# Human-environment interactions in rural and agricultural communities: Identifying opportunities for sustainability efforts using quantitative, qualitative, and GIS methods

by

Amariah Fischer

B.S., University of Nebraska-Lincoln, 2016
M.A., Kansas State University, 2018

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Geography and Geospatial Sciences
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2024

# Abstract

The United States agriculture industry, especially in the Midwest, is expected to be adversely impacted by the consequences of climate change, with temperature and precipitation changes making sufficient crop production exceedingly difficult to achieve. Further, the agriculture industry is also a significant contributor to climate change and faces a rising global population with increased food demands. The combination of these circumstances creates a context in which members of agriculture and food systems must adapt to a changing climate to increase food production while simultaneously rethinking traditional approaches to agriculture to mitigate contributions to climate change. This makes the study of agricultural sustainability, and the sustainability of the many rural communities that rely on agriculture, essential for the future of our planet. However, given the complex nature of problems in agricultural and rural sustainability, solutions often require an interdisciplinary approach and the consideration and integration of both human and natural systems. The goal of this research was to contribute to agriculture and rural sustainability by conducting three different research projects that each focused on an area of agricultural or rural sustainability.

In chapter three, we investigate how the physical water environment shapes water conservation norms among farmers in the High Plains-Ogallala Aquifer, the largest source of groundwater in the United States. These questions were approached in terms of cultural adaptation to the physical environment, comparing irrigators with dryland farmers using survey and environmental data. I used the values-beliefs-norms (VBN) framework to develop a conceptual model to integrate the physical water context as an exogenous explanation of water conservation norms. Grouped simultaneous equation models indicate a limited form of cultural adaptation in the region that, from a biological perspective, could be considered evidence of mal-

adaptation. Both irrigators and dryland operators in more water-rich environments hold stronger water conservation norms and those in more arid environments hold weaker water conservation norms. For irrigators, the relationship between the water context and norms is partially mediated by worldviews where irrigators in more water scarce contexts tend to hold more ecocentric worldviews that motivate conservation. The findings suggest the importance of considering farmers' practices (dryland farming or irrigation) and their places (physical water context) in shaping their decision-making in an integrated socio-ecological context.

In chapter four, measures of rurality were investigated. Government agencies and researchers often rely on quantitative measures to map where rural places are and who belongs to rural communities. To better understand the consistency, or lack thereof, across different quantitative rural measures, we compare four common measures applied at the county level for the contiguous United States. My purpose was to (1) quantify and map the degree of rural agreement among these selected rural measures and (2) describe key characteristics of counties classified as rural through urban. Comparing different measures yielded little agreement on rural places with consensus achieved for only 114 of 3,108 counties (3.7%). County variables contributing to good separability in rural to urban classifications included remoteness, population density, percent of the population aged 65 and over, employment in the agricultural sector, and both developed and grassland landcover. Closer examination of the underlying characteristics of the 114 consensus rural counties provides an opportunity to reflect on the nature of popular rural measures and the variables they use. If these counties are not representative of how researchers conceptualize "rural" across US regions, it is motivation for working toward new and/or spatially adaptive rural measures that better represent the communities that policy and research intends to help.

In chapter five, the process of regenerative agriculture adoption was examined. To address the negative environmental impact of industrial agricultural practices, research has been dedicated to the adoption of regenerative agriculture (RA) as it has been shown to reduce agriculture's overall contribution to climate change and better prepare farming operations for future changes in climate. The adoption of RA practices has been linked to systems thinking, with farmers employing regenerative farming practices reporting higher engagement with systems thinking. This study interrogates this relationship further by examining how industrial and regenerative farmers demonstrate systems thinking skills. To do this, sixteen cognitive maps of individual farm systems were collected through qualitative interviews with farmers in central Kansas. These cognitive maps were then used to compare systems thinking skills across farmers employing practices along the spectrum of industrial to regenerative. Results showed that regenerative farmers demonstrated more developed systems thinking skills when compared to industrial farmers. Further, the cognitive maps of regenerative farmers prioritized internal and ecological farm factors, particularly soil health, while those of industrial farmers emphasized external and human-driven farm factors.

# Human-environment interactions in rural and agricultural communities: Identifying opportunities for sustainability efforts using quantitative, qualitative, and GIS methods

by

Amariah Fischer

B.S., University of Nebraska-Lincoln, 2016
M.A., Kansas State University, 2018

A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Geography and Geospatial Sciences
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2024

Approved by:

Co-Major Professor
Dr. Matthew R. Sanderson

Approved by:

Co-Major Professor
Dr. J. M. Shawn Hutchinson

# Copyright

© Amariah Fischer 2024.

# Abstract

The United States agriculture industry, especially in the Midwest, is expected to be adversely impacted by the consequences of climate change, with temperature and precipitation changes making sufficient crop production exceedingly difficult to achieve. Further, the agriculture industry is also a significant contributor to climate change and faces a rising global population with increased food demands. The combination of these circumstances creates a context in which members of agriculture and food systems must adapt to a changing climate to increase food production while simultaneously rethinking traditional approaches to agriculture to mitigate contributions to climate change. This makes the study of agricultural sustainability, and the sustainability of the many rural communities that rely on agriculture, essential for the future of our planet. However, given the complex nature of problems in agricultural and rural sustainability, solutions often require an interdisciplinary approach and the consideration and integration of both human and natural systems. The goal of this research was to contribute to agriculture and rural sustainability by conducting three different research projects that each focused on an area of agricultural or rural sustainability.

In chapter three, we investigate how the physical water environment shapes water conservation norms among farmers in the High Plains-Ogallala Aquifer, the largest source of groundwater in the United States. These questions were approached in terms of cultural adaptation to the physical environment, comparing irrigators with dryland farmers using survey and environmental data. I used the values-beliefs-norms (VBN) framework to develop a conceptual model to integrate the physical water context as an exogenous explanation of water conservation norms. Grouped simultaneous equation models indicate a limited form of cultural adaptation in the region that, from a biological perspective, could be considered evidence of mal-

adaptation. Both irrigators and dryland operators in more water-rich environments hold stronger water conservation norms and those in more arid environments hold weaker water conservation norms. For irrigators, the relationship between the water context and norms is partially mediated by worldviews where irrigators in more water scarce contexts tend to hold more ecocentric worldviews that motivate conservation. The findings suggest the importance of considering farmers' practices (dryland farming or irrigation) and their places (physical water context) in shaping their decision-making in an integrated socio-ecological context.

In chapter four, measures of rurality were investigated. Government agencies and researchers often rely on quantitative measures to map where rural places are and who belongs to rural communities. To better understand the consistency, or lack thereof, across different quantitative rural measures, we compare four common measures applied at the county level for the contiguous United States. My purpose was to (1) quantify and map the degree of rural agreement among these selected rural measures and (2) describe key characteristics of counties classified as rural through urban. Comparing different measures yielded little agreement on rural places with consensus achieved for only 114 of 3,108 counties (3.7%). County variables contributing to good separability in rural to urban classifications included remoteness, population density, percent of the population aged 65 and over, employment in the agricultural sector, and both developed and grassland landcover. Closer examination of the underlying characteristics of the 114 consensus rural counties provides an opportunity to reflect on the nature of popular rural measures and the variables they use. If these counties are not representative of how researchers conceptualize "rural" across US regions, it is motivation for working toward new and/or spatially adaptive rural measures that better represent the communities that policy and research intends to help.

In chapter five, the process of regenerative agriculture adoption was examined. To address the negative environmental impact of industrial agricultural practices, research has been dedicated to the adoption of regenerative agriculture (RA) as it has been shown to reduce agriculture's overall contribution to climate change and better prepare farming operations for future changes in climate. The adoption of RA practices has been linked to systems thinking, with farmers employing regenerative farming practices reporting higher engagement with systems thinking. This study interrogates this relationship further by examining how industrial and regenerative farmers demonstrate systems thinking skills. To do this, sixteen cognitive maps of individual farm systems were collected through qualitative interviews with farmers in central Kansas. These cognitive maps were then used to compare systems thinking skills across farmers employing practices along the spectrum of industrial to regenerative. Results showed that regenerative farmers demonstrated more developed systems thinking skills when compared to industrial farmers. Further, the cognitive maps of regenerative farmers prioritized internal and ecological farm factors, particularly soil health, while those of industrial farmers emphasized external and human-driven farm factors.

# Table of Contents

List of Figures ..... xiii
List of Tables ..... xiv
Acknowledgements ..... xv
Dedication ..... xvii
Chapter 1 – Introduction ..... 1
1.1 Overview ..... 1
1.2 Dissertation Structure ..... 5
Chapter 2 – Literature Review ..... 6
2.1 Human-Environment Research ..... 6
2.2 Geography and the Human-Environment Tradition ..... 8
2.3 Sustainability Science ..... 10
2.4 Relevant Themes in Sustainability Science ..... 16
2.4.1 Scale ..... 16
2.4.2 Systems Thinking ..... 20
2.5 Agricultural Sustainability ..... 23
2.6 Rural Sustainability ..... 28
2.7 Conclusion ..... 32
Chapter 3 – Water, Culture, and Adaptation in the High Plains-Ogallala Aquifer Region ..... 33
3.1 Introduction ..... 33
3.2 Literature Review ..... 36
3.2.1 Environment and Culture: Farmer Adaptation ..... 36
3.2.2 Adaptation as Interpretation ..... 39
3.2.3 Interpretation as a social-psychological process ..... 40
3.3 Methods ..... 44
3.3.1 Study Context and Data Collection ..... 44
3.3.2 Variables ..... 46
3.3.2.1 Physical Environment: PDSI ..... 46
3.3.2.2 Values ..... 47
3.3.2.3 Beliefs ..... 49

3.3.2.4 Climate Change Beliefs ..... 50
3.3.2.5 Belief – Awareness of Consequences ..... 50
3.3.2.6 Belief – Ascription of Responsibility ..... 50
3.3.2.7 Groundwater Conservation Norms ..... 51
3.3.2.8 Well Capacity ..... 51
3.3.3 Analytical Approach ..... 52
3.4 Results ..... 55
3.4.1 The Physical Water Context and Water Conservation Norms ..... 55
3.4.2 Structural Relationships: Physical Water Context and Water Conservation Norms ..... 55
3.5 Discussion ..... 63
Chapter 4 – Where is rural? An analysis of the agreement between quantitative measures of rurality ..... 70
4.1 Introduction ..... 70
4.2 Methods ..... 74
4.2.1 Study area ..... 74
4.2.2 Rural measures ..... 74
4.2.3 Analysis ..... 79
4.3 Results ..... 83
4.3.1 Consequences of how different measures identify rural counties ..... 83
4.3.2 Where measures agree on rural counties ..... 85
4.3.3 Pairwise map comparisons of reclassified rural measures ..... 91
4.4 Discussion and conclusions ..... 92
Chapter 5 – Imprinted in the mind and on the landscape: Piloting a cognitive mapping approach to understand regenerative agriculture adoption ..... 98
5.1 Introduction ..... 98
5.2 Background ..... 100
5.2.1 Regenerative agriculture adoption ..... 100
5.2.2 Systems thinking and cognitive mapping ..... 103
5.3 Methods ..... 107
5.3.1 Interview Process ..... 109
5.3.2 Analysis ..... 112

5.4 Results and Discussion ..... 114
5.4.1 Quantitative results ..... 115
5.4.2 Feedback loops ..... 117
5.4.3 Map factors — as mapped ..... 120
5.4.4 Map factors – as discussed ..... 122
5.5 Conclusion ..... 134
Chapter 6 – Conclusions ..... 137
6.1 Summary of key findings ..... 138
6.1.1 Key findings in Chapter 3 ..... 139
6.1.2 Key findings in Chapter 4 ..... 140
6.1.3 Key findings in Chapter 5 ..... 142
6.2 Future directions ..... 143
6.2.1 Agricultural and rural sustainability ..... 143
6.2.2 Interdisciplinary science ..... 144
References ..... 149
Appendix A Supplementary materials for Chapter 4 ..... 178

# List of Figures

Figure 3.1 Conceptual model of VBN framework adapted from Stern et al. (1999). .....41
Figure 3.2 Irrigator path diagram. *Note:* Statistically significant relationships are shown in bolded lines and accompanied by their respective standardized coefficients. •p < .1. *p < .05. **p < .01. ***p < .001.....57
Figure 3.3 Dryland farmer path diagram. *Note*: Statistically significant relationships are shown in bolded lines and accompanied by their respective standardized coefficients. •p < .1. *p < .05. **p < .01. ***p < .001.....58
Figure 4.1 Maps of the original outcomes for four rural measures after data acquisition or replication and prior to any reclassification. *Note.* Dark green and dark purple represent the most rural and urban counties, respectively. .....84
Figure 4.2 Map representing frequency of rural agreement according to reclassified rural measures. *Note.* Counties in dark green indicate all four measures resulted in a rural classification. Lighter shades of green signify fewer measures concurrently classifying a county as rural. .....87
Figure 4.3 The distribution of key rural variable values (y-axes) by rural measure agreement (x-axes). For example, a measure agreement of two indicates that only two of four measures agreed that a county was rural. Outliers in the boxplots have been omitted for clarity. .....89
Figure 5.1 Conceptual representation of regenerative (R), transitioning (T), and industrial (I) farmers' systems orientations as depicted by the map factors in their cognitive maps. This figure is not meant to communicate that regenerative or industrial farmers did not produce cognitive maps that incorporated factors from both ends of each axis, but instead is meant to make clear the differences in frequency and emphasis of the factors observed in the groups of maps. .....115
Figure 5.2 All in-going and out-going connections for soil health factors, grouped by regenerative (R), transitioning (T), and industrial (I) farmer maps are shown. Connections where soil health was influencing another factor (out-going) were shown with purple arrows, while connections where a factor is influencing soil health (in-going) were shown with green arrows. .....125

# List of Tables

Table 3.1 Sample composition. ....46
Table 3.2 Variable descriptive statistics. ....47
Table 3.3 Variables and measures. ....48
Table 3.4 Correlation matrix. ....53
Table 3.5Variable inflation factors (VIF)....54
Table 3.6 Groundwater conservation norms. ....55
Table 3.7 Irrigators: standardized path coefficients. ....59
Table 3.8 Dryland farmers: standardized path coefficients. ....60
Table 4.1 Datasets and data sources used in each of the rural measures selected for analysis. ....77
Table 4.2 Summary statistics of key rural datasets for the 114 counties identified as rural by all measures. ....86
Table 4.3 Dunn Post-Hoc test results for comparisons of all variables and combination of measure agreement values. ....90
Table 5.1 Mean index values for Complexity Index and Flow-Hierarchy Index per group. ....117

# Acknowledgements

My doctoral journey has been long and arduous, but it would have been entirely impossible without the support of my advisors, Dr. Shawn Hutchinson and Dr. Matt Sanderson. To Dr. Hutchinson, thank you for being my mentor for the past eight years. You have encouraged and guided me in my research, pushed me out of my comfort zone, reminded me to always prioritize my own well-being, and believed in me enough that it became impossible for me not to believe in myself. To Dr. Sanderson, thank you for taking a chance on me five years ago, a student you had not even met. I am incredibly grateful for the significant amount of time and energy you have invested in developing me as a researcher, and the way you have continually tried to learn how best to mentor me given my numerous quirks. To both of my advisors, thank you for your compassion and patience as I navigated some of the most difficult seasons of my life, and for continually reminding me that I could take as much time as I needed to finish my degree. I fully believe that I would not be at the point of even writing this acknowledgement if I had not had the two of you for advisors. Thank you.

I would also like to thank my committee members. To Dr. Kate Nelson, thank you for your expertise, for checking in on me, and for always being a calm and safe space to ask questions. To Dr. Stacy Hutchinson, thank you for your expertise, your interest and investment in my career development, and for encouraging me to get the most from my degree.

Thank you to the Department of Geography and Geospatial Sciences for funding me for half of my degree and for supporting travel for research and conferences. I'd especially like to acknowledge Dr. Chuck Martin, thank you for the flexibility in my teaching assignments that has allowed me to not only continue my doctoral research with significantly less financial stress, but has also allowed me to continue growing as an instructor. Also, thank you to all my peers in the

department for your friendship and community, with a special thanks to Jordan Watson, Rebecca Lima Albuquerque Maranhão, and Clay Robertson.

I'd like to acknowledge the Rural Resource Resiliency NSF Research Training program (NSF #1828571) that not only funded two years of my doctoral degree and kicked off my training as an interdisciplinary researcher, but also connected me with an entire cohort of incredibly talented, creative, and kind students who will undoubtedly change the world someday. I would also like to recognize the vital research funds provided from the Natural Resources and Environmental Sciences Graduate Fellowship, the USDA National Institute of Food and Agriculture, Hatch/ Multi State project W5001: Social, Economic and Environmental Causes and Consequences of Demographic Change in Rural America, and the USDA National Institute of Food and Agriculture, Hatch/Multi State project NC1190: Catalysts for Water Resources Protection and Restoration: Applied Social Science Research.

Lastly, I would like to acknowledge the invaluable contributions of the farmers who completed surveys and participated in the interviews that provided the majority of the data used in this dissertation.

# Dedication

In loving memory of my dear friend Jonathon D.R. Hogue.

“We ain’t angry at you, love / You’re the greatest thing we’ve lost”

Noah Kahan

# Chapter 1 – Introduction

## 1.1 Overview

The United States agriculture industry, especially in the Midwest, is expected to be adversely impacted by the consequences of climate change. From increased temperatures and precipitation leading to crop reproduction failure, to soil erosion and plant diseases, future climate change will make sufficient crop production exceedingly difficult to achieve (Angel et al., 2018; Conant et al., 2018; Gowda et al., 2018; Mastrandrea et al., 2015). Further, farmers will be facing these climate challenges while the global population continues to rise, increasing food demands (Godfray et al., 2010). While farmers are already in a difficult position given these circumstances, agriculture is also a significant contributor to climate change, accounting for at least 30% of greenhouse gas emissions globally (Foley et al., 2011; Vermeulen et al., 2012). The combination of these realities creates a context in which members of agriculture and food systems must adapt to a changing climate while increasing food production, and simultaneously rethinking traditional approaches to agriculture in order to mitigate climate change. This makes the study of agricultural systems and their long-term viability essential for the future of our planet.

Agricultural sustainability research considers both the resiliency of agricultural systems – the ability of a system to endure stress— and the persistence of agricultural systems – the ability of a system to continue functioning over the long-term (J. Pretty, 2008). Agricultural sustainability research is interested in 1) integrating biological and ecological processes, 2) minimizing the use of inputs that harm the environment, farmers, or consumers, 3) leaning on the expertise of farmers, and 4) when appropriate, working together to solve collective agricultural and natural resource problems (J. Pretty, 2008). Agronomists, agricultural economists,

geographers, agricultural and environmental sociologists, and agriculture and biosystems engineers have all contributed to research aimed at making agricultural systems viable for the long term. From studying the adoption of sustainable practices (J G Arbuckle & Roesch-Mcnally, 2015; Carlisle, 2016; L. S. Prokopy et al., 2019), to investigating the impact of policies technologies on farm profitability and resource use (Mishra et al., 2009; Ward & Pulido-Velazquez, 2008), to researching ways soil biology and ecosystem services can be leveraged to improve farm environmental health (Dale & Polasky, 2007; Kremen & Miles, 2012; Lehman et al., 2015; Teague & Kreuter, 2020), agricultural sustainability is being approached from varying perspectives.

Adjacent to agriculture sustainability is rural sustainability. Most of the world's land area is "rural" and rural areas provide many of the natural resources and ecosystem services for the functioning and well-being of both rural and urban places, as well as global food security (Harrington, 2016). Residents of rural communities are often a part of resource dependent, coupled human-natural systems, such as agriculture production, making rural and agricultural sustainability deeply intertwined. Much research in rural sustainability has highlighted many of the unique challenges faced by rural places, from struggles providing adequate public K-12 education (Beeson & Strange, 2003; Crouch & Nguyen, 2021; Sher, 2019), to challenges with health care access (Curran & Rourke, 2004; Douthit et al., 2015; Farmer et al., 2012), and issues with physical resource allocation in the rural context (Gary Paul Green, 2001, 2014; McNicoll, 2014). This work comes from multiple disciplinary perspectives, including engineering (Arcipowski et al., 2017; M. A. Montgomery et al., 2009), sociology (Gale & Cordray, 1994; Magnani & Struffi, 2009), geography (Harrington, 2016; Nelson et al., 2023; Woods, 2009), and medicine (Bradford et al., 2016; Curran & Rourke, 2004; Farmer et al., 2012)

Given the complex nature of problems in agricultural and rural sustainability, it follows that many disciplines would not only want and have opportunity to contribute to these issues, but also that the nature of these problems would *require* the contributions of multiple disciplines. Problems such as these, those that do not have a clear, singular solution and require the problem to be addressed from multiple perspectives, are sometimes referred to as wicked problems (Churchman, 1967; Rittel & Webber, 1973). To address wicked problems in modern day academia, researchers must engage in multidisciplinary, interdisciplinary, or transdisciplinary research. These three terms, while similar in their meaning, are distinct approaches that can be conceptualized as buildings block for one another.

While multidisciplinarity requires the inclusion of several disciplines on a single research project, each researcher from their given discipline works independently of the other researchers on a specific portion of the project, offering their discipline-specific expertise and perspective. The work of each researcher is only brought together after results are achieved, but there is often not integration through the research process (Stock & Burton, 2011). An interdisciplinary approach builds off of the multidisciplinary approach by requiring a group of discipline-diverse researchers, but in this scenario, there is integration at the data, methods, and theory level of the research process (Institute of Medicine, 2005). Interdisciplinary work involves the integration of techniques and concepts of two or more disciplines in such a way that the research produces outcomes not achieved through multidisciplinary work. Lastly, transdisciplinary research, sometimes called convergent research, is the most integrative off all three approaches and builds off of interdisciplinary work. Transdisciplinary research requires the integration of data, methods, theory, and concepts from multiple disciplines but in such a way that it generates new

paradigms and ideas, and even promotes the development and emergence of new fields of study (National Council Research, 2014).

Given that doctoral dissertation research must be conducted by a student independent of researchers outside of the advisory committee, engaging in multidisciplinary, interdisciplinary, or transdisciplinary research is not possible for a doctoral degree. However, by seeking mentors of diverse academic backgrounds and drawing on research and methods from various disciplines, even a doctoral student can take a step toward the scientific diversity called for in complex, coupled human-natural systems, such as those found in agricultural and rural sustainability research. This dissertation engaged this approach by reporting the findings of three independent research projects that fall under the umbrella of agricultural and rural sustainability. These three projects employ distinct methods, draw theory from various disciplines, and look at problems at different scales. The three projects are as follows:

1. Water, culture, and adaptation in the High Plains-Ogallala Aquifer region

The scale of this project was the High Plains-Ogallala Aquifer region and engaged quantitative analysis of producer surveys to investigate the relationship between producers' water conservation norms and their environment.

2. Where is rural? An analysis of the agreement between quantitative measures of rurality

The scale of this project was the contiguous United States at the county level. This project employed spatial analysis to identify and study counties that multiple rural measures agree are rural.

3. Imprinted in the mind and on the landscape: Piloting a participatory approach to understand regenerative agriculture adoption

The scale of this project was central Kansas at the farm level. This study used farmer interviews and cognitive maps of their farm systems to engage qualitative analysis. The cognitive maps of farmers engaging in different practices were compared to gain a deeper understanding a regenerative agriculture adoption.

## 1.2 Dissertation Structure

This dissertation is comprised of six chapters. Chapter one introduces the broader areas of study in which the research projects are situated and explains the interdisciplinary approach of the dissertation. Chapter two consists of a literature review of relevant fields of study to make clear the lens from which the research was conducted and provide the necessary breadth and context for the research projects. Chapters three through five are each manuscript-format chapters of the three research projects listed in the section above, respectively. Lastly, chapter six is a conclusion chapter synthesizing the findings of the research project and how they relate to the broader aims of the dissertation.

# Chapter 2 – Literature Review

## 2.1 Human-Environment Research

Human-environment research attempts to understand interactions between human beings and the environment. These interactions have been studied along three dimensions: human impact on the environment, consequences of environmental change on human structures, and feedbacks between humans and the environment (Stern, 1993).

Human impact on the environment has examined ways that human activity has drastically altered world climate and ecosystems. In the Amazon, anthropogenic processes, such as deforestation and the fragmenting of rivers, were found to be happening hundreds to thousands of times faster than natural processes (Albert et al., 2023). Land use and land cover changes, particularly deforestation, have been a significant contributor to global carbon emissions (Eva et al., 2012; Houghton et al., 2012). Human activity has influenced marine ecosystems around the globe, with not a single area unaffected by human influence (Halpern et al., 2008). Urbanization has negatively impacted the environment through reduced green space and carbon emissions (Martínez-Zarzoso & Maruotti, 2011; Pauleit et al., 2005).

Effects of environmental change on human structures and systems has been studied through the impacts of climate change, coping in the wake of natural disasters, and the consequences of biodiversity loss. Increased temperatures and changes in precipitation patterns due to climate change are expected to impact agricultural systems resulting in decreased yields, greater vulnerability to plant and animal diseases, and depletion of water resources (Angel et al., 2018; Gowda et al., 2018). Further, climate change is expected to put additional heat stress on urban areas (Mastrandrea et al., 2015). Research has investigated the community impacts of natural hazards (Lindell & Prater, 2003) and humans' vulnerability to and adaptive capacity for

natural hazards (Howell & Elliott, 2019; Klein et al., 2003; Noy & Yonson, 2018). Biodiversity loss has been found to threaten the ecosystem services provided by marine ecosystems (Worm et al., 2006), while agriculture is a leading contributor to biodiversity loss in terrestrial ecosystems (Dudley & Alexander, 2017; Reidsma et al., 2006).

The feedbacks between humans and the environment require human-environment interactions to be viewed as a part of complex, coupled human-environment systems. This area of human-environment research is particularly challenging because feedbacks between social and human structures and the environmental can occur at multiple points in the system and in many ways (Stern, 1993). Researchers are working to understand these feedbacks in particular human-environment systems, for example, in the nascent field of sociohydrology. As a science, sociohydrology recognizes it is not possible to predict dynamic water processes over long periods of time without considering feedbacks between both social and natural systems (Gober et al., 2017), and because of this, treats humans as endogenous to the system to better understand the co-evolution of complex human-water systems over time (Saket Pande & Sivapalan, 2017; Sivapalan, Savenije, & Blöschl, 2011).

Each of these dimensions of human-environment research have been studied by multiple disciplines, including geography, psychology, sociology, ecology, and engineering. Human-environment research, while attracting researchers from a variety of fields, is also rooted within both traditional disciplines, such as geography, and disciplines that have developed out of efforts to steer academia toward a more interdisciplinary focus, such as human ecology, environmental studies, and sustainability science (Rasmussen & Arler, 2010). However, regardless of the multi- or interdisciplinarity nature of human-environment research, disciplines contributing to human-environment research bring with them their particular theories, models, and epistemologies.

Within each discipline, researchers have been trained and socialized to accept certain models, standards, explanations, and assumptions that shape what counts as 'good science' (Rasmussen & Arler, 2010). As these aspects vary from field to field, it is important to be informed about the disciplines in which this human-environment dissertation stems to understand any discipline-specific influences within the research. In the next two sections I focus on human-environment research in geography, as that is the home discipline of this dissertation, and sustainability science, as that is the broader focus of this research, spending time with two relevant themes within sustainability science: scale and systems thinking. These sections are followed by a discussion of agricultural and rural sustainability that is the specific focus of this dissertation.

## 2.2 Geography and the Human-Environment Tradition

Human-environment research has long been a part of geography. Recognized as one of the four traditions of geography (Pattison, 1990), human-environment interactions within the geographic context engage multiple themes central to the discipline including spatial relationships, geographic context, and place characterization (Murphy, 2014). Human-environment research investigates the following:

- how spatial relationships influence human interaction with the environment and how these relationships vary with scale,
- the specific processes and interactions that characterize a given place, for example how human-environment relationships shape the long-term outcomes of specific places,
- the interactions between the particular set of circumstances within a place and how those interactions influence human-environment relationships (Murphy, 2014).

Environmental determinism was a popular early theory posed about the influence of the environment on human societies and culture that first emerged in geography in the early 1900s and was championed by Ellen Churchill Semple (Semple, 1911). The theory held that the environment was the sole determinant of differences in race, customs, moral values, and overall capabilities (Judkins et al., 2008; Semple, 1911; Taylor, 1921). Environmental determinism declined in popularity in the mid 1920s because it lacked sufficient scientific inquiry (Harden, 2012) and was also used to justify racist stereotypes (Peet, 1985). As a reaction to the flaws of environmental determinism, cultural possiblism emerged in the 1920s that theorized a much more limited view of environmental influence. Possiblism considered the environment not as the sole determinant of culture but as a constraint or enabler that could help contextualize culture within the environment (Judkins et al., 2008).

