. When asked to agree or disagree with the statement, "I make management decisions based on what other farmers around me are doing," all but two interviewees disagreed or strongly disagreed. However, other statements point to the belief that they do make decisions based on the behavior of their neighbors in some way, suggesting that the given statement may not necessarily capture the nuance of how farmers react to observed behaviors. For example, Gary plainly stated, "I talk with farmers all the time to find out what they're doing. Sometimes I do what they're not doing, or I avoid doing what they're doing." Other responses were more nuanced. For example, James told me:

> We tend to let somebody else make the mistakes first…We don't want to be the first ones out. We want to let somebody else learn at their own expense and we may be watching it, paying attention to it, but we're probably not gambling men unless we're pretty well convinced that it's gonna work. If there's question marks, we're gonna let somebody else try it out for a while."

Another metric of trend is more straightforward. The presence of pecans already in a farm may indicate or relate to the establishment of more pecan trees within that parcel. This is mapped by associating pecans in each observation window to parcels using zonal statistics. Transitioning otherwise productive land to pecans is not a decision to be taken lightly. It takes about seven years for a pecan tree to start producing fruit that can be sold, meaning that a farmer's rate of return for a new orchard is potentially zero for the better part of a decade. Some farmers will grow crops like cotton between saplings, which can, of course, introduce even more complications, so the practice is uncommon. A cottage industry seems to have sprouted up among other pecan farmers where immature trees are planted much closer together than mature, established orchards. Once these trees age to the point that they can produce fruit, they are transplanted to farms with more room to grow. Also, farmers may accumulate or lease established pecan orchards – incremental conversion to more orchard land often follows. This driver is likely economic in that it positions farmers within the pecan market with already-established production. Gary reflected on his family's history with pecans:

> My grandmother had transitioned most of our farm in the mid- to late-sixties to pecans. I don't know all of her reasons [but] I'm sure one of her reasons had to do with reinvestment in the farm, that moving from seed crops…you had a capital investment in the trees.

Throughout our conversation, Gary would return to the ways that pecans fundamentally change a farmer's investment portfolio. A pecan orchard is an investment that is orders of magnitude longer than annual seed crops, so financial and economic projections are vastly different.

For this reason, it is important to capture information about the cropping history on a parcel before transition to pecan orchard. This information is acquired through the aforementioned Python tool using CDL data for each observation window. Because the CDL represents nominal discrete values for crop type, they were reclassified according to crop value ranked in the New Mexico Annual Bulletin of agricultural statistics provided by the USDA NASS for each year between 2008 and 2017. Crops that transitioned from fallow cropland, barren land, or shrub land are valued at 0, even though this may be a misrepresentation of the value of a fallow crop with water rights. Because more than one crop type within a parcel may be transitioned to pecan, only the most dominant crop is represented as a variable in the attribute table.

Regarding fallow acreage, the value of that land is inherently tied to the associated water right. A consensus among farmers I interviewed is that land that is fallowed is more often than not done so to utilize the water right associated with that land more efficiently elsewhere. Fallow land within a parcel is an easy transfer – farmers won't water that portion of their land and will instead divert it to their active crops. SS-97-101 has made it so that water transfers between farms are now relatively simple, and the amount of these short-term water leases indicates that sometimes the most efficient use of water is to let someone else use it. Of course, because water rights may be transferred, the measure of fallow land within a parcel is not enough to capture the movement of rights across the valley. To that end, I populated another attribute with the distance from every farm centroid to fallow acreage as an explanatory variable of the relationship between fallow land and transition to pecan orchards nearby.

However, while the continued transition to pecan acreage within observed parcels suggests a form of intensification (Stoudmann et al., 2017) relating to capital and market dynamics, fallow land and diverse crops within a parcel relates to more classic forms of agricultural intensification in the form of diversity and the ability both to respond to multiple market pressures and to recover from disturbances in one. Joshua, a 34-year-old farmer who manages nearly 800 acres of land in the Mesilla Valley and thousands more in Texas explains that he always strives to maintain crop diversity as a principle of farm management. Furthermore, while he does own nearly 200 acres of pecan orchards, he uses constant transition between his row crops as a method to consistently utilize water in what he deems to be the most beneficial way possible – growing crops on land he operates. "Our goal," he tells me, "is to have a rotation on our farm that keeps us from having to fallow. There are crops and there are ways to water crops that will keep us from having to dry ground completely up or go out and buy water." Diversity used to be a staple of the pecan market. Whereas today pecans provide a steady investment on return for most farmers in the region, "In the late '80s and early '90s," Gary told me, "pecans started becoming profitable…before that for the most part you just turned the dollars over, there was very little money in the pecan industry. And so, being diversified was very important…and most operations were." I model crop diversity by calculating the zonal variety of pixel cover in each sample parcel using zonal statistics.

Of course, diversification isn't for everyone. James, laughing, told me:

> My two brothers and I formed a partnership and bought some land…and we're so smart, that we bought it specifically to diversify…so we're gonna grow row crops down there. And after about four, five years we thought, 'Shit, we're gonna starve to death.' So we started planting trees and then those were…mostly transplanted trees. We just found you can't even come close to making land payments out of row crops. The guys who are making land payments out of row crops are already farming a thousand acres, they buy another hundred, they take all this money and make their land payments.

As the pecan market has matured so too has the value of the land on which the trees are grown. Land is, of course, both valued by the water rights associated with it and the production of crops that are grown there. Attributes for both land value and total value of land inclusive of structures is provided in the parcels shapefile from the county assessor. Capturing the value of structures on farms is a reliable way to assess the cost of capital investment in terms of stationary equipment invested in the farm operation, like storage or sorting facilities. Joseph tells me that the costs of these structures is compounded by food safety regulation and the rural setting of most farms:

> To get into onions you really need to have your own packing shed. A lot of growers don't have their own packing shed and it's very expensive to get into - especially today because they've got that food safety and you have to have an enclosed building free from animals and birds and stuff like that, so to have a good facility it can run up to $20 million to have a nice facility to pack onions....Most people who have packing sheds - just packing sheds alone - they're pretty wealthy people.

Farmers are able to afford land and structures through leases from and other forms of co-ownership with financial institutions. Banks can dictate the use and acquisition of land through various forms of financial backing. A common refrain among the pecan farmers I interviewed is that loans are hard to come by when growing produce in more volatile markets. Regional competition in different vegetable markets can present higher risks to sudden market shifts. James told me about lettuce:

> There used to be a gap that California couldn't fill at [a certain] time – it was hard for them to fill. So…a lot of times there was a chance you'd have a pretty good market about this time of year [when] they were transitioning…from Salinas down to El Centro or Yuma. Well they've been able to fill that gap now...so there's just not any money there and that's why guys just quit doing it. If there was money there they'd still be doing it, I promise you…I think the last lettuce crop I planted was well over $2000 an acre to put that crop in, and I guarantee you, you spend $2000 an acre on those crops and stick a disc in it and tear it up because there's no market, you're gonna see a grown man cry.

This implies that more profitable crops present a greater risk and therefore higher proclivity of a transition to orchard in the LRG. Moreover, this competition can lead to a general weariness from banks to finance them. Understanding that water rights are a legal property right in the state of New Mexico, financial lending extends to both the leasing of land and water, and that banking practices have had a profound effect on the behavior of farmers. Joshua says:

> In the Mesilla Valley, if you tie it back to water, you see where there's a lot of bigger farmers where there's no way out but up. And once you've had one bad crop and you have a banker come out – and I've had this happen before – and the banker says, "The only way we're gonna get you out of this situation is you're gonna buy another farm. We're gonna over-collateralize you." It took me from 200 acres to 400 acres in three days one time.

That being said, farm size is another scalar variable easily calculated in terms of acreage for each polygon using GIS tools. While credit and money institutions may enable the viability of a farm operation, they can also lead to permanent indebtedness and loss of land despite being a critical coping mechanism of actors within a SES (Hirons, Boyd, et al., 2018). Furthermore, banks will influence the behavior of farmers in ways that sustain the liquidity of the financial institution. Joshua says that though farmers are inherently competitive, behavior influenced by banks takes on a different form:

> I'm a very competitive person by nature. And farmers tend not to work together. 'Oh you drive red tractors, I drive green tractors. You sell hay for this, I sell hay for that. You grow ten acres of lettuce, I'm gonna grow twelve acres of lettuce. We've always just kind of done that. At the same time, when you see a farmer going downhill, you think that farmers are going to rally around one person, and you've start to see it were it's, 'Oh, you know, we're going to start to pick off the bones.' And it's not because the farmer wants to pick off the bones of another farmer, it's because the bank's gonna make him.

As such, I categorized information regarding ownership and co-ownership of land and water rights, which is available both in the parcels shapefile and point of diversion records in the WRRS, as an attribute in the model of sample parcels. Ownership status is coded as a nominal variable in the attribute table, where 1 represents complete private ownership, 2 is bank co-ownership, 3 indicates a financial trust, company ownership, such as limited liability corporations or incorporated companies are coded as 4, and finally, municipal ownership, such as utilities or federal property is coded as 5.

Row crops support pecan orchards in the ability to provide fallow ground and make water rights available across the valleys. Still, competing ideologies for the proper use of land in the region is common among all farmers. Namely, whether land ought to be used for housing or other urban development, or if it should remain in the hands of farmers to grow food. There appears to be a deep-seated contention among farmers against new houses cropping up next to orchards. Sitting around a table with Bruce and his friend Michael, both Mesilla Valley farmers, the conversation quickly focused on housing and domestic wells:

> Bruce: But the thing is, your cities and everything are fighting that because they want the growth, they want that tax revenue increase, they want all that…
>
> Michael: Growth is kind of inevitable too...
>
> Bruce: ...but where's the water coming from? Because this new development – I can tell you – that's going in there's probably two hundred houses in there and if each one of 'em has a domestic well and I'm below it… So, my farm is going to be directly affected by it. Any idiot can figure that one out.

Indeed, this appears to be a salient driver of transition among some pecan farmers. Very bluntly, Gary told me, "one of the reasons we transitioned from row crops to pecans was to keep it from transitioning from row crops to housing." But despite this push, urban land use is expanding throughout the valleys. "The Mesilla Valley has changed drastically since I started farming," Joshua told me. "I remember at [Las] Cruces High School, across the street was cotton fields. And now it's asphalt." Of course, when cropland is paved and turned into a parking lot or cluster of buildings, the irrigation water right, in theory, becomes available for lease or sale. So, at the interface of urban land use and rural agricultural livelihoods, perceptions of the stable state or basic function (Holling, 1973) of the SES in the valley are situated (Carpenter, Walker, Anderies, & Abel, 2001; Haraway, 1991; Kull et al., 2018). In the model, I calculate distance to urban land as a scalar variable from each farm centroid in the attribute table of the model.

Another set of variables which relate to institutional drivers as informed by the adjudication rounds out the rest of the sample model. Though they are direct measures of specific outcomes of the adjudication, few of the variables were explicitly referenced in the interviews. However, the outcomes of the adjudication are generally seen as influential, albeit not always positive. When asked if the adjudication influenced his decision to grow pecans, Gary told me:

> The answer has to be yes, because it could have moved in a way that I decided not to continue to grow pecans. It could have moved in a way that I would decide not to expand our acreage and to simply allow land that was row crop next to me to be sold and developed into housing. So certainly, the adjudication has moved in a way that I believe in the long-term stability of water in our valley, otherwise it would be irrational for me to plat long-term crops. It is my expectation that I can put a pecan tree in the ground this year and that I can see it through the next twenty to thirty years to a reasonable point that…I'm on the same par as having done something else

Bruce, on the other hand, takes issue with the decision in SS-97-101, saying:

> Yeah but nothing's right or legal about that one. That hasn't been challenged…If I own a piece of ground and they tell me that because I don't grow pecans I only get three acre feet – now I'm just using this as an example – okay, my ground is really worth what a water right's worth. Okay, so if I've got a pecan ground over here and they tell – the State Engineer's telling me – that's worth five acre feet is he not penalizing me to the tune of 20, 30 thousand dollars an acre, whatever the water right value is?

Regardless of the stance that irrigators take regarding outcomes in the Adjudication thus far, it has changed the way that water is moved and made available, and certain farm management decisions appear to be affected by it. For example, beyond the realm of SS-97-101, if an irrigator has surface-only water rights, that person's land will likely have very different crops than someone with conjunctive use or even groundwater-only rights. In fact, many farmers believe that surface-only rights are untenable during this ongoing drought. James says:

> You also see there's quite a bit of land in this valley that's out of production right now. [They're either leasing water elsewhere] or they just, a lot of them didn't have a groundwater right, and now they've got nothing. I guess they can't farm it. I've seen people…I've seen some trees out there now that are dead. People planted those and they didn't have groundwater rights and now they have dead trees.

To test this, a nominal attribute representing water source is included in the table where surface-only, groundwater-only, or conjunctive water rights gleaned from the hydrographic survey and the WRRS are associated with any given parcel.

Other variables directly-related to the adjudication are also included in the model. The adjudication status, wherein either an irrigator can make a declaration, the land can be under hydrographic survey, a permit may be issued, the land may be shared under owner management, or the right may be fully adjudicated, is represented by nominal values ranging from one to five, respectively. The amount of irrigable acreage is a value directly related to the total surface water or groundwater deliveries as proscribed in SS-97-101. These scalar values are represented as three attributes in the model. Finally, the priority date reported in the WRRS and well drill date are each grouped together into ten natural breaks (jenks) as ordinal variables. This grouping eliminates data gaps that may introduce interpolation or prediction errors in regression modeling. Table 1 lists all of the independent variables related to the measurement of transition.

3.5 Statistical Analysis

Prior to including all variables in regression models, I tested each one for multicollinearity in their ability to explain the same phenomenon. Pearson's Correlation Coefficient on all 24 independent variables reveals that there are strong associations between variable pairs. Many of the variables in these correlated pairs also demonstrate strong associations with other variables, so using principal components analysis (PCA) I was able to quantitatively reduce grouped sets into singular combined explanatory variables. PCA uses orthogonal transformations on a set of data to convert them to potentially correlated variables. The eigenvectors used to linearly transform each input variable in the dataset relate to the total variance explained in each component in a dataset. Often, most variance is explained in the first few components, and the rest explain statistical noise. Input variables may be grouped to explain the majority of variance through one variable.

I then analyzed each grouped or sufficiently non-correlated variable in sequential univariate analysis in a binary logistic regression to explain the binary conceptualization of transition to pecan orchards, sufficiently isolating only the most statistically significant drivers of change. The dependent variable in the binary logistic regression is a binary association of either transition to pecans, 1, or no transition, 0.

However, because there may be spatial autocorrelation between all analyzed variables across the study area, I used a geographic weighted regression to model spatial heterogeneity of each one. Because geographic weighted regressions cannot analyze categorical variables, I used the acreage of each farm parcel transitioned to pecans as the dependent variable. It was unnecessary to create dummy categorical independent variables, as factor reduction limited the input set to only scalar independent variables. The most significant variables identified in the binary logistic regression model were first subject to a similar global OLS linear regression to determine spatial weights. Spatial divergence was then used as the quantitative basis for final qualitative analysis and evaluation.

Table 1. Mappable variables gleaned from semi-structured interviews.

Variable	Change Category	Source	Data Type
Distance to river	Environmental, Historic	National Hydrography Dataset	Scalar
Soils (Irrigation interpretation rating, USDA)	Environmental	USDA NRCS Soil Survey Geographic Database (SSURGO) Web Soil Survey	Ordinal
Depth to water in well	Environmental, Socioeconomic	NM Office of the State Engineer Water Rights Reporting System (WRRS)	Scalar
Valley (Mesilla or Rincon)	Environmental, Socioeconomic, Historic	Manual	Nominal
Distance to urban	Environmental, Socioeconomic, Historic	USDA NASS Cropland Data Layer (CDL)	Scalar
Trend of transition (hot spots)	Socioeconomic, Historic	CDL	Nominal
Percentage of pecans on farm before transition	Socioeconomic, Historic	CDL	Scalar
Crop transitioned from (ranked by relative value)	Socioeconomic	CDL	Ordinal
Fallow acreage within farm	Socioeconomic, Institutional	CDL	Scalar
Distance to fallow/idle cropland	Socioeconomic, Institutional	CDL	Scalar

(Table continues.)

Table 1. Mappable variables gleaned from semi-structured interviews (continued).

Variable	Change Category	Source	Data Type
Crop Variety	Historic, Socioeconomic	CDL	Nominal
Total acreage of farm	Socioeconomic, Institutional, Historic, Environmental	Doña Ana County Office of the Assessor	Scalar
Land Value	Socioeconomic, Institutional, Historic	Doña Ana County Office of the Assessor	Scalar
Total value (w/ structures)	Socioeconomic, Institutional, Historic	Doña Ana County Office of the Assessor	Scalar
Ownership (private, trust, bank, company, municipal)	Socioeconomic, Institutional	Doña Ana County Office of the Assessor, WRRS	Nominal
Wells on farm	Socioeconomic, Environmental	WRRS	Nominal
Adjudication Status	Institutional, Socioeconomic	WRRS	Nominal
Irrigable acreage	Institutional	WRRS	Scalar
Total water diverted	Institutional, Environmental, Socioeconomic	WRRS	Scalar
Surface water allotment (2016)	Institutional, Environmental, Socioeconomic	WRRS	Scalar
Source (surface only, groundwater only, conjunctive)	Institutional, Environmental, Socioeconomic	WRRS	Nominal
Depth of well	Socioeconomic, Environmental	WRRS	Scalar
Priority date	Institutional	WRRS	Nominal
Well drill date	Socioeconomic, Historic	WRRS	Nominal

4. Results

Pearson correlation coefficient tests of all independent variables related to both binary and scalar conceptualizations of drivers of crop transition to pecan orchard reveals collinearity of a handful of drivers (Table 2). To wit, the number of wells in a farm is strongly correlated with the type of water right a farmer has, be it surface water only, groundwater only, or conjunctive use. The correlation coefficient across all datasets is 0.733. Irrigable acreage is correlated with the total water diversion at 1.00 and with the surface water allotment at 0.986 across all datasets – this is obvious because water right amounts are administered at a fixed rate across the Lower Rio Grande Basin per SS-97-101 as a linear function of acreage. Similarly, surface water allotments are correlated at 0.985 with total water diversions. Despite varying surface water allotments from EBID each year, the total delivery per year is also a linear function of irrigable acreage.

Table 2. Pearson correlation coefficients of selected variables in 2018.

	Land Value	Total Value	Number of Wells	Irrigable Acreage	Total Diversion	Surface Allotment	Source	Priority Date
Land Value	1							
Total Value	0.521**	1						
Number of Wells	-0.031	0.011	1					
Irrigable Acreage	0.015	-0.005	0.099**	1				
Total Diversion	0.005	-0.008	0.101**	1.00**	1			
Surface Allotment	0.021	0.001	0.085**	0.986**	0.985**	1		
Source	-0.020	0.013	0.733**	0.291**	0.294**	0.286**	1	
Priority Date	-0.041	0.005	0.480**	-0.015	-0.013	-0.009	0.560**	1

Regarding the collinearity between explanatory variables, the variation of Pearson's coefficients across datasets suggests that each factor required a quantitative approach to grouping or otherwise selecting primary explanatory variables. The results of principal components analysis (PCA) confirm that the following variables sufficiently explain overall model variance: distance to river, depth to water in wells, distance to urban zones, percentage of pecans extant prior to observed transition, crop transitioned from ranked by value, distance to fallow land, total acreage, land value, total value of parcel, irrigable acreage, total water diversion, surface allotment, and well depth. A scree plot of eigenvalues per components demonstrates that between-component variance tapers off after three components. This is illustrated in Figure 4, a chart of average eigenvalues for all observed datasets. Table 4 reports the factor loadings of scalar variables for 2018.

Table 3. Selected explanatory variables of transition to pecan.

Category	Variables	Calculation
Environmental	Groundwater Level	Interpolation of depth to water and Euclidean distance to river grouped according to PCA
Historic	Overall Trend of Transition	Getis-Ord Gi* hot spots of transition over 10-year period
	Valley	Delineated by polygons in ArcMap
Socioeconomic	Total Acreage	Calculated by Doña Ana County Office of the Assessor
	Distance to Fallow Land	Near feature based on CDL calculated per Euclidean distance in ArcMap
	Percentage of Pecan Prior to Transition	Zonal statistics in ArcMap from CDL
	Distance to Urban Zones	Near feature based on CDL calculated per Euclidean distance in ArcMap
Institutional	Property Value	Calculated by Doña Ana County Office of the Assessor, grouped according to PCA

Figure 4. Scree plot of average eigenvalues.

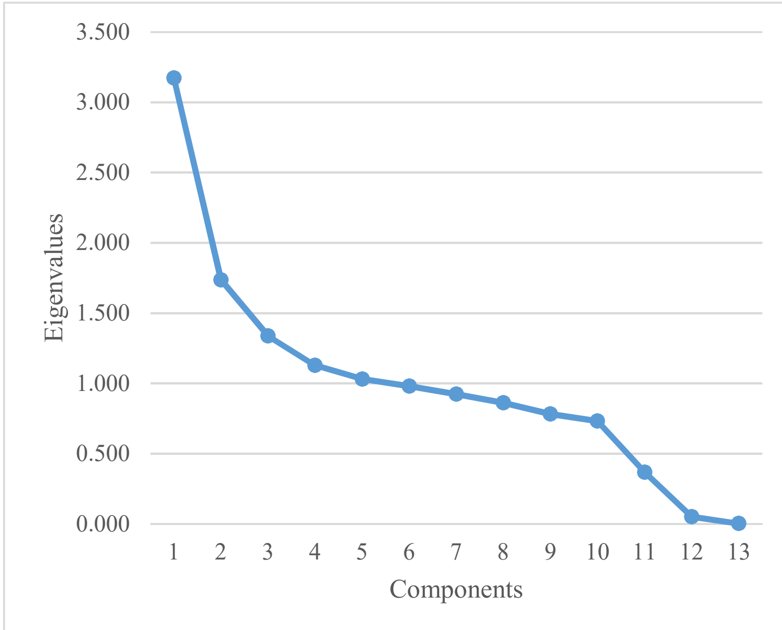


Table 4. Factor loadings from PCA, 2018.

	Initial	Extraction
Distance to river in meters	1.000	0.328
Depth to water in well column	1.000	0.309
Distance to urban	1.000	0.239
Pecans extant before transition	1.000	0.013
Transition from ranked	1.000	0.243
Distance to fallow	1.000	0.121
Total acreage	1.000	0.161
Land value	1.000	0.787
Total value	1.000	0.780
Irrigable acreage	1.000	0.976
Total diversion	1.000	0.976
Surface allotment	1.000	0.966
Well depth	1.000	0.288

Extraction Method: Principal Component Analysis.

The total variance explained by three components ranges from 45.864% to 49.201%. Using Oblimin rotation with Kaiser Normalization, the pattern matrix for all ten observed datasets indicates that the following variables explain the same respective variance: first, total diversion, irrigable acreage, and surface water allotment; second, land value and total property value; and third, depth to water in wells and distance to the river. By rerunning PCA after removing total diversion, surface allotment, land value, and depth to water, I confirmed that there is no significant overlap in explanatory variables in the pattern matrix. Furthermore, replacing the significantly correlated variables in each component with variables grouped by regression confirms that statistical variance is explained and that no significant overlaps in factors remain. These procedures generate similar results for each observed temporal dataset.

Therefore, the results of PCA for factor reduction require me to either give priority over one variable with similar factor loadings or to combine their normal z scores in a regression model. By using univariate binary logistic regression modeling on each sequential variable to describe transition to pecan I determined their individual influences. This is explained by *e* raised to the power of the natural log of the odds of each variable to explain the probability of either transition or no transition. In this odds ratio, if the probability of falling into a target group, in this case transition to pecan, is equal to the probability of falling into the non-target group, the value is one. So, a variable in the regression model may satisfy the significance threshold of $p \leq 0.05$ but must have an odds ratio greater than one to signify any change in group association if the variable value changes. The variables which meet these criteria are the valley in which the farm is located, distance to urban zones, the trend of transition, total farm acreage, property value, and groundwater level (Table 5.). The latter two variables are two of the three grouped sets as informed by PCA.

Table 5. Results of univariate binary logistic regression, 2018

Variable	Sig.	Log Odds
Valley	0.000	0.337
Distance to urban	0.000	1.005
Trend (99% conf. cold spot)	0.000	0.000
Trend (95% conf. cold spot)	0.003	0.127
Trend (90% conf. cold spot)	0.000	0.236
Trend (non-significant)	0.000	0.379
Trend (90% conf. hot spot)	0.157	1.290
Trend (95% conf. hot spot)	0.021	2.762
Trend (99% conf. hot spot)	0.000	5.346
Total acreage	0.000	1.087
Property value	0.029	0.856
Groundwater level	0.001	0.796

Proceeding from univariate regression analyses, I ran a multivariate model inclusive of all variables to establish a baseline from which factors may be reduced. Overall, the results of this set of models are positive, with Nagelkerke pseudo R Square values between .700 and .800, positive significance in the Hosmer and Lemeshow test of goodness of fit, and generally high prediction accuracy of membership with either group one, transition to pecans, or group zero, no transition. However, individual variable significance within the model is broadly and generally low.

A logistic regression of statistically meaningful results explaining membership to group one broadly produces odds ratios per variable that positively relate to crop transition. However, the predictive capability of the model to associate farms to transition is reduced to an average of 33 percent for group zero. Membership to the one group is still positively predicted at an average of 89 percent. Within the six categories of trend, which has a differentially-based change contrast oriented from the last category, only 99% confidence of hot spots, or group six, is consistently significant and associated with transition across all observation models. Also, the Nagelkerke pseudo R square for these models is generally weak, only surpassing 0.2 from observation window 2014 on, but is never higher than 0.226 or lower than 0.153. These results suggest that unidentifiable associations between variables exists.

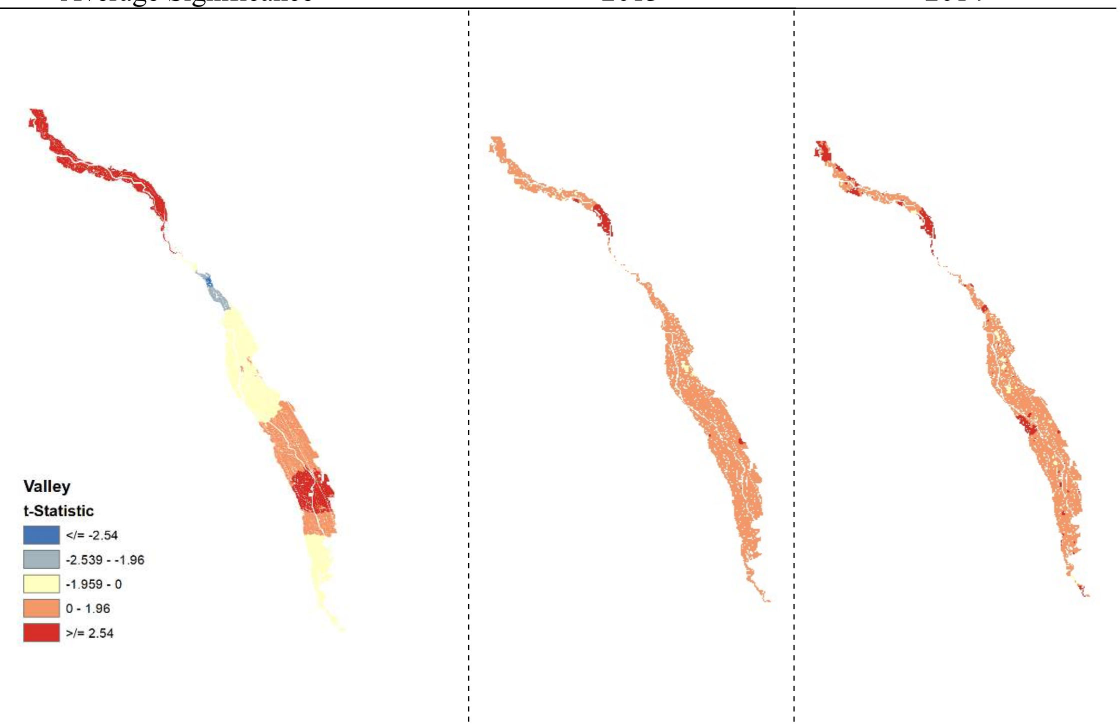
An exploratory analysis of variables included in the model indicates that percentage of pecan before transition, distance to fallow land, and crop value prior to transition, all somewhat consistently improve overall model strength to an R square of greater than 0.5 for all sets. GWR and OLS between valley, distance to urban zones, trend, percentage of pecan before transition, distance to fallow land, total acreage, property value, and the groundwater level as independent variables, and acreage of farms transitioned to pecans as the dependent variable suggest that the significance of each variable is spatially heterogeneous. While OLS models assess variables globally, GWR accounts for local variability. The suitability of one model over the other hinges on the Akaike Information Criterion (AIC), where the model with a smaller AIC values is a better overall fit. In all cases, GWR returns a better AIC than OLS. Furthermore, the overall model strength of GWR has an R square greater than 0.5 for each model with significant variance inflation factors (VIF) for a majority of the variables. Table 6 lists the outputs of OLS and GWR models. Figure 5 illustrates the average spatial variability of significance per variable in terms of t values. Appendix 3 shows spatial heterogeneity of all variables across all observation windows.

Significance is represented by t-statistics calculated by dividing local residuals by the local standard error of each variable within each model. The results are uniform across all models with the exception of 2013 and 2014 for all eight variables. These outliers are also represented in Figure 5

Figure 5. Average spatial heterogeneity of variable significance.

	Average Significance	2013	2014

Valley



(Figure continues.)

Figure 5. Average spatial heterogeneity of variable significance.

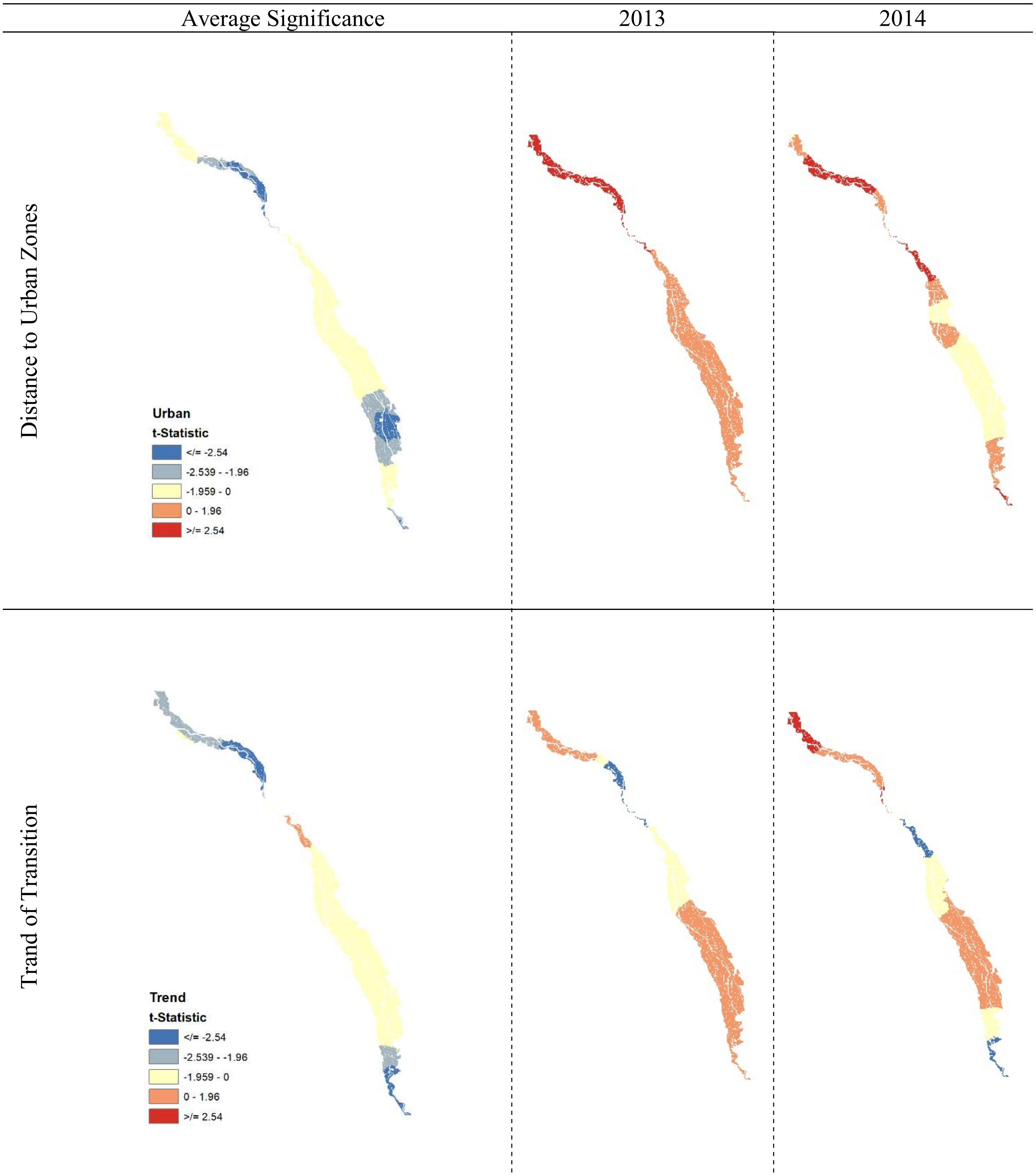


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Figure 5. Average spatial heterogeneity of variable significance (Continued).