Cultural possibilism lost popularity in the 1960s and from that point forward many new ways of thinking about the relationship between humans and the environment emerged and are still employed in present day research. These ideas often involved recognizing key aspects of the human-environment relationship that previous approaches had not focused on or acknowledged (Ellen, 1982). Systems theory sought to understand how culture responded to changes in the environment, specifically how characteristics of humans both at the individual and societal level could lead to adaptation or maladaptation (Butzer, 1989, 1990). Behavioralism was key in recognizing humans as active participants in shaping the environment and aimed to understand processes behind individual and group decision-making (Vayda & McCay, 1975). Structuralism emphasized the institutional restraints in human culture and how they influenced human-environment interactions (Blaikie & Brookfield, 1987). While these approaches to understanding human-environment relationships in some cases stemmed from disciplines outside of geography,

such as anthropology and human ecology, they are widely recognized as a part of the history of geographic thought in the context of the human-environment tradition.

Research in the human-environment tradition of geography in the past 50 years has engaged these ways of thinking and applied them to different topical areas within human-environment research. Research focused on human vulnerability and response to natural hazards led to the emergence of concepts such as social vulnerability, resiliency, and adaptation. More recently, interest in this topic has shifted to focus more on human responses to climate change (Harden, 2012). Researchers interested in human impact on the environment have focused on the opposite relationship by studying environmental response to human action. This area of research seeks to understand the extent and severity of human impact on the environment, both directly and indirectly, to reduce the anthropogenic changes. Research on sustainability has been the most recent focus of human-environment research within geography. Sustainability research treats human-environment interactions as part of a coupled human-natural system with multiple points of feedback and aims to better understand this system in hopes of meeting the needs of humans and the environment in the long-term, with many geographers arguing that geography as a discipline is specifically well situated to engage in sustainability research given its scope of both social and physical sciences (D. E. Bennett, 2013; Harden, 2012). This dissertation is rooted in the human-environment tradition of geography, specifically engaging the sustainability focus of human-environment research in geography.

## 2.3 Sustainability Science

From a cumulation of efforts in the 1980s and 1990s within sustainable development research, sustainability science emerged in the early 2000s aiming to leverage science and technology to meet sustainable development goals, with a more formal start of the science

beginning in 2002 at the World Summit on Sustainable Development. Sustainability science seeks to find balance between the goals of societal development and the environmental limitations of the planet over the long-term (Clark & Dickson, 2003). However, with this ambitious aim, sustainability science also recognizes key characteristics that are necessary to make meaningful progress toward achieving it. Sustainability science must engage in a systems approach, actively working to identify the feedbacks between social and natural systems to better understand coupled human-natural systems as a whole instead of individual component parts (Clark & Dickson, 2003; Spangenberg, 2011). Sustainability science requires the combination of both theoretical and applied sciences (Bettencourt & Kaur, 2011; Clark, 2007), and works to co-produce knowledge through the collaboration of scientists, stake-holders, and practitioners (Clark & Dickson, 2003) through a transdisciplinary approach. Lastly, sustainability science studies and engages these research goals over time and space as sustainable solutions at one scale may be unsustainable at another (Kates et al., 2001; Spangenberg, 2011).

This type of effort to define and develop a science, one that has urgent goals requiring a transdisciplinary approach, is arguably unprecedented in the scientific community, and sparked a debate on if it was even possible to create such a science (Bettencourt & Kaur, 2011). With over two decades for the proposed science to develop, it is clear to see sustainability science has become its own field. The amount of peer-reviewed research studying sustainability has grown exponentially since the 1990s (Bettencourt & Kaur, 2011). Graduate programs for both master's and doctorate degrees in sustainability now exist in many countries across the globe (Kates, 2011). Sustainability science publications have a wide international spatial distribution with developed and developing nations contributing to contemporary sustainability research (Bettencourt & Kaur, 2011).

While there is evidence to support sustainability science as a distinct field of study, it is still in the process of maturing and its identity is still somewhat unclear. In this uncertainty, there is growing unity and definition in the questions sustainability science seeks to answer. Some of these questions include (Kates, 2011; Kates et al., 2001):

1. How can theory and models be developed to better represent the dynamic relationship between humans and the environment?
2. What determines resiliency, vulnerability, or adaptability in a human-environment system?
3. What are the long-term trends relevant to sustainability and what is influencing them?
4. How can proposed sustainable solutions be evaluated?
5. Is it possible to define scientifically meaningful limits within human-environment systems as a means of warning?

These overarching questions, along with the aims and characteristics of sustainability science, have resulted in a field of study that is not defined by a specific discipline, but instead by the problems it addresses and the approaches used in their study (Clark, 2007).

This can be seen in the diversity of disciplines participating in sustainability research. In a bibliometric analysis, social science, biology, and engineering were the top contributing disciplines to sustainability publications, with medicine, infectious diseases, and earth sciences among the other major contributors (Bettencourt & Kaur, 2011). Social science has added to sustainability research in the areas of environmental and human resource management, regional studies, rural and urban studies, and political geography. Biology has contributed through research in conservation, soil analysis, and molecular ecology and ecological modeling. Lastly, engineering's participation falls mainly within the subjects of soil quality and science, renewable

energy, water waste and water policy, and environmental pollution. Other research has used citation network analysis to identify the following core areas (clusters) of published research within sustainability science: agriculture, climate, fisheries, forestry, economic development, water, energy and resources, health, and biodiversity (Kajikawa, 2008; Kajikawa et al., 2007). These forms of analyses demonstrate the diversity of disciplines and core research areas contributing to sustainability science, as is necessary to meet the transdisciplinary aims of the field, but they also allow us to track the evolution of these research foci over time.

From 2007 to 2013, the core research areas in sustainability demonstrated a shift to more interdisciplinary research efforts. For example, the research areas identified in 2013 were environmental systems, economy and business systems, forestry and fishery systems, energy systems, water resources, health, and urban and transport systems (Kajikawa et al., 2014). But even more compelling are the research themes overlapping these core research areas: resiliency, vulnerability, adaptation in social-ecological systems; social-economic systems; transition management; and knowledge systems and transdisciplinarity. This study provides support for the argument that sustainability science is evolving into a more interdisciplinary field and taking a systems approach to address overarching research questions.

Sustainability science is understood as a transdisciplinary effort, but interdisciplinarity is a necessary step to reach transdisciplinarity, and neither is without its challenges. Disciplines vary in their ontologies, epistemologies, theories, and models, making the integration of knowledge necessary for inter- and transdisciplinary work exceedingly difficult. When working in an inter- or transdisciplinary setting, these differences have be shown to cause challenges with forming a consensus of what the core issues are, identifying appropriate methods, and interpreting results (Lang et al., 2012). Other issues that arise stem from over or under

representation of relevant actors, barriers preventing relevant actors from participating in inter- or transdisciplinary research, and even fear of failure pressuring actors to revert to more comfortable and established solutions (Lang et al., 2012). Lang and colleagues (2012) provided a framework for transdisciplinary collaboration including three phases: 1) collaborative framing and building collaborative research teams; 2) co-creation and solution-focused and transferable knowledge via collaborative research; and 3) iterative integration and application of co-created knowledge. Each of these phases then has suggested subareas with guiding questions to provide a foundational framework for collaborative transdisciplinary work.

While Lang and colleagues (2012) focused on a framework for overcoming challenges with group organization in transdisciplinary research, other scholars have offered approaches and conceptual models to progress toward a more unified methodology. In a review of approaches for engaging in sustainability science, Kajikawa (2008) found seven key steps across the literature: goal setting, indicator setting and measurement, causal chain and problem-solution chain analysis, forecasting, and backcasting. In this case, the goal is the overarching goal of the system and indicators are quantitative measures that allow for assessing progress toward the set goal. Causal chain analysis requires analyzing the cause-and-effect linkages between factors in a system (Kates & Dasgupta, 2007), while problem-solution analysis focuses on rigorous understanding of the problem at hand, plausible solutions, and the assessment of potential unintended consequences of proposed solutions (Ostrom, 2007). Forecasting leverages past and current data to predict future trends within the system, while backcasting works backward from the desired state of the system to the current state (Kajikawa, 2008). These studies, through their reviews of challenges and approaches in sustainability science research, provide practical guidance for a science that is complex and often messy.

The cumulation of research and literature defining, tracking the progress of, and providing frameworks for sustainability science has advanced the field of study and provided the explicit discussion necessary for researchers to continue to contribute and make progress in the field. However, this does not mean that other working definitions have not been used or remain popular. Arguably, the most common alternative conceptualization of sustainability as a combination or intersection of social, economic, and environmental systems or perspectives, sometimes referred to as the 'three pillars' of sustainability (Giddings et al., 2002; Purvis et al., 2019). This conceptualization emerged in the 1980s, predating definitions of sustainability science, and is more often associated with sustainable development or sustainability more broadly (Barbier, 1987). However, with the emergence of sustainability science in the early 2000s, this understanding of sustainability has become intermingled with sustainability science. Often referred to as the triple bottom line or the three pillars concept (Alhaddi, 2015), this approach is typically visualized via three circles—representing social, economic, and environmental areas of study—overlapping in a section labeled sustainability. Alternatively, three pillars are used to represent the three areas of study with sustainability depicted as the 'roof' they are upholding. These visualizations and the general conceptualization of sustainability are not only vague but also lacking a theoretical framework and explanation of how this understanding could be operationalized (Purvis et al., 2019). However, regardless of the ambiguity surrounding the foundation and meaning of the 'three pillars' conceptualization of sustainability, this definition of sustainability is used frequently in research and has become a common part of sustainability research even as it extends to sustainability science.

There is clear evidence in the literature that sustainability science is continually advancing as a distinct field of study with core questions, both theoretical and practical,

frameworks for collaboration, and approaches for transdisciplinary research. However, the question remains: How can researchers facing barriers to participation in inter- and transdisciplinary work, for example a PhD student who must complete research independently, participate in sustainability science research? Spangenberg (2011) identifies two veins of sustainability science. The first is the science *of* sustainability which aligns with the description of sustainability science presented in this section. The second is science *for* sustainability. This second vein of sustainability science, according to Spangenberg, is monodisciplinary and highly focused on a specific aspect of sustainability relevant to the home discipline of the research. This research contributes to our knowledge of sustainability issues but follows traditional approaches to science in which stakeholders do not participate and the research, either through collaboration or development, and does not extend beyond the academic community (Spangenberg, 2011). Research in this dissertation is science *for* sustainability, due to the constraints of doctoral research, but has as its goal to be best prepared for the science *of* sustainability post-graduation.

## 2.4 Relevant Themes in Sustainability Science

### 2.4.1 Scale

Spatial and temporal scale are often cited as challenges to sustainability science (Cash et al., 2006; Kates et al., 2001; Martens, 2006; Spangenberg, 2011; Wilbanks, 2007, 2015). The need to address systems from multiple scale levels, understand interactions between scales, and to determine appropriate minimum scales (particularly for time) are all among the reasons cited for why scale is a challenging aspect of sustainability science research. However, an added layer of complexity within the conversation of scale in sustainability is the inter- and transdisciplinary nature of sustainability science. Different epistemological perspectives of scale exist across disciplines and how researchers approach interactions between scale levels is influenced by their

scale epistemologies (Manson, 2008). When engaging in inter- and transdisciplinary work these differences in scale epistemologies need to be explicitly discussed to form a unified foundation for addressing other scale issues with the systems being researched. Scale is inconsistently discussed, with epistemological differences sometimes explicitly, implicitly, or not at all discussed by the researchers across sustainability literature. An overview of the main epistemological perspectives of realist, hierarchical, and constructivist scales presented by Manson (2008) helps highlight this challenge.

Realist scale is founded on the assumption that an objective observable reality exists. This scale uses the terms extent and resolution with extent referring to the scope of the scale and resolution referring to the smallest unit of observation. Realist scale also introduces the ideas of scale of observation and scale of explanation. The scale of observation is the scale at which a given data can be observed. For example, new tools and technology allowing researchers to observe data at a new scale would be considered advancements in the scale of observation. The scale of explanation is the scale that is best suited to understand the data, processes, or system being studied. The idea of scale of explanation is reliant on the premise of an objective reality as it allows for a 'best' scale to be determined at all. Lastly, scale dependence and scale variance provide the most distinct characteristics of realist scale. Scale dependence claims that while an objective 'best' scale can be determined for all phenomena, researchers may have to vary the scale level to determine the best scale, but that ultimately, through this process, the best scale will be determined by reality and not the observer. Scale variance then states that if there is enough distance between two scales of the same phenomenon, then this single phenomenon can be treated as two unrelated phenomena.

Hierarchical scale pulls away from the claims of realist scale by recognizing interactions between scale levels which do not exist under realist scale. The interactions between scale levels in understood through hierarchical orders within the systems being studied. While the importance of interactions between different scale levels is distinct from realist scale, hierarchical scale engages many of the same terms and concepts as used in realist scale. Hierarchical scale only begins to lean toward a more constructivist point of view through the observance of emergent hierarchies. Emergent hierarchies develop from the interactions of phenomena at different scale levels, the identification of which is at times considered subjective. Hierarchical scale maintains elements from realist scale, while also introducing new ideas in the form of hierarchy that ultimately lead into constructivist scale concepts.

Constructivist scale takes the opposite position of realist scale in that it posits scale is created, not only because of its socially constructed definition but also because it is founded on subjective understandings of reality. While this view can be taken to the extreme and interpreted as every aspect of reality is subjective, it is often understood that this claim of subjectivity means that many aspects of reality are based on subjective conceptualizations, if not all aspects of reality. Because constructivist scale is based on subjective realities, scale is understood as socially constructed and influenced. One of the ways we can observe this social influence is through the manipulation of scale. By defining and redefining scale to intentionally distort the data and conclusions drawn about the data, scale is being constructed and then manipulated in a way that has tangible impacts. The social construction of scale can also be seen in 'policy scale', a term describing the scale at which policy decisions are made and implemented (Wu & Li, 2009). Lastly, network scaling is unique to constructivist scale. Network scaling claims that scale inherently includes flows in networks between social aspects of systems. These network

flows allow for a single object within a system to be an important part of multiple scale levels at the same time due to its connections to other phenomena in the system.

These perspectives on the epistemological scale continuum have been associated with specific areas of science, mostly with realist scale driving the natural sciences' approach to understanding scale and social sciences engaging a more constructivist scale perspective (Gibson et al., 2000). However, there are examples of sustainability science research engaging combinations of realist and hierarchical scale (Cash et al., 2006; Gibson et al., 2000) and hierarchical scale and constructivist scale (Wilbanks, 2007, 2015). Further, discussions of spatial and temporal scale issues in sustainability science have been discussed using the terminology common with in realist scale, such as extent and resolution, while also recognizing the challenge of social influence in the systems and within scale itself, drawing on constructivist ideas (Kates et al., 2001; Martens, 2006). The variation in scale perspectives within sustainability science makes two points clear: 1) there is no unified epistemological perspective on scale within sustainability science and 2) establishing an agreed upon scale perspective within the field or at the very least among collaborating researchers, will become increasingly important as sustainability science continues to move from inter- to transdisciplinary.

Manson (2008) makes three suggestions for approaching these challenges surrounding scale in sustainability science. First, he argues that collaborators need to explicitly discuss and explore each scale perspective to determine which perspective or particular combination of perspectives based on an assessment of their strengths and weaknesses, is best suited to address a research objective. Second, Manson argues that in sustainability, where social and natural systems are being integrated, scale perspectives drawing more heavily on hierarchical scale assumptions and concepts are often more palatable to a wide range of researchers contributing to

sustainability science. However, he follows this claim up with his third point that constructivist scale needs to play at least a minor role in sustainability research because although it can be complicated and uncomfortable to acknowledge the ways subjectivity influences systems, it is a part of our reality and is a necessary step in developing our understanding of social and natural systems.

The differences in scale perspectives implicit in sustainability science stem from the broader challenges of engaging in inter- and transdisciplinary science. Addressing any issues of scale in the complex human-environment systems studied in sustainability science will require explicit and transparent discussion of scale perspectives to align collaborators in their understandings of scale moving forward. This dissertation, engaging in sustainability *for* science, does not explicitly assess interactions between scale levels, but it does lean toward hierarchical and constructivist views of scale. Each research project conducted for this dissertation was done so at a different scale, at times leaning toward a hierarchical scale perspective (chapter four) and at other times leaning toward a constructivist scale perspective (chapter 5), but ultimately recognizing the need for research multiple scales to address sustainability challenges.

### 2.4.2 Systems Thinking

Engaging systems approaches is often cited as a core aspect of sustainability science (Clark & Dickson, 2003; Spangenberg, 2011; Weinstein, 2010). A systems approach is presented as the framework for studying the interactions between social and natural systems, understanding system function, and ultimately moving coupled human-environment systems to a desired state. At the core of the systems approaches discussed in sustainability science is systems thinking.

Systems thinking has been claimed to originate in many different fields, such as computer science, biology, and ecology, and to have emerged at varying points in academic history.

However, the discipline with arguably the strongest claim on systems thinking is operational and organizational research (Jackson 2007). While scholars in this field acknowledge how systems thinking concepts have been demonstrated by many, from ancient philosophers to physical scientists, systems thinking has been formally studied in operations research since the 1940s. Systems thinking has continued to develop over time as an area of study, and is now considered a part of systems science, an interdisciplinary field focusing on understanding and engaging systems.

Systems thinking definitions vary from vague to highly specific, practical and applied to abstract, but there are key themes that permeate most definitions. Systems thinking can be conceptualized as the opposite of linear thinking, engaging holistic thinking that seeks to integrate data instead of dissect data (Monat & Gannon, 2015). Through this holistic thinking, the aim is to understand, assess, predict, and influence a system and its function (Arnold & Wade, 2015). To meet these aims, systems thinking researchers often identify and examine the elements, interconnections, feedbacks, structure, and purpose of a system (Arnold & Wade, 2015; Williams et al., 2017), employing the core concepts of interconnectedness, feedback loops, and self-organization. When applied, systems thinking concepts and elements can be used to build a system model, either conceptual or computational, that can then be studied to better understand the system. Through use of systems thinking concepts and practices, a better understanding of interactions between system scales (Arnold & Wade, 2015) and improved complex decision-making and problem-solving abilities can be achieved (Maani & Maharaj, 2004). In this sense, systems thinking can be conceived of as a combination of three major components: 1) a way of thinking, holistically with focus on relationships, 2) a specific language

for communicating complex and interconnected relationships, and 3) a tool for modeling the complex relationships that come together to form a system (Maani & Maharaj, 2004).

While systems thinking research stemmed from operations and management studies, many disciplines have applied systems thinking concepts to their fields of study, particularly since the 1990s when systems thinking began its growth in popularity within academia (Ullah et al., 2020; Williams et al., 2017). Operations and management studies is still among the top contributors to systems thinking research, but social science, decision science, and engineering also hold a strong presence in the systems thinking literature (Ullah et al., 2020). Notably, social-ecological systems was also found to be a main research theme within published systems thinking research (Williams et al., 2017), demonstrating a movement toward more integrated human-environment studies employing systems thinking.

When applying systems thinking to sustainability science, the process and outcomes look different than applications in other fields. Sustainability science seeks to find an ideal state of existence that balances the goals of societal development and the environmental limitations of the planet over the long-term. However, because our world is constantly changing, sustainability is not a goal that can be achieved or an issue that can be solved. In this sense, sustainability is seen as a 'moving target' (Levin & Clark, 2010). When applying systems thinking to sustainability, then, the purpose is not to alter the system to a desired end state, but instead, to understand and influence the ability of a system to persist and adapt to the continually changing conditions of our world (Williams et al., 2017).

Research has used systems thinking for sustainability efforts by assessing how student systems thinking skills influence sustainability understanding (Palmberg et al., 2017); using systems approaches to model conflict in human-natural systems (Fisher & Rucki, 2016);

studying systems thinking as a tool to improve decision-making regarding climate action (Lalani et al., 2023); and employing systems thinking to better understand adoption of sustainable farm practices (Church et al., 2020; Hoffman et al., 2014). This dissertation engaged a systems approach more subtly in research chapters three and four through the integration of data from both natural and social systems and more explicitly in the analyses of systems thinking among farmers presented in chapter five.

## 2.5 Agricultural Sustainability

Industrial agriculture is an approach centered around monoculture, mechanization, synthetic chemical inputs, biotechnology, and government subsidies (Horrigan et al., 2002; Rhodes, 2017). Substantial evidence has shown industrial agriculture practices cause serious environmental harm in a variety of ways, including soil erosion (D. R. Montgomery & Matson, 2007), water pollution and depletion (Foley et al., 2011; Ikerd, 1993), ecosystem services and biodiversity loss (Power, 2010b), and greenhouse gas emissions (Foley et al., 2011; J. N. Pretty et al., 2005; Vermeulen et al., 2012).

The term sustainable agriculture became popular in the 1980s and is considered an alternative approach to industrial agriculture (Rhodes, 2017). In the 1990 Farm Bill, sustainable agriculture was defined as an integrated crop and livestock production system that balances environmental quality, human food needs, quality of life, and farm economic viability over the long term (USDA 1990). Sustainable agriculture has since been defined in many ways, but some of its goals include integrating biological and ecological processes into farm systems, conserving natural resources and ecosystems, and minimizing use of non-renewable and off-farm inputs (Gomiero et al., 2008; Oberč & Schnell, 2020; J. Pretty, 2008).

As agricultural sustainability is a topic-specific application of sustainability science, sustainable agriculture also engages a systems approach. Sustainable agriculture descriptions reference the systems aspect of this approach both implicitly and explicitly (Velten et al., 2015). One of the often repeated attributes of this approach to agriculture is adjusting farms to mimic natural ecology (Gomiero et al., 2008; Harwood, 1990; J. Pretty, 2008; Rhodes, 2017). This attribute implies and necessitates the use of systems thinking and systems approaches as transforming a farm to mimic an ecosystem necessarily requires thinking of the farm as a system itself. Further, many definitions call for integrating environmental limits and human needs, both for food and well-being, suggesting a coupled human-natural system. Others have stated this point clearly in their descriptions of sustainable agriculture, making viewing and assessing the farm as a system the foundation of the approach (Harwood, 1990; Ikerd, 1993).

Sustainable agriculture, while not being defined by a specific set of practices, promotes practices that simulate processes in the natural environment, leveraging ecosystem services, to avoid long term environmental harm. These practices center on the issues such as water resource depletion, soil quality and erosion, and energy usage within agricultural production (Rhodes, 2017). Individual practices that support sustainable agriculture goals include diverse crop rotations, reduced tillage or no tillage, and reduction of synthetic chemical inputs. Aside from individual practices, there are also efforts that use a systems approach to outline principles and general practices that support agricultural sustainability such as conservation agriculture, regenerative agriculture, and permaculture.

Conservation agriculture is founded on four core concepts (Lal 2012; Pretty 2009). The first founding principle is minimal to zero soil disturbance by adopting no-till or conservation tillage techniques. Reducing the amount of tillage helps prevent the loss of soil organic carbon,

reduces soil erosion, and improves water infiltration and moisture retention (Pretty 2009; Lal 2015; Baker et al. 2007; Franzluebbers 2002). The second principle is the use of cover crops which grow in conjunction with main crops or in the off-season. The third principle is integrated nutrient management (INM) which matches natural nutrient cycling with the application of inorganic and organic sources of nutrients to minimize the use of chemical fertilizers and enhance overall soil health (Pretty 2009; Wu and Ma 2015). The final principle is the use of crop residue as mulch. Leaving the remaining crop residue in the field after crops are harvested can improve soil health through the retention of soil organic matter and improved nutrient cycling (Turmel et al. 2015). Further, though, when these practices are integrated together within a single farm system, they can yield even greater environmental benefits (Pittlekow et al. 2015), such as aiding in adaptation to climate change and producing equivalent yields compared to conventional methods (Thierfelder and Wall 2010; Mastrandrea et al. 2015).

While building on the core practices of conservation agriculture, regenerative agriculture goes beyond conservation agriculture by incorporating livestock practices and actively seeking to regenerate soils (Oberč & Schnell, 2020). Regenerative agriculture is a systems-based, soil-centric approach to rebuilding agroecosystems that is founded on five core principles: 1) minimize soil disturbance, 2) keep soil covered year round, 3) maintain a living root in the soil, 4) encourage biodiversity, and 5) integrate animals (Brown, 2018; Khangura et al., 2023). Regenerative farms have been shown to be more profitable than industrial farms, especially in times of environmental stress (LaCanne & Lundgren, 2018). Further, crops and livestock raised on regenerative farms were found to have higher nutritional content when compared to those raised on industrial farms or found in supermarkets (D. R. Montgomery et al., 2022).

Permaculture follows the principle of creating a farm system that mimics nature but with a particular emphasis on the cultivation of perennial plants (Ferguson & Lovell, 2014; Rhodes, 2017). The term permaculture comes from the combination of the words “permanent” and “agriculture”, but the term has evolved to include both the aim of a sustainable agroecosystem and a sustainable social system in recognition that land use systems are not capable of functioning separate from social systems (Krebs & Bach, 2018). The main design structure of permaculture centers around three aims: care for people, care for earth, and being mindful of consumption while sharing any surplus (Holmgren 2002), and uses these aims to design a layered and integrated system that focuses on the relationships between elements to achieve a resilient system (Rhodes, 2017).

To measure the effectiveness of the practices and approaches discussed above in reaching agriculture sustainability goals, researchers have used various indicators as a means of evaluation. Indicators are variables that are used to provide information on more difficult to access variables that can be used in decision-making (Latruffe et al., 2016). In agricultural sustainability, as most decisions are made at the farm level, farm-scale indicators are used. Environmental indicators centered around the human impact on the environment and can be sorted into two themes: 1) input management, including nutrients, pesticides, and non-renewable resources, and 2) quality of natural resources, including soil quality, greenhouse gas emissions, and biodiversity (Lebacq et al., 2013). Other indicators, though less common than the environmental indicators, focus on the economic and social aspects of farm sustainability. Economic indicators included farm profitability, stability, and productivity (Latruffe et al., 2016). Social indicators were sorted into internal and external. Internal social indicators focused on working conditions and quality of life while external ones focused on quality of products,

culturally acceptable agricultural practices, and quality of rural areas (Latruffe et al., 2016; Lebacq et al., 2013).

Assessment of sustainable agriculture practices using indicators has showed promise. Cover crops have been shown to help reduce soil erosion and increase soil moisture, but they also aid in nutrient cycling and providing crop diversity which can lead to better resilience against pests (Pretty 2009; Lal 2015; Kasper et al. 2001). Regenerative agriculture has demonstrated the ability to improve profitability over conventional farming approaches (LaCanne & Lundgren, 2018), increase biodiversity (L. R. Soto et al., 2021), and create farms that are more resilient to future environmental change (Toensmeier, 2016). However, assessment of sustainable agriculture practices and approaches in terms of only yield comparisons has been less consistent. Organic agriculture has been criticized for not being able to meet the demands of global food needs (J. Pretty, 2008; Seufert et al., 2012) as earlier research demonstrated lower food productivity in organic farming systems when compared to industrial farming systems (Caporali et al., 2003). However, research has shown that under specific conditions, particularly during drought conditions, organic farms out-produce industrial farms (Gomiero et al. 2008). Conservation agriculture practices have been shown to increase yields when compared to industrial practices, but again, this increase is specific to dry conditions and is dependent on implementing at least two the four conservation agriculture principles (Pittelkow et al., 2015). Continued research efforts assessing the long-term yield patterns in sustainable agriculture approaches and practices compared to industrial practices, especially as the climate continues to change, will be increasingly important for determining the viability of these practices.

The potential productivity trade-offs when moving from industrial to sustainable practices can be a barrier to sustainable agriculture for some farmers, but barriers to adoption of

sustainable agriculture practices exist at the structural level as well. For example, government subsidies have been shown to incentivize the use of synthetic chemical inputs and discourage crop diversity, making it difficult for farmers to risk transition from an industrial system to a sustainable system (Horrigan et al., 2002). Beyond barriers to sustainable agriculture adoption on the farmer side, minimal research funding for systems-based agricultural sustainability studies is available to researchers, with the largest portion of funding under the umbrella of sustainable agriculture devoted to improving the efficiency of input usage in industrial farming systems (DeLonge et al., 2016). The research in this dissertation studied issues of agricultural sustainability through investigation of the relationship between farmers' perceptions of natural resource conservation and their physical environment and examining the process of adopting sustainable agriculture approaches.

## 2.6 Rural Sustainability

As an area of study, rural sustainability is notable for its less formal definition as compared to sustainability science and even agricultural sustainability. While there is certainly a body of researchers, spanning many disciplines, conducting rural sustainability research, much of this work views and defines the research area differently. The body of literature includes rural development research (Sonnino et al., 2008) and rural resiliency research (Kim et al., 2020), but it also includes sustainability science research applied to a rural context (Harrington, 2016). These categories of research are unified in their focus on rural contexts and sustainability, but due to lack of clear or consistent understanding of what 'rural' and 'sustainability' mean within and between these studies, it is difficult to draw generalizations about what is means to engage in rural sustainability research (Nelson et al., 2023).