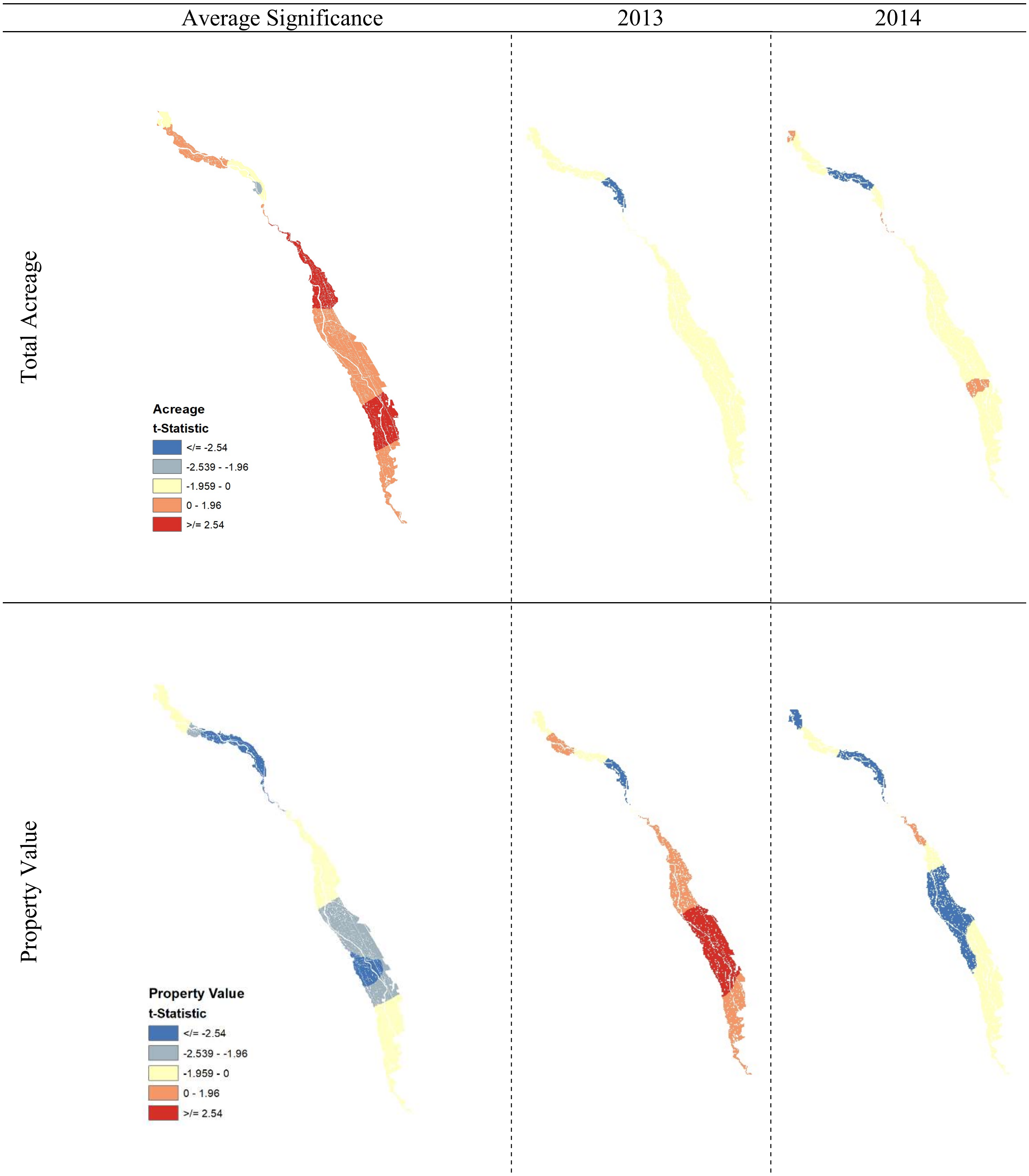

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Figure 5. Average spatial heterogeneity of variable significance (Continued0.

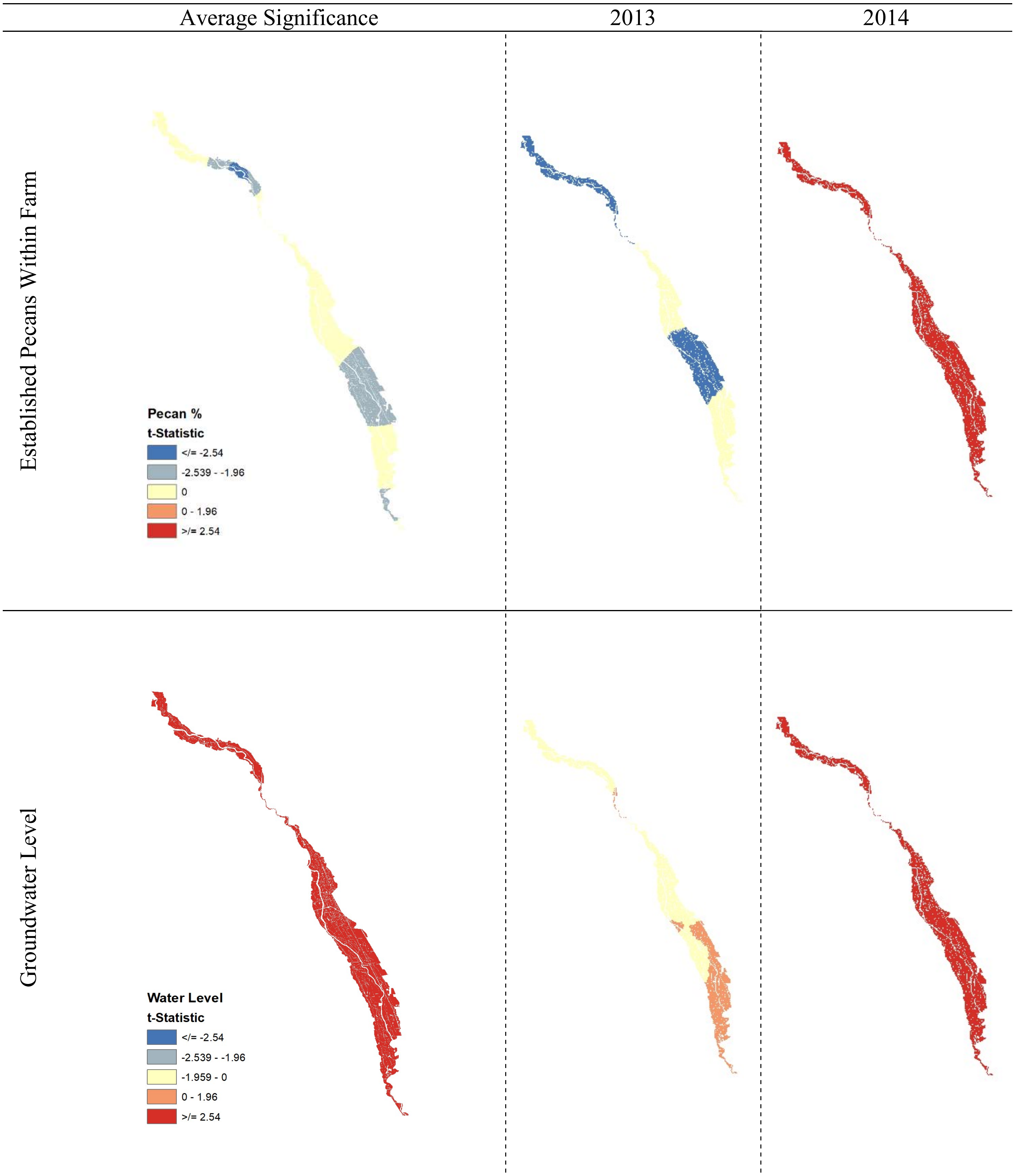

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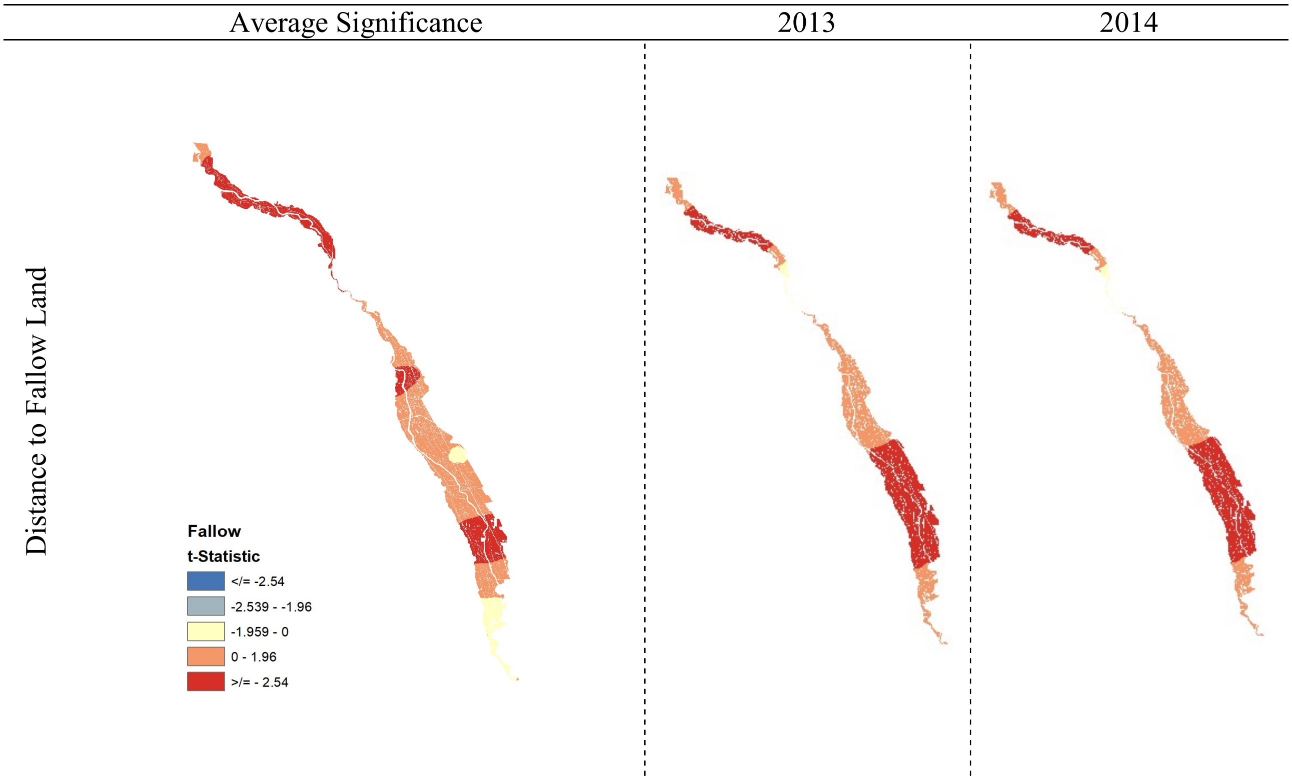
Figure 5. Average spatial heterogeneity of variable significance (Continued).



Farms in the Rincon Valley and the southwestern portion of the Mesilla Valley tend to demonstrate a strong association with transition based on their relative geographic location. The relationship between valley and transition is positive, suggesting that more pecan orchards are established in the Mesilla Valley, which is given a value of one in the binary association with the Rincon Valley. In all regression models, the relationship between transition and distance to urban is positive, indicating that farms farthest from urban areas are more likely to experience transition to pecan than those abutting developed land. Trend of transition as a proxy for diffusion of innovation is highly centralized as a significant factor in the northernmost reach of the Mesilla Valley. The portions of insignificant t-statistics coincide highly with percentage of existing pecans as a predictor of transition. Interestingly, the significance of property value closely mirrors the sections of the study area in which percentage of extant pecans are statistically insignificant. Three of the eight variables demonstrate the most global meaningfulness – distance to fallow land, total acreage, and groundwater level. All three of these relationships are positive, suggesting that relatively larger farms above a relatively lower water table that are farther from fallow land are more likely to experience change widely. There is some small-scale local variation of this relationship across the valley, particularly with distance to fallow land and acreage.

Finally, I tested the spatial autocorrelation of model GWR and OLS model residuals using Moran's *i* to determine whether the assumptions of each regression have been met and are independent and identically distributed. The results of Moran's *i* show that there is little to no clustering of the residuals.

Table 6. Outputs of OLS and GWR models.

Variable	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Valley	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Distance to Urban	1.012**	1.011**	1.005**	1.007**	1.023**	1.012**	1.013*	1.021**	1.013*	ns
Trend	ns	ns	ns	ns	1.059*	1.02*	ns	1.022*	ns	ns
Pecans before transition	1.045**	1.02**	1.011**	1.022*	1.047**	1.06**	1.018**	1.008**	1.03**	1.023**
Distance to Fallow	1.013*	1.025**	1.012**	ns	1.076*8	ns	1.019*	1.018**	ns	ns
Acreage	1.034**	1.049**	1.038**	1.035**	1.049**	1.048**	1.048**	1.034**	1.053**	1.042**
Property Value	1.024*	1.022**	1.022**	1.025**	1.022*	ns	1.02**	1.021**	1.021*	1.021*
Groundwater Level	ns	ns	ns	ns	ns	1.057**	ns	ns	ns	1.031*
n	1430	1430	1430	1430	1430	1430	1430	1430	1430	1430
R^2 for OLS	0.428	0.371	0.333	0.321	0.327	0.489	0.459	0.340	0.378	0.443
R^2 for GWR	0.543	0.543	0.537	0.545	0.533	0.650	0.533	0.534	0.533	0.535
AIC for OLS	8006.2	8138.8	8223.5	8249.0	8235.4	7842.9	7924.8	8208.7	8123.3	7966.2
AIC for GWR	7773.3	7778.9	7791.1	7766.7	7804.6	7384.8	7805.7	7801.3	7799.5	7794.6
Moran's *I* for OLS Model Residuals	0.026	0.027*	0.026	0.024*	0.035*	0.037**	0.020*	0.025*	0.021*	0.017*
Moran's *I* for GWR Model Residuals	0.005*	0.003**	0.006**	0.010**	0.009**	0.020**	0.009*	0.002**	0.011*	0.011*

ns: Relationship is Not Significant
** Significant at p < 0.05*
*** Significant at p < 0.01.*
AIC = Akaike's Information Criterion;

In all, statistical analyses demonstrate that after quantitative factor reduction and combination, thereby reducing the set of explanatory variables from 25 to 20. From those, GWR and univariate logistic regressions sufficiently reduce the number of primary drivers of landscape change in the study area to 8 key variables. Regardless, the remaining 12 do provide explanatory power via inter-variable association in the transition to pecan from another crop or land use. The models for 2013 and 2014 demonstrate very different levels of spatially varying significance than the other eight years observed. This is likely explained by the relationship between drought severity and surface water releases.

5. Discussion: Scales of Values and Perceptions of Change

The results of statistical analysis demonstrate that a majority of the variables that might be used to explain crop transition are largely negligible or redundant. Of the quantifiable variables identified in a semi-exploratory analysis, spatial heterogeneity of the explanatory power of each appears to be the norm. In this section I will review my discussions with farmers in the valleys to help logistically explain the results, first in terms of what they represent directly and then by exploring implied understandings of what these variables and models may omit. Finally, I will interrogate the likely drivers of spatial fluctuation in terms of power differentials, and the potential repercussions of land use change on biophysical properties and social stratification valley-wide.

5.1 Drawing Explicit Conclusions from Positivist Data

I have used a number of methods to show that transition to pecan orchards is to some degree relative to demonstrable behavior across both valleys. The hot spot analysis I employ as a material input to statistical analysis shows this at the most basic level, with trend of transition as a proxy of diffusion of innovation. Beyond requiring a different specialized set of expertise and machinery, pecan orchards also represent radically different biophysical properties in relation to water uptake and root structure, and characteristics of fruit production and harvest. Along with the distinctive characteristics of yield and the longer lifespan of pecan orchards comes a diverse set of financial structures and predictions. Farmers with long term cash crops have a different portfolio and longer-term projections of stability. Furthermore, pecan orchards are treated differently in terms of governmental subsidies. Gary, as a recognized expert in pecans, tells me:

> With the trees you had a capital investment in the trees that could change your asset structure in ways that could be beneficial...so that's a reason, and I'm sure there were others. My grandmother never really went all that in depth with it. I know my father was always very frustrated with crop subsidies in row crops and how they distorted markets, and [he] wanted something that was not involved in that. And pecans still are not.