The work in this dissertation applied the sustainability bounds and characteristics provided within the field of sustainability science, however this field is still fairly new. Researchers have been studying sustainability in various ways for much longer than the establishment of the field of sustainability science (Mebratu, 1998), and as such, have conceptualizations and approaches to sustainability that vary from sustainability science. The definition for sustainable development provided in the 1987 Brundtland report has often been considered the starting point for the evolution of sustainability definitions stating, "Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their needs" (Brundtland, 1987). This definition was provided for sustainable development and is notoriously vague but has nonetheless been used for defining sustainability. Further, the definition provided in the Brundtland report sparked many initiatives and brought the discussion of sustainable development to a wider audience, ultimately resulting in this definition being adopted for broader sustainability conversations and opening up the understanding of sustainability to different interpretations (Mebratu, 1998). We see this variety of interpretations of sustainability today when engaging with the rural sustainability literature. This variation ranges from rural sustainability research that offers no definition of sustainability (Doukas et al., 2012), study-specific definitions of sustainability (Shucksmith & Rønningen, 2011), to research that draws on definitions from sustainable development (Sobczyk, 2014) or sustainability science (Harrington, 2016). The different conceptualizations of sustainability in rural sustainability research make reviewing the research area's aims, motivations, and progress more challenging. The same issue arises with the term 'rural'.

As many academic disciplines contribute to rural research, there are many different understandings of rural used in rural literature. This variation is demonstrated not only in explicit

definitions of rural, but also through implicit characterizations and conceptualizations of rural stemming from quantitative measures of rurality. Nelson and colleagues (2021) conducted a systematic literature review of definitions and measures of rurality, focusing particularly on the components and methods used in quantitative measures of rurality. Over time, definitions of rural have changed from largely population-based conceptualizations and a view of rural as equating to 'non-urban' to including a variety of components to capture the diversity of rural communities. Rural measures now include variables related to industry employment, health care access, remoteness, land use, and land cover, and engage statistical, mathematical and spatial analyses and processes to calculate these measures (Nelson et al., 2021). The variety and combination of components and approaches used to measure rurality has led to a wide range of both explicit and implicit definitions of rural, adding to the lack of clear definition of rural sustainability as an area of study.

Even given the lack of explicit definition of rural sustainability, as an area of research it is still getting attention in the literature (Knickel et al., 2018; McManus et al., 2012; Nelson et al., 2023; Roberts et al., 2017; Scott, 2013), and still highly relevant to broader conversations on sustainability. Most of the world's land area is "rural" and rural areas provide many of the natural resources and ecosystem services for the functioning and well-being of both rural and urban places, as well as global food security (Harrington, 2016; Zucaro et al., 2014). Those living in rural communities often work in connection to industries that rely on ecosystem services necessary for supporting larger populations, such as agriculture, mining, and timber (Harrington, 2016). This circumstance situates rural communities within integrated social and ecological systems that depend on the sustainable use of natural resources to sustain the community at large (Lawrie et al., 2011; Marshall et al., 2007; Stedman et al., 2004). Further,

rural communities in the United States are vulnerable to future changes in climate (Angel et al., 2018; Conant et al., 2018; Gowda et al., 2018). Not only does climate change threaten the very natural resources and ecosystems that rural communities depend upon (Angel et al., 2018; Conant et al., 2018), but rural communities are also often more limited in their adaptive responses due to poverty and limited resources (Gowda et al., 2018). Rural communities exist at a particularly vulnerable intersection of socio-ecological systems, being responsible for the management and sustainable use of vital resources for large populations of people, but also living in a time when the resources their communities rely on are threatened. This reality makes research dedicated to the sustainability of rural places extremely important, and only likely to become more relevant as the consequences of climate change continue to unfold.

Recent work has identified unifying elements across rural sustainability research, providing a clearer picture of progress within this area of study. Nelson and colleagues (2023) conducted a systematic literature review of rural sustainability research, particularly focusing on studies that examined the influence of drivers on indicators of sustainability outcomes. While a variety of methods were used in the identified studies, most evaluated policy interventions, particularly agricultural policy interventions, as drivers of rural sustainability. In terms of outcomes, the majority of the studies used factors related to economic capital, such as farmer income, to assess sustainability outcomes. However, even with common ground found among the studies in the review, sustainability and rurality were largely poorly defined within the studies, and when these terms were clearly defined, there was little agreement between studies on those definitions (Nelson et al., 2023). These findings within rural sustainability reflect the same challenges found in the broader areas of rural research and sustainability research, making it challenging to measure progress in the field, as studies approach and define rural sustainability

so differently. Research in this dissertation contributed to rural sustainability research by comparing measures of rurality to add perspective to the conversation of the breadth of rural definitions.

## 2.7 Conclusion

The research presented in chapters three through five of this dissertation attempts to represent an interdisciplinary effort and approach within the confines of a graduate degree program. As such, each of the research chapters focuses on a different topic and contains its own in-depth literature review, while still falling under the umbrella of agricultural and rural sustainability. This literature review chapter took a broader approach to help situate these topically diverse research chapters within their common ground. By 'zooming out' to gain a broader context of the fields of study this research stems from but also contributes to, the connecting themes between these different research projects are more easily seen.

# Chapter 3 – Water, Culture, and Adaptation in the High Plains-Ogallala Aquifer Region

## 3.1 Introduction

The Ogallala aquifer lies underneath the soil of eight states in the United States Great Plains region and is responsible for approximately 10% of agricultural production in the U.S. (Smidt et al., 2016). However, due mainly to irrigation demands, groundwater levels across large areas of the aquifer have been decreasing for decades (Haacker et al., 2016; Scanlon et al., 2012). Continued depletion of the aquifer threatens a resource supporting a significant portion of U.S. agriculture, tens of thousands of farmers, and the many rural communities in the region that depend on the aquifer as the base for their economies and as a primary source of drinking water (Bessire, 2021; Sanderson & Frey, 2015; White, 1994).

Farmers in the region recognize that groundwater depletion is a serious problem (Lauer & Sanderson, 2020) and many strategies to conserve the aquifer have been developed over the past four decades, but the aquifer continues to be depleted at an unsustainable rate in many areas (Lauer et al., 2018; Sanderson & Frey, 2015; Scanlon et al., 2012). Developing and implementing conservation plans that are viable in economic, environment, and human terms, while ensuring aquifer sustainability at any scale – regional, state, or local – has proven exceedingly difficult. Region-wide interventions are especially difficult to implement, given the spatial extent of the aquifer, which spans eight states, each with differing groundwater policies and regulations (Griggs, 2019). Structural dynamics shaped by actors situated well beyond the farm level also influence the context within which farmers make decisions about resource use and conservation (Bessire 2021; Sanderson and Hughes 2019). These difficulties are compounded by climate change, which is expected to exacerbate depletion (Conant et al., 2018).

Nevertheless, conservation efforts in this context are increasingly focused on devolving decision-making authority to more local levels in attempts to allow individual farmers to develop plans sensitive to particular conditions (Griggs, 2017). In a very real sense, more sustainable groundwater use depends on the decisions of thousands of farmers in the region, each of whom makes critical choices about a declining resource in the context of structural influences, and a changing climate (Bessire, 2021).

In this context, it is essential to understand whether, and if so how, the physical environment shapes farmers' norms: their beliefs about what they ought to do (Dietz & Whitley, 2018) or their feelings of moral obligation to act for water conservation. Norms encourage individuals to feel an obligation to act in alignment with what they believe is morally correct, right, or justified (Steg, 2016). Thus, investigating pro-environmental norms, such as water conservation norms, allows an understanding of the potential for action regarding water conservation. To our knowledge, and somewhat surprisingly, the relationship between the physical water context and water conservation norms remains an open question, despite the importance of norms for addressing environmental problems (Nyborg et al., 2016). We approach the relationship between the physical water context and water conservation norms as a question of cultural adaptation (Adger & Vincent, 2005; Engle, 2011), that is, of the correspondence between the physical water context, which we conceptualize as the relative availability of moisture in the environment, and farmers' norms toward water conservation.

We understand culture to have both agential and structural, or institutional, manifestations. Here, we focus on individuals as the unit of analysis, which allows us to investigate culture as a set of resources that can be applied and interpreted, however inconsistently or heterogeneously, across actors in a social context (Bourdieu, 1990; DiMaggio,

1997; Sewell, 1992; Swidler, 1986). We investigate the following question: how does the physical water context correspond to farmers' norms toward water conservation? That is, where does the physical environment intervene in the social-psychological process of human decision-making? We couch this question in the values-beliefs-norms (VBN) theoretical framework, which specifies environmental perception and decision-making as a social-psychological, or cognitive process linking values to beliefs to norms. The VBN framework informs a path analysis, or simultaneous equations model, which makes it possible to empirically assess which aspects of internalized culture – values, beliefs, and/or norms – are shaped by the physical water context.

As the largest aquifer in the U.S., the spatial extent and climatic variation across the High Plains-Ogallala aquifer region provide an opportunity to assess these questions, as the aquifer spans 10 degrees in latitude, 10 degrees in longitude, totaling 450,000 $km^2$ (Qi, 2010) and covering two distinct Köppen-Geiger climate classifications, including the harsh mid latitude climates on the eastern parts of the region, and a semiarid climate on the western and southern areas (Peel et al., 2007). We exploit the climatic variation among water contexts in the region in an attempt to more thoroughly understand the relationship between the physical environment and farmers' norms toward water conservation. This analysis has both theoretical and practical implications. By offering more nuanced knowledge of the relationship between the physical environment, culture, and decision-making, more realistic modeling scenarios of this region can be developed. Further, identifying how culture and environment interact, opens up the possibility of developing conservation policies that are more tailored to the human-environment contexts in which they will be applied (Lauer et al., 2018). We begin by placing our study in the context of previous research on socio-cultural adaptation among farmers and then proceed into a more

focused discussion on adaptation as cultural interpretation, which motivates our conceptual model.

## 3.2 Literature Review

### 3.2.1 Environment and Culture: Farmer Adaptation

Climate sets the context for the physical water environments, the communities that live within them, and the dynamics that link humans and water systems (Vörösmarty et al., 2015). Not surprisingly, much of the prior research into the relationship between environmental conditions and farmer attitudes focuses on farmers' perceptions of climate change as a risk motivating adaptation of farming operations. We understand adaptation as "the process of adjustment to actual or expected climate and its effects" (IPCC, 2014, p. 118).

Research shows that farmers vary widely in their perceptions of climate change (J Gordon Arbuckle et al., 2014, 2017; Arbuckle Jr et al., 2013; Gramig et al., 2013; Head et al., 2011; Morton, Roesch-Mcnally, et al., 2017; Running et al., 2017), both across and within nations (Linda S Prokopy et al., 2015). Nearly 90% of farmers surveyed in the upper Midwest perceived there was too much uncertainty about climate change to justify adopting adaptive strategies (Morton, Roesch-Mcnally, et al., 2017). Farmers who were confident in their own capabilities to cope with problems or who were optimistic about the capabilities of technology to solve problems were less concerned about climate change impacts and less likely to support adaptation strategies (Gardezi & Arbuckle, 2020; Han et al., 2021). However, farmers who perceived climate change as a serious risk were more likely to support adaptation and were more engaged with agricultural networks that could aid in adaptation when compared to farmers who were uncertain about the risks of climate change or did not believe climate change is a risk (J Gordon Arbuckle et al., 2014, 2017; Arbuckle Jr et al., 2013). However, the relationship between

climate change perceptions and adaptation may not be unidirectional. Wheeler et al. (2021) found evidence suggesting a feedback loop between climate change risk perceptions and farmers' adaptive behaviors, with farmers perceiving climate change as a risk and then engaging in adaptive behaviors subsequently reporting decreased climate change risk perceptions after engaging in adaptive behaviors. These findings underscore the complexity of the relationship between culture and adaptation among farmers.

Climate change perceptions among farmers seem to be influenced by both experiences with extreme weather events and by perceptions of past weather. Farmers who perceive or experience more severe weather tend to believe more strongly in climate change, and they also tend to be more likely to engage in adaptation strategies (Diggs, 1991; Han et al., 2021; Morton et al., 2015; Niles et al., 2015), or to plan adaptive strategies (Seidl et al., 2021; S. Wheeler et al., 2013). However, the connection between past climate experiences, future climate concerns, and adoption of adaptation practices has been found to be limited to more regional and local conditions (Niles et al., 2015). In other words, farmers who perceive climate change as a risk express concern regarding local climate changes, but they do not necessarily seem to connect their concerns to global climate change patterns. Regardless of how climate change is perceived, research consistently indicates a general commitment to the idea of environmental 'stewardship' among farmers (J Gordon Arbuckle et al., 2014; L. S. Prokopy et al., 2019; Running et al., 2017).

Within a changing physical environment, farmer adaptations include water conservation intentions and actions. The physical environment has been shown to shape the likelihood that farmers will adopt water conserving tillage practices. Saak et al. (2021) found that adoption of conservation tillage was higher in areas with less precipitation, for example. Running et al. (2019) showed that farmers who were required to decrease water use due to an agreement aimed

at conserving groundwater in Idaho's Eastern Snake Plain Aquifer utilized a variety of adaptation strategies both across the region and within a single farming unit, with responses ranging from adapting strategies to use less water to market-based strategies, such as planting higher value crops.

Farmers have been found to engage in water conservation as an adaptive response to drought, flooding, and climatic shifts in the growing season (Morton, McGuire, et al., 2017). In the U.S. Midwest, variation in seasonal precipitation influenced farmers' management strategies, including implementation of no-till techniques, installation of drainage infrastructure, and planting on highly erodible lands (Morton et al., 2015). Further, higher long-term temperatures were positively associated with farmers' decisions to downsize their farms and sell water allocations (Zuo et al., 2022). In the Murray-Darling Basin in Australia, farmers using irrigation were more likely to implement adaptive groundwater management strategies on their farms if they perceived changes in climate (Sanderson & Curtis, 2016). In general, perceptions of higher-risk weather-related scenarios in the future tend to increase the likelihood farmers will adopt water conservation practices (Roesch-Mcnally, Gordon Arbuckle, et al., 2017).

As the above discussion makes clear, the physical environment influences farmers' perceptions. What remains less clear, however, is *how* the physical environment shapes farmers' perceptions. That is, where in the social-psychological process of farmer decision-making does the physical environment intervene? To address this gap in understanding, we turn next to a discussion of the role of culture, focusing especially on values, beliefs, and norms, as mediators linking the physical environment to perceptions that influence conservation decisions.

### 3.2.2 Adaptation as Interpretation

Culture shapes environmental decision-making (Dietz, 2020; Dietz et al., 1998, 2020), as actors draw implicitly or explicitly on internalized values, beliefs, and norms to interpret environmental cues and guide their behaviors in the environment (Dietz & Whitley, 2018; Slimak & Dietz, 2006; Weber & Stern, 2011). Farmers, like all others, do not necessarily respond directly to cues from the physical environment, but instead, they *interpret* environmental cues; they give these cues meaning and make sense of them by drawing on pre-existing values, beliefs, and norms within a community of practice (Bell, 2004; Brock et al., 2021; Krzywoszynska, 2019). As a result, whether, and how, adaptation occurs in response to environmental cues is shaped in key respects by the cultural capacity for adaptation (Burton et al., 2008; Burton & Wilson, 2006). That is, as a response to the physical environment, adaptation depends on the implicit values, norms, and beliefs that farmers draw on to interpret information from the physical environment, and to choose among alternative courses of action.

Adaptation is thus closely bound up with questions of identity, as farming is a practice that draws upon prescribed roles about what it means to be a 'good farmer' (Burton et al., 2020). Farmers can be seen as actors in a community of practice (Bell, 2004). Communities of practice endow members with prescribed scripts and roles that guide, limit, and enable action. Research has shown differences between 'productivist' farmers – those who define the 'good farmer' as one who, above all, strives for maximum yields and tidy fields, for example – and 'conservationist' farmers – those who believe the 'good farmer' tries to balance environmental health and farm production (Burton, 2004a, 2004b; Mcguire et al., 2013), among other types of farming identities (Hyland et al., 2016). Farmer identities are interpretive frames that shape and guide attitudes and behaviors (Cusworth, 2020; Riley, 2016; Sutherland & Calo, 2020). They are

also used to evaluate and ascribe status to members of the community (Burton, 2004a). As such, they influence farmers' on-farm decisions (Lavoie & Wardropper, 2021; McGuire et al., 2015), their willingness to adopt new practices in their operations (Cope et al., 2011; Mitter et al., 2019; Morton, McGuire, et al., 2017).

As cultural constructs, farmers' identities are linked to internalized values, beliefs and norms derived from engagement within their communities of practice (Burton et al., 2020). Next, we review prior research linking cultural values to environmental behaviors, focusing especially on research employing the VBN framework, which informs our conceptual model.

### 3.2.3 Interpretation as a social-psychological process

Research on the role of cultural factors in environmental decision-making commonly employs a VBN framework (Dietz et al., 2007; Stern et al., 1995, 1999; Stern & Dietz, 1994). The VBN theoretical framework operationalizes a social-psychological, or cognitive decision-making process that links held values to beliefs and norms and ultimately to environmental behavior (Dietz et al., 2005; Stern, 2000). From this perspective, decision-making is grounded in values, which inform generalized beliefs, or worldviews. Worldviews, in turn, support more specific beliefs about whether a specific condition is important for a relevant object (awareness of consequences), which in turn is expected to induce an ascribed responsibility to act. These beliefs are posited to shape personal norms, which are moral obligations that motivate particular actions toward the environment (Figure 3.1).

By operationalizing environmental cognition as a social-psychological process, the VBN framework makes it possible to analytically disentangle the complex web of relationships among cultural factors in environmental decision-making. In doing so, it allows for the possibility of

assessing *how*, or more precisely *where*, the physical environment intervenes, or influences, this process.

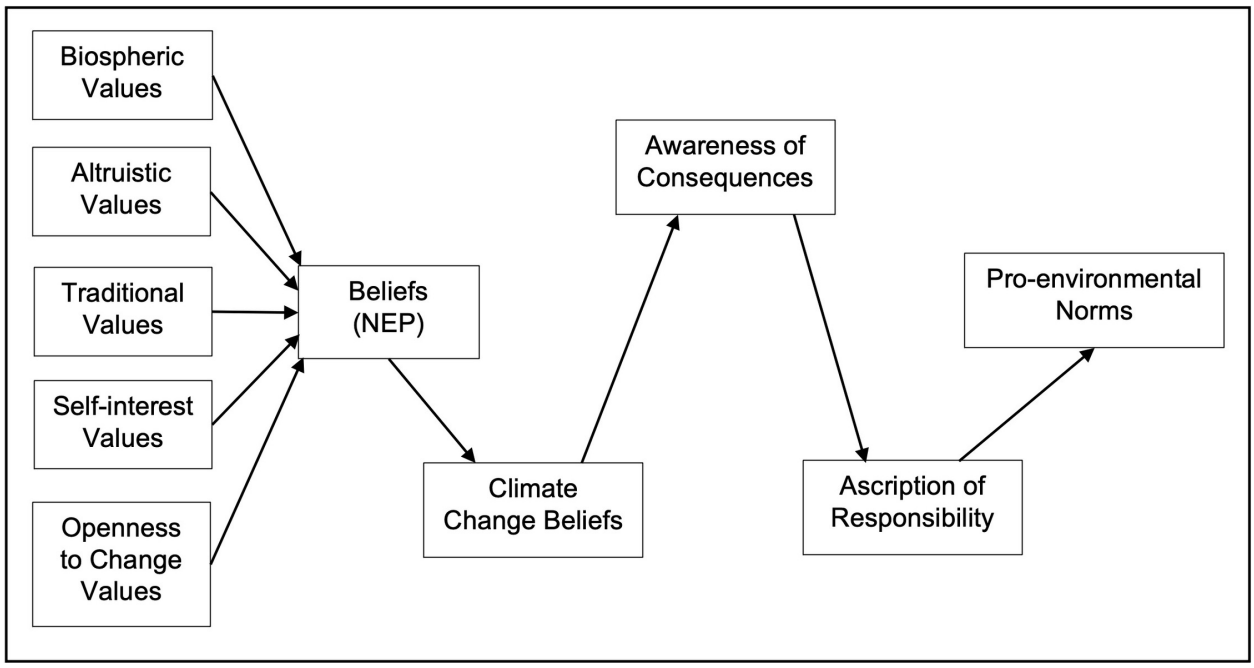



Figure 3.1 Conceptual model of VBN framework adapted from Stern et al. (1999).

Cultural factors have been the focus of much prior research on environmental behavior in non-farming populations (see, for example, Bouman et al., 2020; de Groot & Steg, 2008; Poortinga et al., 2004; Steg et al., 2005), but they have received relatively less attention in farming populations. Environmental values are moral principles regarding something's worth (Dietz et al., 2005). Values are important for understanding farmers' orientations toward the environment – their worldviews or beliefs – and for farmers' perceptions of climate change (Boonstra et al., 2011; Floress et al., 2017; Sanderson et al., 2018; Thompson et al., 2015; Wardropper et al., 2020). Environmental values, sometimes referred to as biospheric values, represent a commitment to unity with nature and are a part of a larger set of values used to investigate pro-environmental action (de Groot & Steg, 2008; Dietz et al., 2005; Steg & Vlek,

2009). Values have been found to explain ecological worldview, climate change perceptions, conservation policy support, and the implementation of adaptation strategies among farmers (Sanderson et al., 2017, 2018). For example, farmers holding stronger environmental values were found more likely to engage in on-farm adaptation strategies, including water conservation (Sanderson & Curtis, 2016). Research examining the concept of 'soil ethic,' an expression of values and identity surrounding responsible soil management among farmers, has emphasized the important role of values in shifting farmers toward adopting conservation practices (Roesch-McNally et al., 2018).

Values are usually more likely to exert indirect effects on norms and actions, working through worldviews and more specific beliefs (Dietz et al., 2005). Evidence demonstrating the distinct ways values combine to influence beliefs suggests that understanding the relationship between values and beliefs is important (Sanderson et al., 2018), especially given the indirect, but clear connection between values, worldviews, and action.

Beyond values, prior research shows that worldviews are also important explanations of environmental attitudes among farmers. Adaptive capacity, understood as the "ability to mobilize scarce resources to anticipate or respond to perceived or current stresses" (Engle, 2011, pp. 648), is implicit within one's worldview. A stronger anthropocentric worldview implies weaker adaptive capacity, to the extent that it holds that humans are more separate, or apart, from the natural environment. And, vice versa, a stronger eco-centric worldview implies stronger adaptive capacity, to the extent that it sees oneself as a part of the natural environment. Thus, farmers holding more eco-centric worldviews are more likely to perceive climate change as a serious, human-caused threat, while farmers holding anthropocentric worldviews are more likely to perceive climate change as a hoax, not caused by humans, or not a threat at all (Barnes & Toma,

2012; Hyland et al., 2016; Sanderson et al., 2018; Sanderson & Curtis, 2016, 2017; Stuart et al., 2012). For example, farmers with anthropocentric worldviews have been found to deny the environmental impacts of nitrogen fertilizer use, specifically in relation to water quality and carbon emissions, and deny the existence of climate change (Stuart et al., 2012). Others found that farmers focused solely on production and profits were the more likely to believe climate change was not a serious risk (Barnes & Toma, 2012) and have a low capacity for adopting adaptive strategies (Hyland et al., 2016). On the other hand, farmers with a strong sense of environmental responsibility have been shown to have more knowledge about climate change and believe it is human caused (Hyland et al., 2016). Further, research shows how worldviews explain differences in climate change beliefs between dryland farmers and irrigators, with irrigators expressing less concern for the environment and a stronger rejection of climate change (Sanderson & Curtis, 2017).

Given that climate change beliefs have been shown to be related to various forms of farmer adaptation, it is reasonable to believe that climate change beliefs may be important for understanding how the physical environment shapes water conservation norms. We leverage the VBN framework to assess the role of climate change explicitly against values, beliefs, and norms in a model of water conservation norms among farmers. Research that applies VBN theory to understand water conservation attitudes among farmers is relatively scant. However, in one such study in Murray-Darling Basin in Australia, climate change beliefs predicted both past and intended adoption of water conservation behaviors among irrigators (Sanderson & Curtis, 2016). To our knowledge, there is no prior research that assesses how the physical water context shapes water conservation norms in a social-psychological framework.

## 3.3 Methods

### 3.3.1 Study Context and Data Collection

The study focused on farmers in the High Plains-Ogallala Aquifer region of the U.S. Underlying parts of eight states, 450,000 km$^2$, and 10 degrees in latitude, the aquifer spans a diverse range of climates.[1] The northeast area of the region, which includes most of the state of Nebraska and parts of the state of Kansas, is a harsh mid latitude climate that is wet year-round with hot summers and severe winters.[2] The western and southern parts of the region is a cold steppe, or a semiarid climate that for the majority of the year, evaporates more water than it receives through precipitation and has an average annual temperature of < 18°C (64°F) (Peel et al., 2007).[3] We exploit the variation in climatic conditions, including precipitation and temperatures, in this region to investigate the relationships between the physical environment and farmers' water conservation norms.

We developed a dataset that linked physical environment data with social data derived from a region-wide survey. The climatic measure used to represent the physical water context for this study was the Palmer Drought Severity Index (PDSI) (Palmer, 1965). Past research has integrated water scarcity data with cultural variables (Switzer & Vedlitz, 2017), but to our knowledge, this is the first study to incorporate PDSI into the VBN framework. PDSI incorporates surface air temperature and a physical water balance model that captures the basic effect of climate on drought through changes in potential evapotranspiration (Dai, 2019), making

[1] We define climates using the Köppen-Geiger climate classification system, which determines climate categories based on a unique combination of annual temperature and precipitation patterns.

[2] The referenced area is classified as a Dfa climate.

[3] The referenced area is classified as a Bsk climate.

it a more comprehensive representation of the environmental conditions farmers experience on their land than either precipitation or temperature measures considered separately. PDSI values can range from -10 (dry) to +10 (wet). PDSI data were obtained from the National Oceanic and Atmospheric Administration at the climate division level (Vose et al., 2014).[4] To calculate PDSI values at the county level, we used the Inverse Distance Weighted (IDW) interpolation tool in ArcGIS. The IDW interpolation tool was used to conduct spatial interpolation, or the prediction of values that fall within the range of data points for a locationally dependent variable. Specifically, the IDW interpolation tool predicts values by assuming the variable being mapped decreases in influence as distance from the sample location increases. In this application, the locationally dependent variable is PDSI, and the sample data points are the points associated with each climate division.

The social data were collected through a region-wide survey of all 227 counties over the High Plains-Ogallala Aquifer in 2018, which covered portions of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas. The aim of the survey was to get a clearer picture of the attitudes and practices surrounding groundwater use among farmers in the Ogallala aquifer region. The survey targeted farmers and ranchers with planted acres and/or livestock. A sample of 8000 farmers were initially contacted through advance postcards, and survey packets and paper surveys were mailed one week later. Reminder postcards were mailed the week following the delivery of the surveys, and a second survey packet and paper survey were mailed to each non-respondent, following the two-stage Dillman process. A total of 1,091 completed and usable

[4] Climate divisions are sub-state regions delineated by drainage basins, county boundaries, or major crops, that represent areas of climatic homogeneity (Guttman & Quayle, 1996). The divisions, used by NOAA, contain multiple weather stations gathering daily data that is then used to calculate monthly and annual averages for different climatic variables for each climate division in the contiguous US.

responses were returned from 206 counties, for an effective response rate of 15.9%. The sample is generally representative of the farm population in the region, as it compared favorably to Census data on key demographic characteristics, including age, education, and income (Table 3.1). Nearly one-half (48%) of respondents were age 65 or older, and 28% were between the ages of 55-64. Males were predominant in the sample (88%), 47% of respondents held an associate's degree or bachelor's degree, and 30% of respondents held a high school diploma. The majority of respondents (51%) reported income in the $25,001 - $100,000, and the sample leaned toward the conservative end of the political spectrum, as 66% identified as moderately to very conservative in political orientation.

Table 3.1 Sample composition.

| Variable | Irrigator (n=578) | Dryland Farmer (n=513) | Agricultural Census (2017) |
|---|---|---|---|
| Age | 61 | 66 | 59 |
| Sex | 93% Male | 83% Male | 74% Male |
| Education | 58% Associate's degree or more | 53% Associate's degree or more | 46% Some college, college degree, or beyond |
| Political orientation | 31% Moderately conservative | 27% Moderately conservative | N/A |
| Mean income | 32% $25,001-$75,000 | 38% $25,001-$75,000 | $32,077 (mean) |

*Note.* N = 1,091.

## 3.3.2 Variables

### 3.3.2.1 Physical Environment: PDSI

PDSI values for each county in the study area were obtained for the years 1988-2017. The surveys were mailed in 2018, and farmers were asked about their 2017 growing seasons. Annual PDSI data were gathered from 2017 back to 1988 in order to capture the 'climate normal', a three-decade average of a climatic variable, for each county, as a thirty-year average

is considered among climatologists and meteorologists as capturing recent climate (National Centers for Environmental Information). Thus, for each county, a thirty-year average was calculated using the data from 1988 through 2017. This variable represents the long-term, physical water context for farmers in the Ogallala aquifer region. Because we are interested in understanding the effects of the long-term physical water context on culture, measurement of the physical water context (1988-2017) precedes measurement of the social variables (2018) in time. This is important for assessing the directionality of the relationship using cross-sectional, observational data. Descriptive statistics for this variable can be found in Table 3.2.

Table 3.2 Variable descriptive statistics.

| | Mean | SD |
|---|---|---|
| PDSI | 0.506 | 0.395 |
| Well capacity | 2.227 | 1.422 |
| Traditional values | -0.007 | 0.898 |
| Biospheric values | 0.012 | 0.912 |
| Altruistic values | -0.001 | 0.862 |
| Self-interest values | 0.004 | 0.852 |
| Openness to change values | 0.004 | 0.889 |
| Worldviews | -0.007 | 0.895 |
| Climate change beliefs | 3.242 | 1.118 |
| AC | 13.768 | 3.938 |
| AR | 4.818 | 1.835 |
| Norms | 18.869 | 3.076 |

*Note.* SD = standard deviation; PDSI = Palmer Drought Severity Index; AC = awareness of consequences; AR = ascription of responsibility

**3.3.2.2 Values**

Values were measured using fifteen survey items developed by Dietz et al. (2005). Farmers were asked to rank how important each of the fifteen statements is as a guiding principle in their lives, from 'not at all important' (1) to 'very important' (5). These fifteen items were used to measure five different values – altruistic, traditional, biospheric, self-enhancement, and openness to change – with three survey items for each measured value. Factor scores, using Thompson estimation, were then calculated as indicators for each of the five values using maximum-likelihood factor analysis. Factor loadings for each of the factor variables can be found in Table 3.3.

Table 3.3 Variables and measures.

| | | Loading/Mean |
|---|---|---|
| **Values** | Guiding principles in your life; 1 = not at all important; 5 = very important | |
| *Biospheric* | Respecting the earth, harmony with other species | 0.767 |
| | Protecting the environment, preserving nature | 0.857 |
| | Unity with nature, fitting into nature | 0.884 |
| *Altruistic* | Equality, equal opportunity for all | 0.628 |
| | A world of peace, free of war and conflict | 0.737 |
| | Social justice, correcting injustice, care for the weak | 0.786 |
| *Traditional* | Honoring parents and elders, showing respect | 0.776 |
| | Self-discipline, self-restraint, resistance to temptations | 0.810 |
| | Family security, safety for loved ones | 0.698 |
| *Self-interest* | Authority, the right to lead or command | 0.748 |
| | Influential, having impact on people and events | 0.797 |
| | Wealth, material possessions, money | 0.474 |
| *Openness to change* | A varied life, filled with challenge, novelty, and change | 0.804 |
| | Curiosity, interested in everything, exploring | 0.789 |
| | An exciting life, stimulating experiences | 0.721 |
| **Worldviews** | 1 = strongly disagree; 5 = strongly agree | |
| | People are severely abusing the environment. | 0.699 |
| *Reverse-coded* | People are meant to rule over the rest of nature. | 0.501 |
| *Reverse-coded* | Nature is strong enough to cope with the impacts of modern industry. | 0.631 |

| | | |
|---|---|---|
| | The earth is like a spaceship with very limited room and resources. | 0.597 |
| | If things continue, we will soon experience a major ecological catastrophe. | 0.788 |
| *Reverse-coded* | People have the right to modify the natural environment to suit their needs. | 0.406 |
| *Reverse-coded* | The so-called "ecological crisis" facing us have been greatly exaggerated. | 0.625 |
| | Plants and animals have as much right as people to exist. | 0.521 |
| **AC** | 1 = strongly disagree; 5 = strongly agree | |
| | Groundwater levels area problem for my household/farm/family. | 3.1 |
| | Groundwater levels are a problem for my community. | 3.2 |
| | Looking back, there was more groundwater available in the past. | 3.7 |
| | Looking to the future, there will be less groundwater available. | 3.9 |
| **AR** | 1 = strongly disagree; 5 = strongly agree | |
| | I feel personally responsible for groundwater depletion in my area. | 2.2 |
| | I should reduce or minimize my groundwater use. | 2.7 |
| **Norms** | 1 = strongly disagree; 5 = strongly agree | |
| | Groundwater should be conserved today so that… | |
| | …future generations in my areas can enjoy the benefits I have experienced. | 4.1 |
| | …my children and grandchildren can enjoy the benefits I have experienced. | 4.1 |
| | …it is available to producers if commodity prices are higher in the future. | 3.2 |
| | …it is available to producers if drought becomes more frequent in the future. | 3.6 |
| | …jobs and business opportunities continue to be available in my community in the future. | 3.8 |

*Note.* For values and worldviews, loadings from factor analyses are reported. For the variables awareness of consequences (AC), ascription of responsibility (AR), and norms that were calculated through additive indices, means for each survey item are reported.

#### 3.3.2.3 Beliefs

Beliefs are conceptualized as general beliefs, or worldviews, in the VBN framework, as this variable indicates farmers' broad beliefs about the world, human influence on the world, and general consequences to the environment (Stern et al., 1999). Worldview beliefs were measured

using a reduced New Ecological Paradigm (NEP) scale containing eight items (Dunlap et al., 2000), measured on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The NEP measure has been used as a unidimensional scale to gauge an individual's attitudes about their relationship to the environment. In this case, factor scores (Thompson estimation) derived from maximum-likelihood factor analysis were used to establish the unidimensional scale, where higher values represent stronger eco-centric beliefs and lower values represent stronger anthropocentric beliefs (Table 3.3). To achieve an accurate scale, responses from half of the items were reverse-coded prior to factor analysis so that higher values corresponded to stronger eco-centric beliefs (Table 3.2).

#### 3.3.2.4 Climate Change Beliefs

Climate change belief measures a farmer's perception that the climate is changing. This variable measured agreement with the statement 'the climate is changing' using a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree) (Table 3.2).

#### 3.3.2.5 Belief – Awareness of Consequences

Awareness of consequences (AC) measures farmers' awareness of the consequences of groundwater depletion for their operations and their communities. This variable was calculated through an additive index of four items (Table 3.2 and Table 3.3). These items used a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree) and gauged agreement that groundwater levels are a problem at the farm and community levels, as well as agreement that groundwater has been depleted and will continue to be depleted in the future.

#### 3.3.2.6 Belief – Ascription of Responsibility

Ascription of responsibility (AR) measures the extent to which a farmer ascribes responsibility for groundwater depletion to themselves. This variable is a behavior-specific belief

that is directly influenced by farmers' awareness of consequences in the VBN framework. This variable was calculated using an additive index comprised of two items measured on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The two items used to calculate this variable gauged the level to which farmers agreed they were responsible for groundwater depletion in their area and should reduce or minimize their groundwater use (Table 3.2 and Table 3.3). Farmers' awareness of consequences regarding groundwater depletion and farmers' belief that they could engage in behaviors that help avoid those consequences then in turn influence norm activation and ultimately behavioral change (Stern et al., 1999).

#### 3.3.2.7 Groundwater Conservation Norms

Groundwater conservation norms is the endogenous variable in the model. This variable measures a farmer's sense of moral obligation to conserve groundwater. This variable was calculated using an additive index of five items using a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree)(Table 2). All items proposed different reasons for why groundwater should be conserved today (Table 3.3). The first two items focused on future generations and farmers' children and grandchildren being able to enjoy the benefits they have experienced. The third through fifth items focused on future increases in commodity prices, future increases in drought, and continuation of business opportunities in their communities in the future. Together, these items represent a diverse range of reasons for why farmers may agree groundwater should be conserved and combine to represent the groundwater conservation norms of farmers in the region.

#### 3.3.2.8 Well Capacity

Well capacity is a variable used to control for groundwater access. It is reasonable to expect that farmers who have greater well capacity may hold different norms about groundwater

conservation. Moreover, prior research has shown dryland farmers and irrigators hold differing environmental values, worldviews, beliefs, and norms (Sanderson & Curtis, 2017). The survey asked farmers to list all of their groundwater wells and well capacities in gallons per minute of pumping capacity, defined in terms of 12 qualitative categories from less than 500 gallons per minute to more than 1,200 gallons per minute[5]. To identify the well capacity for each respondent, we multiply the number of wells by the mid-point of the range for each category. The products are summed and then logarithmically transformed to correct for a skewed univariate distribution (Table 3.2).

### 3.3.3 Analytical Approach

Using a VBN framework, and drawing upon prior research on farmers' perceptions, we construct a model to identify the relationships between the physical water context and groundwater conservation norms. We conduct a path analysis, a form of simultaneous structural equation modeling (SiEM), using maximum likelihood estimation with missing values, to assess the conceptual model (Wooldridge, 2013). More specifically, we use a grouped SiEM to estimate models for both dryland famers (n=513) and irrigators (n=578) as distinct groups. Our approach is represented by the following equations:

$$WV_i = \alpha_i + \gamma_1 w_i + \gamma_2 v_i + \varepsilon_i$$

$$CC_i = \alpha_i + \gamma_1 w_i + \gamma_2 v_i + \beta_1 WV_i + \varepsilon_i$$

$$AC_i = \alpha_i + \gamma_1 w_i + \beta_1 WV_i + \beta_2 CC_i + \varepsilon_i$$

$$AR_i = \alpha_i + \gamma_1 w_i + \beta_1 WV_i + \beta_2 CC_i + \beta_3 AC_i + \varepsilon_i$$

[5] While self-reported data on well capacity can have reporting errors, these data are the only extant data on well capacities currently available across entire region. The well capacity data cannot be externally-validate, as a result.

$$NORM_i = \alpha_i + \gamma_1 w_i + \gamma_2 v_i + \beta_1 WV_i + \beta_2 CC_i + \beta_3 AC_i + \beta_4 AR_i + \varepsilon_i$$

In this series of equations, the outcome of the first equation is worldviews (*WV*), then climate change beliefs (*CC*), awareness of consequences (*AC*), ascription of responsibility (*AR*), and water conservation norms (*NORM*), respectively. In these equations, the subscript *i* refers to the individual, α is the intercept, and ε is the error term. $W_i$ denotes the two physical water context variables, well capacity and PDSI, while $v_i$ denotes the set of five values. The parameters β and γ are regression coefficients representing the change in the respective outcome variables.

Farmers that reported not using irrigation on any of their acres were classified as dryland farmers, while farmers reporting using irrigation on a least a portion of their land were classified as irrigators. Past research supports distinguishing between members of the two groups in analyses, as irrigators tend to hold different worldviews, climate change beliefs, and weaker conservation beliefs than dryland operators (Sanderson & Curtis, 2017).Because path analysis uses simultaneous equations with multiple dependent variables, it allows identification of direct, indirect, and mediating effects between variables in the model (Bollen, 1989), making it especially well-suited for our purposes. Aside from the previously reported logarithmic transformation of well capacity, none of the variables were transformed. Pearson correlation coefficients for all variables can be found in Table 3.4, and variance inflation factors can be found in Table 3.5.

Table 3.4 Correlation matrix.

| | PDSI | Well capacity | Trad. values | Biospheric values | Altruistic values | Self-interest values | Openness to change values | WV | Climate change beliefs | AC | AR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Well capacity | 0.012 | | | | | | | | | | |
| Trad. values | -0.034 | 0.028 | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Biospheric values | 0.05 | -0.107 | 0.357 | | | | | | | | |
| Altruistic values | 0.098 | -0.073 | 0.483 | 0.625 | | | | | | | |
| Self-interest values | 0.023 | 0.041 | 0.334 | 0.435 | 0.508 | | | | | | |
| Openness to change values | 0.01 | -0.015 | 0.307 | 0.537 | 0.499 | 0.676 | | | | | |
| WV | -0.013 | -0.192 | 0.036 | 0.512 | 0.354 | 0.055 | 0.218 | | | | |
| Climate change beliefs | 0.01 | -0.064 | -0.033 | 0.346 | 0.259 | 0.025 | 0.19 | 0.508 | | | |
| AC | -0.439 | -0.207 | 0.053 | 0.103 | 0.051 | -0.01 | 0.082 | 0.303 | 0.2 | | |
| AR | -0.117 | 0.124 | -0.086 | 0.071 | 0.031 | -0.013 | 0.049 | 0.147 | 0.165 | 0.211 | |
| Norms | 0.009 | 0.142 | 0.195 | 0.21 | 0.16 | 0.161 | 0.207 | 0.093 | 0.079 | 0.07 | 0.098 |

*Note*. PDSI = Palmer Drought Severity Index; Trad. Values = traditional values; WV = worldviews; AC = awareness of consequences; AR = ascription of responsibility.

Table 3.5Variable inflation factors (VIF)

| Variable | VIF |
|---|---|
| PDSI | 1.29 |
| Well capacity | 1.23 |
| Traditional values | 1.46 |
| Biospheric values | 2.30 |
| Altruistic values | 2.20 |
| Self-interest values | 2.15 |
| Openness to change values | 2.17 |
| Worldviews | 1.87 |
| Climate change beliefs | 1.44 |
| AC | 1.51 |
| AR | 1.12 |

*Note*. PDSI = Palmer Drought Severity Index; AC = awareness of consequences; AR = ascription of responsibility.

## 3.4 Results

### 3.4.1 The Physical Water Context and Water Conservation Norms

The data showed that farmers in the region tend to hold rather strong water conservation norms (see Table 3.6). Of the five survey items used to construct the water conservation norms index, four items elicited at least 59% agreement among farmers. The strongest consensus was among respondents who believe that groundwater should be conserved for intergenerational equity, as 81% felt an obligation to conserve groundwater so that future generations could enjoy the benefits that they had experienced.

Table 3.6 Groundwater conservation norms.

| Groundwater should be conserved today so that… | Mean | |
|---|---|---|
| | Irrigator (n=578) | Dryland Farmer (n=513) |
| …future generations in my areas can enjoy the benefits I have experienced. | 4.1 | 4.2 |
| …my children and grandchildren can enjoy the benefits I have experienced. | 4.1 | 4.2 |
| …it is available to producers if commodity prices are higher in the future. | 3.3 | 3.1 |
| …it is available to producers if drought becomes more frequent in the future. | 3.7 | 3.5 |
| …jobs and business opportunities continue to be available in my community in the future. | 3.8 | 3.7 |

*Note.* N = 1,091.

### 3.4.2 Structural Relationships: Physical Water Context and Water Conservation Norms

Figure 3.2 and Figure 3.3 display the path models for irrigators and dryland farmers, respectively, with standardized coefficients for each of the paths. The model fits the data very well. The root mean squared error of approximation (RMSEA) is .037, the comparative fit index

(CFI) is .988, and the Tucker-Lewis index (TLI) is .948 (Kline, 1998). We turn next to a reporting of how the physical water context shapes water conservation norms by describing the findings of the structural relationships, or path coefficients, in the model, which are interpreted by tracing the significant relationships between variables in the model, paying close attention to the directionality of relationships while progressing through the paths within the model.

There are two key findings from the analysis. First, and most importantly, the physical water context influences water conservation norms among farmers in the High Plains-Ogallala aquifer region. Second, the effects of the physical water context vary between dryland operators and irrigators, who perceive, and are motivated to conserve water in different ways.

For both groups, the physical water context has a direct, unmediated effect on water conservation norms. Dryland operators ($\beta = .078$, $p < .1$) and irrigators ($\beta = .098$, $p < .05$) hold stronger water conservation norms in wetter contexts. Alternatively, water conservation norms are weaker among both types of farmers in more arid contexts.

Tracing the links between the physical water context and water conservation norms reveals that the effects of the physical water context are also partially mediated, operating through worldviews, climate change beliefs, and more specific water-focused beliefs. And again, the effects of the physical context on decision-making varies between dryland operators and irrigators.

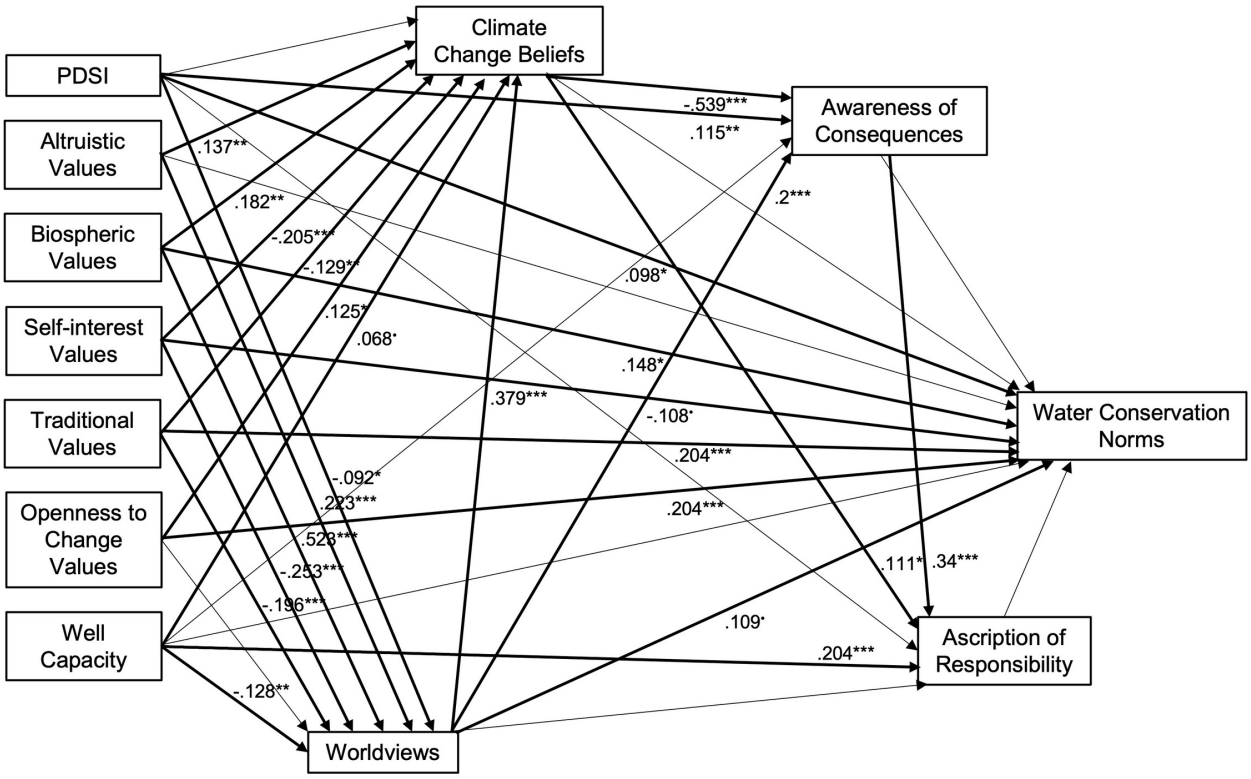



Figure 3.2 Irrigator path diagram. *Note:* Statistically significant relationships are shown in bolded lines and accompanied by their respective standardized coefficients. •p < .1. *p < .05. **p < .01. ***p < .001.

Among irrigators, the physical water context exerts an influence early, or deep, in the decision-making process, as it shapes general worldviews (Table 3.7). In more arid contexts, irrigators hold stronger eco-centric worldviews (β = -.092, $p < .05$). For irrigators, holding a more eco-centric worldview translates into both a stronger acceptance of climate change (β = .379, $p < .001$), and a stronger awareness of the consequences of groundwater depletion (β = .199, $p < .001$), and these beliefs, in turn, lead irrigators to hold themselves more personally responsible for groundwater depletion (AC, β = .34, $p < .001$; CC, β = .11, $p < .05$). However, ascribing responsibility for depletion to oneself does not translate into stronger water

conservation norms among irrigators (β = .028, $p$ = .52). Instead, water conservation norms among irrigators are shaped mainly by values.

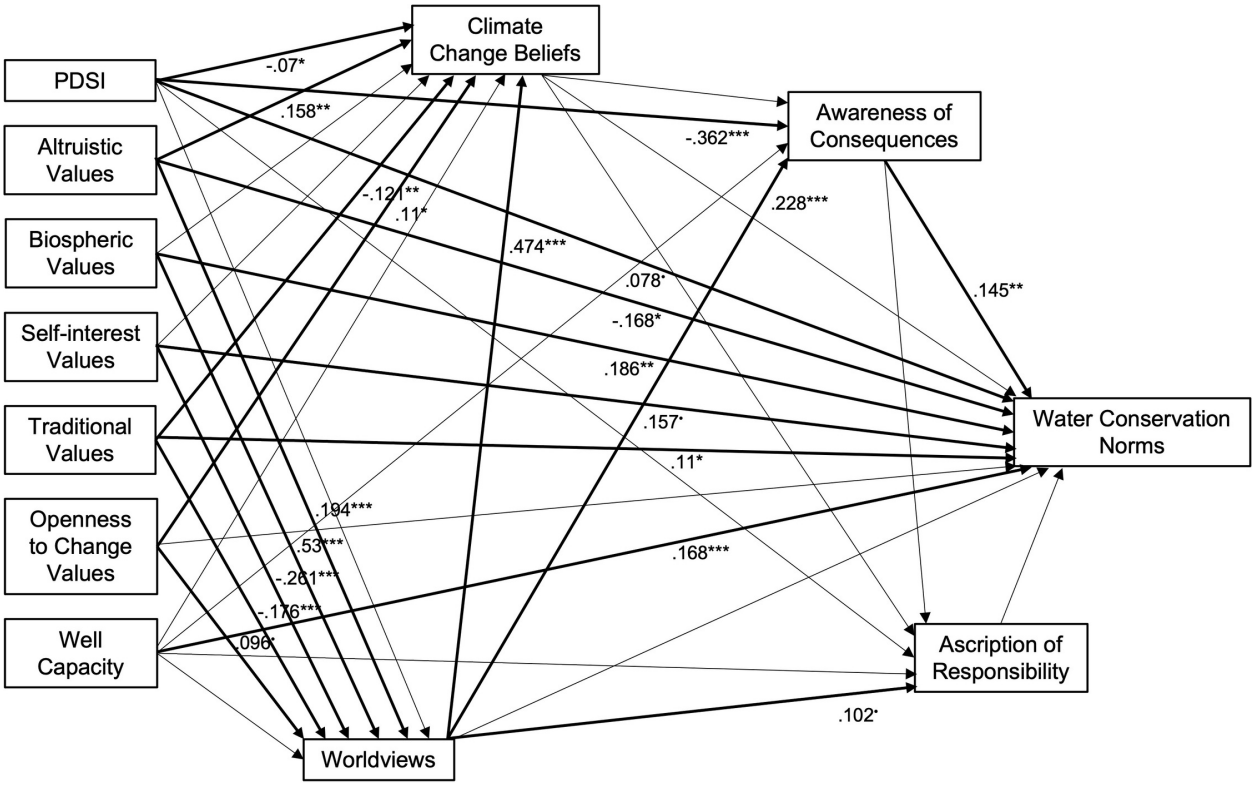



Figure 3.3 Dryland farmer path diagram. *Note*: Statistically significant relationships are shown in bolded lines and accompanied by their respective standardized coefficients. •p < .1. *p < .05. **p < .01. ***p < .001.

Values exert direct, unmediated influences on water conservation norms among irrigators. Several distinct values shape water conservation norms among irrigators. Holding stronger environmental (biospheric) values (β = .148, $p$ < .05), traditional values (β = .204, $p$ < .001), and openness values (β = .204, $p$ < .001) corresponds to stronger water conservation norms among irrigators. Traditional and openness values are counterposed in Schwartz's (1992) typology used to measure values, but these results show that holding either, or both, values more

strongly lead to stronger norms toward water conservation among irrigators. There is also some indication that irrigators who hold self-interest values do not believe as strongly in the need for conserving water ($\beta = -.108$, $p < .1$).

Table 3.7 Irrigators: standardized path coefficients.

| Endogenous | | Exogenous | Estimate | P-value |
|---|---|---|---|---|
| Norms | ← | Worldviews | .109 | .053 |
| Norms | ← | Climate change beliefs | -.049 | .325 |
| Norms | ← | AC | .032 | .547 |
| Norms | ← | AR | .028 | .521 |
| Norms | ← | PDSI 30-year average | .098 | .042 |
| Norms | ← | Altruistic values | .002 | .976 |
| Norms | ← | Biospheric values | .148 | .018 |
| Norms | ← | Self-interest values | -.108 | .087 |
| Norms | ← | Traditional values | .204 | .000 |
| Norms | ← | Openness to change values | .204 | .001 |
| Norms | ← | Well capacity | .032 | .486 |
| AR | ← | Worldviews | .019 | .701 |
| AR | ← | Climate change beliefs | .111 | .017 |
| AR | ← | AC | .340 | .000 |
| AR | ← | PDSI 30-year average | -.072 | .123 |
| AR | ← | Well capacity | .204 | .000 |
| AC | ← | Worldviews | .200 | .000 |
| AC | ← | Climate change beliefs | .115 | .004 |
| AC | ← | PDSI 30-year average | -.539 | .000 |
| AC | ← | Well capacity | -.037 | .349 |
| Climate change beliefs | ← | Worldviews | .379 | .000 |
| Climate change beliefs | ← | PDSI 30-year average | -.008 | .834 |
| Climate change beliefs | ← | Altruistic values | .137 | .009 |
| Climate change beliefs | ← | Biospheric values | .182 | .001 |
| Climate change beliefs | ← | Self-interest values | -.205 | .000 |
| Climate change beliefs | ← | Traditional values | -.129 | .002 |
| Climate change beliefs | ← | Openness to change values | .125 | .026 |
| Climate change beliefs | ← | Well capacity | .068 | .077 |
| Worldviews | ← | PDSI 30-year average | -.092 | .011 |
| Worldviews | ← | Altruistic values | .233 | .000 |
| Worldviews | ← | Biospheric values | .533 | .000 |
| Worldviews | ← | Self-interest values | -.253 | .000 |
| Worldviews | ← | Traditional values | -.196 | .000 |
| Worldviews | ← | Openness to change values | .030 | .589 |
| Worldviews | ← | Well capacity | -.128 | .001 |

*Note*. PDSI = Palmer Drought Severity Index; AC = awareness of consequences; AR = ascription of responsibility.

Among dryland operators, the effect of the physical water context on water conservation norms is mostly direct and unmediated (Table 3.8). Dryland operators in more arid areas hold weaker water conservation norms, just as do irrigators in more arid areas, but the physical water context has limited indirect effects on water conservation norms among dryland operators. These indirect effects of the physical water context on water conservation norms among dryland operators are outcomes of a decision-making path linking values to worldviews, which influence awareness of the consequences of water depletion, and in turn influences groundwater conservation norms. These relationships can be seen by tracing the links in the model from values to water conservation norms.

Table 3.8 Dryland farmers: standardized path coefficients.

| Endogenous | | Exogenous | Estimate | P-value |
|---|---|---|---|---|
| Norms | ← | Worldviews | -.040 | .508 |
| Norms | ← | Climate change beliefs | .082 | .101 |
| Norms | ← | AC | .145 | .003 |
| Norms | ← | AR | .045 | .327 |
| Norms | ← | PDSI 30-year average | .078 | .077 |
| Norms | ← | Altruistic values | -.168 | .016 |
| Norms | ← | Biospheric values | .186 | .006 |
| Norms | ← | Self-interest values | .157 | .013 |
| Norms | ← | Traditional values | .110 | .042 |
| Norms | ← | Openness to change values | .027 | .672 |
| Norms | ← | Well capacity | .168 | .000 |
| AR | ← | Worldviews | .102 | .075 |
| AR | ← | Climate change beliefs | .026 | .629 |
| AR | ← | AC | -.056 | .257 |
| AR | ← | PDSI 30-year average | .008 | .857 |
| AR | ← | Well capacity | -.032 | .455 |
| AC | ← | Worldviews | .228 | .000 |

| | | | | |
|---|---|---|---|---|
| AC | ← | Climate change beliefs | .061 | .195 |
| AC | ← | PDSI 30-year average | -.362 | .000 |
| AC | ← | Well capacity | -.037 | .349 |
| Climate change beliefs | ← | Worldviews | .474 | .000 |
| Climate change beliefs | ← | PDSI 30-year average | -.070 | .044 |
| Climate change beliefs | ← | Altruistic values | .158 | .006 |
| Climate change beliefs | ← | Biospheric values | .002 | .970 |
| Climate change beliefs | ← | Self-interest values | -.086 | .103 |
| Climate change beliefs | ← | Traditional values | -.121 | .005 |
| Climate change beliefs | ← | Openness to change values | .110 | .040 |
| Climate change beliefs | ← | Well capacity | -.050 | .150 |
| Worldviews | ← | PDSI 30-year average | -.001 | .969 |
| Worldviews | ← | Altruistic values | .194 | .000 |
| Worldviews | ← | Biospheric values | .530 | .000 |
| Worldviews | ← | Self-interest values | -.261 | .000 |
| Worldviews | ← | Traditional values | -.176 | .000 |
| Worldviews | ← | Openness to change values | .096 | .069 |
| Worldviews | ← | Well capacity | .022 | .525 |

*Note*. PDSI = Palmer Drought Severity Index; AC = awareness of consequences; AR = ascription of responsibility.