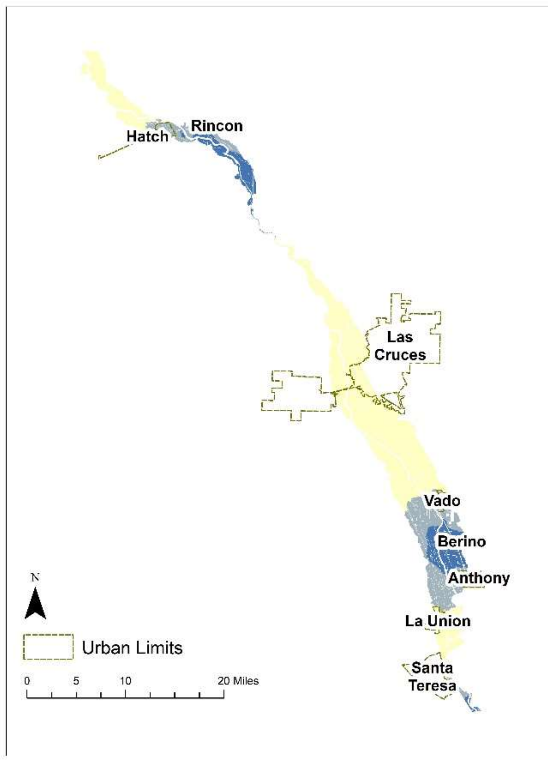
The scale of transition in terms of hot spot analysis is much more localized than the geographically weighted regression suggests. In fact, one of the most salient associations with transition is in which valley the farm is situated. Indeed, and even though the association with orchard establishment in the lower valley isn't steep, it is still positive. So, there is a stronger push toward orchards south of Seldon Canyon, which separates both valleys, and this could likely be a function of the amount of land available to be transitioned in the larger valley of the two. This should not, however, be interpreted to mean that transition is uncommon north of Seldon Canyon.

Las Cruces – the economic hub of southern New Mexico – is in the heart of the Mesilla Valley, and it is, like many southwestern cities, experiencing suburban sprawl in most directions. At the same time, many of the neighboring communities are growing – this includes new housing north in Hatch and south in Santa Teresa, Sunland Park, and Anthony. And while urban encroachment is not limited to extant farmland, irrigable land is still replaced with subdivisions with names like The Sanctuary and Villa Esperanza (Village of Hope). Housing developments present an existential threat to the livelihoods of agriculturalists, and this sentiment was widely reflected in my conversations with them. Interestingly, though, the strongest meaningful correlations between urban land uses and general agriculture to explain transition to pecan are negative and positioned largely on either side of the most prominent urban areas. These regions of insignificance extend from Hatch at the north to the top of Seldon Canyon and then south of the larger Las Cruces metropolitan area through small towns such as Vado, Berino, and La Union, to the northern limits of Anthony and Santa Teresa – where urban encroachment has not, at least yet, become a pressing concern.

Looking at zones of insignificance, we can see that three other strong areal associations exist in trend of transition, extant pecans, and property value. This suggests that superficially and as a whole urban and agricultural land uses are dichotomous. More specifically, I posit that extant pecan growth does not necessarily serve as a sturdy barrier between the two, and that whether or not established orchards do demonstrate a positive return on investment relating to the total value of the land, land value is a function that supersedes the pecan/row crop dialectic as it relates to demonstrated financial success as a farmer, which has been largely attainable through relative autonomy from housing and cities. Joseph, reflecting on threats to water availability moving forward, told me:

> Well it's different…you know Las Cruces is growing and Santa Teresa is also growing, and that could affect our water situation. And [in the] Supreme Court, what's going on, we're kind of in the dark. We're hoping it's not going to take too much water away from us. Hopefully zero.

Figure 6. Map showing t-statistic of distance to urban zones and key cities and towns.



The three most globally confounding factors relating to orchard establishment are as follows in order: total acreage, distance to fallow land, and the groundwater level. Because the rate of financial return on a pecan orchard is lower per acre per year than higher value, and often higher economic risk, crops like onions, pecan orchards are naturally larger than their row crop counterparts. This is also likely a function of banking and other financing activity that favors long-term investments. The distance of a crop to fallow land as an explanation of crop transition is somewhat of a misnomer. While it suggests that fallow crop rotation has extended beyond the boundaries of any individual's farm, and further that the adjudication has enabled farmers to "stack" water rights from any location in their respective valley regardless of physical gravitational transport of water, it doesn't necessarily imply that as water rights become available in the form of inactive farms, farmers look to faraway rights to irrigate their new or extant orchards. Rather, the assumption here is that as more land goes fallow, the ratio of idle to active cropland has increased across both valleys. A quick enumeration supports this claim: the amount of fallow acreage in the study area has increased from an average of 370 acres per year between 2008 and 2015 to a current average of 553 acres.

Despite the groundwater level being the most broadly significant factor in a transition to pecan orchards, I argue that this still supports my hypothesis. Because the other two most confounding factors are property value and total acreage, where larger and more solvent farms are more prone to transition to orchards, the normalization of water rights appropriation has reified water availability as an economic decision. If the water table continues to decline, the costs associated with pumping it effectively increase to the point where, for managers of small farms, the most beneficial use of water is to either transfer it to someone who can afford to stack enough rights to produce food or to sell their land to a housing developer. The decisions of the adjudication court or of farmers can be understood in terms of either adaptive or maladaptive techniques, where risk the appraisal or adaptation appraisal of future behaviors informs methods that may carry long-term positive outcomes (i.e. intelligent crop rotation patterns), negative outcomes and short-term losses in economic and environmental viability (i.e. threat denial, wishful thinking, or fatalism) (Grothmann & Patt, 2005). Adjudication has led to the "illusion" of resilience (Brown, 2014) in the Lower Rio Grande, but is maladaptive both in stimulating complacency among irrigators and observers, and in levying unequal strain on the social-ecological fabric of water and agriculture in the region.

5.2 Barriers to Adaptation

Within the scope of my research, adaptation is viewed as the ability of farm managers to respond to modes of governance, particularly and explicitly in the form of water adjudication in a way that they can maintain the basic function of their land as productive crops. The normalization of water rights administration is generative of new behaviors relating to agricultural intensification, farm idling, or land abandonment. The interviews that I conducted have led me to believe that the perceived intention of the adjudication court was never to stimulate or even incentivize a large scale transition to pecans, nor that fallow land would be the primary means to irrigate a majority of this transition. Regardless of intentions of the court or the actions of well-meaning farmers, this is the case – and now farmers across both valleys are required to respond to the adjudication and broader State water law in order to either continue farming or ostensibly to leave the industry of irrigated agriculture. Under the terms of beneficial use of water in New Mexico, rights holders can lose their water rights in two ways. First, water rights may be forfeited through nonuse as determined by statutory law – in general, nonuse of water for four years provides the basis for forfeiture. Second, a water right can be abandoned under common law if the owner chooses to relinquish their right. New Mexico Statute § 72-6-3 (New Mexico Statutes Chapter 72 - Water Law, 2015b) dictates that the leasing of water does not affect a right in terms of beneficial use. Fallowing land for the sake of aquifer recharge is protected under the Ground Water Storage and Recovery Act as detailed in § 72-5A-8 (New Mexico Statutes Chapter 72 - Water Law, 2015a). Despite this protection, groundwater storage and aquifer recharge does not provide a financial benefit whereas leasing does. In this way, the decision to lease or purchase water is a viable one protected under established State water law that allows irrigators to avoid relinquishing their costly water right.

Depth to water is a globally meaningful metric in irrigable agriculture, however the results of meaningfulness cannot and should not be misconstrued to imply that as the water table continues to decline as a result of runaway super drought and human over extraction and overconsumption, that the valley will become a pecan monocrop. Instead, it should be clear that the presence of fallow land is a crutch upon which pecan orchards are perched, and that this crutch has been constructed by the adjudication court. The farmers that are able to lease and utilize water rights from fallowed land are those who have larger farms with higher overall property value. The power mechanisms embedded in this system are hardly out of sight. The knowing eye (Haraway, 1991) of the water appropriators has deemed all farms to act alike in important and seemingly incorrect ways. Normalizing water for all as a linear function of farm size while giving pecan orchards an extra acre foot allotment preference – which, of course, has yet to be addressed in the OSE's water rights system – has done the direct opposite of levelling the playing field of water accessibility. Rather, it has made fallowing land a more reasonably beneficial use of an irrigable water right for some irrigators.

Ecologically, though, this may hold true. Despite remaining relatively unstudied, deliberate flooding of fallow land can promote aquifer recharge (O'Geen et al., 2015), and, more likely in the arid Lower Rio Grande Basin, taking significant portions of groundwater pumping offline will allow the water table to incrementally recover. In the latter instance, fallowed ground is the byproduct of actions designed to support aquifer health. As a whole though, conjunctive use of groundwater and surface water is understudied, particularly in terms of the socioecological implications of a simultaneously reflexive and slow-recovering system (Turral et al., 2011). The results of this study certainly indicate that groundwater is connected to more than river systems. The explanatory power of land use patterns and parcel size as indicators of modes of inequality are a direct result of groundwater adjudication.

As a side note, it is difficult to know exactly how much irrigation water has been transferred in the basin, but the consensus of farmers I interviewed is that the entirety of water rights associated with every inch of fallowed land are used to grow crops – this includes both surface water and ground water diversions. This would have been more complicated and was much less common prior to SS-97-101.

Even though leasing water is a mechanism by which irrigators can maintain their water right ownership, fallowed land provides a remarkably different return on investment compared to productive agriculture. If the intention of the adjudication court was to support continued agricultural production, the inability to grow crops presents a barrier to adaptation that is largely driven by the inability to attain enough water through the stacking of leased rights among farmers who, according to my analysis, have smaller farms with an overall lower value. SS-97-101 is an emblem of technocratic state institutions that alter and control access to water resources by locking irrigators into a potential means of dispossession by the diminished return on investment between productive crops or leased water rights (Gallardo et al., 2017; Hall et al., 2015).

The results pertaining to the relative significance of distance to urban land provide some interesting insight into another and more insidious limit to adaptation. Because the output of this metric either represents statistical insignificance closer to urban areas or a negative relationship in the more rural ones, we can infer that distance to urban areas as a driver of transition becomes moot where, as Michael states, "growth is kind of inevitable." This is an adoption of a fatalist worldview which limits the willful capacity of actors to respond to perturbations or adapt to them (Grothmann & Patt, 2005; Hirons, Boyd, et al., 2018; O'Brien & Wolf, 2010).

Perhaps one of the largest institutional fears that irrigators in the valleys face currently is the uncertainty surrounding the Supreme Court case. The risk presented by the lawsuit to such long-term investments notwithstanding, and despite this fear, farmers are persistently transitioning to pecans – a behavior which is almost certainly enabled through the adjudication and general mistrust of politics and politicians. James tells me:

> I don't think [the lawsuit has] made any difference to us; **we're scared to death of it**. I have a friend who attended the Supreme Court hearings in January…And he got back, and I asked him, 'What's your overall sense of it? What do you see?' There were four parties there. Texas, New Mexico, Colorado, and the United States. And he said, 'Texas and Colorado were very well represented, New Mexico and the U.S. were also there.'

When asked if he has a backup plan if New Mexico loses the case, James told me, "We don't, to be honest with you." After a pause, he continued, "And don't think we haven't thought about it. The only backup plan we have is [to] go out and buy a bunch of land and move that water over." Other row croppers are less trusting in the longevity of pecans and a secure investment. Bruce tells me:

> I think financially, or economic-wise, pecans have proven to be one of the major deals in our valley and I understand that we're number two now in the nation on pecan production and then I think we've seen that in cotton with our allotments and all that. Pecans haven't seen it in any production in government intervention. And they will with tariffs, and they will with all the stuff coming up. And what it's gonna cost and who's gonna pay the bill, that's yet to be in the picture.

Despite philosophies about the longevity of pecan orchards, many of the sentiments of the outcome of the lawsuit among large scale farmers in the Mesilla and Rincon valleys is that they will be insulated by their ability to buy water in order to continue to operate. However, others are getting out. On one hand, some irrigators are moving to where they believe the future of water to be more stable. Joshua, for example, when asked if the lawsuit has affected his decisions replied without missing a beat, "You're sitting in Texas right now, aren't you?" In general, his belief mirrors that of many farmers in New Mexico. He continued, "It's [affected me] a whole lot. This is a good example of what politics do. When politicians get involved in a process that they know nothing about, bad things happen." Others still are turning in the keys to their farm altogether. Peter, reflecting on his decision to retire, tells me that he would have walked away from the farm anyway for personal reasons, but that:

> [The lawsuit] gave me pause. You know, how long is it coming? Is it a good time to get out? [My] decision to sell the farm really had nothing to do [with] the lawsuit and about the dwindling water supplies…I probably would have sold anyway…but I probably wouldn't have sold for another three to five years… Is this a good time to get out? Yes, because Elephant Butte is at three percent, and nobody knows how the lawsuit will go. There is a complacency.

Complacency or fatalism, the responses of farmers have been drastically altered by the legal administration and management, or as some irrigators see it, mismanagement, of water in New Mexico.

5.3 Scales of Diversity and the "Key" to Successful Agriculture

> The pecans that we have were an existing orchard when we purchased them. I believe that the key to life is having a lot of diversity. I don't ever feel like painting myself into one picture is ever going to be a good idea for me.

This quote by Joshua both illustrates an explanation for instances when extant pecans do not predict continued expansion, and the importance of crop diversity. Indeed, much of the valley is experiencing a pronounced transition toward pecan orchards, but this expansion has not yet turned the valley into a monocrop of pecans. If the key to life, as Joshua puts it, is diversity, then we can expect to see a degree of variety in productive crops. This diversity is indeed one of the predicates to ensuring the availability of land that can go idle on relatively short notice. It also ensures the presence of microclimates basin-wide. Since Franklin's (1955) seminal work on microclimatology in agriculture, research has shown that diverse farming practices are directly related to localized variation in climactic trends. The historic array of crop types in the valley serves, therefore, as a bridging factor between environmental and social benefits of the ecological synergism of multiple interactions on landscapes (Altieri & Rosset, 1996; Zimmerer & Bassett, 2003). Ecological synergism, in this context, refers not only to biodiverse plant, animal, and insect life, but also to biophysical processes of water flux and the carrying capacity of soils, and at a larger scale, to economic and social reliance of humans. One of the most important benefits perceived by farm managers I interviewed is the general lack of between-farm drift of herbicides, pesticides, or fungicides. Peter tells me this is one of the reasons he was able to operate an organic farm in a largely inorganic region, and Joshua says, "Yeah, there's always the big talk of drift, which in the Mesilla Valley you don't see a whole lot of that, just in the fact that pecan trees become a great isolation barrier…and homes, and trees [do too]."

While some of the farmers I spoke with do maintain a degree of crop diversity within their operations, the majority do not, relying more on the expectation that as a whole, the agricultural industry in the valleys will provide it. The question remains as to whether the arrangement where seed crops act as a failsafe for permanent crops is a viable long-term solution, and to that end whether a system-wide scale of diversity ensures the same degree of success that more individualized local scales of crop rotation does.

I argue that at times, as enabled by the capricious transfer of water rights, a more beneficial application of irrigation water is urban development. Taking a farm off of the market does not necessarily take the associated water out of the cycle of (over)appropriated water. Gary suggests this by giving an example of commercial real estate development in Las Cruces' limits:

> The textbook example of that was the K-Mart parking lot…on El Paseo (Road), [which was] once farmland. When they paved it over into a parking lot it received no EBID water. Okay, what do you do with it? You can sell it to other farmers.

This sort of transfer, though, is paradoxical. The shoring up of agricultural longevity in terms of increased transferrable water rights by converting land to parking lots or other forms of development appears to contradict the beliefs and deep-seated values of many agriculturalists on the urban-rural fringe.

5.4 Explaining Statistical Outliers

Table 7 lists fallow, pecan, and transition acreage per year, as well as annual surface water allotments from EBID.

Table 7. Transition acreage and surface water deliveries per year.