As is the case for irrigators, values influence worldviews among dryland operators. Environmental values, ($\beta = .530$, $p < .001$) and altruistic values ($\beta = .194$, $p < .001$) are associated with more eco-centric worldviews, and self-interest values ($\beta = -.261$, $p < .001$) and traditional values ($\beta = -.175$, $p < .001$) are associated with more anthropocentric worldviews among dryland operators. And, as is the case for irrigators, more eco-centric worldviews are also associated with stronger awareness of the consequences of water depletion among dryland operators. However, unlike irrigators, being more aware of the consequences of water depletion translates into stronger water conservation norms for dryland operators.

A few other findings are worth noting. Well capacity does not directly shape water conservation norms among irrigators. It is reasonable to believe that access to water would influence the extent to which an irrigator would feel obligated to conserve water. The results

indicate that well capacity does shape irrigators' water conservation norms, but the relationship between well capacity and norms is mediated by worldviews. Access to larger well capacities is associated with more anthropocentric worldviews among irrigators ($\beta = -.128$, $p < .001$), and more anthropocentric worldviews translate into weaker water conservation norms ($\beta = .109$, $p < .1$).

Much of the previous research on farmers' perceptions focuses on climate change beliefs. We incorporate climate change beliefs into the model as a mediating variable in order to assess their roles and influences in a VBN context. The results suggest that climate change beliefs do not directly or indirectly shape water conservation norms among either irrigators or dryland operators. Climate change beliefs are clearly shaped by values and worldviews among both dryland operators and irrigators. In both groups, holding stronger altruistic values ($\beta_{irrigator} = .136$, $p < .01$; $\beta_{dryland} = .158$, $p < .01$), and openness values ($\beta_{irrigator} = .125$, $p < .05$; $\beta_{dryland} = .110$, $p < .05$), correspond to stronger belief in climate change. One notable difference in the two groups is that environmental values influence climate change beliefs for irrigators ($\beta = .182$, $p < .01$), but not dryland operators ($\beta = .002$, $p = .97$). Holding stronger traditional values ($\beta_{irrigator} = .129$, $p < .01$; $\beta_{dryland} = .121$, $p < .01$), and self-interest values ($\beta_{irrigator} = -.205$, $p < .001$; $\beta_{dryland} = -.086$, $p = .10$) corresponds to weaker belief in climate change. And holding stronger climate change beliefs is associated with a stronger ascription of responsibility for depletion among irrigators ($\beta = .110$, $p < .05$). But climate change beliefs do not affect water conservation norms among members of either group.

Finally, ascription of responsibility for depletion does not translate into water conservation norms among members of either group. The VBN framework posits that norm activation depends on the extent to which the individual places responsibility on one's self for

the undesirable consequences to things of value. We do not find evidence to support this proposition. Instead, water conservation norms for farmers, whether they irrigate or not, are activated by other social-psychological factors in the interpretation and decision-making process.

## 3.5 Discussion

The High Plains-Ogallala Aquifer is a vital groundwater resource for a large share of agriculture in the U.S., and the many communities that depend on it for drinking water supplies. For decades, the aquifer has been depleted at an unsustainable rate, threatening the agricultural and rural communities dependent on this resource. Because the Ogallala aquifer region spans multiple states, each with differing groundwater regulations and policies, region-wide interventions are difficult to achieve, leaving the burden of achieving more sustainable groundwater use on thousands of individual farmers, each of whom is making difficult decisions about a threatened resource in the context of manifold challenges to their farming operations.

Within this context, we investigated whether, and how the physical water environment shaped farmers' norms toward water conservation. We approached these questions in terms of cultural adaptation to the physical environment, and we compared irrigators with dryland farmers.

The physical water context matters. Whether it is accessed naturally, via precipitation, or artificially via groundwater wells for irrigation, the physical water context shapes farmers' cultural decision-making processes. This finding provides a deeper understanding of the relationship between farmers and the environment. Previous research has explored the relationship between the environment and engagement in adaptation behaviors surrounding water conservation (Morton et al., 2015; Morton, McGuire, et al., 2017; Saak et al., 2021; Zuo et al.,

2022). The findings here provide an understanding of the pathways through which the physical environment influences cultural factors that shape decision-making processes.

The effects of the physical water context differed by the type of farming in which a farmer is engaged: irrigated farming or dryland farming. The decision to irrigate changes one's relationship to the physical water context. These different relations vis-à-vis the physical water context mean that different constellations of cultural factors motivate water conservation norms, and that physical water context influences norms through different pathways. This latter finding supports previous work highlighting cultural differences between irrigators and dryland farmers (Sanderson & Curtis, 2017).

Have farmers culturally adapted to the physical water context? This is a more complicated question to answer, in part because the research literature on farmer adaptation tends to employ rather limited definitions of adaptation. Again, we understand adaptation as a "process of adjustment to actual or expected climate and its effects" (IPCC, 2014, p. 118). Our analysis revealed an association between the physical water context and culture. Ostensibly, this relationship is bi-directional, involving feedbacks between the physical context and culture that render this relationship dynamic, not static (S. A. Wheeler et al., 2021). Observational data collected at multiple time points would allow assessment of the question of adaptation with much more precision than was possible in this study. This would certainly be a worthwhile avenue for future research.

Nevertheless, the findings indicated that both dryland farmers and irrigators held stronger water conservation norms in wetter contexts. Alternatively, water conservation norms were weaker among both types of farmers in more arid contexts.

These findings could be interpreted as evidence of adaptation: farmers have simply accepted that water is worth conserving where there is more water, and where there is less water, they have simply adapted to that physical reality. However, from a biological, or ecological, standpoint, these findings could be considered evidence of *mal*-adaptation. If water is vital for survival, as it is for all biological organisms, then it should be expected that humans would conserve water in more arid contexts and that conservation would be weaker in wetter contexts. That is not what our results indicated. Instead, we found that farmers felt more strongly compelled to conserve water where there was more water to conserve, and they felt less compelled to conserve water where there was less water to conserve. In this sense, as biological creatures, farmers in the High Plains-Ogallala region have not adapted to the physical water context.

But humans are not only biological creatures; they are also social creatures. In addition to environmental cues, they respond to the social context, which includes political, economic, and cultural cues relevant for decision-making, and indeed, survival. The decision to irrigate is made in this more-than-biological, social context. The decision is not only a response to the physical water context, but it is also a response to the vicissitudes of agricultural markets, government policies, community cultures, and family relations. And the social context conditions the farmers' relationships with the natural environment, and thus, their norms. This is evident in the differences in the relationships between the physical water context and worldviews among irrigators and dryland operators.

Irrigators are commonly viewed as more business and profit-motivated, with correspondingly weaker ecocentric worldviews than dryland farmers. Perhaps surprisingly, we found some evidence of cultural adaptation not among dryland operators, but among irrigators.

The relationship between the physical water context and norms was partially mediated by worldviews. Again, worldviews were an important factor shaping water conservation norms for both irrigators and dryland farmers, but only irrigators' worldviews were shaped by the physical water context [dryland operators (*p* non-significant); irrigators ($\beta = -0.092$, $p < .05$)]. Irrigators in more arid regions tended to hold more eco-centric worldviews, which implies stronger adaptive capacities, that in turn, translate into stronger water conservation norms ($\beta = 0.109$, $p < .1$). The findings for well capacity provide additional evidence to support this interpretation. Among irrigators, lower well capacities were associated with more eco-centric worldviews ($\beta = -0.128$, $p < .01$), and stronger water conservation norms ($\beta = 0.109$, $p < .1$)., and vice versa, higher well capacities were associated with more anthropocentric worldviews and weaker water conservation norms. Put simply, irrigators more strongly believe that water should be saved as they have less water. Thus, we found some evidence of limited cultural adaptation among irrigators in the region. It is adaptation in the sense that the worldview adjusts to the physical water context. However, it is a limited form of adaptation because drawdown of a non-renewable source of groundwater is, by definition, unsustainable (Bierkens & Wada, 2019).

Our results provide motivation for further investigations into the nuances of the concept of adaptation in working agricultural landscapes (Eaton et al., 2019), where the concept of adaptation is related especially closely to the question of sustainability (Kates 2005). Cultural change is a key aspect of both socio-ecological challenges and the prospects for sustainable development (Beddoe et al., 2009; Kinzig et al., 2013; Princen, 2003; Speth, 2008; Steffen et al., 2007), and the historical record is replete with examples of socio-ecological collapse resulting from the inability of human cultures to adapt to their natural environments (Diamond, 2005; Ophuls, 2012; Tainter, 1988). Cultural adaptation, as a process of adjustment to the physical

environment, means that values, worldviews, and norms become more closely aligned with, or fitted to, physical environment so that both the culture and the natural environment can be sustained (J. S. Brooks et al., 2018; Caldas et al., 2015; Waring et al., 2015). One extension of the results presented here would be to apply the model in a region where the relationship between groundwater use and groundwater stocks is more sustainable; that is, where irrigation draws from a renewable source of groundwater, at a rate commensurate with the rate of recharge.

These results add nuance to the question of how the physical water context shapes water conservation norms among farmers. In particular, caution is warranted before drawing aggregated conclusions from analyses that do not distinguish between irrigators and dryland operators in the same sample. Further, our results showed that place matters for members of each of these groups. Not only did decision-making process differ between dryland operators and irrigators, these processes also differ within each group when accounting for the role of the physical water context. It is especially important to account for the physical water context in which farmers exist when assessing attitudes, perceptions, and decision-making. Place – the physical environment – matters.

These findings are potentially useful for crafting more effective water conservation policies. The findings demonstrate that one-size-fits-all approaches to policy development and implementation are likely to be less effective than approaches that are sensitive to the role of the physical environment, and its relationship to culturally motivated decision-making processes. Freshwater challenges are ubiquitous across the globe despite decades of efforts to more equitably and sustainably manage and govern these resources. Addressing these challenges requires a thorough, nuanced understanding of how cultural factors influence adoption or rejection of policies. While our data did not allow us to model a policy outcome, our model

could be extended to include policy preferences as an outcome of the value-belief-norm process (see, for example, Sanderson, et al. 2017). These types of models could be used to inform more refined understandings of the culturally motivated decision-making processes that exist in a particular context. As a result, it could be possible to craft policies that resonate more strongly with existing cultural decision-making frames, increasing the likelihood these policies would be adopted. Similarly, Groundwater-dependent agricultural regions and communities include both dryland farmers and irrigators, and members of both groups participate in deliberations regarding conservation policies. The ability to identify shared values, worldviews, and norms motivating support for policies could be useful for finding areas of consensus, and divergence, among members of these groups.

Finally, longitudinal data offer the possibility of significantly advancing our understanding of the question of adaptation. The ability to capture variation in both space and time could allow more precise assessment of reciprocal relationships linking environment and culture. Our findings suggest that values would warrant especially close attention in such research.

Values were the strongest explanation of water conservation norms for both dryland operators and irrigators. Biospheric, or environmental values, exerted the strongest total effect on norms among members of both groups ($\beta_{irrigator} = .195$, $p < .001$; $\beta_{dryland} = .208$, $p < .001$). The analyses also uncovered differences in the types of values motivating norms among members of the two groups. One particularly worthwhile avenue for future research would be to investigate whether values are endogenous to the physical context, an increasingly important question being considered in the emerging interdisciplinary area of socio-hydrology (Caldas et al., 2015; Konar et al., 2019; Saket Pande et al., 2022; Sivapalan, Savenije, & Bloschl, 2011). Recent work in this

area  investigates the co-evolution of human-water systems by modeling outcomes of potential water management and policy efforts (Elshafei et al., 2016; Garcia et al., 2016), reconstructing societal and water resource changes of ancient civilizations (S Pande & Ertsen, 2014), and the use of local newspaper articles to understand the evolution of the societal value of water resources in an area (Wei et al., 2017), This work requires longitudinal data on both the physical variables, which are usually available, and on the cultural variables, which are rather demanding to collect. However, this research would make a significant contribution to our understanding of how place, environment, and culture interact to shape adaptation.  Humans are exerting more control over natural processes, a defining characteristic of the Anthropocene (Crutzen, 2006). Anthropogenic emissions of carbon dioxide, methane, and nitrous oxide are changing the climate (IPCC, 2021). Humans are now responsible for more the majority - 57 percent – of all fluctuations in fresh surface water globally (Cooley et al., 2021), and human actions are now the dominant driving force in the Earth's sediment cycle (Syvitski et al., 2022). Our understanding of these dynamics will only become more important as human-environment dynamics become even more strongly coupled, and as the challenges that emerge from these dynamics continue to accumulate.

*This chapter is published in the Journal of Rural Studies. Full citation:
Fischer, A., and M. Sanderson. 2022. Water, culture, and adaptation in the High Plains-Ogallala Aquifer region. *Journal of Rural Studies* 95 (September):195–207.

# Chapter 4 – Where is rural? An analysis of the agreement between quantitative measures of rurality

## 4.1 Introduction

Sustainability efforts seek to maintain or improve the quality and existence of desirable resources or conditions over the long term (Harrington, 2016). Researchers examine sustainability issues at a variety of spatial scales by engaging in a systems approach, actively working to identify the feedbacks between social and natural systems to better understand coupled human-natural systems as a whole instead of individual component parts (Clark & Dickson, 2003; Spangenberg, 2011). Rural sustainability is the branch of sustainability research specifically applied to rural places and contexts and has received increased attention in the literature (Knickel et al., 2018; McManus et al., 2012; Nelson et al., 2023; Roberts et al., 2017; Scott, 2013). Most of the world's land area is "rural" and rural areas provide many of the natural resources and ecosystem services for the functioning and well-being of both rural and urban places, as well as global food security (Harrington 2016).

Much research in rural sustainability has highlighted many of the unique challenges faced by rural places. This work comes from multiple disciplinary perspectives, including engineering (Arcipowski et al., 2017; M. A. Montgomery et al., 2009), sociology (Gale & Cordray, 1994; Magnani & Struffi, 2009), geography (Harrington, 2016; Nelson et al., 2023; Woods, 2009), and medicine (Bradford et al., 2016; Curran & Rourke, 2004; Farmer et al., 2012).

Rural communities often struggle with financial support for schools, staffing issues, adequate access, and student attendance (Beeson & Strange, 2003; Crouch & Nguyen, 2021; Sher, 2019). Students from rural communities are less likely to attend institutions of higher education and, for those who do, to earn a degree (Maltzan, 2006). Rural communities also

experience a scarcity of medical services and lower quality of healthcare owing to difficulties attracting and retaining trained medical professionals (Curran & Rourke, 2004; Douthit et al., 2015; Farmer et al., 2012). Access to existing healthcare services is further hampered by a lack of public transportation and reliable, high-speed internet access (Douthit et al., 2015). Other research has focused on specific struggles related to employment opportunities (Gary P. Green, 2007; Gary Paul Green, 2014) and physical resource allocation in the rural context (Gary Paul Green, 2001, 2014; McNicoll, 2014).

Recognizing the many, and often unique, needs of rural communities, federal and state governments employ a variety of policies and programs to improve rural sustainability. Some policies are based on broad economic sectors and focus not on rural places but on the dominant activities that occur in rural areas, such as agriculture (Partridge et al., 2009). This is also common with entrepreneurship programs (Goetz et al., 2010). Placed-based policies and programs can also target rural areas and communities. For example, the United States Department of Agriculture Rural Development (USDA RD) agency provides financial support for development projects in rural communities (Vilsack, 2016). The USDA RD programs include efforts to improve agriculture, water infrastructure, energy, and broadband internet access (Kandilov & Renkow, 2010). In Kansas, the Rural Opportunity Zone program attempts to incentivize recent college graduates to move to rural communities through student loan repayment assistance and/or full state income tax credits (M. M. Brooks, 2021). Further, many entrepreneurship, loan, and small business programs exist in localized areas to improve economic conditions in rural communities.

However, a prerequisite to the implementation of place-based rural policies is to first characterize what “rural” is and where such places are found (National Academies of Sciences,

Engineering, and Medicine 2016). This makes understanding the diversity of approaches used for measuring rurality a critical first step.

Many measures of "rural" exist but often these measures emphasize different dimensions associated with how we perceive rurality (Long et al., 2021). Among federal government entities, the Office of Management and Budget (OMB), US Department of Agriculture (USDA), and US Census Bureau each produce their own rural measures. OMB produces Core Based Statistical Areas (CBSA) that identify metropolitan and micropolitan areas that, in turn, are used in other measures. For example, Rural Urban Continuum Codes (RUCCs) from the USDA Economic Research Service (ERS) divide the binary "metro" and "nonmetro" areas classified by OMB into nine categories based on population size and adjacency to a metro area. Alternatively, Frontier and Remote (FAR) Access Codes, also produced by the USDA ERS are largely based on low population size and proximity to nearby urban areas as measured by driving time and use the Urban Areas/Urban Clusters produced by the US Census Bureau.

Given these federal government measures of "rural" are essentially based on two variables – population and remoteness - many researchers have developed alternative approaches for defining rurality that use these same variables in unique ways and/or incorporate additional and more diverse variables to better describe and map the complexity of rural places and communities. One popular approach applies thresholds to a combination of the US Census Bureau urban-rural and the OMB metro-micro systems (Isserman, 2005). Others have noted limitations of these threshold-based approaches and developed an alternative continuous measure of rurality via a non-weighted index (B. Waldorf & Kim, 2015; B. S. Waldorf, 2006). Many other measures can also be found in the rural literature that are based upon mathematical combinations (Caschili et al., 2015; Cohen et al., 2017; Inagami et al., 2016), statistical cluster

analysis (Hedlund, 2016), and spatial analysis (Cromartie et al., 2013; Mao et al., 2015; Zhao et al., 2019).

Politicians, policymakers, and researchers are now inundated with a wide array of measures that define what and where "rural" is very differently and often with significantly different results. This suggests that what it means to be rural is more complex defies simple "rural" or "urban" labels.

To illustrate and better understand the inconsistencies associated with using different measures of rurality, this study employs four common measures or approaches from both government agencies and the literature to identify rural counties in the contiguous United States. Previous research by Long et al. (2021) has compared eight federal government measures of rurality. Each measure was simplified to dichotomous categories of rural and non-rural, to examine urban-rural inequality, and results showed large differences in the number of people residing in rural communities and their access to health care services across the eight measures. This study builds on this previous work by using methodologically unique measures of rurality, each of which are based on a minimum of four classes. We focus on methodologically unique measures to best represent the diversity of popular approaches for measuring rurality. By examining popular, but methodologically unique, measures our analysis attempts to capture the range of variability in rurality that could reasonably be expected to be relevant in many applications of rurality measures. Further, by expanding the analysis from a binary urban-rural structure to four classes ranging from urban to rural, we are better able to honor the structure of the original measures and decrease simplification needed for the comparison of measures. We find all measures agree that 114 of the 3,108 counties (3.5 percent) in the contiguous United States are "rural". Our results also describe the characteristics of counties within each rural (or

non-rural) classification, the spatial distribution of the rural classes, and the degree of agreement between the four measures with the goal of generating a deeper appreciation of how multiple measures and approaches impact the identification of rural places.

## 4.2 Methods

### 4.2.1 Study area

The study area for this work was the contiguous United States at the county level. Counties in the study area were the spatial unit of analysis given that many government-based rural measures produced by the federal government are developed at this scale.

### 4.2.2 Rural measures

For this research, we understand a rural measure to be any data product that provides a ranking, classification, or numerical value for distinguishing between rural and non-rural places or identifying relative degrees of rurality. Four rural measures that use methodologically unique approaches for the identification of rural and non-rural areas were included in this analysis. To be considered, a measure had to be (1) readily accessible or replicable, (2) likely to be used by policymakers or researchers, or (3) be representative of current familiar approaches appearing in the rural literature.

The first rural measure selected was the 2013 Rural-Urban Continuum Codes (RUCC) from the USDA ERS which was last updated in 2020. OMB classifies counties or clusters of counties as metropolitan areas if they contain an urban area with a population of 50,000 or more, with all other counties classified as non-metro. RUCC breaks down the OMB metro/non-metro county classification into nine codes. The metro counties are divided into codes 1 through 3 based on the population of their respective metropolitan areas. For example, code 1 includes metro counties with metropolitan area populations of one million or greater, while code 2

includes metro counties with metropolitan area populations of 250,000 to 999,999. The non-metro counties are divided into six codes (4-9) based on urban population, similar to the metro codes, but also by their adjacency to metro areas. For example, code 4 includes non-metro counties with an urban population of 20,000 or more that are also adjacent to a metro area, while code 5 includes non-metro counties with an urban population of 20,000 or more that are not adjacent to a metro area.

The second and third measures used both originated in highly cited works appearing in rural research literature. The Urban-Rural Density Typology (URDT) classifies counties as either rural, mixed rural, mixed urban, or urban based on a combination of population and population density thresholds (Isserman, 2005). Rural counties must meet two requirements. First, they must have a population density less than 500 people per square mile, and second, rural counties must have 90 percent of the population in rural areas (nonmetro) or have no urban areas with a population of 10,000 or more. Urban counties have three requirements. First, they must have a population density of 500 people per square mile or greater; second, 90 percent of the county must live in urban areas (metro); and last, the county's population in urban areas must be at least 50,000 or 90 percent of the county population. If a county meets neither the requirements for rural or urban classification, it will fall in either the mixed rural or mixed urban classifications. Counties are mixed rural if they have a population density of less than 320 people per square mile, and counties are mixed urban if they have a population density of 320 people per square mile or greater. While URDT relies on population metrics and thresholds similarly to RUCC, this measure is unique from RUCC as URDT centers population density and does not consider remoteness, while RUCC exclusively deals with total population thresholds and measures remoteness through adjacency to urban areas.

The Index of Relative Rurality (IRR) employs a continuous measure of rurality as a function of population and remoteness with 0 and 1 being the least and most rural, respectively (B. Waldorf & Kim, 2015; B. S. Waldorf, 2006). The four variables used for this measure include the logarithm of total population, the logarithm or population density, the percent of the population living in urban areas, and the distance to the closest metropolitan area. All of these variables are scaled and then combined via an unweighted average to result in each county being assigned a number from 0 to 1 representing their degree of rurality in relation to all other counties. IRR is distinguishable from URDT and RUCC as it uses a combination of the variables from URDT and RUCC, but more importantly because it combines these variables using a linking function (unweighted average), instead of a series of threshold requirements.

The fourth, and final, rural measure of rurality used (Cluster) can neither be downloaded from a website nor reconstructed from an approach described in a single research paper. Instead, it represents a common approach in the literature, statistical cluster analysis (Bogdanov et al., 2008; Hedlund, 2016). Statistical cluster analysis is unique from the three previous measures as it draws on a much wider variety of variables for analysis (e.g., infrastructure, land cover, access to healthcare, industry employment), while the first three selected measures are similar in their reliance on concepts of population and remoteness. Further, by engaging statistical cluster analysis, the method for how the variables are manipulated is also unique.

The data and data sources used in the downloaded, replicated, or calculated measures are summarized in Table 4.1. Cluster variables were drawn from a list of common variables used to define “rural” based on a systematic literature review (Nelson et al., 2021). For clarification, the variable “% Agriculture” included the areas of both the cultivated crop and pasture/hay classes from the 2016 National Landcover Database (NLCD) (Dewitz 2019). The “% Forest” variable

included the deciduous, evergreen, and mixed forest NLCD classes, and "% Developed" combined the NLCD classes for developed high, medium, and low intensities. Remoteness was calculated using the Near tool in ArcGIS Pro (Esri, Redlands, CA) by calculating the planar distance between each county edge and the nearest county edge representing a metro area as determined by the OMB.

Table 4.1 Datasets and data sources used in each of the rural measures selected for analysis.

| Dataset | Data Source | Measures | | | |
|---|---|---|---|---|---|
| | | RUCC | URDT | IRR | Cluster |
| % Population Urban/ Rural Areas | U.S. Census Bureau (2020) | | ■ | ■ | |
| Total Population in Urban Areas | U.S. Census Bureau (2020) | ■ | | | |
| CBSAs | OMB | ■ | ■ | | |
| Total Population | U.S. Census Bureau (2020) | | ■ | ■ | ■ |
| Population Density (people/km$^2$) | U.S. Census Bureau (2020) | | ■ | ■ | ■ |
| % Population 65+ | ACS 2019 5-Year Estimate | | | | ■ |
| Remoteness* | OMB, ArcGIS Pro | ■ | | ■ | |
| % Employed in Agriculture | ACS 2020 5-Year Estimate | | | | ■ |
| % Employed in Manufacturing | ACS 2020 5-Year Estimate | | | | ■ |
| Median Household Income ($) | ACS 2019 5-Year Estimate | | | | ■ |
| % Agriculture Landcover | NLCD 2016 | | | | ■ |
| % Forest Landcover | NLCD 2016 | | | | ■ |
| % Grassland Landcover | NLCD 2016 | | | | ■ |
| % Shrub/Scrub Landcover | NLCD 2016 | | | | ■ |

| | | | | | |
|---|---|---|---|---|---|
| % Developed Landcover | NLCD 2016 | | | | |
| Hospital Beds (per 1000 people) | Homeland Infrastructure Foundation-Level Dataset | | | | |

*Note.* The variable "% Employed in Agriculture" includes employment in agriculture, forestry, hunting, and fishing. *While RUCC and IRR both use OMB data to determine remoteness, they do so in unique ways as described previously.

The RUCC data was downloaded from USDA ERS (https://www.ers.usda.gov/data-products/rural-urban-continuum-codes/). URDT (Isserman, 2005) and IRR (B. Waldorf & Kim, 2015; B. S. Waldorf, 2006) measures were replicated using their descriptions in the literature discussed previously in this section and using the variables highlighted in Table 1, then mapped at the county level also using ArcGIS Pro.

The cluster analysis measure (Cluster) was executed in R (R Core Team 2023) using the "cluster" package (Maechler et al. 2022) and agglomerative clustering of the twelve variables selected for inclusion (see Table 4.1). Agglomerative clustering operates in a bottom-up manner treating each observation (here a county) as a single-element cluster then combining the most similar clusters in an iterative process until only a single cluster remains. To differentiate clusters, linkage methods were employed in the clustering algorithm to calculate dissimilarity between observations. For each linkage method, an agglomerative coefficient was calculated that measured the degree of clustering structure found. The Ward method was used to update between cluster distances during the iterative process.

After assessing the dendrogram resulting from the clustering algorithm, six was determined to be the appropriate number of clusters using the cut-tree method (Appendix A Figure A.1). This decision was supported by using the NbClust function in R package NBClust which provides the results of 23 indices for determining the appropriate number of clusters for

analysis (Charrad et al., 2014). The results of the NbClust function showed three out of the 23 tested indices determined six to be the optimal number of clusters. The only results having a higher number of indices supporting their usage were two and four clusters, which were identified by five and four indices, respectively, as being the optimal number of clusters to use. However, since our analysis required a minimum of four classes, we evaluated the results produced by both four and six clusters and qualitatively determined six clusters resulted in the most distinct clusters of the two options by examining cluster sample size and means. Last, to understand the characteristics of each cluster, summary statistics were calculated for each of the twelve variables for each cluster, allowing us to identify which clusters were more representative of rural counties versus urban counties (Appendix A Table A.1). The classification of clusters was determined by examining the cluster means for the variables used in its analysis, primarily focusing on the population variables, as total population or population density were used in all four measures.

### 4.2.3 Analysis

For the first stage of analysis, we mapped counties based on each of the rural measures selected for study and compared the number of counties identified as being rural, their total population, total area, and regional frequency. Once data for each rural measure was acquired or replicated with updated sources, counties classified as rural by each measure were extracted to include their geospatial boundaries and county-level data for total population and area.

However, because none of the measures selected for study were simple dichotomous typologies of “urban” and “rural”, aggregation was used to merge various categories, codes, values, or clusters into a single rural class before moving forward with the analysis. For URDT, rural counties were those that fell into the “rural” category. For RUCC, codes 8 and 9, which

included counties that were deemed “completely rural” in their code descriptions, were classified as rural. Since IRR is calculated as a continuous scale from 0 (urban) to 1 (rural), the range of values in the index was subdivided into four equal intervals and counties in the uppermost interval were assigned the rural label. Previous research has classified IRR using deciles (Cohen et al., 2017). However, we used an equal interval approach instead of a quantile approach as it best aligns with the other measures (RUCC and URDT) which use thresholds for classification and do not require an equal number of counties in each class. Lastly, based on comparable summary statistics of their component variables, two clusters representing rural counties from the Cluster measure were identified. The two selected clusters had the lowest mean population densities of the six clusters (approximately 10 people per square kilometer) and were classified as rural after confirming no differences among the variable statistics suggested the two clusters should not be classified as rural. Once each measure was filtered to include only rural counties, data for the underlying county population and area data were extracted and summary statistics calculated for comparison (Appendix A Figure A.2).