Year	Fallow Acreage	Pecan Acreage	Transition Acreage	EBID Allotment (inches)
2008	467.8371144	925.8073129	-	18
2009	467.8371144	1029.183829	275.7843783	30
2010	172.7414543	824.6843974	130.7755556	24
2011	136.6541914	893.5748932	235.2195668	4
2012	337.995617	802.845228	99.38823612	8
2013	410.8669798	908.0602079	180.4363144	3.5
2014	380.7917897	987.1363856	198.1018747	8
2015	357.1808751	1008.834705	162.578012	11
2016	442.3432572	1067.887937	129.500492	11
2017	560.9686435	1110.254147	118.8255416	18
2018	546.0533656	1131.670766	44.64946268	10

Using the annual surface allotment from EBID as a way to understand human response to drought severity, we can see that 2013 was the most severe year in terms of water unavailability basin wide. It is understandable that behaviors in 2014 would be partially in response to the prior year. Despite lower water deliveries in these years, a concerted effort to continue a rather steady trajectory of pecan orchard establishment stands in opposition to other water conservation efforts and is enabled by the motion and trajectory of water rights as set forth in the adjudication. If, for example, the valleys went mostly fallow or if transition to long-term investments declined precipitously, this would be a likely response to a severely diminished water supply. To this end, the observed landscape change during these two to four years of intensified drought effects supports my hypothesis that the administration of water rights has profound effects on the perceptions and behaviors of farmers in the LRG.

5.5 Historic Social and Ecological Drivers of Agricultural Land Use

The construction of the Rio Grande Project at the turn of the 20th century had profound effects on the people who lived and farmed there prior. Competition as a result from a substantial influx of homesteaders who established farms south of Caballo Reservoir gave preference to only the most profitable crops. Farming in EBID entered national commodity marketplaces once a new set of irrigation techniques were learned and honed through trial and error (Schönfeld LaMar, 1984). Most of the land in the valleys prior to the Rio Grande Project was privately owned. The establishment of Elephant Butte Dam by the Reclamation Service is a direct response to Nathan Boyd's intention to privatize irrigation. "One is almost driven to account for its irrelevancy by concluding that it was written by a congenital idiot, borrowed for such purpose as the nearest asylum for the insane," Boyd wrote of Reclamation's intent (Littlefield, 1999). Vituperative though his comments were, Boyd's sentiments reflect a persistent indictment of political modes of land use regulation in the valley. It is common to see distrust of larger governmental bodies that are perceived as intent on imposing top-down doctrines of land and resource administration from outside the purview of the valley. Today, EBID is perhaps the only quasi-governmental agency that doesn't elicit such powerfully anti-government sentiments, largely because it is comprised of farmers with the intent of serving the interests of all farmers under its purview. One EBID manager told me, "I like to say that I don't have a big farm, but in a way, I have the biggest one of them all – the entire district."

In the following sections, I will explore how governance plays a vital role in local variance of landscape and land use, drawing on implied factors and discursive mechanisms of resource users from my interviews to describe the perceived purpose of natural processes. The local variations in land use coalesce to form broad landscapes, so it follows that the understanding of landscape change must be rooted in an exploration of the ways that institutions dictate individual livelihood practices that shape landscapes and resulting socioeconomic outcomes (Hirons, Boyd, et al., 2018).

5.6 Drawing Implicit Conclusions from Non-Modeled Factors

Beyond the eight key factors that I have identified in a positivist exploratory statistical analysis of perceptions relating to agrarian change, which only carry an explanatory power of just more than 50 percent, my interviews suggest that there are more esoteric factors worth mentioning that undoubtedly relate to this observed phenomenon of orchard establishment. This is not to say that the ability of quantitative analysis to account for landscape change are not critical, rather that they imply losses in the fidelity of true understanding of these phenomena. In the following sections I will explore the salient drivers as presented by agricultural managers that, in the words of Ojha and colleagues (2017), transcend linear models of landscape change.

1.1.3 Labor, Competition, and Nationalism

The entirety of EBID is within 100 miles of the Mexican Border. In many ways, this proximity places Rincon and Mesilla Valley farmers at the forefront of many contemporary debates pertaining to migrant labor, immigration, international competitions and tariffs, and nationalistic ideologies. The story I heard from most of the farmers I spoke with is that one of the most important distinctions between pecans and most row crops is the harvesting technique, which requires far less manpower and is primarily mechanized. In fact, some of the larger orchards south of Las Cruces have immense sorting facilities with conveyor belts passing in-shell pecans under a computer sensor testing for quality. In this sense, agricultural intensification has taken the form of cutting edge technological innovations. The skill sets of pecan farmers are distinct from those with a few dozen laborers in their field picking green chile or cotton. In this way, pecan harvesting is a technological innovation with substantial associated costs. George, a hobby farmer and water manager explains:

> You need the labor. I think, you know, I used to pick cotton for my dad – that's a pain – but when the cotton pickers came in, what a change to the industry. And the same thing

> with the pecans. What a change to the low-profile way that they can harvest their crops and then come in and prune their trees. It's a highly productive farmer who can come up with the capital that he has to put out there to invest in something like a pecan tree. It's not cheap.

Certainly transition to pecan doesn't defray the costs associated with hiring laborers, and a driver of this is undoubtedly contemporary immigration policies regarding day labor and broader governmental intervention on border crossings. Peter reflects on times past, saying:

> I think politics weighs in, too, and it used to be that before 9/11 when the border was a lot more open you could go a hundred kilometers either way, there used to be busloads of…farm workers that came up from Mexico and picked chile, picked lettuce, picked onions, whatever, and then they went back to Mexico the same day…they went back and forth and back and forth. That's why we used to have beer cans all the way from here to Mexico. So, I think that the labor shortage is dealt with not very well and one of the impediments to the farmer is labor availability and cost of course. So, they've decided to reduce their acreage in [row crops] ever so much and go to pecans, which [are] much more mechanized, and require less labor.

But even though inexpensive human labor is not crossing the international border to pick produce in the United States, much of that labor is still utilized domestically in Mexico. Competition from south of the border has been a constant for generations, and in the current marketplace they have a real edge in the alfalfa and red chile markets. Joseph explains, "We're concerned about Mexico bringing in chile, and we're hoping that [President] Trump does put a tax on the chile coming across. That's a way that we're gonna compete with Mexico."

National and international competition from places other than Mexico is another perceived threat among many EBID farmers. Roughly 20 percent of the world's pecans are grown along the Rio Grande Project from Elephant Butte Dam to Fort Quitman, Texas. The Stahmann family operates the largest pecan orchard in the southern hemisphere located in New South Wales, and now pecans and red chile are coming out of China. Joseph relayed his son's doubts, saying:

> My son's feeling like backing off because he [says], "Boy they're putting pecans in Mexico and China and everywhere," and if the market does slip, go down, you're in trouble because you've got those trees in there and it's very expensive. And if you have to take the trees out it might put you out of business. It may not ever go there, but we have that fear.

Despite fears of increased competition in the pecan market pushing them out of economic relevance in New Mexico, for the moment they are believed to be one of the most viable options. Joseph continued:

> [Pecans are] a crop that will cash flow at this time…we raise different crops, and some crops we're in the red. Like…wheat and onions. You don't know what the market's gonna be next year on an onion crop. Like this year, we just broke even because there were too many onions everywhere, all over the United States, because we're competing with the rest of the farmers.

The confidence that comes with pecan growing is met with an equal set of fears that competition presents moral and existential threats. Ways of life and livelihoods are perceived as based in largely constructs of competitiveness with long-lasting repercussions. Throughout our conversation, Joshua voiced his concern over the effects that behaviors and actions today will have on future generations:

> I know local farms in the Mesilla Valley that have built their businesses off of Mexican produce, and for them it works today but what's gonna happen to their kids three or four generations down the line? [But importing] is gonna weed out those who can't perform, who can't market.

And because of the valleys' proximity to the Mexican border, the signs of competition are immediate and clear:

> I hate driving by our headquarters in Las Cruces because all of the Mexican trucks stop for diesel right across the street. And so, you go by at 5:00 in the morning and there's 45 trucks sitting there loaded up with hay and chile…but all it does is make me think, 'How do I get more efficient? How can I be able to compete against the guy that's gonna pay a $5 a day wage where [my] lowest-paid employee is $10.50 an hour?

Resistance against competition and a drive to remain economically resilient is deeply rooted in domestic norms, practices, laws, and policies that offer validation for locally-oriented and, at times, exclusionary values.

1.1.4 Dialectics of Appropriate Land Use

Competing ideologies of land use as perceived by the farmers living and operating in EBID can be synthesized into three dialectics: row crop-pecans, agriculture-urban, and environmental protection-extraction. Dialectical examination of environmental discourses is a helpful technique to understand the ways that people "symbolically and materially construct, constrain, and change" social and environmental relationships of resource and land use (Milstein, 2009). I will borrow from theoretical research into discursive mechanisms within an ecocultural framework (Dickinson, 2014; Milstein, 2009) to understand these relationships.

The rule in SS-97-101 allowing pecan farmers to prove up to 5.5 afay did not precipitate an opposing relationship between tree and seed farmers, although it likely exacerbated it. I have demonstrated that the financial asset structures and modes of managing each crop are distinct. However, prior to the pecan prove up, this distinction did not pit the two operations against each other – both are necessary to the secure functioning of the economic and ecological networks of the Lower Rio Grande. Decisions on what to grow are based largely on personal and familial experience. James, Gary, Peter, George, and a handful of unnamed farmers I spoke with all described their inability to grow and manage row crops, opting at times for a diversity manager – a person who grows row crops beside orchards. However, Bruce, a consummate row cropper, tells me about transitioning to pecans, "Well, years ago when I started farming, I cleared a lot of brush off of my farm and I don't intend to do that again (laughter)." These preferences are the key to diversity valley-wide.

While most of the farmers I spoke with still reflect this peaceable sentiment among row crops and pecan orchards, citing the necessity of diversity and equitable appropriation of water basin-wide, others still feel slighted by decisions in the adjudication. Michael, speaking about what he perceives the fate of the lawsuit to be, said:

> Michael: I think that a lot of those pecans are going to dry up if it doesn't go [New Mexico's] way. It looks to me like a lot of people are making decisions to put their farms permanently in pecans because of this five acre foot appropriation policy that the State Engineer had way back.

The biophysical properties of the agricultural realm in this region are shaped by the row crop-pecan orchard dialectic occurring within the wider network of agriculture. Systemwide microclimatic variability is a result of historic and cultural and economic relationships generative of new conceptualizations of inter-network behaviors and values. Beyond the tug-and-pull (Dickinson, 2014) of ideologies and practices within agriculture there are larger-scale dichotomies of appropriate land use, relating to urban developmental and rural agricultural modes of resource utilization. We see this plainly in Gary's suggestion that one of the main drivers of transition of row crops to pecans is as a physical, and possibly metaphorical, barrier between agriculture and housing. The insistence that pecans can sustain broader forms of farming serves as a unifying factor between housing developers and food growers. The suggestion that distance to urban land use is a reliable predictor of certain farming practices supports this. If urban growth is inevitable, as Michael says, and the distance between farms and urban land is only meaningful at greater distances, then the opposing relationship between the two land use types is explained as a powerful struggle between them.

At an even broader scale, the extraction-preservation dialectic of land use calls into question the value of land at its core – specifically, whether every inch of land ought to be used as an immediate resource of human livelihood. Among the older farmers I interviewed, being an environmentalist is viewed as taboo. Deep into our conversation, James told me:

> As you may have guessed I'm [not] really fond the environmentalists. They're wannabe environmentalists! They're wannabes. I called up [U.S. Senator Martin] Heinrich's office this morning, chewed their ass, [and] just because [it's] election time, they gotta listen to me.

This sentiment reflects many of the underlying views and values of farmers, who perceive themselves to be functionally at odds with ecological preservationists. Of course, though, farmers do not want for the environment to become untenable for their continued use, and as such they are interested in maintaining that viability.

Environmental factors which influence farm management decisions are wide-ranging. Rainfall and temperature were cited frequently as important. Rain doesn't accumulate in New Mexico to the point where surface water deliveries will change after a storm, but the timing of those deliveries – which are determined at the beginning of the irrigation season – may conflict with storm events. Water pumped from wells is a more responsive approach to the immediate variability of weather patterns. Overall temperature and the timing of freezes is a crucial element to most harvests. For example, pecan trees rely on two freezes on either end of the growing season to bring nuts to maturity and then finally to harvest. Winter freezes are a cost-effective and natural way to drop pecans, but because freezing temperatures don't cause all pecans to fall from their trees, pecan growers have large machines to shake the trees until they do. As winter freezes occur later as a result of global warming, mechanized shaking increases. In this sense, environmental factors are largely a function of financial overhead at the farm level. Bruce told me that in his environmental decisions, "First of all it's the water…because without water we don't have anything." However, he says, "I think the marketplace predicts more than the environment. Because the environment is fairly predictable. Even in a drought the expenses change, but the availability of water is there because of the wells, right?"

Joshua, on the other hand, has a more wide-ranging conceptualization of what constitutes an environmental factor. Beyond water quality and storm patterns, he discusses the larger effects of climate change and cities:

> I want to know [about] climate change as far as year-to-year what our weather patterns are doing. If we're dry, if we're wet, if the storms are more intense or less intense. Urban encroachment, which I would call would be in the same environmental impact because we start to see a larger carbon footprint when there's more people. And so, the way that we're able to move resources from farm to farm become a lot more difficult. And then…consumption of natural resources is a huge thing. How much water we're using, you know, depending on the crop that's growing there. How much sunlight do we use for that? And how the climate plays an effect on whatever we're growing. And we have to look at what inputs we're putting on our crops, be it herbicides, pesticides, and also the seeds that we put in the ground.

According to Adger and colleagues (2013), culture is intrinsically linked to climate change. Since farming practices are often in direct response to climate change, they serve as a fundamental proxy for understanding the dynamism of culture in the Lower Rio Grande. Yet, normative perceptions of cultural change are situated. Joshua's broad take on environmental factors notwithstanding, there is still sweeping discursive opposition against steps that environmental activist groups take toward securing natural resources for the sake of biodiversity. From off-handed discussion about what ranchers do when they see an endangered specie on their land, which is to kill it and keep quiet, to treating the river solely as a conduit for deliveries to Texas and Mexico, philosophical conceptualizations of the meaning natural processes are staunchly opposed between resource users and groups formed to protect or restore natural entities. Michael, summing up the role of water management, says:

> The State Engineer's office exists to protect water owners and to help them exploit their resource. They're not environmentalists. They're not preservationists. They're there to bring some order and some regulation that protects the owners of water, whether it's consumptive, farming, cities, or whatever. And, but in recent…decades they've become more of water police with other things on their mind: environment, preservation, the money that it runs uphill to and all that. I know that Steve Reynolds (the State Engineer from 1955 – 1990), his whole mantra was, 'We're here to help the owner of the water keep and develop his water."

On the other hand, Joseph says:

> Be careful with the government, because you can't trust [them]. Like environmentalists…the fear is because they're going to make a monument…south of us, and we won't be able to go in there and put control dams to hold water.

Indeed, this dialectic exists in the perceived space of influence from environmental groups and resource users on governmental entities. Further it suggests that the sway that may be exerted on environmental groups is generative of mistrust from either group.

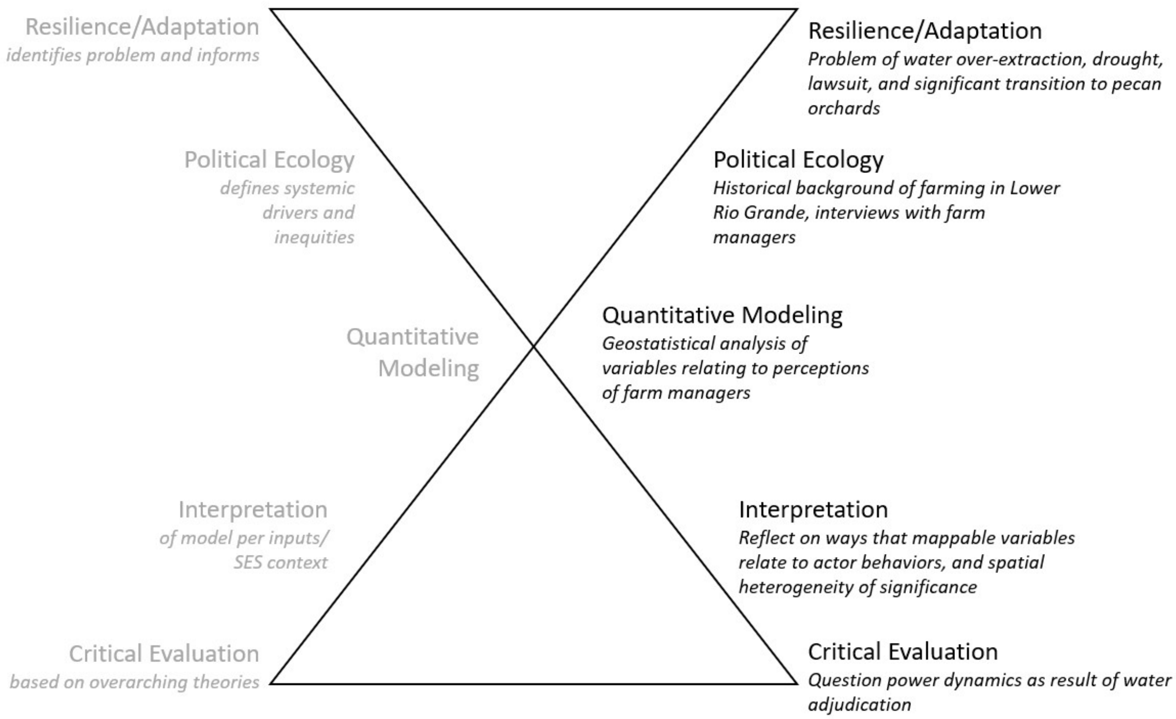
I question the motivations of agriculturalists as resource users. Much of the extant agrarian change literature at national or global scales interrogates the impacts of said change on overall food security – a function of disbursing one's produce to larger markets, providing food for the physical wellbeing and health of unseen and large populations. In the realm of irrigated agriculture, food security was largely absent in my discussions with farmers. Rather, the economic security of farm managers and their employees is situated as a primary concern. The noble drive of being able to feed oneself or one's staff fails to interrogate whether agriculture is the most geographically-appropriate use of land in the Lower Rio Grande in terms of feeding broader populations. In her dissertation, Schönfeld LaMar (1984) in part sought to understand how the promise of regulated water has affected land use patterns and the associated disenfranchisement of people as economic aspirations overrode individual livelihoods in the Mesilla Valley. If the perceived adaptive capacity of actors within a SES is predicated on making people richer, little can be done to increase it (Grothmann & Patt, 2005), and if sustenance is a product of economic gain, then it is necessary to understand how financial prosperity for some is connected to the loss of livelihood for unheard others.

6. Conclusion

As part of the Lower Rio Grande Adjudication, Stream System Issue 97-101 was designed to ensure the economic, and by extension, livelihood, resilience of farmers to irrigate their crops in the face of diminishing and uncertain water supplies. However, this resilience disproportionately favors pecan farmers who have larger and more valuable farms that are relatively farther away from rural areas. The available capital required to lease or purchase water rights to irrigate crops, including pecan orchards, to a productive outcome is essentially nonexistent for farmers – often row croppers – whose most viable recourse during any given irrigation season may be to simply retain their water right under precepts of beneficial use according to New Mexico water law by leasing it, and thereby incurring costs of lost opportunity in agricultural markets. Under this framework, economic resilience and the adaptive capacity of agriculturalists is predicated on capital. This mode of resilience is defined by the ability to avoid the ramifications of increased aridification and potential risks of lost water rights through litigation in the Supreme Court. The tipping point, or threshold, of system-wide resilience has yet to be actualized, though it will likely come to fruition when leased water doesn't satisfactorily offset the requirements of water-dependent crops. This may be precipitated by continued drought, sweeping judgment in Texas v. New Mexico and Colorado, or resistance from farmers intent on retaining their livelihoods or culturally important crops, like green chile. Using political ecology as a theoretical framework to understand mechanisms of resilience, I argue that system-wide resilience is not devoid of intrinsic power differentials.

This conclusion does not intend to presuppose that pecan farmers are intentionally or maliciously exercising individual power against row croppers, but rather that they are responding in turn to newly formed laws with built-in inequity and design flaws within the Adjudication that fail to address the spatial and social heterogeneity of diverse modes of irrigation and other water uses. As a method of disciplining water rights, Stream System Issue 97-101, which rigidly defines the consumptive irrigation requirement of every crop in the Basin and allows farmers to utilize capital assets to reach that amount is akin to a “shotgun marriage,” per Rutgard Boelens (2009), wherein the absorption of a local normative order into broad legal mechanisms has made the ability of water transfers the primary method by which continued over-extraction of actual available water is the primary means of functioning as a productive farmer. This is done so by the abstraction of liquid water into water on paper that can be transferred, regardless of gravity-fed deliveries or local depressions in the water table, with the stroke of a pen.

Figure 7. Application of theoretical union between resilience and political ecology to model social-ecological systems.



Through semi-structured interviews of farmers who operate within EBID, I uncovered drivers and the nature of drivers which pertain to the observed phenomenon of large-scale transition to pecan orchards. In the instances where these discrete drivers explain the same or similar actions, I used statistical analyses to reduce or combine variables input into logistic, linear, and geographically weighted regression models of agrarian change. Of the observable variables, eight represent the most salient drivers: broad geographic location (Rincon or Mesilla Valley) distance to existing urban development, overall trend of transition, total acreage of farm demonstrating some degree of change, property value, the presence of pecan orchard prior to land use change, groundwater level, and the distance to fallow land.

Each of these eight variables are qualitatively meaningful, though they quantitatively only explain half of the potential drivers of crop change. Using established theory in political ecology, resilience, and overall agrarian change, I suggest that unmappable characteristics offset this explanatory power. Economic competition at national and international scales is closely related to migrant labor restrictions and nationalist ideologies. Competing philosophies of the role of land use are explained through dialectics of farm types, urban or rural livelihoods, and the protection or extraction of land and resources.

The contributions of this research are threefold. First, it furthers our understanding of how human responses to climate change are influenced by policies that fundamentally introduce new avenues by which capital may contribute to power imbalances. Second, by employing a sequential exploratory mixed methodology, I have demonstrated how research design can effectively navigate the academic politics between two epistemologies – in this instance, political ecology and resilience – to broaden and enrich our understanding of social and environmental phenomena. Third, and specifically to New Mexico, I show how the LRG Adjudication has favored capital assets over broad livelihood assurances through the ability to accumulate multiple water rights at a premium that is positively correlated with higher value crops. Current agricultural marketplaces dictate that pecans retain that power, though trends may move in the direction of other crops for economic competitiveness and solvency.

It follows that economic power differentials have become more pronounced as a result of SS-97-101 by allowing farmers with the sufficient capital to purchase and stack water rights from fallowed farmland to plant expensive pecan orchards. The adaptive capacity of pecan farmers, therefore, is greater than small parcel farmers who are unable to secure the necessary financial backing to operate in the increasingly important pecan market in New Mexico. The resilience of agriculture in the LRG is fundamentally linked to the reified control over natural resources and resultant power. Future work ought to focus on the specific drivers of turning cropland fallow in the LRG, and broadly, how actors in SES adapt to policy and governance in different contexts. Furthermore, continued work into the theoretical intersections of resilience, political ecology, and geospatial modeling as mixed methodologies may help to solidify the union of the three and to understand the complex and scalar functions of SES.

Water and other so-called natural resources have long been abstracts driven by economic principles. In the case of the Mesilla and Rincon Valleys, and beyond, this extraction was humanized elegantly in my interview with Michael, who said:

I think the sort of basic thought to all of this is that water is still an economic decision to be had. The owners of water, they don't do altruistic – they don't make altruistic decisions. They don't say, 'Okay, we're in the middle of global warming so I'm gonna do something about that.' What is it they say, 'Think globally, act locally?' You know, they don't do that. They're gonna look at the crop they need to grow and they're gonna look at the government and the water they have and they're gonna make economic decisions in the marketplace. And that doesn't change. It doesn't change in the face of the lawsuit, it doesn't change in the face of the drought…it doesn't change in the face of whoever's marching down the street. They're gonna grow what they believe they can grow and feed their families.

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7.1 Data Sources

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Appendix 1. Human Subjects Research

Because my research is predicated on data derived from interviews with people, I am required to ensure the safety of each interview subject. Per the University of New Mexico Office of the Internal Review Board (OIRB):

> All researchers (persons who are responsible for designing and/or conducting research, performing data analysis, or reporting activities) are required to complete a human subjects protections training course prior to engaging in a human subjects research project at UNM. The training is valid for three years from the date of completion. It is the responsibility of the researcher to complete and maintain this training requirement every three years and provide a copy of the completion certificate with an IRB project.

All of my records of completion are on file with the OIRB, who approved my research on July 24, 2018.

Any requests for documentation or complaints may be addressed to the OIRB at UNM Office of the IRB, (505) 277-2644, irbmaincampus@unm.edu. Website: http://irb.unm.edu/

Appendix 2. Interview Script

Thank you for taking the time to meet with me today. As I mentioned, I am a graduate student researcher at the University of New Mexico conducting research for my master's thesis in Geography and Environmental Studies. I hope to better understand the extent that water policy and governance influence the land use decisions of farmers in the Rincon and Mesilla Valleys.

Despite ongoing legal cases and popular understandings and beliefs of water conservation or use in the Southwest, we observe land use changes that may not necessarily be designed to conserve water resources. Of the understood drivers of agrarian change, to what extent does water adjudication influence that change here? To answer this, I am framing institutional changes in the form of water adjudication, water policy, and Texas v. New Mexico, as risk factors to which farmers may react. Their adaptive capacity is the ability to respond to these externalities.

The goal of my research is to create a holistic geospatial representation of the observed change here over the last 10 years, and through statistical analysis, to provide a thoughtful and detailed analysis of that change. The results will help shed light on and dispel assumptions surrounding how land and water is perceived in a changing political and ecological environment for water users, managers, and policy makers.

The questions will be separated into three categories: 1) short answers about you, your land, and your irrigation techniques, 2) open-ended questions about the factors that influence your management decisions, and 3) you will be asked how much you agree or disagree with a set of statements regarding drivers of change. Please feel free to ask me questions at any point during the interview. Everything you say will remain anonymous. With your permission and as indicated in the consent form I will record the audio of the interview; however, you may ask me to stop recording at any point.

Short answer questions:

1. How old are you?
2. What is your education level?
3. Approximately how many acres do you operate?
4. How many wells do you have and how deep are they?
5. Has your family farmed in this region for more than one generation?

Semi-structured interview questions:

1. What environmental factors influence your farm management decisions, and in what ways?
2. When water is tight, how do you and your peers deal with it?
3. Have you ever transitioned from a row crop to a pecan orchard? Why or why not?
4. What sorts of farming changes do you see happening in this valley?
5. How do markets influence your decisions to either grow pecans or other crops?
6. Has the Lower Rio Grande Adjudication changed the way you make decisions about what to grow? Has Texas v. New Mexico? How?
7. What lasting effects do you think Texas v. New Mexico will have on agriculture in the valley?

Likert-style questions:

On a scale from 1 to 5, with 1 being very little and 5 being very strongly, how much do you agree with the following statements:

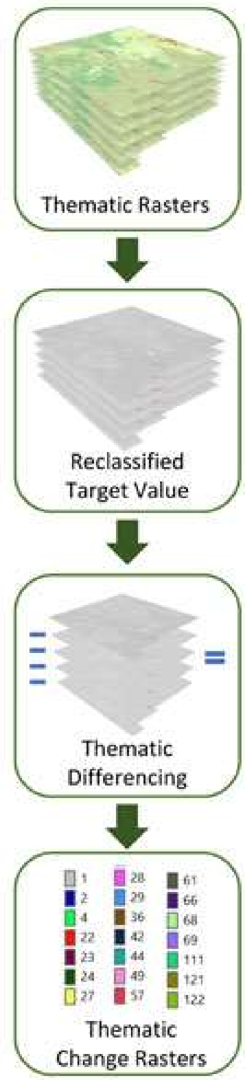
1. I collaborate with other farmers to manage water in sustainable ways.
2. I am concerned about the availability of water in the future.
3. Groundwater is critical to my success as a farmer.
4. I make management decisions based on what other farmers around me are doing.
5. Local water laws and policies enable me to maximize the productivity of my crops.
6. Stream System issue 101, which determined CIR and FDR of crops influenced my decision to grow pecans or to continue row cropping.
7. The availability of inexpensive labor has changed in the last decade.
8. I rely on migrant labor to operate my farm.
9. I stay up to date with the newest technology to maximize the productivity of my crops.

Appendix 3. Thematic Raster Temporal Differencing Python Tool

1. Tool Introduction

Notwithstanding the many needs of the current case study, the development of an extensible tool is the primary objective of this exercise. Extensibility relates to the graceful extension of computational systems and processes that can address diverse needs of end users and dynamic computing environments (Johansson and Löfgren, 2009). For example, a researcher may wish to quantify the degradation of mangrove forests in the South Pacific over a 50-year period. Considerations such as these have driven me to develop a tool that navigates the boundary of specificity and generalizability.

Figure 1. Workflow of Thematic Change Raster Analysis tool



This toolset performs thematic differencing on a flexible set of thematic rasters based on a user-specified target value, the output of which is a set of change rasters which display only those pixels that have changed to the target value (Figure 1). The original values of transitioned pixels are displayed, and every other pixel is stripped to null. The resultant raster dataset is largely empty, with only pixels of interest represented.

2. Thematic Change Analysis

The first step of the script is to import the arcpy module, from the arcpy module env, and from arcpy.sa (Spatial Analyst), all functions are imported. A scratch workspace for intermediate data processing is called in memory, and the ability to overwrite output features is enabled. Finally, because the tool relies on ArcGIS tools that are accessed using the Spatial Analyst extension, the script is contained within an error handling statement that either checks out said extension or returns the following error: “Spatial Analyst license is not available.”

The Thematic Change Rasters tool has three arguments that are called using the arcpy.GetParameterAsText function: the thematic raster list, the target feature, and the output workspace. The list of thematic rasters is flexible insofar as the number of inputs may be as few as two and as many as the given computational environment can feasibly process. This list is split by a semicolon delimiter and treated as a Python list of rasters, which is then converted to raster objects in the arcpy module for subsequent processing.

Following the conversion to raster objects, each object is reclassified according to the user-specified target value. Each pixel in a thematic raster is defined by unique digital numbers that relate to specific a land use or land cover (LULC). For example, pecan orchards are given a pixel value of 74, as defined by the CDL. Next, the script uses conditional logic to reclassify only the target LULC value to 1000. Once each target pixel value is reclassified, an iterative loop is employed to subtract each precedent raster from its antecedent – for example, reclassified 2008 is subtracted from reclassified 2009, 2009 from 2010, and so on until the full set is differenced. From this set, a new list of rasters is defined and populated with the results of each calculation.

The resultant rasters then have pixel values ranging from -999 to 999. Because the tool is concerned with LULC pixels that transitioned *to* the target value rather than those that transitioned *from* it, the full set is reclassified according to the following rules: if the pixel value is less than 255 it is given a value of 0; if the value is more than 255 it is recalculated as 1000 minus the extant pixel value. Finally, each 0 value, which relates to pixels that demonstrate no change, is given a null value. Similarly, a new list of rasters is defined and populated with the results of these conditional statements.

The final process in this tool saves each doubly reclassified raster object as output rasters named using the following iterative logic: each raster is titled “diff” plus its position in the list followed by the position it differenced (e.g diff_2_1).

3. Graphical User Interface

Because the procedure for converting a raw Python script into a usable tool in the ArcMap environment is well-documented (Esri, 2018), this section will document the transition between tool environments or arguments and parameters in the GUI. The Thematic Raster Change Analysis script tool (Figure 3) calls for three parameters from user input using the arcpy.GetParameterAsText function. First, the list of rasters is called as a required multipart raster layer input that is split in-script by the semicolon delimiter. Second, the target feature is called as an integer value. Finally, the output workspace is called as a workspace or raster dataset.

The tool sidebar provides the following description:

> Generates a raster illustrating change to target land cover type from set of thematic rasters. Land use/land cover datasets may be user-generated or extracted from common sources (e.g. NLCD or CDL). This tool handles up to 8-bit raster data values.

As the user moves the cursor into each field, the following descriptions are returned in the sidebar:

> **Thematic Rasters** – A series of thematic LU/LC raster datasets input for temporal differencing;
> **Target Feature** – String value representing digital number (pixel value) associated with LU/LC type;
> **Output Workspace** – Unique workspace output for post-processed raster datasets. Can be folder or geodatabase.

Once all tool arguments have been satisfied via user input, the processing toolbox displays messages (Figure 4) that inform the user what raster is being reclassified per the target value at any given moment, what raster is being subtracted from another, that values are being recalculated into the final raster format, and finally when processing is complete.