Next, we assessed general levels of agreement among the four measures as to which counties were considered rural and how the values of key rural variables (Table 4.1) varied as the county designations ranged from rural to urban. To accomplish this, the outputs from each original rural measure were reclassified into four, and only four, categories. Since URDT already uses four categories, this measure served as the baseline for restructuring the remaining measures. The RUCC dataset was reclassified with the following codes which correspond to classes adapted from the URDT: Rural (8, 9), mixed rural (6, 7), mixed urban (4,5), and urban (1, 2, 3). For RUCC, the rural class was comprised of the codes that were labeled “completely rural”, and the urban class was comprised of codes with exclusively metro counties. The mixed

urban and mixed rural classes included codes for non-metro counties, with the mixed urban class including codes with higher urban populations than the mixed rural class. The IRR was reclassified using the four equal intervals produced in previous analysis, with the interval containing the lowest values being “urban” and the interval with the highest values being “rural”. For Cluster, using an interpretation of summary statistics for key underlying demographic data, the original six clusters were also divided into rural (2 clusters), mixed rural (2 clusters), mixed urban (1 cluster), or urban classes (1 cluster) (Appendix A Table A.1). The clusters for the rural class were heavily influenced by very low population densities as low population density is commonly associated with rurality, and the subsequent classes sorted clusters based on increasing population densities from mixed rural to urban. All other variable statistics were examined at this time, but no variable statistics contradicted the underlying assumptions about rurality and population density.

After reclassification, the rural measures were mapped and the frequency at which each county was identified as rural by one or more of the four measures determined. County-level data for many of the key rural variables outlined in Table 4.1 were extracted and summary statistics were generated for each of the reclassified categories. Additional statistical analysis followed, including non-parametric Kruskal-Wallis and Dunn Post-Hoc tests to assess whether significant differences existed between the four rural classes (factor variables) and their underlying key rural data.

Finally, we sought to better understand how the selected rural measures varied in terms of the number of counties in each reclassified category (i.e., rural, mixed rural, mixed urban, and urban). This was accomplished through a series of pairwise map comparisons of the rural categories derived from each rural measure and calculating map differences according to the

quantity, exchange, and shift components of their contingency tables (Pontius & Millones, 2011; Pontius & Santacruz, 2014). These metrics allowed us to compare each class for a pair of measures and observe how the county classifications changed (from one class to another) or persisted (remained in the same class) between different measures. When a county was classified the same by both measures in a comparison, this was considered "persistence" and a percentage was provided representing the percent of all counties in the study area that persisted both per class and in the overall comparison. Counties that were classified differently by compared measures were characterized by their "quantity", "exchange", or "shift" movement for each class. The term "movement" is used here to signify a county has changed classes in a comparison.

Quantity movement is described as the overall loss or gain of counties within a class when comparing measure X to measure Y. However, the exchange and shift metrics represent a change in the counties within a class that did not result in a gain or loss of the overall number of counties in the class but, instead, a *replacement* of counties. Exchange involves two categories and occurs, for example, when a county might be classified as rural in measure X (e.g., URDT) and mixed rural in measure Y (e.g., RUCC) while a different county is mixed rural in measure X (e.g.,URDT) and rural in measure Y (e.g. RUCC), essentially resulting in measures X and Y *exchanging* counties between two classes. For the shift metric, counties were not exchanged between two classes but *shifted* between three or more classes. For example, if in measure X there are counties in the mixed rural class and in the mixed urban class, and in measure Y these counties are classified as mixed urban and urban, respectively, they are counted as having shifted as their classifications have "shifted" to adjacent classes.

As pointed out by Pontius and Santacruz (2014), albeit in a remote sensing error assessment context, interesting insights may be gained by examining the differences between two maps in terms of quantity and allocation (i.e., exchange and shift) differences. Quantity differences between a reference and comparison map are likely due to category measures being either too narrowly or too broadly defined. However, if two classes (one from each of the two measures being compared) are calculated using data with similar information content, that similarity could result in exchange differences rather than quantity differences. By measuring quantity, exchange, and shift differences we can learn the degree of "persistence" (the number of counties classified identically in a pairwise comparison) and, where differences do occur, which classes lack comparative consistency.

## 4.3 Results

### 4.3.1 Consequences of how different measures identify rural counties

There is wide variation in the number of thematic categories used to represent the rural to urban gradient across the four rural measures studied and a considerable range in the resulting number of counties considered to be rural (Figure 4.1).

The measures resulting in the most and fewest rural counties were URDT and IRR, respectively. URDT classified 2,285 of the 3,108 counties (74 percent) in the contiguous US as rural, while the IRR resulted in 141 total counties (4.5 percent) as rural. RUCC classified 627 counties as rural, and the Clustering approach classified 671 counties as rural. In terms of population, 54.3 million people (or 17 percent of the contiguous United States population) lived in a rural county based on the URDT measure while only half a million people (<0.01 percent) were in a rural county according to IRR. Considering area, URDT showed rural counties comprising over 5.8 million square kilometers (75 percent of the contiguous United States) while

counties in IRR rural class had a total area of 530,000 square kilometers (7 percent). This range in the total rural area represents a difference of over 5.2 million square kilometers. Additional summary differences in rural counties by each measure can be found in the supplementary materials (Appendix A Figure A.2).

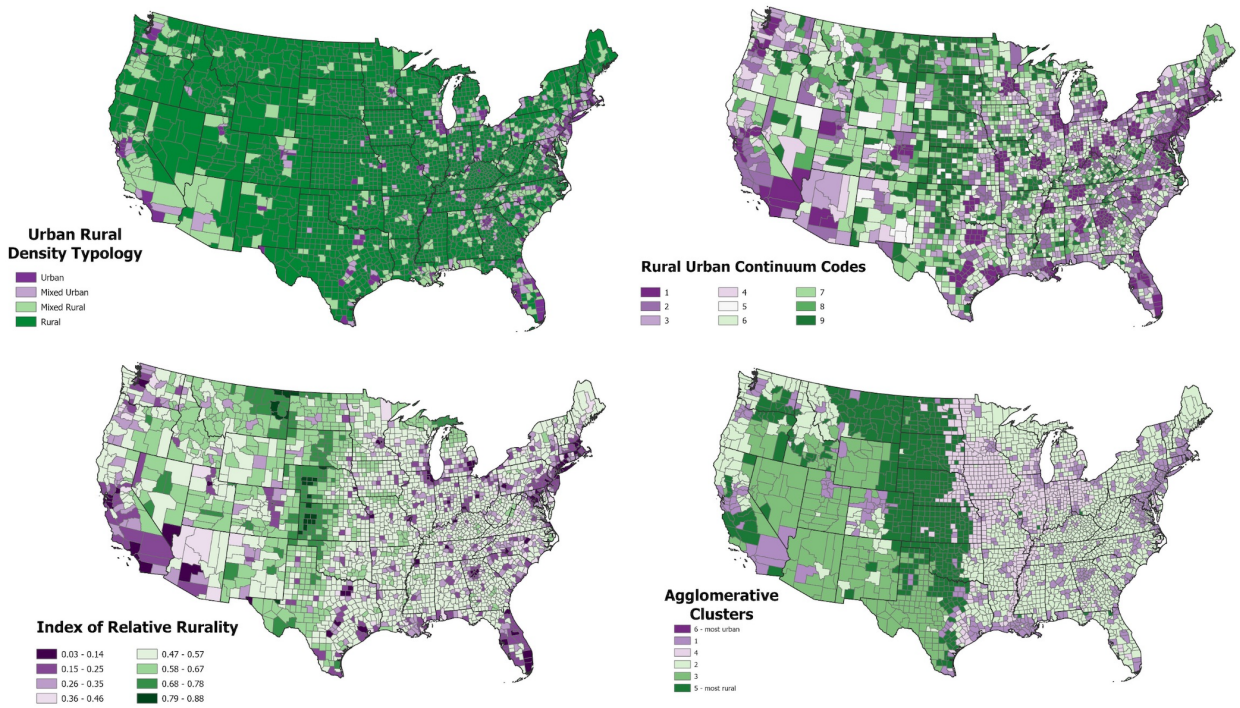



Figure 4.1 Maps of the original outcomes for four rural measures after data acquisition or replication and prior to any reclassification. *Note.* Dark green and dark purple represent the most rural and urban counties, respectively.

As a specific example of how rural measures impact the classification of a county, consider Butler County, Kansas (FIPS 20015). Butler County had a total population of 67,380, a population density of 18 people per square kilometer, and less than 5 percent of its land area developed. Butler County is directly east and adjacent to Sedgwick County, Kansas (FIPS

20173) where Wichita, the most populous city in the state, is located. Butler county was classified as urban by RUCC (code 2), mixed rural by URDT and IRR (0.695), and rural by Cluster. The proximity of Butler and Sedgwick County, combined with Butler County's population, strongly influences the urban classification under RUCC. Further, proximity to Sedgwick County results in Butler County being classified as a metro county, but with a low population density leading to the URDT mixed rural classification. Similarly, the IRR mixed rural classification results from the combination of low population density but also low remoteness, again due to proximity to Sedgwick County. Finally, since Cluster does not consider proximity to metro areas and includes landcover and industry variables, it considered the county to be rural.

### 4.3.2 Where measures agree on rural counties

After reclassifying the results from each original measure into the four categories of rural, mixed rural, mixed urban, and urban, we found that all four reclassified measures agreed that 114 counties, or nearly 3.5 percent of the total counties in the contiguous United States, were rural. These ensemble rural counties were distributed primarily across the Great Plains region, with some scattered throughout the western portion of the United States.

These counties represent 0.08 percent of the total population of the contiguous United States, or less than 257,000 people and are characterized not only by low total population but also low population densities (Table 4.2). Additionally, they had minimal urban development with predominant mixtures of agricultural landuses and grassland, but limited forested landcover. Last, there was a high percentage of the population aged 65 years or older and employed in agriculture, forestry, hunting, or fishing as compared to manufacturing.

Table 4.2 Summary statistics of key rural datasets for the 114 counties identified as rural by all measures.

| Dataset | Rural | | Non-rural | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Total Population | 2253 | 1344 | 343,848 | 622,190 |
| Population Density (people/km$^2$) | 0.81 | 0.54 | 380 | 1,294 |
| Remoteness (km to nearest metro area) | 111,768 | 50,757 | 79 | 1077 |
| % Population 65+ | 23 | 5 | 16 | 4 |
| % Employed in Agriculture | 25 | 10 | 1 | 2 |
| % Employed in Manufacturing | 4 | 3 | 12 | 6 |
| Median Household Income ($) | 50,501 | 10,246 | 61,397 | 16,560 |
| % Agriculture Landcover | 34 | 25 | 27 | 23 |
| % Forest Landcover | 2 | 6 | 32 | 22 |
| % Grassland Landcover | 46 | 25 | 3 | 5 |
| % Shrub/Scrub Landcover | 13 | 24 | 3 | 7 |
| % Developed Landcover | 2 | 1 | 23 | 20 |
| Hospital Beds (per 1000 people) | 8 | 11 | 3 | 3 |

*Note.* See Table 4.1 for sources of data. The variable "% Employed in Agriculture" includes employment in agriculture, forestry, hunting, and fishing.

The frequency by which a county was identified as rural by the reclassified measures was also calculated and mapped to illustrate how rural agreement varied spatially across the county (Figure 4.2). The measures more consistently agree on rural counties in the Great Plains region and intermountain west. Pockets of limited rural agreement, where only 1 or 2 measures classified counties as rural, are found throughout the eastern portion of the United States and mixed with areas of no agreement. Last, there are areas of counties along both coasts where all measures agree the counties are *not* rural, or where zero measures identify the county as rural.

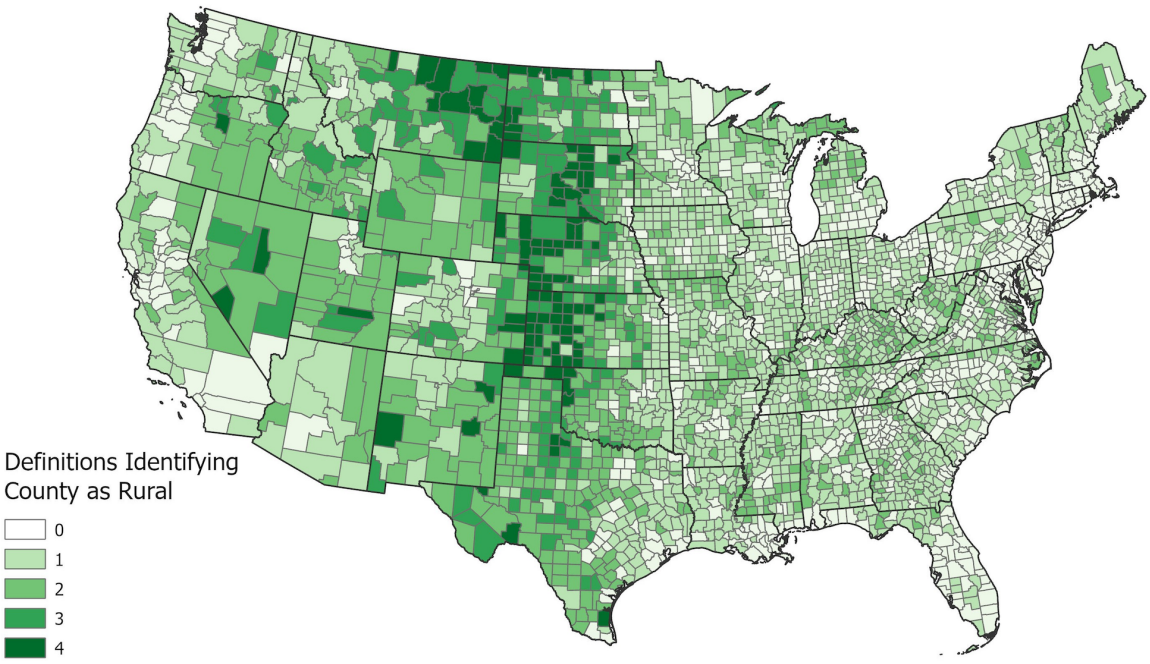



Figure 4.2 Map representing frequency of rural agreement according to reclassified rural measures. *Note.* Counties in dark green indicate all four measures resulted in a rural classification. Lighter shades of green signify fewer measures concurrently classifying a county as rural.

The data from key county-level rural variables were summarized for each measure agreement class whose values can be interpreted as meaning “non rural” (0), or complete agreement that a county is not rural, to “most rural” (4), or complete agreement that a county is rural (Figure 4.3). Population density and the percentage of developed landcover show large declines between the non-rural (0) category and the category of counties identified as rural by only one measure (1), then gradual declines between the remaining categories. The percentage of the working population employed in manufacturing and the percentage of forest landcover variables also presented declining trends, but this pattern was observed among the rural

categories only, with the non-rural (0) category not following the trend. Other variables, including remoteness, the percentage of the population over the age of 65, the percentage of the working population employed in agriculture, forestry, hunting, and fishing, and the percent of grassland show gradual increases across the levels of rural agreement. Finally, the remaining variables – the percentage of shrub/scrub landcover, household income, percent of agricultural landcover, and number of hospital beds per 1,000 people - show no consistent patterns across the values for rural measure agreement.

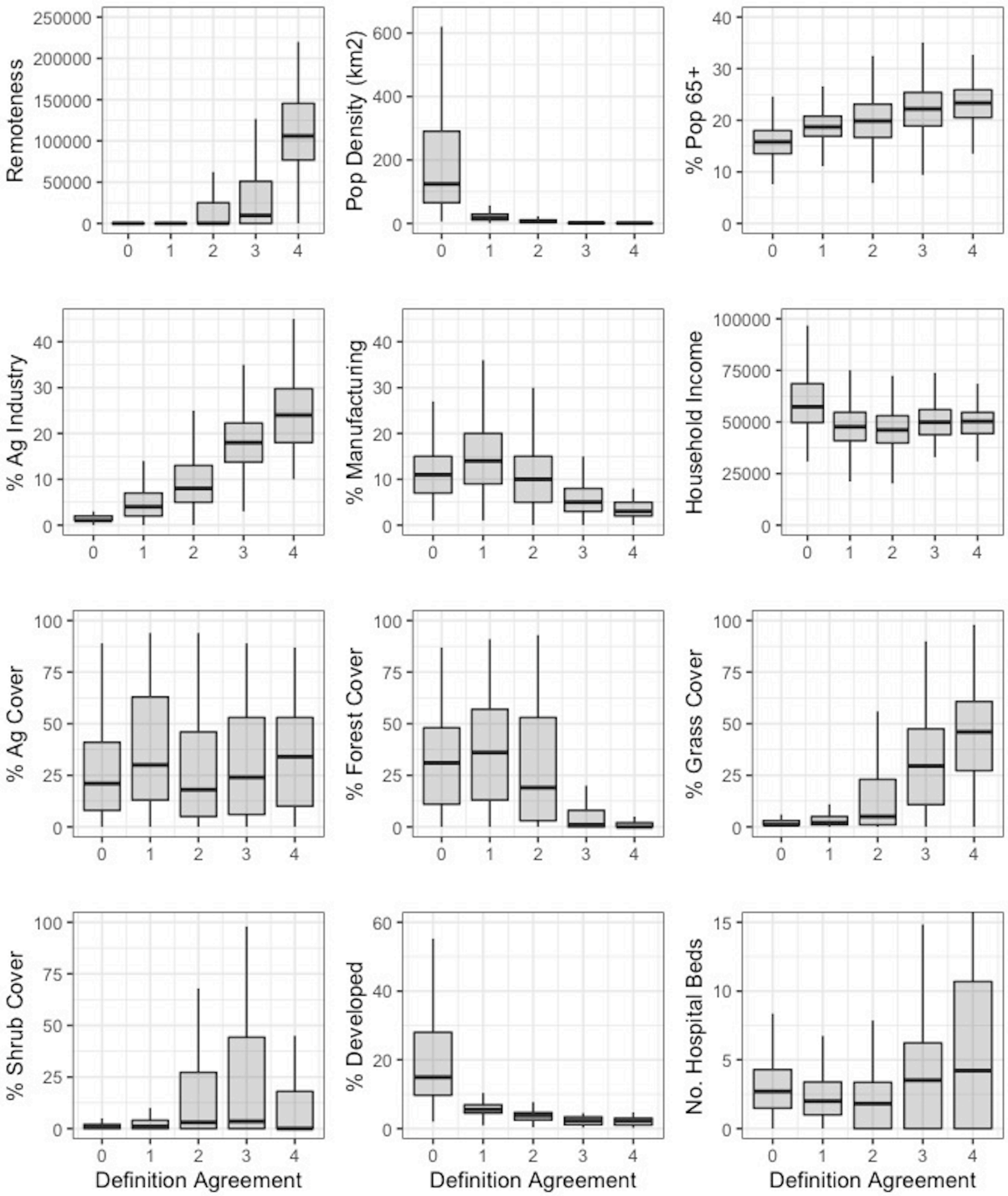



Figure 4.3 The distribution of key rural variable values (y-axes) by rural measure agreement (x-axes). For example, a measure agreement of two indicates that only two of four measures agreed that a county was rural. Outliers in the boxplots have been omitted for clarity.

Next, and using measure agreement as a factor variable, a series of non-parametric Kruskal-Wallis tests were performed to assess whether significant differences across the rural agreement categories existed for the key rural variables. All variables reported significant differences ($p < 0.001$). Since each rural variable was reported to have significant differences across the rural agreement categories at large, Dunn Post-Hoc tests were then used to compare each pair of rural agreement categories for each variable to obtain a more detailed understanding of the differences between rural agreement categories. For half of the 12 variables, significant differences ($p < 0.05$) were found for all of the rural agreement category comparisons (Table 4.3). Notable exceptions to this were the variables percentage of agriculture landcover and the number of hospital beds per 1,000 people. Further, across the rural variables, the comparison between rural agreement of 3 measures and rural agreement of all 4 measures was noticeably inconsistent.

Table 4.3 Dunn Post-Hoc test results for comparisons of all variables and combination of measure agreement values.

| Variable | Measure Agreement Comparison | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-1 | 0-2 | 1-2 | 0-3 | 1-3 | 2-3 | 0-4 | 1-4 | 2-4 | 3-4 |
| Remoteness | | | | | | | | | | |
| Population Density | | | | | | | | | | |
| % Population 65+ | | | | | | | | | | |
| % Employed Agriculture | | | | | | | | | | |
| % Employed Manufacturing | | | | | | | | | | |
| Median Household Income ($) | | | | | | | | | | |
| % Agricultural landcover | | | | | | | | | | |
| % Forest Landcover | | | | | | | | | | |
| % Grassland Landcover | | | | | | | | | | |
| % Shrub/Scrub Landcover | | | | | | | | | | |
| % Developed Landcover | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hospital Beds (per 1000 people) | | | | | | | | | | |

*Note.* Cell shading indicates significance with dark and light grey indicating the 99% ($p < 0.001$) and 95% ($p < 0.05$) confidence levels, respectively. Unshaded cells show insignificant ($p > 0.05$) comparisons.

### 4.3.3 Pairwise map comparisons of reclassified rural measures

A high degree of inconsistency in county rural category assignment among the pairwise comparisons of reclassified measures is evident when examining persistence values. Persistence describes the counties that are classified the same by both measures in a comparison. Persistence is the percentage of the counties with the same classification for both measures out of all the counties in the study area and is calculated per rural category and summed for an overall persistence value. Overall persistence ranged between 12-59 percent across the pairwise comparisons of rural measures. When examining the persistence for each rural category across all comparisons, persistence was always highest in the rural and mixed rural categories, averaging 10 percent and 19 percent, respectively. Persistence in the mixed urban and urban classes was lower, averaging 2 percent and 4 percent respectively. Considering only the rural category, persistence was highest in the URDT and RUCC comparison (20 percent) and lowest for IRR and Cluster comparison (4 percent) and the IRR and RUCC comparison (4 percent).

Given infrequent persistence in county category assignments between maps, the nature of these differences were quantified for further analysis. When counties were not classified the same for two measures, the differences in classification were conceptualized as quantity, exchange, or shift. Quantity differences, representing a net loss or gain of counties in each rural category when comparing two measures, made up the majority of differences between compared measures (Appendix A Figure A.3). Across all pairwise comparisons, quantity differences

averaged 46 percent, with no consistent pattern relating to the specific rural categories that experienced the most or least loss or gain across comparisons. Disagreement between two maps for a given category are specific to pairwise comparisons and can be assessed in general terms based on which classifications have proportionally more (net gain) or less (net loss) counties in a category. For example, in the URDT and RUCC comparison, RUCC has proportionally fewer counties in the rural category and more in the mixed rural, mixed urban, and urban categories versus URDT. This is evident in the large quantity difference in the rural class indicating that a large proportion of counties that are rural in URDT are other categories in RUCC without reciprocal differences, indicating a higher degree of inclusivity in the rural category for the URDT measure relative to RUCC.

Exchange and shift differences represent differences that do not result in a net loss or gain in counties when comparing measures, but instead describe a replacement of counties. Exchange describes trade of counties between two categories, and shift describes a replacement of counties between three categories. The degree to which exchange and shift occurred overall varied across measure comparisons, with exchange rates ranging from 0-16 percent and shift rates ranging from 3-20 percent. However, when examining these metrics per category, the mixed rural and mixed urban categories were consistently the categories with the highest percentage of counties exchanged or shifted.

## 4.4 Discussion and conclusions

Progress in rural sustainability research often relies on quantitative measures distinguishing what and where rural is as a means of targeting specific areas for rural research and policy efforts. In this analysis, we replicated and mapped four unique quantitative measures of rurality at the county level for the contiguous United States to better understand the degree of

consistency across measures of rurality. We then compared their individual results in terms of number of rural counties, area identified as rural, and the total population living in rural areas. Next, we quantified the level of agreement among measures in how they identify a county as rural and explored statistical differences among key county-level rural variables in the resulting rural agreement classes. Finally, a series of pairwise comparisons were performed between reclassified rural measures to assess the level of consistency in rural category assignments as well as differences in rural category classifications to better understand disagreements in county classifications among rural measures.

Rural measures are key to the distribution of government resources to both individuals and local communities. Previous research in rural literature has demonstrated the wide variety of both qualitative and quantitative rural measures (Nelson et al., 2021) and the lack of agreement between United States government measures (Long et al., 2021). The results reported here further illustrate that different rural measures yield very different outcomes in terms of the number, location, total area, and population of supposedly rural counties, underscoring how consequential selection of rural measures can be. While this is not a novel conclusion, this study can help researchers and policymakers better understand the differences between these measures and some of the important underlying characteristics that shape the rural (or non-rural) nature of counties in the United States.

For example, the results highlighted the wide variation in the degree of inclusivity for rural county classification - with URDT including nearly 55 million people in its rural counties while IRR only included half a million people - and the way different variables influence classification of rural counties, such as the influence of adjacency to metropolitan counties for RUCC or the influence of regional landcover for Cluster. Further, because we used four

methodologically unique measures of rurality, the differences observed aim to represent the diversity of measures in rural literature and allow for interrogation of how specific methods lead to different results. This work also connects the variables and methods used in these rural measures to the outcome of county classification and spatial distribution of rural counties through the side-by-side comparisons of four unique measures.

The four methodologically unique measures used in this study captured many of the approaches used in quantitative measures of rurality in rural literature. RUCC used multiple binary variables (metro/non-metro, adjacent/not adjacent to metro), providing representation of measures that rely on binary variables. URDT used thresholds for population density and urban population variables, providing representation to threshold-based measures in the literature. IRR represented continuous index measures, and Cluster provided representation of measures using statistical cluster analysis. These four measures are, of course, not capable of capturing the entirety of existing quantitative rural measures. The selected measures are limited in this objective by the fact there only four were selected, but they are also limited in their ability to represent the range in complexity across rural measures. For example, RUCC and URDT are arguably more complex than other measures that rely on binary variables and thresholds, and IRR and Cluster are arguably less complex compared to other continuous indices and cluster analysis approaches. However, despite these limitations, these four measures capture a wide variety of the measures in rural literature and therefore are likely to capture a wide range of the variability and inconsistency across measures that may reasonably be expected to apply to many applications of rural measures.

Our results highlighted how little consistency actually exists between the classification of rural counties by rural measures. This study identified only 114 counties that all four reclassified

measures agreed were rural. Further, when conducting pairwise comparisons, the consistency in classification even when only comparing two of the four measures at a time was generally low. Overall persistence averaged 36 percent across rural measure comparisons, with the values ranging from 12 percent to 59 percent. However, even in instances where the overall persistence was higher (IRR and Cluster comparison, 59 percent), the majority of that consistency came from persistence in the mixed rural category (50 percent persistence) and was almost absent in the rural category (4 percent persistence).

These findings not only emphasize the lack of consistency and agreement between measures' classifications of rural counties, but also demonstrate, through the pairwise comparisons, that the limited agreement among the four measures is not the result of a single measure skewing the results as there is limited persistence in pairwise comparisons as well. In fact, quantity differences, the differences in the total number of counties classified per category in a comparison, averaged 46 percent, higher than calculated persistence, exchange, and shift. Given that differences were mostly related to quantity movement, it suggests that rural measures in some cases may be either too narrow or too broad. For example, URDT has a quite broad rural category and experienced high quantity differences, averaging 60 percent across its comparisons. This could be because the URDT approach is based on threshold values for its variables and was published in 2005. Given that our population has changed since 2005, it is reasonable to assume that the thresholds decided upon in 2005 may not be suitable today as argued by Waldorf (2006). Other sources of inconsistency were differences resulting from counties being traded between categories (exchange and shift movement) and were most prominent in the mixed rural and mixed urban categories. This indicates that these categories are likely more difficult to define across all the measures selected, a finding that is in accordance with contemporary discussions of

urban-rural continuums that suggest that boundary conditions between urban and rural conditions are fuzzy, complex, and regionally varying (K. J. Bennett et al., 2019; Lichter & Brown, 2011; B. Waldorf & Kim, 2015).

While there was little rural agreement among the four measures, noting the counties each measure identified as rural is valuable. Each of these 114 counties had low total populations and low population densities with a large proportion of older residents, low developed land use areas, and a high percentage of the population employed in agriculture, fishing, forestry, and hunting. Measures of rurality inherently imply a characterization or conceptualization of what it means to be rural through the variables selected to develop the measure and how those variables are manipulated or prioritized in the development of the measure. By looking at the common characteristics of these 114 counties, we can see where these methodologically unique measures aligned in their implied characterizations of rurality.

Together, these findings elucidate some of the uncertainties involved when employing a single rural measure for research and policy purposes. There was great variation in the number and location of rural counties across the four rural measures examined, leading to large differences in the total area of, and total population in, rural counties. There was also little agreement among the four rural categories (rural, mixed rural, mixed urban, and urban). That disagreement was largely driven by differences in the number of counties classified as rural or urban across approaches. Interestingly, county classifications were often shifted or exchanged between the mixed rural and mixed urban categories perhaps highlighting the challenge distinguishing classes that are not on the clear ends of the rural-urban spectrum. Closer examination of the underlying characteristics of the 114 consensus rural counties provides an opportunity to reflect on the nature of popular rural measures, their approaches, and the variables

they use. If these counties are not representative of how rural researchers conceptualize rurality across each region of the United States, it should serve as motivation for working toward new and/or spatially adaptive rural measures that better represent the communities that policy and research intends to help.