Figure 3. Thematic Raster Change Analysis tool GUI

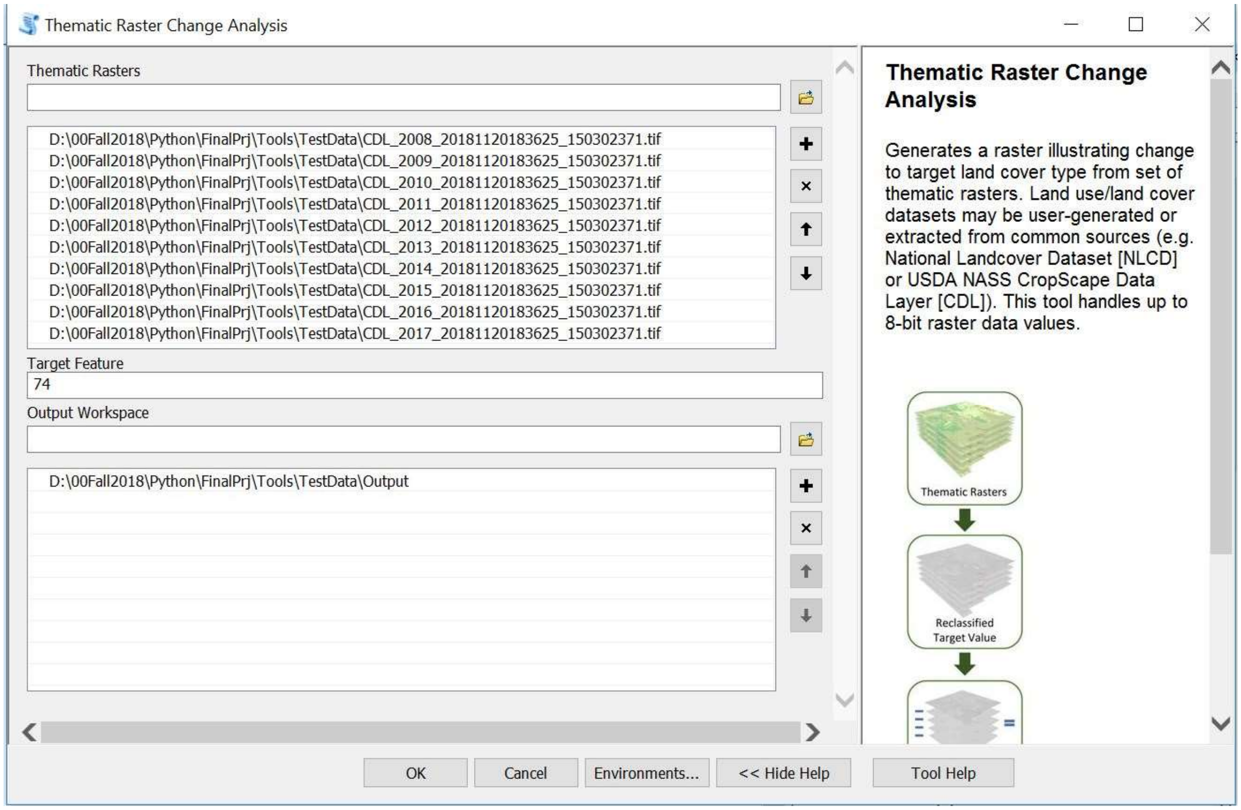
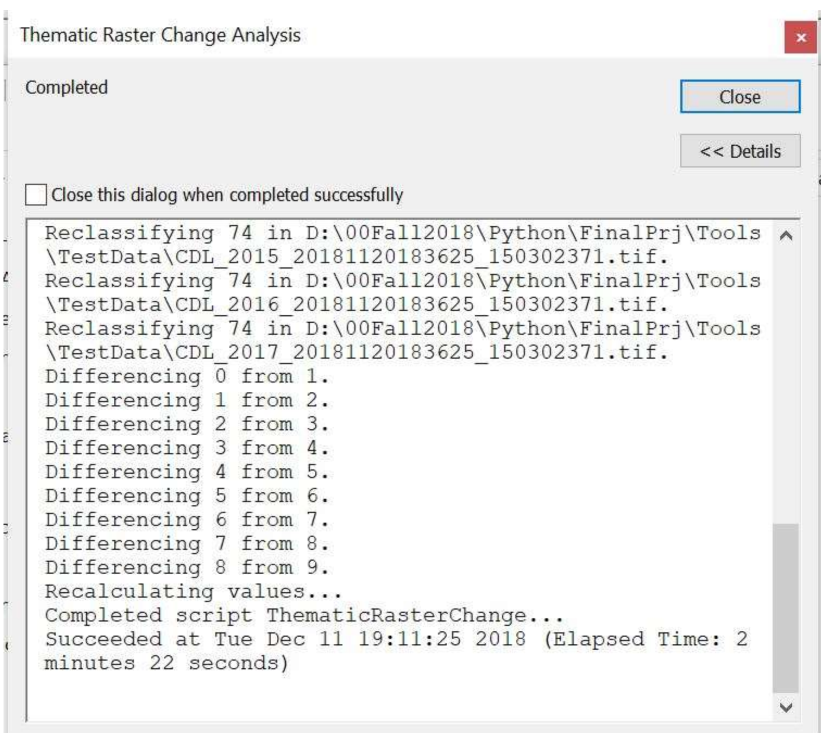


Figure 4. Messages displayed during Thematic Raster Change Analysis tool processing



4. Reference

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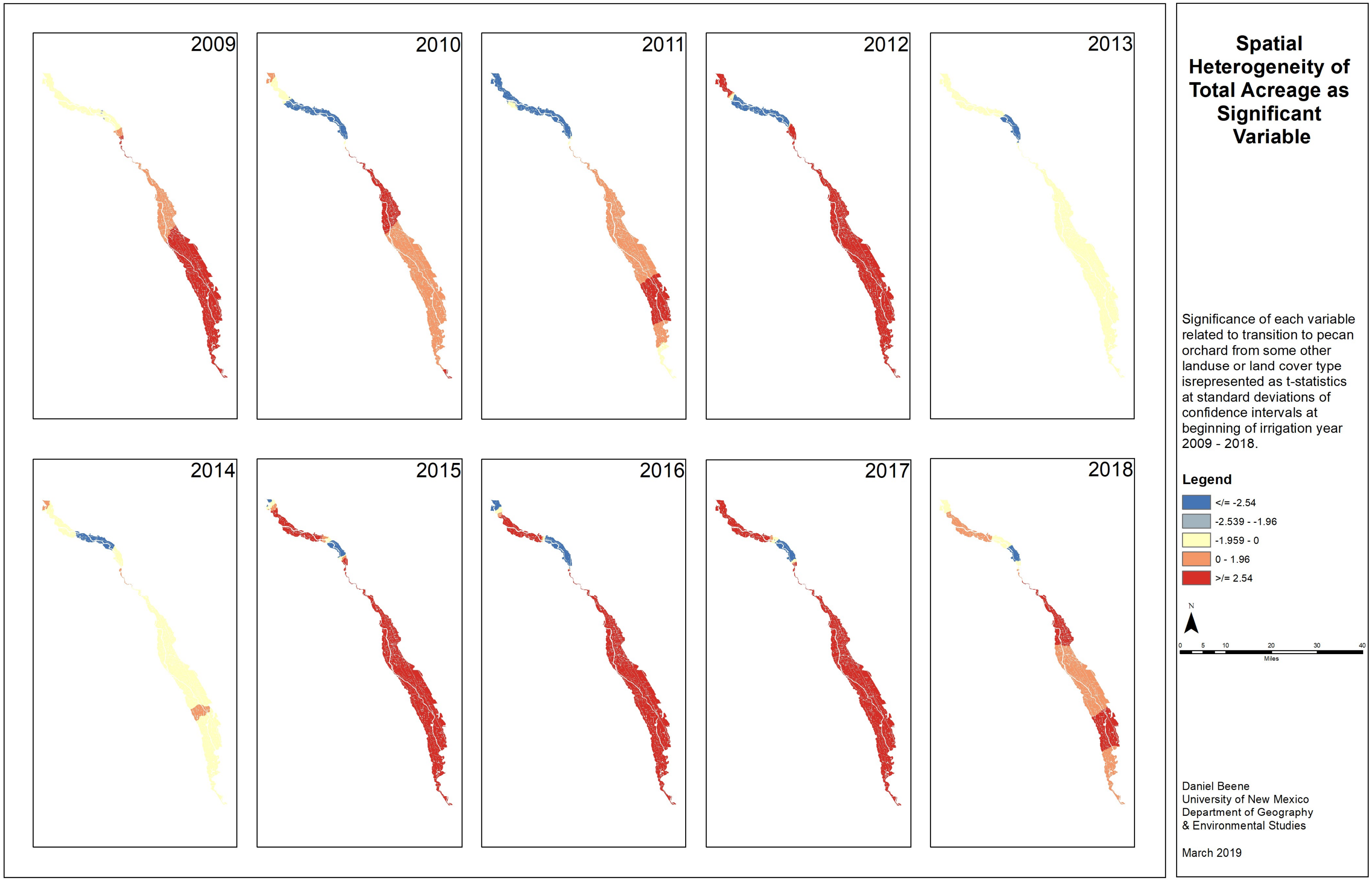
Appendix 4. Spatial Heterogeneity of Quantitative Variable Significance per Year




2009
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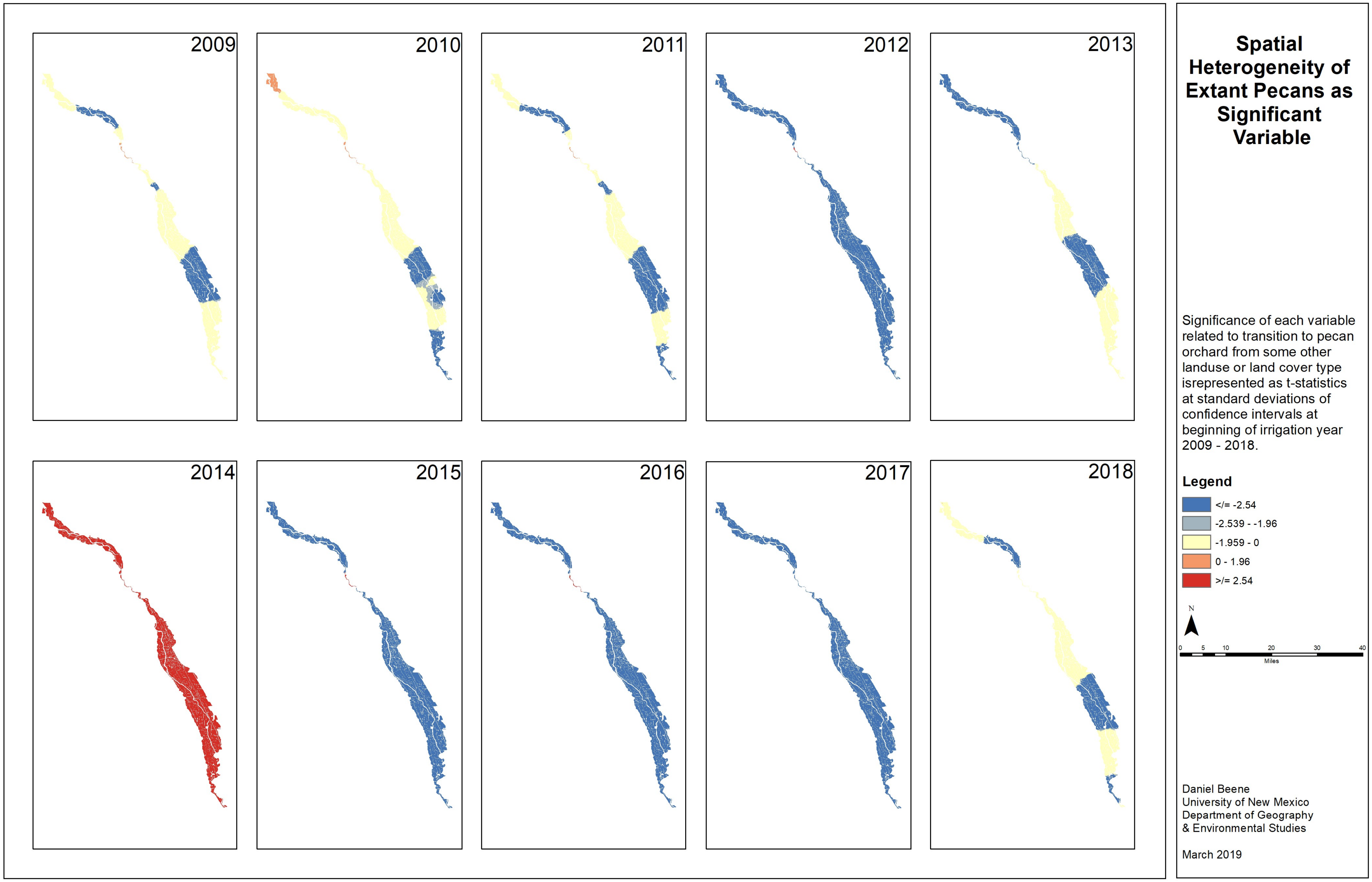
2018
Spatial Heterogeneity of Distance to Fallow Land as Significant Variable
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.
Legend
</= -2.54
-2.539 - -1.96
-1.959 - 0
0 - 1.96
>/= 2.54
N
Miles
Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies
March 2019


2009
2010
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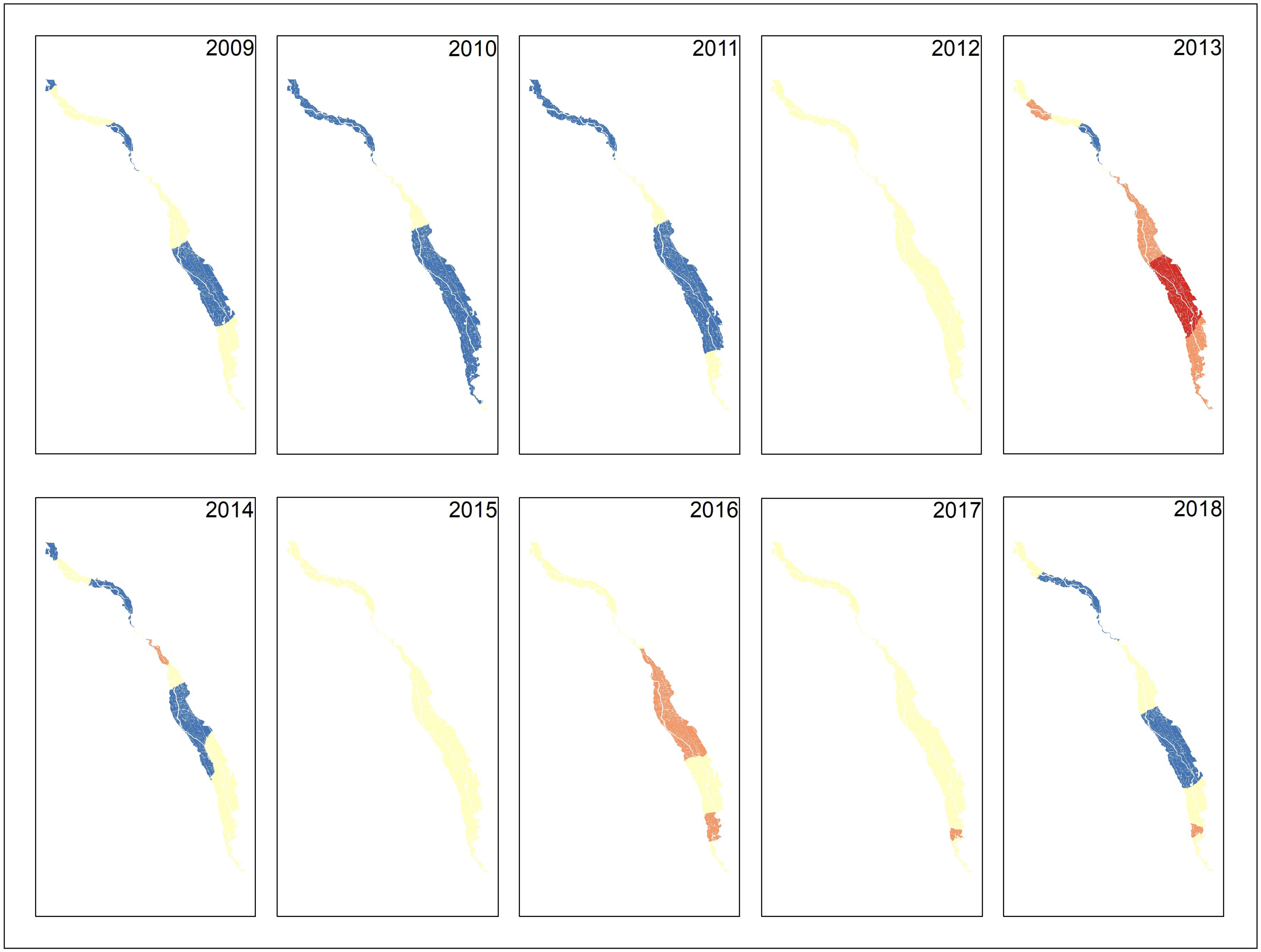
2018
Spatial Heterogeneity of Extant Pecans as Significant Variable
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.
Legend
</= -2.54
-2.539 - -1.96
-1.959 - 0
0 - 1.96
>/= 2.54
N
Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies
March 2019