# Chapter 5 – Imprinted in the mind and on the landscape: Piloting a cognitive mapping approach to understand regenerative agriculture adoption

## 5.1 Introduction

Across the Midwest and the Great Plains region, climate change is predicted to have damaging effects on agriculture. Increased temperatures during the growing season are expected to exceed optimum conditions for most crops in the region, putting them at risk of reproductive failure (Angel et al. 2018; Conant et al. 2018). Increased humidity and precipitation in the spring is expected to increase soil erosion, and in combination with increased temperatures, increase the ability for fungal growth and bacterial plant diseases (Gowda et al. 2018; Mastrandrea et al. 2015). Lastly, while future drought behavior is still uncertain, soil moisture levels will be excessive in the spring while insufficient during the summer (Gowda et al. 2018; Angel et al. 2018; Conant et al. 2018; Mastrandrea et al. 2015).

While the continued progression of climate change will undoubtedly harm farmers in the region, farming is also a significant contributor to climate change and broader environmental harm. Industrial farming practices have serious environmental consequences: water pollution (Evans et al., 2019; Ghaly & Ramakrishnan, 2015; Schulte-Uebbing et al., 2022), soil erosion (D. R. Montgomery & Matson, 2007; Quinton et al., 2010), loss of biodiversity and ecosystem services (David Tilman et al., 2002; Diaz & Rosenberg, 2008; Power, 2010a; Tegtmeier & Duffy, 2004), and the mining of natural resources (Aeschbach-Hertig & Gleeson, 2012; Childers et al., 2011; Horrigan et al., 2002). Further, deforestation for the expansion of agricultural lands,

methane emissions from livestock, and nitrous oxide emissions from fertilized soils combine to make agriculture a leading contributor to global climate change, accounting for at least 30% of greenhouse gas emissions (Foley et al., 2011; Tilman et al., 2011; Vermeulen et al., 2012).

Given this context, engaging in more sustainable agricultural practices is not only important for the future of the planet but also for farmers who are facing an increasingly hostile climate and environmental landscape. Regenerative agriculture, a soil-health and systems-based farming approach (Lal 2020), has been gaining popularity in recent years as an alternative to industrial, or conventional, agriculture (Newton et al. 2020). While many definitions of regenerative agriculture exist, most definitions agree on five core principles (Brown, 2018; Khangura et al., 2023; Newton et al., 2020): minimize soil disturbance, keep soil covered year round, maintain a living root in the soil, grow biodiversity, integrate animals. Regenerative agriculture has been shown to increase biodiversity (L. R. Soto et al., 2021), increase water infiltration rates (Daverkosen et al., 2022), sequester carbon (Rhodes, 2017), and improve farms resiliency to environmental change (Toensmeier 2016).

Evidence for the potential of regenerative agriculture as a sustainable alternative to industrial agriculture continues to grow, but our understanding of the factors that motivate adoption of regenerative agricultural practices is still limited. Recently, systems thinking has been linked to farmer engagement with regenerative farming practices (Gordon et al., 2022; Gosnell et al., 2019; Mann et al., 2019). Self-identified regenerative farmers and even farmers engaging only a subset of the RA principles have reported viewing their farms as interconnected systems, a demonstration of employing systems thinking (Church et al., 2020; Gosnell et al., 2019). This study examines this relationship by comparing systems thinking engagement among farms using a wide range of practices, from regenerative to industrial, to those in between. We

specifically ask the questions:  1) how do farmers demonstrate systems thinking skills? And 2) are there differences between how regenerative farmers and industrial farmers put systems thinking into practice? Below, I discuss the state of regenerative agriculture adoption research and how it relates to systems thinking. Then, we engage quantitative and qualitative analyses of farmer cognitive maps, a systems thinking tool, to explore the relationship between regenerative agriculture adoption and systems thinking.

## 5.2 Background

### 5.2.1 Regenerative agriculture adoption

Regenerative agriculture (RA) has received increased attention from researchers and farmers(Newton et al., 2020). While multiple definitions and descriptions of RA exist, it is understood that RA centers on soil health and engages a systems approach to farming (Lal, 2020). While building on the core practices of conservation agriculture—maintaining soil cover, employing crop rotations, and minimal soil disturbance (Kassam et al., 2009)—regenerative agriculture goes beyond conservation agriculture to incorporate livestock practices and promote biodiversity through creating a farm ecosystem that attempts to mimic natural processes that cycle nutrients and resources to replenish, or regenerate, the ecology needed for farming (Oberč & Schnell, 2020).

The benefits of RA, both for planet and for people, are continuing to be researched and understood. RA, as a systems-based approach to farming, argues that utilizing a single practice that supports an RA principle does not have the same outcome as using multiple practices that support all the RA principles simultaneously. Essentially, when it comes to RA, the whole is greater than the sum of its parts.

Researchers have tested these claims by comparing fields that use varying combinations of practices that support RA principles. Soil health was found improved when reduced tillage, cover crops, and manure or organic fertilizers were used simultaneously compared to these practices used individually (L. R. Soto et al., 2021). Similar soil health benefits have been found when combining cover crops and organic amendments (Xu et al. 2019), crop diversification and livestock integration (Blanco-Canqui and Ruis 2018), no till and crop diversification (Nunes et al. 2018), and permanent cover, livestock integration, and no till (Daverkosen et al., 2022). Regenerative farms have been shown to be more profitable than industrial farms, especially in times of environmental stress (LaCanne & Lundgren, 2018). Further, crops and livestock raised on regenerative farms were found to have higher nutritional content when compared to those raised on industrial farms or found in supermarkets (D. R. Montgomery et al., 2022).

Given the potential for RA to benefit planet, farmer, and consumer, understanding the factors that motivate adoption of the RA farming approach is of growing importance. Research has made progress addressing barriers to adoption for isolated regenerative agriculture practices such as cover cropping (Roesch-Mcnally, Basche, et al., 2017) and conservation tillage (Derpsch et al., 2010), or the adoption of soil health practices more broadly (Carlisle, 2016). Other work has focused specifically on the adoption of RA through interviews with farmers, researchers, and trainers regarding the barriers to adoption (Kenny & Castilla-Rho, 2022), and the process of transitioning from industrial to regenerative practices (Gosnell, 2022).

More recently, systems thinking has been linked to farming practices that support RA (Ranjan et al. 2019). Studies using qualitative interviews aimed at understanding farmers' perceptions of regenerative practices have found that farmers who had adopted regenerative practices often described conceptualizing their farms as systems in that they were able to see

interconnections between different aspects of their farms in a more holistic way (Arbuckle and Roesch-McNally 2015; Bossange et al. 2016; Brummel and Nelson 2014; Kennedy et al. 2016; Roesch-McNally et al. 2017). A recent study has even quantified this relationship through the use of a survey asking farmers about their cover crop practices and questions pertaining to their view of their farms as interconnected systems (Church et al. 2020). The results showed that farmers who reported thinking of their farm from a systems perspective were significantly more likely to use cover crops on their farm and understand their environmental and agricultural benefits.

These studies make progress toward understanding the adoption of specific practices supporting RA and RA as a farming approach more generally. However, regenerative agriculture is a systems-based approach and therefore the process of regenerative agriculture adoption needs to be examined within the context of the whole farm system. The research linking systems thinking to RA adoption provides a useful starting point for this work. These studies have been important for exposing systems thinking as a potential influencing factor in the adoption of regenerative practices. However, these studies did not directly compare farmers' systems thinking engagement, but instead relied on self-reporting and perceived behaviors. This study investigates RA adoption by comparing the systems thinking engagement of industrial and regenerative farmers through their own mental maps, or internal depictions of their farm systems. This work not only looks at RA as a whole, instead of focusing on a single RA farming practice, but also further investigates the connection between systems thinking and RA adoption with clear comparisons between farming engaging in different farming approaches.

### 5.2.2 Systems thinking and cognitive mapping

Systems thinking can be used to interpret the world around us not as a set of disconnected components, but as an integrated set of relations linking people and ecosystems (Meadows, 2008). Systems thinking can be conceptualized as the opposite of linear thinking, engaging holistic thinking that seeks to integrate data instead of dissect data (Monat & Gannon, 2015). Through this holistic thinking, the aim is to understand, assess, predict, and influence a system and its function (Arnold & Wade, 2015). To meet these aims, systems thinking researchers often identify and examine the elements, interconnections, feedbacks, structure, and purpose of a system (Arnold & Wade, 2015; Williams et al., 2017), employing the core concepts of interconnectedness, feedback loops, and self-organization that characterize systems thinking. Further, when one engages in systems thinking, systems thinking skills can be developed and conceptualized on a continuous scale from basic to highly developed (Draper, 1993; Stave & Hopper, 2007). Systems thinking skills existing on a spectrum means that these skills can be taught, fostered, and grown over time, but also that these skills can be assessed to determine where someone falls along the spectrum at a given point in time. Many methods for assessing systems thinking skills have been used in research and education including approaches based on mapping, environmental scenarios, and open-ended and oral assessments (Dugan et al., 2022).

The study of systems thinking has been steadily gaining popularity since the 1990s, especially in fields such as operations and organizations research, sustainability, and management studies (Williams et al. 2017). Systems thinking has been shown to improve complex decision-making and problem-solving abilities (Huz et al. 1997; Cavaleri and Sterman 1997; Maani and Maharaj 2004). In agriculture, systems thinking has been used in a variety of ways. Agriculture innovation systems have used systems thinking to improve communication

between researchers and stakeholders and recognize the many actors that contribute to progress in agriculture (Bosch et al. 2007; Bawden 1991; Klerkx et al. 2012; Pigford et al. 2018). Systems thinking has also been utilized by scholars to develop our understanding of the complex socio-ecological systems in which agriculture takes place (King 2008; Hahn and Nykvist 2017; Linstadter et al. 2016).

There are many ways to engage with systems thinking skills, one of which is cognitive mapping (Dugan et al., 2022). A cognitive map is a qualitative, visual representation of a person's conceptualization of a system that draws on mental models. Mental models are individually held cognitive representations of external reality that inform how we interact with the world (Jones et al., 2011). Mental models are molded from personal experiences and perceptions of the world and form the basis for reasoning and decision making (Jones et al., 2011). There are many ways mental models have been translated to external, visual representations including influencing diagrams, concept maps, and cognitive maps (Van Winsen et al., 2013). These various approaches to visualizing mental models differ in their structure and organization of model content. Cognitive maps are distinct in that they represent mental models as integrated systems of causal relationships between mental objects drawn from the mental models (Croasdell et al., 2003), engaging systems thinking in the process of development.

The construction of a cognitive map includes the identification of the salient factors of a system and the relationships between those factors, allowing for the most important factors of the decision-making process to emerge (Eden, 1992). Advantages of the systems-based representation used in cognitive maps is that while capturing the most important relationships within the system, they also capture relationships that are less significant, but still relevant to system function and outcomes (Van Winsen et al., 2013), providing a more complete and richer

context for decision making. Further, cognitive maps make often implicit relationships, explicit, allowing decision-making processes, the factors that contribute to decisions, and the behaviors that result from those decisions to be clearly communicated and examined—all within the context of the broader system. This then allows for a closer investigation of events or experiences that trigger change in the decision-making process and subsequent behavior (Eden et al., 1992; Özesmi & Özesmi, 2004).

As cognitive mapping is used to depict systems, the relationships within them, and their function, they are particularly well suited for assessing systems thinking. By comparing the cognitive maps of regenerative farmers and non-regenerative farmers, we can gain insight as to how systems thinking skill vary between the groups and add to the research investigating the relationship between RA adoption and systems thinking. However, cognitive maps also make clear how farmers view their farm systems and the context and processes that are a necessary part of decision-making, lending valuable insight to the decision to adopt or not adopt new practices. Lastly, cognitive maps can be used as tools of bi-directional learning between researchers and farmers. Researchers learn the priorities of farmers through the communication of the farmer's cognitive map of the farm system, but through this exercise, farmers also learn through reflecting on the structure of their farm system and the factors that influence their decision-making and actions, allowing them to recognize opportunities for change and improve decision-making abilities (Van Winsen et al., 2013).

Cognitive mapping is an approach that has been used in agricultural research to study farmers' sustainability perceptions (Averbuch et al., 2022; Levy et al., 2018), risk perceptions (Van Winsen et al., 2013), local knowledge (Isaac et al., 2009), water use (Douglas et al., 2016), land management practices (Vuillot et al., 2016), and adoption of conservation agriculture

(Lalani et al., 2021) and regenerative agriculture practices (Kenny & Castilla-Rho, 2022; L. Soto et al., 2021a), with many of these studies using cognitive mapping to explicitly measures systems thinking (Douglas et al., 2016; Kenny & Castilla-Rho, 2022; Lalani et al., 2021; Levy et al., 2018; L. Soto et al., 2021a). Beyond the variety of topics in studies that have employed cognitive mapping in agriculture research, studies have also leveraged cognitive mapping in different ways. The clearest difference is between studies that use cognitive mapping versus those that use *fuzzy* cognitive mapping. Fuzzy cognitive maps assign weights between [-1, 1] to the relationships within a system (Özesmi & Özesmi, 2004). Studies using fuzzy cognitive mapping more often quantitatively analyze the maps, either through statistical analysis (L. Soto et al., 2021a) or network analysis (Averbuch et al., 2022; Kenny & Castilla-Rho, 2022), in addition to the qualitative analysis approaches often used in non-fuzzy cognitive mapping studies.

Many studies have farmers draw their own cognitive maps (Fairweather & Hunt, 2011; L. Soto et al., 2021a; Tessier et al., 2021; Vuillot et al., 2016), but some researchers develop farmer cognitive maps themselves based off of farmer interviews (Hoffman et al., 2014; Isaac et al., 2009; Van Winsen et al., 2013). Further, while many farmer cognitive mapping studies focus on the systems view of individual farmers, some use cognitive mapping as a collaborative exercise, bring a group of farmers together to develop the cognitive map (Douglas et al., 2016; Hoffman et al., 2014; Kenny & Castilla-Rho, 2022). One study investigating RA perceptions of farmers in Spain even collected fuzzy cognitive maps from individual farmers twice over a three-year span, then combined the maps, creating two group fuzzy cognitive maps to compare changes in farmer perceptions of RA over time (L. Soto et al., 2021a).

This prior work demonstrates the ability of farmers and researchers to successfully develop cognitive maps both individually and collaboratively, as well as the efficacy of cognitive

mapping for measuring systems thinking. We collected individual, farmer developed cognitive maps as previous research has provided detailed procedures for successfully replicating the mapping exercise. Further, because this study is focused on the adoption of new practices, a highly personal choice, individual farmer cognitive maps were deemed most suitable for investigating this process of adoption. Drawing on the methods of previous literature, we not only qualitatively analyzed the cognitive maps, but also conducted quantitative analysis, using key network analysis metrics from fuzzy cognitive mapping studies (Lalani et al., 2021; Özesmi & Özesmi, 2004). Lastly, while the body of literature at the intersection of systems thinking, cognitive mapping, and farming is continuing to grow, research in this intersection focused on RA adoption is more limited (Kenny & Castilla-Rho, 2022; L. Soto et al., 2021a), and to our knowledge, none have explicitly compared systems thinking between regenerative and industrial farmers. This study, leveraging previous work on cognitive mapping and systems thinking, collected and compared the cognitive maps of regenerative and industrial farmers to better understand the role of systems thinking in the process of RA adoption.

## 5.3 Methods

Semi-structured, in-person interviews were conducted with 19 farmers between July-August 2021 and March 2023. All farmers resided in central Kansas, in the United States' Great Plains region. Using purposive sampling, 11 farmers enrolled in a regenerative agriculture pilot program supported by a large food corporation were interviewed. To diversify and expand the sample, farmers in the initial round of interviews were asked to identify other farmers who they believed would be willing to complete an interview. Further, we reached out to agriculture professionals in the region to identify additional farmers to interview. Through both these processes, we identified 8 additional farmers.

While there are many overlapping definitions of RA (Newton et al., 2020), we define RA as a systems-based, soil-health approach to rebuilding agroecosystems that is founded on five core principles: 1) minimize soil disturbance, 2) keep soil covered year round, 3) maintain a living root in the soil, 4) encourage biodiversity, and 5) integrate animals (Brown, 2018; Khangura et al., 2023). These principles were then used to identify four practices that worked to support the enactment of these principles within farm systems. The specific identification of practices, or processes, for marking progress toward the overarching RA principles is often referred to as a process-based interpretation of RA (Newton et al., 2020). As this research aimed to compare regenerative, industrial, and transitioning farmers, a mechanism for distinguishing them was necessary. Process-based definitions of RA inherently produce a continuum from industrial to regenerative (Page & Witt, 2022), where industrial is the most extractive and regenerative is the least extractive.

The following four practices were used as a basis for classifying farmers along the spectrum of industrial to regenerative: 1) no till, 2) cover cropping, 3) reducing synthetic inputs, and 4) integrating livestock as part of the cropping system. These practices were adapted from previous research developed to distinguish industrial and regenerative farmers residing in the United States' Great Plains region (Fenster et al., 2021). Each farmer interview began with asking for an overview of their farming operation and questions regarding these practices, specifically. As interviews progressed, the nuance of engaging these practices became clearer, and our method for classifying farmers developed to represent the flexibility necessary to capture this nuance. For a farmer to be classified as 'regenerative' they had to be currently and consistently using all four practices (N = 7). For example, if a farmer was currently engaging in cover cropping but stated they do not use this practice every year or only use this practice on a

small portion of their farm, it would not count as consistent use of the practice. A farmer was classified as 'industrial' if they currently and consistently engage in zero or one of the practices (N = 7). Classification of farmers transitioning from industrial to regenerative practices was more complex. Many RA experts recognize the significant time and energy investment required to fully transition to RA. We recognized that because of this, processes of transition may look different from farmer to farmer. Some farmers may opt to fully implement practices one at a time, while others may partially implement multiple practices at once. As such, farmers were classified as 'transitioning' if they were currently and consistently engaging in at least two practices, or if they communicated explicit intention and demonstrated clear progress toward implementing at least three practices (N = 5).

### 5.3.1 Interview Process

I conducted all the interviews and sought to be aware of my positionality throughout the interview process. I am a young, white woman with minimal farming background, and as such, not considered an insider to the farming community. However, many farmers mentioned having adult children similar in age. Further, I was transparent about my lack of farming background and took on the role of student when learning from interviewees about farming terminology and processes. This circumstance aided in balancing any discomfort on the farmer's side during the cognitive mapping portion of the interview. Because it is an interactive, dialogic and participatory method, cognitive mapping requires that the interviewer take on the roles of both teacher and learner. On the one hand, I taught the rules of mapping to the interviewee. On the other hand, the interviewee taught me how they interpret their farming operations in a systems context.

Every step of the interview process was taken from previously established procedure detailed in published literature. Throughout the below description of the interview process, for each step, we cited the previously published research from which that step was drawn. Each interview began with an overview of the farmer's operation and specific questions about their farming practices. This discussion not only allowed us to classify each farmer along the industrial to regenerative spectrum, but it also provided me with valuable information about the farmer's operation that allowed me to help guide the farmer through the cognitive mapping exercise (Tessier et al., 2021). Once this part of the interview was complete, I transitioned into the cognitive mapping exercise. This included a brief description of cognitive mapping and an explanation of a non-agriculture related example of a cognitive map (Fairweather & Hunt, 2011; Özesmi & Özesmi, 2004; L. Soto et al., 2021a; Tessier et al., 2021). After this, each farmer was asked to identify and list the factors in their farm system on note cards (Douglas et al., 2016; Kenny & Castilla-Rho, 2022; Özesmi & Özesmi, 2004). A list of potentially relevant factors developed from a previous study that had farmers map their farm systems was provided as a means to get farmers started if they struggled to think of factors (Fairweather and Hunt 2011).

Once the factors were identified, the farmer was asked to select the most important factors and add them to their map (Fairweather & Hunt, 2011; Tessier et al., 2021). I would begin going through each of these factors and asking: 1) what influences this factor? and 2) what does this factor influence? Arrows, or connections, were then drawn between factors to signify relationships and their direction (Averbuch et al., 2022; Douglas et al., 2016; Fairweather & Hunt, 2011; Kenny & Castilla-Rho, 2022; Özesmi & Özesmi, 2004; L. Soto et al., 2021a; Tessier et al., 2021). Through this process, additional factors are added to the map and the process continued until the farmer is satisfied with the map. Most farmers explained the meaning of

connections between factors while they were being drawn on the map, but if they did not, the farmer was asked to discuss the connections once it was complete (Fairweather & Hunt, 2011; Tessier et al., 2021). Regardless of when or how the farmer discussed the factors and connections of their map, their discussion was carefully compared to the physical map to determine if the verbal description matched how the relationships were drawn (Averbuch et al., 2022; Douglas et al., 2016; Özesmi & Özesmi, 2004). For example, if a farmer was explaining their map and seemed to say something that contradicted their map, I asked, "Are you saying A influences B?" or "From what I understand, you are saying C causes D, is that correct?" This process confirmed the farmer's interpretation of the map but also allowed for corrections to be made (e.g., adding in an arrow where there wasn't one before). This approach has been successfully used in previous studies (Fairweather and Hunt 2011; Tessier et al. 2021).

Once the cognitive map was completed, I asked questions to better understand the function of the farm system as depicted by the farmer. This portion of the interview focused on the leverage points and trade-offs of the farmer's cognitive map, concepts used to qualitatively assess systems thinking (Gray et al., 2019; Kenny & Castilla-Rho, 2022). Leverage points are particular points within a system that can be altered to direct the system toward a desired state. Trade-offs represent the balance between benefits and costs of introducing changes to a system. These questions served to expose how the farm system functions, how it responds to challenges, and where its weak points are, all from the perspective of the farmer. As systems thinking is based on an understanding that the whole is more than the sum of its parts, discussing leverage points and trade-offs moves the conversation beyond the individual relationships between factors and allows farmers to demonstrate how their farm system works as a whole. Further, when embedding questions on leverage points and trade-offs within the context of RA adoption, we

can gain insight as to how farm systems overcome barriers to adoption, how farm systems changed in response to changes in practices, and for those that have not adopted new practices, how the farm system structure and function make adoption challenging.

### 5.3.2 Analysis

All interviews were recorded and transcribed. All cognitive maps were scanned for digital storage. The cognitive maps were analyzed both quantitatively and qualitatively.

There are many approaches to assessing systems thinking skills using cognitive maps, both qualitatively (Gray et al., 2019) and quantitatively (Lalani et al., 2021; Levy et al., 2018; Özesmi & Özesmi, 2004). To quantitatively assess how farmers demonstrated systems thinking skills, we employed two network analysis metrics previously used in agricultural research for assessing the degree of systems thinking in mental models (Lalani et al., 2021; Levy et al., 2018). The first measure used was the complexity index which is the ratio of receiver factors, map factors that only have in-going connections, to the number of driver factors, map factors with only out-going connections (Lalani et al., 2021). A map with many receiver factors is considered to account for many of the outcomes that result from the internal function of the system (Eden et al. 1992), while a map with many driver factors is considered to have a more top-down structure that is not indicative of high systems thinking engagement (Özesmi & Özesmi, 2004), resulting in higher ratios indicating greater engagement with systems thinking. The second measure is the flow-hierarchy index. This index measures top-down thinking by identifying to proportion of connections within a map that are not a part of any feedback loops (Lalani et al., 2021). Feedback loops are ‘loops’ within a cognitive map that are created by individual causal connections that start at a factor and can be traced between factors until connected back to the starting factor, exposing reciprocal relationships in the system. More

connections not participating in feedback loops indicates less engagement with systems thinking, as such, lower values indicate greater demonstration of systems thinking skills.

We qualitatively analyzed the interview transcriptions and the cognitive maps using the general inductive approach outlined by Thomas (2006). Inductive analysis requires multiple readings of raw text to derive themes and frameworks directly from the data, as opposed to the application of previously developed models, with the overarching goal of developing a framework for understanding the experiences or processes relevant to the research topic (Thomas, 2006). We did this by reading the interview transcripts and coding for recurring themes, particularly themes related to farming practices and the process of learning about and adopting new practices. Cognitive maps were similarly analyzed, with recurring themes among the map factors being coded. As the dialogue from the interviews described relationships between the map factors, the analysis of the interview text data and the cognitive maps was deeply intertwined and required an iterative process of evaluating themes both across farmer interviews and between a respective farmer interview and farmer cognitive map.

While there were 19 farmers interviewed, three interviews included pairs of farmers, two married couples and one pair of business partners, that held equal responsibility over their farming operations and as such developed a single cognitive map collaboratively, resulting in 16 cognitive maps. For each case in which pairs of farmers were interviewed, the farmer who was initially contacted for the interview expressed desire to have their spouse or partner present for the interview as they were considered a vital part of decision-making on the farm. Of these 16 cognitive maps, six were developed by industrial farmers, six by regenerative farmers, and four by transitioning farmers. The farmers interviewed were largely representative of the farmers in

the region as 80% were self-identified white, non-Hispanic men. Their farms ranged in size from less than 500 acres to 24,000 acres, with an average of 5,867 acres.

## 5.4 Results and Discussion

The quantitative and qualitative analyses of the cognitive maps revealed key differences in the role of soil health and other RA related practices in the farm systems of each group of farmers, exposing a broader framework of structural and thematic differences between farmer groups. First, farmers of both types demonstrated systems thinking, but industrial farmers made more linear connections while regenerative farmers made more circular feedback connections associated with highly developed systems thinking skills. Second, farmers in each group were differentiated by the ***source***, and ***type***, of the factors that serve as main motivators for their thinking and action (Figure 5.1). Regenerative farmers were more influenced by on-farm factors, such as farm biodiversity, animal health, and management practices. Industrial farmers demonstrated more of external focus through the more linear structure of their farm systems maps and an emphasis on off-farm map factors, such as government policies, advisors, and markets. Further, regenerative farmers prioritized ecological factors and connections within their farm systems leading to an *internalization* of ecological system processes *within* the farm system, with farmers often discussing these ecological connections in terms of farm resiliency. In contrast, industrial farmers prioritized human driven factors leading to a system centered on external, human structures and processes discussed in terms of financial gain and risk management tactics. Below, we unpack these findings in detail, connecting both quantitative analysis of the cognitive maps, but also qualitative analysis of the cognitive maps and farmer interviews.

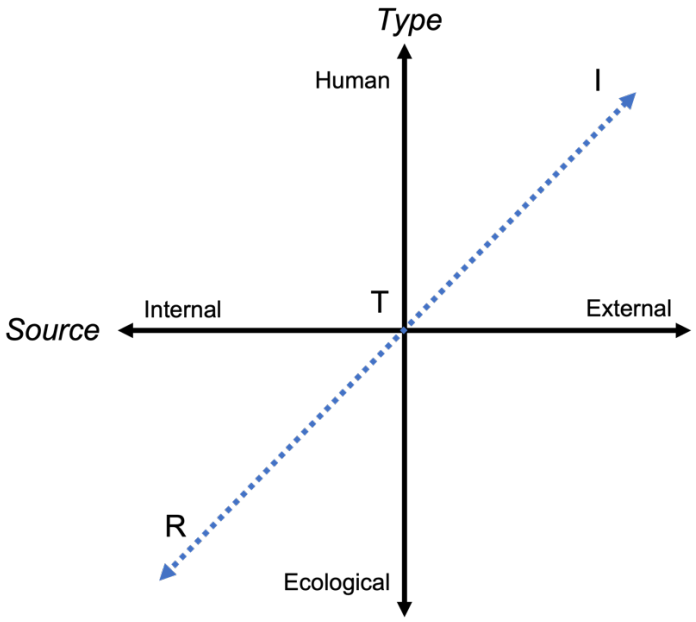



Figure 5.1 Conceptual representation of regenerative (R), transitioning (T), and industrial (I) farmers' systems orientations as depicted by the map factors in their cognitive maps. This figure is not meant to communicate that regenerative or industrial farmers did not produce cognitive maps that incorporated factors from both ends of each axis, but instead is meant to make clear the differences in frequency and emphasis of the factors observed in the groups of maps.

### 5.4.1 Quantitative results

The quantitative results of the network analysis metrics used to evaluate the farmer cognitive maps for degree of systems thinking engagement supported previous research suggesting regenerative farmers engage in systems thinking (Ranjan et al., 2019), but also demonstrated a clear internal-external divide between regenerative and industrial farmers. The mean Complexity Index value was highest for cognitive maps made by regenerative farmers and lowest for cognitive maps made by industrial farmers (Table 5.1). Higher Complexity Index values suggest a map accounts for the outcomes internal to the system and lower values indicate

that a map focuses on multiple causes and has a top-down structure. Regenerative farmers, having a mean higher score, demonstrated greater engagement with systems thinking skills for this metric when compared to the other groups of farmers. The Flow-Hierarchy Index measured systems thinking by focusing on feedback loops, a key part of systems thinking, identifying the proportion of connections within a map that are not a part of any feedback loops. For the Flow-Hierarchy Index, where lower values indicate greater systems thinking while higher values indicate more linear thinking, maps from regenerative farmers had, on average, the lowest value, again demonstrating a greater degree of systems thinking (Table 5.1).