Spatial Heterogeneity of Property Value as Significant Variable

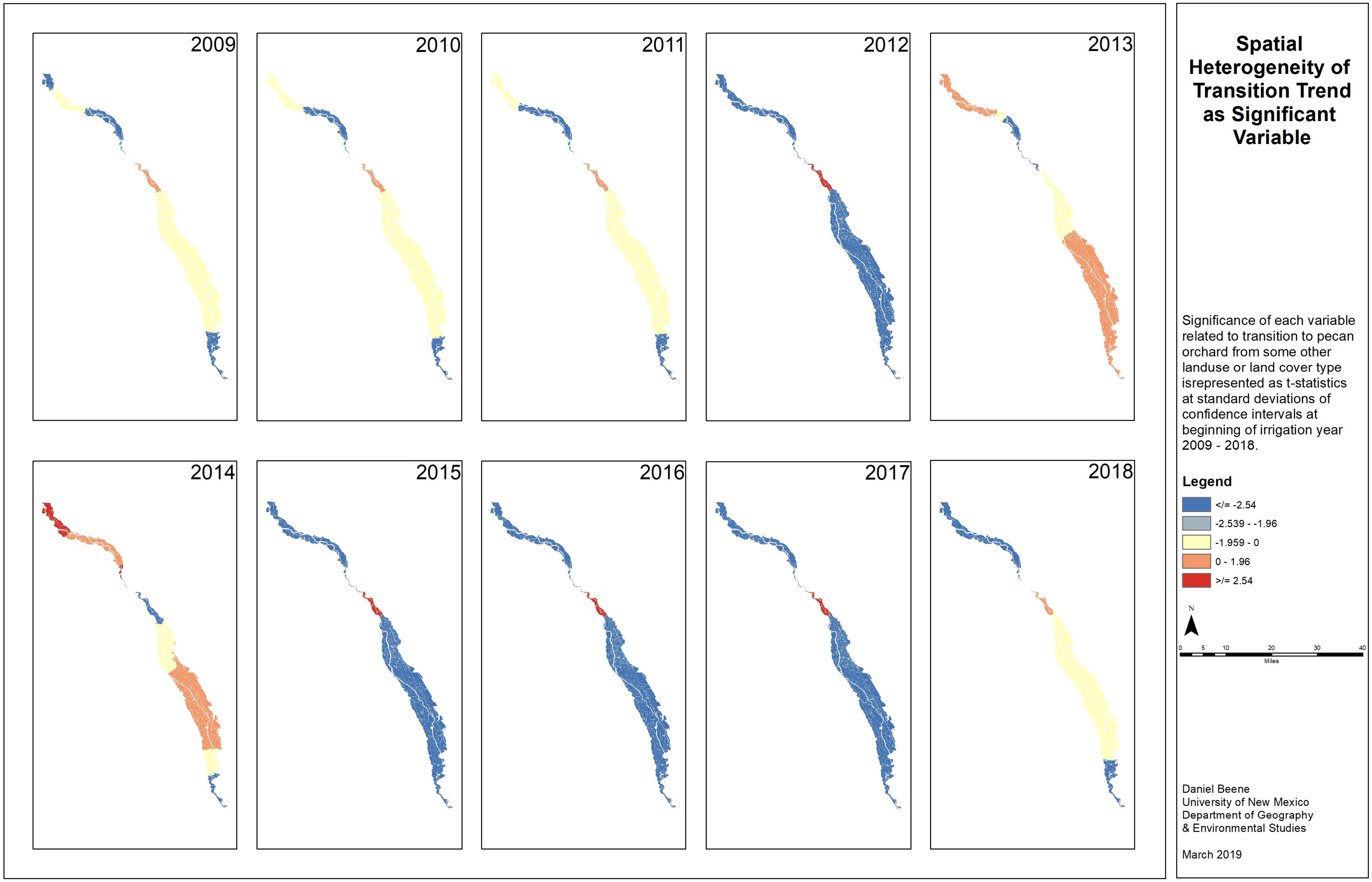
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.

Legend

- </= -2.54
- -2.539 - -1.96
- -1.959 - 0
- 0 - 1.96
- >/= 2.54

Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies

March 2019


2009
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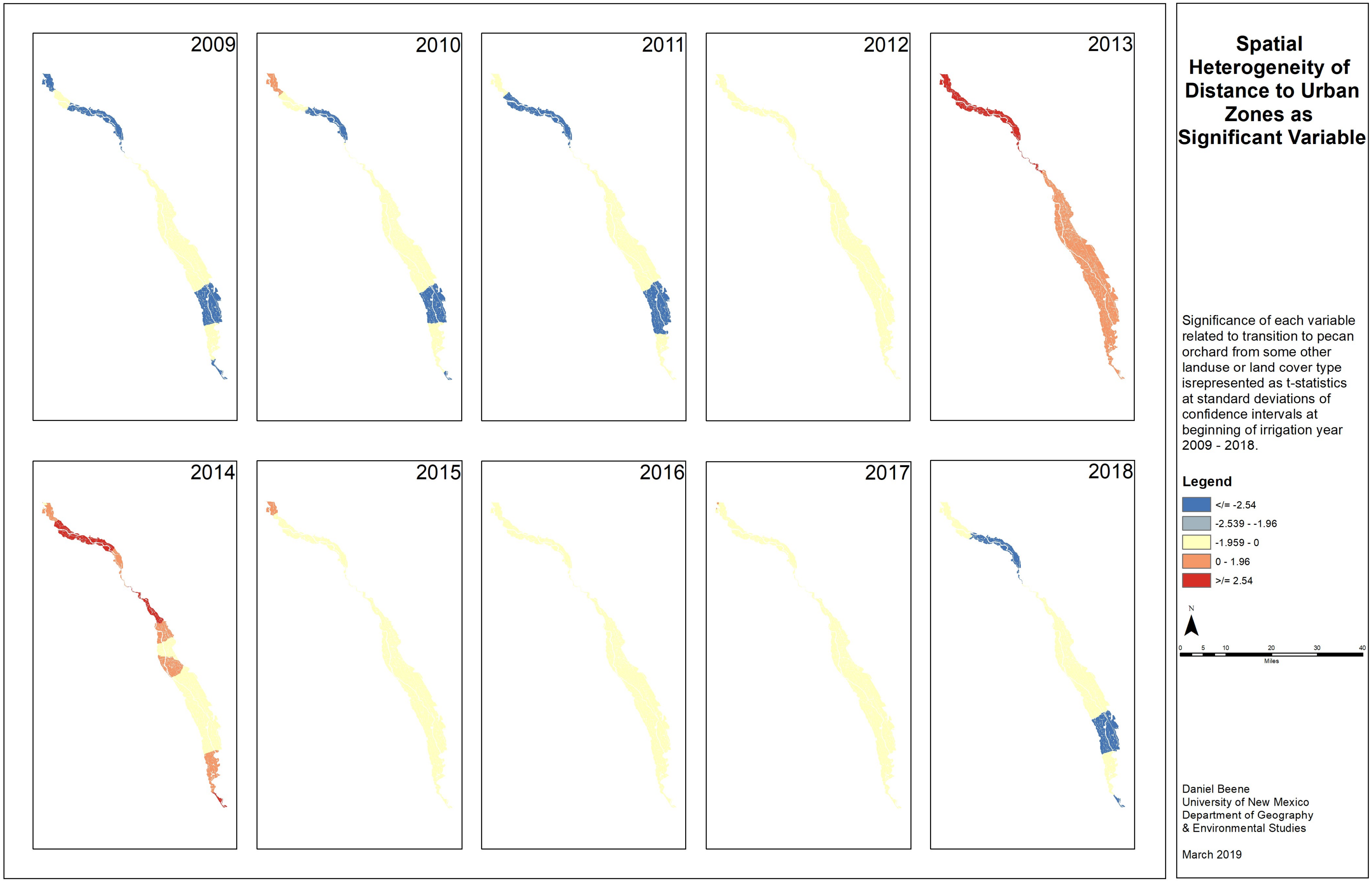
Spatial Heterogeneity of Transition Trend as Significant Variable
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.
Legend
</= -2.54
-2.539 - -1.96
-1.959 - 0
0 - 1.96
>/= 2.54
N
Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies
March 2019


2009
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Spatial Heterogeneity of Distance to Urban Zones as Significant Variable
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.
Legend
</= -2.54
-2.539 - -1.96
-1.959 - 0
0 - 1.96
>/= 2.54
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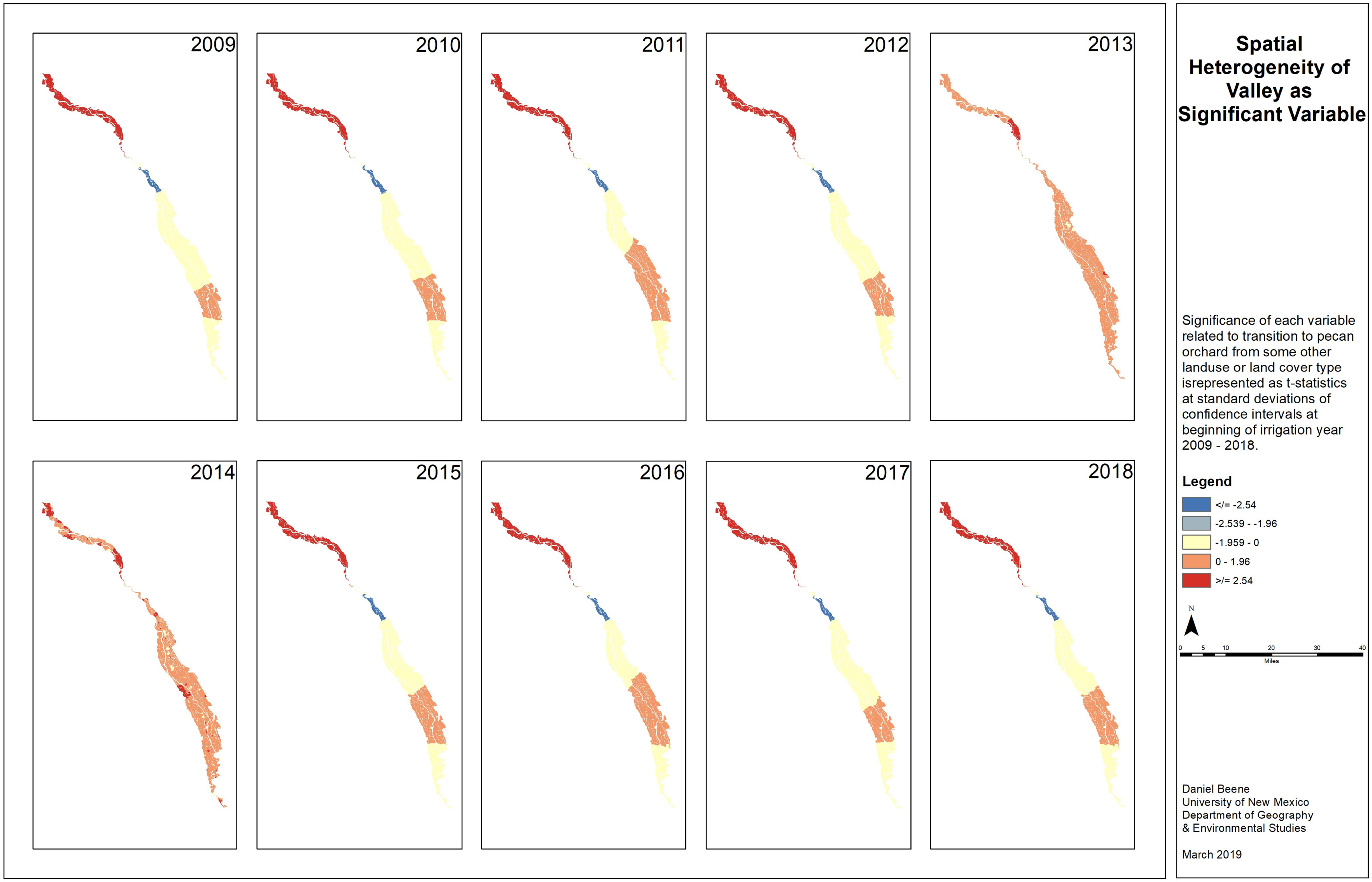
0 5 10 20 30 40
Miles
Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies
March 2019


2009
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Spatial Heterogeneity of Valley as Significant Variable
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.
Legend
</= -2.54
-2.539 - -1.96
-1.959 - 0
0 - 1.96
>/= 2.54
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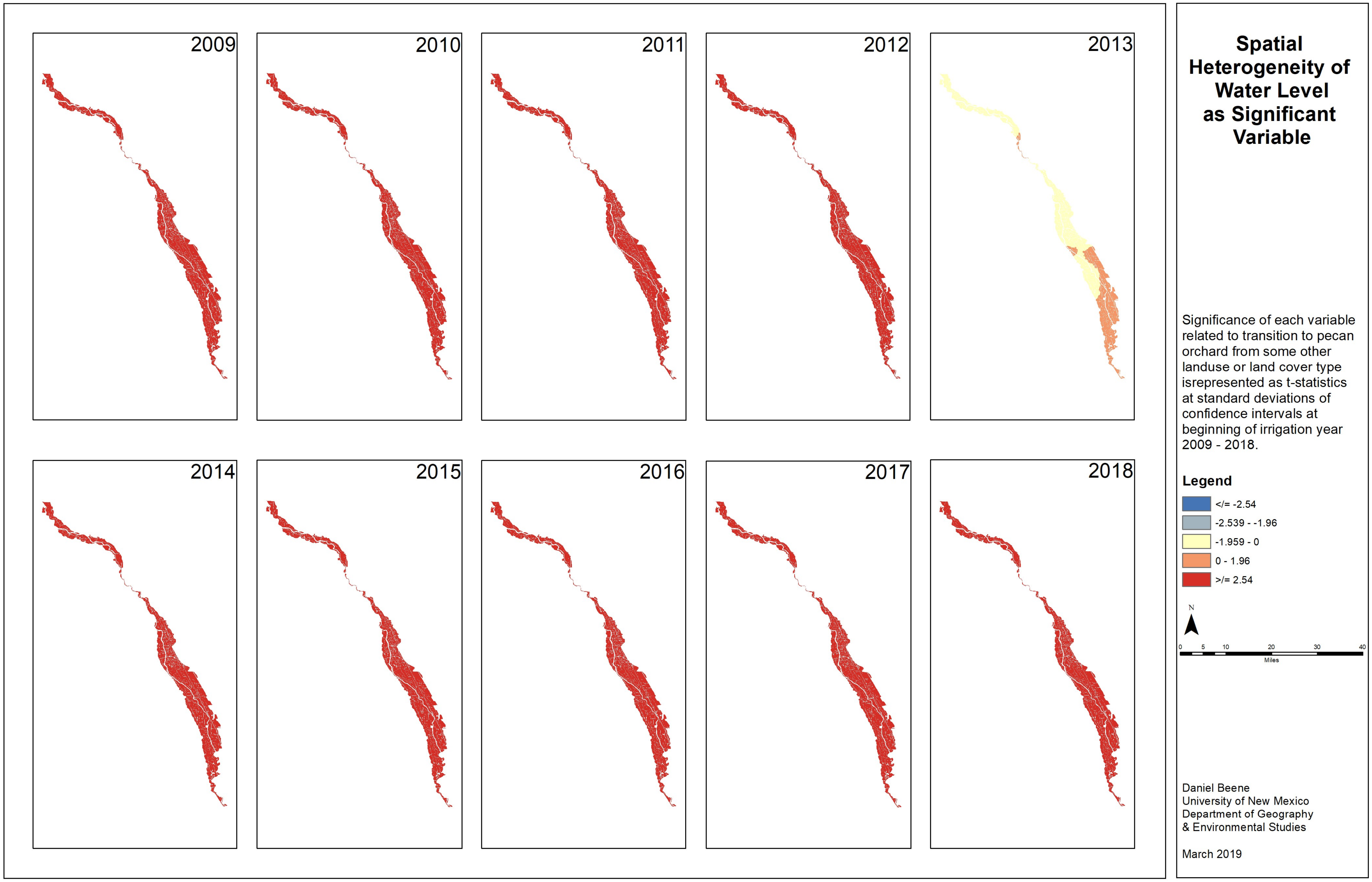
0 5 10 20 30 40
Miles
Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies
March 2019


2009
2010
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2016
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2018
Spatial Heterogeneity of Water Level as Significant Variable
Significance of each variable related to transition to pecan orchard from some other landuse or land cover type isrepresented as t-statistics at standard deviations of confidence intervals at beginning of irrigation year 2009 - 2018.
Legend
</= -2.54
-2.539 - -1.96
-1.959 - 0
0 - 1.96
>/= 2.54
Daniel Beene
University of New Mexico
Department of Geography
& Environmental Studies
March 2019