The results of both of these metrics demonstrated the group of regenerative farmers viewed their farm systems with an interconnected, systems-based understanding, emphasizing the internal structure of this view of their farms. The results of these metrics for industrial farmers, in contrast, demonstrated less engagement with systems thinking skills, leaning toward linear thinking and viewing their farm systems in terms of inputs and outputs. This is understood as a more externally focused structure as their cognitive maps accounted for less internal outcomes. These results of these metrics lend credence to previous research that has suggested regenerative farmers engage in systems thinking (J G Arbuckle & Roesch-Mcnally, 2015; Bossange et al., 2016; Brummel & Nelson, 2014; Church et al., 2020; Kennedy et al., 2016; Roesch-Mcnally, Gordon Arbuckle, et al., 2017), but through the comparison with industrial farmers, has also suggested regenerative farmers demonstrate greater engagement in systems thinking than industrial and transitioning farmers.

Table 5.1 Mean index values for Complexity Index and Flow-Hierarchy Index per group.

| | Complexity Index | Flow-Hierarchy Index |
|---|---|---|
| Regenerative | .69 | .65 |
| Transitioning | .4 | .82 |
| Industrial | .19 | .71 |

### 5.4.2 Feedback loops

Beyond differences in systems thinking complexity demonstrated in the cognitive maps through the network analysis metrics, we analyzed the feedback loops present in the cognitive maps across groups as feedback loops are key part of systems thinking and a way to differentiate a more internal or external focus within a mapped system (Arnold & Wade, 2015; Meadows, 2008; Williams et al., 2017).

The presence of feedback loops within the cognitive maps across groups was fairly consistent (12/16), with 4/6 regenerative farmer maps containing at least one feedback loop, 2/4 transitioning farmers, and 6/6 industrial farmers. On average, regenerative farmers had the most feedback loops present in their mapped systems at 12, with industrial farmers cognitive maps averaging 7 feedback loops per map and transitioning farmers just 4 feedback loops per map. Feedback loops communicate the interconnectedness of a system and demonstrate that relations in a system are reciprocal. As such, the more feedback loops within a system, the more internal the structure. Maps from each group of farmers contained feedback loops, and given that systems thinking skills exist on a spectrum of less to highly developed, this is not surprising (Draper,

1993; Stave & Hopper, 2007). However, regenerative farmer maps, on average, had the highest number of feedback loops per map, again suggesting more developed systems thinking skills and a more internalized system structure when compared to the other groups of farmers.

Notably, the two regenerative farmers whose maps did not contain any feedback loops had the highest and the fourth highest scores on the Complexity Index out of all the farmers interviewed, meaning these maps still demonstrated an internal focus as higher scores on this index indicate a cognitive map accounts for more outcomes internal to the system. This lack of feedback loops in conjunction with higher Complexity Index scores is likely due to these two farmers' cognitive maps containing factors that were more specific than those included in the other farmers' cognitive maps. For example, where many farmers had a *soil health* factor as a part of their mapped system, these two farmers not only included *soil health* but also factors such as *soil armor*, *diversity of soil biology*, *mycorrhizal fungal communities*, *living roots*, *soil aggregation*, and *nutrient cycling*. Many of the regenerative farmers who mapped a single factor for soil health discussed these more specific aspects of soil health when explaining the relationship between *soil health* and other factors on their maps, even though they chose not to map these factors directly. As these two farmers without feedback loops chose to add these more specific factors related to soil health to their maps, many connections that would have created feedback loops if these factors were housed under a single concept of soil health were diverted to these other factors, leading to maps that had zero feedback loops but still high Complexity Index scores.

While the network analysis metrics and the presence of feedback loops in the cognitive maps demonstrated a more internal focus for regenerative farmers and a more external focus for industrial farmers, the specific maps factors that were a part of the feedback loops also revealed a

divergence between the groups. The map factors that comprised the feedback loops in industrial farmer maps were more external and human driven while the regenerative farmer maps were internal and ecologically driven. The feedback loops in regenerative farmer maps notably included *soil health* more than any other factor. For one regenerative farmer map, all 22 feedback loops present in their map included *soil health*. This finding aligned with previous work that found regenerative farmers centralized soil fertility and soil biodiversity as map factors in their farm systems (L. Soto et al., 2021a). Other factors common in regenerative farmer feedback loops were *management practices* and *animal health*. The factors *soil health* and *animal health* clearly centered ecological aspects of the farm, suggesting regenerative farmer systems reflect the core tenets of RA described in the literature (Brown, 2018; Khangura et al., 2023; Newton et al., 2020). This is further demonstrated by the presence the *management practices* factor. As the cognitive maps were from regenerative farmers, the management practices being referenced were those in support of the RA principles. This means all the most common feedback loop factors for regenerative farmers centered ecological aspects and processes within the farm system, not only emphasizing ecology but an ecology internal to the farm.

In contrast, industrial farmers' feedback loops most often contained the factors *profit, labor*, and *markets*. This finding is supported by previous work that has also found industrial farmers centralize profit and income in their cognitive maps (Tessier et al., 2021). These factors expressed a human driven, business-oriented system focus. *Labor* was the clearest example of human driven focus, but *profit* and *markets* demonstrated a business orientation that prioritized highly external social structures such as the global grain and cattle markets referenced by the *markets* factor. Further, the business orientation indicated by these factors suggests industrial

farmers view their farm systems in a more human context, particularly when compared to the ecological focus of the regenerative farmer cognitive maps.

Lastly, only 2/4 transitioning farmers' cognitive maps contained feedback loops. Notably, the circumstances found in the regenerative farmer maps without feedback loops were not found in the transitioning farmer maps without feedback loops. While one of these farmers had a high Complexity Index score (third highest of all farmers), the other had an average score, and neither of their maps used highly specific map factors that may have diverted feedback loops. Of the transitioning farmer maps with feedback loops, factors within the loops aligned with both regenerative (*soil health, reduce synthetic inputs*) and industrial (*profit, labor*) farmer maps.

Given that feedback loops expose interconnected causal relationships throughout the system, factors that are heavily present in feedback loops are highly consequential to the system. Because of this, the differences in the factors found in the feedback loops of regenerative and industrial farmers pointed to differences in their systems at large, particularly along the internal-external and human-ecological axes.

### 5.4.3 Map factors — as mapped

Beyond themes found within the factors included in feedback loops, the factors included and excluded in farmers maps further distinguished farmer groups along the axis of internal to external. Industrial farmer maps often included factors such as: *advisors/consultants, government policies/regulations, and crop insurance*. All these factors were depicted as driver factors and each exist beyond the immediate farm boundary or local context. For example, *advisors/consultants* were actors from outside the farm that advised about farm operations, and *government policies/regulations* and *crop insurance* are both decided at a state or federal level,

much beyond the farm. Further, these factors human driven and a part of social structures within farming.

Regenerative farmers' cognitive maps again depicted a more ecological and internal focus, a focus on factors within the farm. Regenerative farmer maps often included factors related to farm biodiversity (*wildlife, plant and animal biodiversity*), soil health (*soil armor, nutrient cycling, soil biology*), and farmer education (*knowledge, observation skills, education*). These factors each operated within the boundaries of the farm, with the farmers themselves through education or through the biodiversity and soil health practices meant to improve farm ecosystem function. Further, these factors functioned as ordinary factors, both influencing and being influenced by other factors within the system.

The internal versus external emphasis differences between regenerative and industrial farmer maps was observed in the way a singular variable functioned differently within the different groups of farmers' maps. For example, the factor *weather/climate* was present in 13 out of 16 farmer cognitive maps, however, this factor functioned differently within the farm systems depicted from group to group. All industrial farmer maps (n=6) included *weather/climate*, and for all these maps, this factor was a driver factor, a factor that only influences other factors and is not influenced by any map factors in return, depicting *weather/climate* as an external influence. For transitioning farmers (n=4), all maps included *weather/climate*, with two farmers drawing it as a driver factor and two drawing it as an 'ordinary' factor, one with both in-going and out-going connections. Lastly, of the regenerative farmer maps (n=6) only three had the *weather/climate* factor, with the remaining three regenerative farmer maps not identifying it as relevant to their farm systems. Out of the three regenerative farmer maps including *weather/climate*, one drew it as a driver factor while the other two drew it as an ordinary factor.

Notably, for the majority of instances of *weather/climate* being influenced by another factor, both in regenerative and transitioning farmer maps, *weather/climate* was depicted as being influenced by *soil health*. Further, industrial farmers drew *weather/climate* as the most influential of all the groups, average seven connections from *weather/climate* to other map factors per map. Transitioning farmers averaged three connections per map, and regenerative farmers just two.

The comparison of how *weather/climate* functions in the systems of industrial and regenerative farmers accentuates the external-internal divide. However, this difference found within the role of a single factor emphasized how the focus and orientation of a system can greatly influence how even a seemingly straightforward map factor functions within a farm system. Here, industrial farmers viewed *weather/climate* as an external factor that had influence over many aspects of their farms. But regenerative farmers viewed *weather/climate* as less influential and capable of being influenced by other factors in the farm system, particularly soil health. Regenerative farmers viewed the ecological factor *weather/climate* as embedded within their farm systems instead of as an external threat, and this was only for regenerative farmers who viewed *weather/climate* as important enough to even include in the cognitive maps at all.

### 5.4.4 Map factors – as discussed

Looking more closely at the *soil health* factor, the divergence along the human-ecological axis between the groups of farmers is even more apparent. Many of the cognitive maps (13/16) included a factor related to soil health. Most maps included a factor explicitly titled *soil health*. However, some industrial and transitioning farmers used the factor name *soil fertility* but as these farmers referenced the factor as both "soil health" and "soil fertility" interchangeably throughout the interview, they were included in this discussion of soil health factors. Soil health played a distinct role in the farm systems from group to group. The figure below (5.2) shows all in-going

and out-going connections for soil health factors, grouped by regenerative (R), transitioning (T), and industrial (I) farmer maps. Connections where soil health was influencing another factor (out-going) were shown with purple arrows, while connections where a factor is influencing soil health (in-going) were shown with green arrows. The number of arrows between soil health and another factor indicate how many farmer maps drew said connection (Figure 5.2).

Industrial farmer maps had the fewest connections to and from soil health, with the main factors connected to soil health being *profit*, *labor*, and *advisors*. These factors were similar to those found in the industrial farmer feedback loops, demonstrating a human, business-oriented focus within industrial farmer systems. The addition of *advisors* further underscores the external, human focus of the farm as advisors are hired from off-farm.

The regenerative farmers' maps stood in stark contrast to industrial farmers' when looking at how soil health was embedded in the farm systems represented. There was a clear increase in the number of factors connected to soil health and the strength of the connections (the number of arrows connecting a factor to soil health) in regenerative farmers' maps. However, the types of factors connected to soil health were also distinct. Many of the factors connected to soil health were ecologically focused: *weather/climate, plant and animal diversity, water quality, community environmental health*. Further, a subset of factors was specifically focused on the soil ecosystem: *soil armor, nutrient cycling, erosion reduction, soil biology diversity, synthetic input reduction*. *Management practices*, *grazing,* and *knowledge/education* were also unique influencing factors to soil health in regenerative farmer maps. Management of practices that support RA principles prioritizes ecological processes. Grazing was discussed in terms of grazing management to ensure grazing practices were in alignment with broader ecological goals of the farm. Lastly, knowledge/education was referenced as continued efforts to learn more about

soil health and RA practices. These factors connected to soil health all worked to move the system toward a state of better ecological function, but specifically ecological function internal to the farm.

Soil health in transitioning farmers' systems was similar to industrial farmers, including the factors *profit* and *advisors*. However, transitioning farmer maps also connected ecological factors to soil health, such as *biodiversity* and *weather/climate*, and included the factor *management practices*, all factors strongly related to soil health in the regenerative farmer maps. This finding is not entirely surprising. However, transitioning farmers being situated in the middle of the human-ecological axis supported our observations of the differences found between regenerative and industrial farmer cognitive maps.

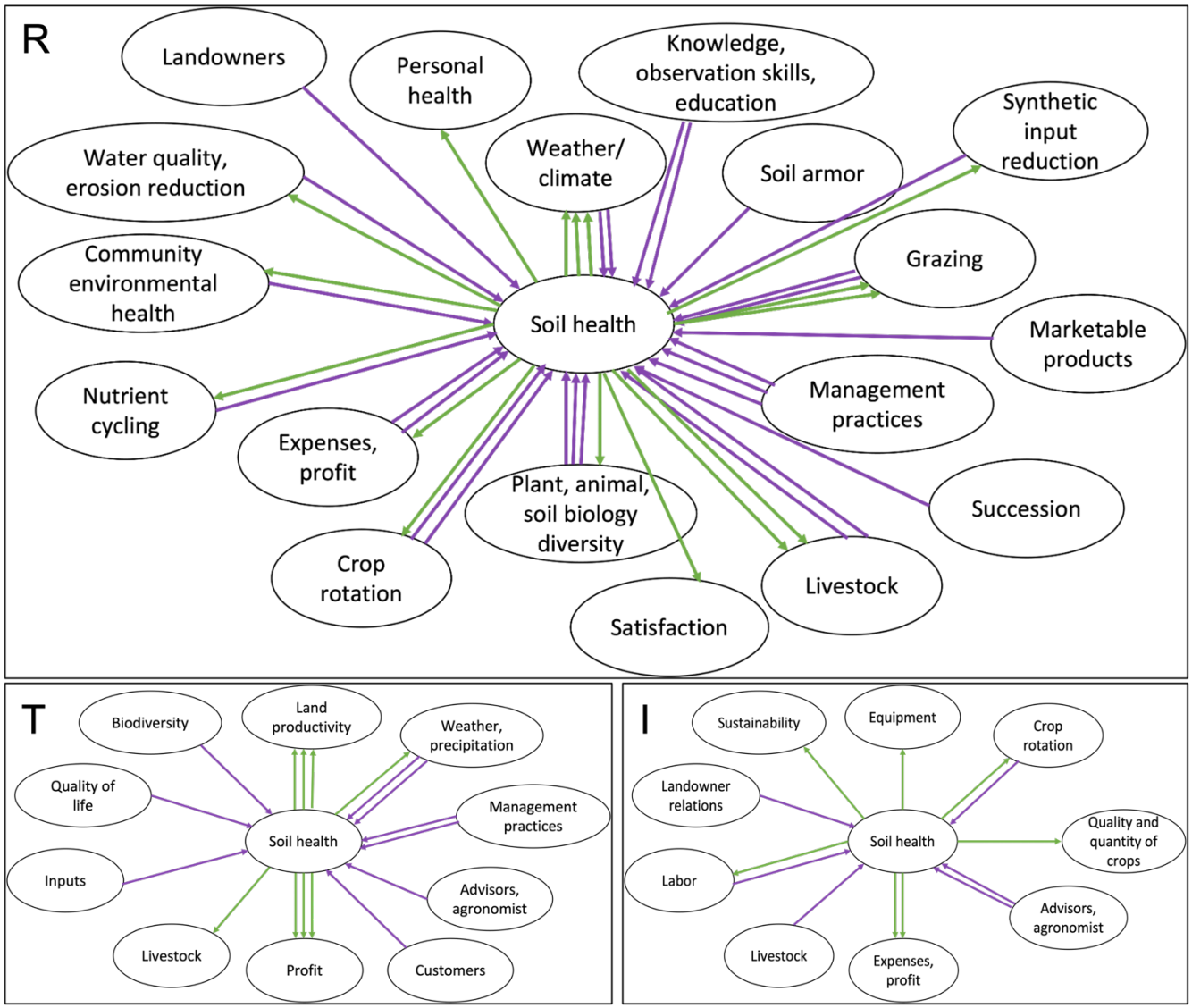



Figure 5.2 All in-going and out-going connections for soil health factors, grouped by regenerative (R), transitioning (T), and industrial (I) farmer maps are shown. Connections where soil health was influencing another factor (out-going) were shown with purple arrows, while connections where a factor is influencing soil health (in-going) were shown with green arrows.

These differences in the role of soil health within farm systems between groups were also found in the way farmers spoke about soil health during the discussion of their cognitive maps. Regenerative farmers explicitly expressed the importance of soil health to their farm systems.

This regenerative farmer put it plainly: “I think this idea of soil health or the health of the land itself is the basis for the whole farm.” Another regenerative farmer when explaining his reluctance to engage a practice what would require harvesting at night said: “I may have a preconceived notion that [the practice] doesn't work ‘cause it's not gonna let me sleep. It might be the best thing for that ground, and it has to be not what I want to do, but what the soil needs.” Another regenerative farmer when asked to discuss his cognitive map started by saying he “built it around the soil” and later in the discussion that, “Taking care of the soil is essential. It’s gonna take care of us.”

Regenerative farmers also discussed soil health in the context of biology, farm resiliency, biodiversity, and ecological processes. Regenerative farmers discussed improving soil health as a biological process, referencing the increase of “soil bugs” and “soil microbes” and the improvement and protection of “mycorrhizal fungal communities” and “microbial communities”. Regenerative farmers spoke about improved soil health as a way to build resiliency to unfavorable weather conditions. This relationship was expressed a soil health creating a “buffer” to harsh weather, improving farm ability to “withstand” unfavorable weather, and increasing farm “flexibility” in regard to changes in the environment. Regenerative farmers also talked about building soil health as a way to improve ecological processes on the farm. For example, one regenerative farmer explained it:

> “The more diverse our farm can be, the more we're gonna impact soil health. We can have a more diverse web of life, and then that also is able to support greater soil diversity and more wildlife. And we're including in wildlife, more than just the big macro species.

> We're including biology, soil biology populations, bird populations, insect populations, badgers, deer, raccoons, snakes."

Another regenerative farm even struggled to describe soil health as he viewed it as interconnected with other ecological aspects of his farm stating:

> "To me my farm is this constant interplay between me and the physical beings around here. So I think of that as the environment, the soil, what's growing on it, the animals that are here, the land… it is kind of embodied all together."

Many of these sentiments were explained comprehensively by one regenerative farmer:

> "You know, when the neighbor asks, 'how much rain did you get?' The answer needs to be all of it. Every drop that falls on my farm needs to not move more than an inch. I mean, it needs to infiltrate. And so I need the soil aggregation, the pore space, the soil structure to take in all that moisture and not let a bit of it run off. And then I need the soil armor to keep my soil cool and allow me to hang onto that moisture in the profile, to bridge those 6, 7, 8 week gaps between rain events in the summer… So if you can slow down the speed at which raindrops hit the soil, you can prevent crusting, and you can improve infiltration. You can also slow down the evaporation. So, you're gonna keep more water in the soil. But then you're also going to transpire it out through plants. So it's, in a way, it's stretching out the water cycle rather than having it all run down the river right away."

In this quote, the farmer touches on other sentiments expressed by regenerative farmers. He discussed the importance of crop residue decomposition (soil armor) for building resiliency to dry weather and the multiple aspects of soil that are important for soil function. However, the farmer demonstrated how ecological processes, such as the water cycle, are embedded in regenerative farms. Here, he discussed the water cycle not as an external ecological process occurring out of the farmer's control, but as a process that could be manipulated and bent to the farmer's benefit specifically through the improvement of soil health. The discussion of soil health among regenerative farmers expressed an ecological focus within their systems, with soil health at the center, but specifically an internalization of broader ecological processes within their farms.

Industrial farmers spoke about soil health quite differently from regenerative farmers. While we have already seen how soil health connected to different factors in industrial farmer maps compared to regenerative farmer maps, these differences were also observed in conversation. Industrial farmers discussed soil health exclusively in terms of soil chemistry and soil erosion and associated these characteristics with labor and profits. Industrial farmers often cited using soil testing, an evaluation of their overall soil health, specifically referencing testing for nitrogen and Ph levels. These soil tests were either conducted themselves or through agricultural advisors, as a means of determining the amount synthetic fertilizer and herbicide application to keep costs of inputs as minimal as possible. These conversations showed an interpretation of soil health that centered soil chemistry as opposed to soil biology, as the testing was done to determine soil chemistry and synthetic fertilizers are chemical additives to the soil.

Labor was often tied to this process referring to the time and energy required to apply the necessary synthetic inputs recommended from soil testing results.

Industrial farmers also discussed soil health in terms of reducing soil erosion through no till practices. One farmer explained that the most important part soil health was having the no till equipment. Further, another industrial farmer explained how this view also extends to landowners of rented land:

> "[Landowners] don't want to be out seeing their ground blow or something like that, you know. I've got messages where I sent pictures. I've got some neighbor's stuff that's blowing really bad, and ours is sitting and tight and firm, and they appreciate that."

This context from industrial farmer interviews underscored how industrial farmers' systems prioritized human activity and business operations, through viewing soil health as a means for reducing costs and labor, maximizing profit, and maintaining good relationships with landowners. Further, the view of soil health from the industrial farmers' perspectives again emphasizes the way their systems repeatedly engage and prioritize external factors such as advisors and landowners.

While industrial farmers were not explicit in stating the centrality of profit within their farm systems as regenerative farmers were with soil health, their business orientation and the prioritization of profit was implicit in their discussion of the cognitive maps. While this was seen through the discussion of soil health as a concept and its implications in the farm systems of industrial and regenerative farmers, this was also seen in the discussion of cover crops.

For example, many industrial farmers had experimented with using cover crops, but their reasoning for when and why they chose to plant cover crops demonstrated a clear financial motivation. Industrial farmers viewed cover crops as a potential cash crop, a means of reducing herbicide costs, and a low-cost approach to feeding cattle. Further, industrial and transitioning farmers emphasized the importance of not utilizing cover crops in years of less precipitation for fear of the cover crop using vital soil moisture that is needed for the main cash crop, with multiple farmers saying cover crops "suck out the moisture" from the soil. As an industrial farmer described his perspective on cover cropping:

> "[Cover crops] can help you with expenses because summertime burn down expenses—herbicide applications—get expensive. And it goes back to being in a wet year. If you're wet, that cover crop will actually be cheaper than spraying herbicide all summer."

Another industrial farmer further comments on his motivations for cover cropping while also demonstrating how even the practice of cover cropping can be interpreted flexibly from farmer to farmer:

> "I like to plant double crop milo because, you know, if you can get 50-70 bushel of yield off of double crop milo and then you can also graze that in wintertime. To me, that's a cover crop. Get some cash out of it as well, you know, and utilizing cows with the cover crop. That's how to make those profitable."

These perspectives on cover crops emphasized maximizing profit from the practice but also minimizing risk to other profitable parts of the farm (main cash crop). Regenerative farmers, whose maps centralized soil health, discussed cover crops differently. While regenerative farmers noted similar benefits for cover cropping as industrial farmers, such as reduced herbicide usage and grazing, these benefits were framed as helping meet soil health goals and RA principles. One regenerative farmer explained cover crops as tool to not only reduce synthetic inputs to reduce expenses, but as a way to eliminate synthetic inputs from his system completely:

> "[My dad's] goal with cover crops is to reduce the herbicide load. And that's also my goal. But my goal is also to reduce the synthetic fertilizer inputs. So my 5 year goal is to not use any more synthetic fertilizers. Reducing herbicide is much more difficult, in my opinion, than fertilizers and so I guess you could say that's my 10 year goal."

Another regenerative farmer commented on cover crops being a key part of the farm system:

> "We went no till in 2013, but we didn't understand a couple of things: we didn't understand the importance of residue and soil armor, and we didn't understand how you need the cover crops to make the whole system work."

Lastly, a transitioning farmer who rents most of his land commented on the sentiment that cover crops deplete soil moisture necessary for the cash crop and how prioritizing soil health contradicts this sentiment:

> "Among older landlords, and certainly older family members, there was this idea of storing up moisture, and I don't think our climate allows that mentality anymore, because we don't know when the dry spells are gonna be a summer one or gonna be a winter one. We really don't know. And all you can do- if you believe in soil health is the most important thing for the land- is just keep planting, and when it works it works."

While the focus of regenerative farmer maps and industrial farmer maps differs, this does not mean that regenerative farmers do not consider profitability or that industrial farmers do not consider soil health. Both factors were common across maps from each farmer group. However, this difference in focus represented a difference in prioritization within the farm system or a difference in the goals of the system. One regenerative farmer explained this well:

> "I think one of the things that really impresses me most about regenerative ag is just based upon principles and not upon practices. So you have these principles about keeping the ground covered, about biodiversity, about living roots, less disturbance, incorporating livestock, and those sorts of things, but it may be different for every field. You might make a decision, but if you have those principles in mind, and how you can maintain the principles to make the decision, that's gonna probably be best for whatever you need to do for profitability."

These differences of system foci and priority connected to how concepts and practices were operationalized with farm systems. This was observed with the factor *soil health* and the diverging roles it played in regenerative and industrial farmer maps. But this is also observed

even more clearly with the practice of cover cropping. Industrial and regenerative farmers view cover crops in two distinct ways, but this view, as dictated by their system focus or orientation, connected to how each group of farmers engaged with cover cropping on their farms. For example, regenerative farmers used cover crops every year and on all their crop acres, often using a crop mix instead of a single crop. However, many of the industrial farmers had tried cover crops in the past but did so in a different way. Industrial farmers often stated only using cover crops in a year with what they perceived to be adequate precipitation, only planting cover crops on a small fraction of their crop acres, and often planting a single crop. This difference in the operationalization of cover cropping demonstrated how engaging a practice in and of itself does not align farmers in their approaches. How farmers engage a practice can vary, and we found this variation to align with differing farm systems orientations. This finding is further supported by a regenerative farmer who discussed their process of transitioning from industrial to regenerative agriculture and how this changed how they engaged in cover cropping:

> "And I started with cover crops a long time ago. I would plant them where they met my needs not necessarily where they met the soils needs. So you know, I would use them just in a couple of places where I could graze livestock. So I mean I was doing that right, although I was way over grazing the cover crop. But then everything else about it, I did completely wrong. You know it was still for my needs, not for the soil's needs."

Through this quantitative and qualitative analysis we found distinct differences in how industrial and regenerative farmers view their farm systems, both along an external to internal axis and a human to ecological axis. Regenerative farmers' cognitive maps demonstrated greater

engagement in systems thinking and more internal structures, while also prioritizing internal and ecological factors, resulting in cognitive maps that primarily depicted internalized ecological systems leveraged for human (farmer) benefit. Industrial farmers' cognitive maps demonstrated less engagement with systems thinking and had more linear, top-down structures. Their maps prioritized factors that were external to the farm but also that prioritized human driven factors, particularly those related business, resulting in cognitive maps that primarily depicted human systems supported by ecological services. Transitioning farmers were found in the middle of these two axes, with systems that demonstrated qualities of both regenerative and industrial farmer cognitive maps, while also engaging in less systems thinking than both other groups by some measures. Perhaps most importantly though, the results showed that these differences in system focus did not preclude industrial and regenerative farmers from including similar factors on their maps or even engaging in the same practices. This indicated that a difference in system focus or orientation, clearly demonstrated by the cognitive maps, influenced the way farmers conceptualized and operationalized shared concepts and practices within their farm systems from group to group. This suggests that the defining quality of regenerative farmers may not be the practices they engage but how they view their farms on a systems level, and that RA adoption rests not in a change of practices but in a reorientation of the farm system.

## 5.5 Conclusion

Climate change is predicted to have damaging effects on agriculture across the Midwest, threatening the future of farming in the region (Angel et al., 2018; Conant et al., 2018; Gowda et al., 2018; Mastrandrea et al., 2015). Industrial agriculture not only contributes to climate change but also to broader environmental harm (Evans et al., 2019; Foley et al., 2011; Power, 2010b; Tilman & Clark, 2014). RA has been proposed as an alternative to industrial agriculture that can

reduce environmental harm while also building farm resiliency to future changes in climate, making the adoption of RA practices of particular interest (Newton et al., 2020; L. R. Soto et al., 2021). Our understanding of the factors that motivate adoption of RA is still limited, but recently systems thinking has been linked to engagement of RA farming practices (Ranjan et al., 2019).

Our results align with previous research findings connecting regenerative farming with systems thinking, but our work also suggests that industrial farmers engage less with systems thinking in comparison, making systems thinking a skill somewhat unique to regenerative farmers. Our results do not reveal whether regenerative farmers develop systems thinking skills after or through the process of adoption, or if farmers with more developed systems thinking skills naturally gravitate toward RA. However, regardless, this finding suggests that systems thinking plays a vital role in regenerative farming and it will continue to be a focal point of RA adoption research.

The differences found in systems orientation between industrial and regenerative farmers could mean that when working with farmers to encourage adoption of RA, changing a farmer's systems focus may be more important than changing their practices, as system focus is connected to *how* farmers engage a practice. This finding resonates with other work that found regenerative farmers often cited a change in mindset when transitioning to regenerative farming (Gosnell, 2022).

This study was limited its ability to investigate transitioning farmers. These farmers often aligned with characteristics of both industrial and regenerative farmers, but with only four farmers in this category, patterns and themes were challenging to find. This could be due to the nature of transitioning from industrial to regenerative agriculture. The process of transitioning spans years and can look different for each farmer, particularly depending on their starting state

and how they choose to implement the RA practices. With clear differences in the farm systems orientations between regenerative and industrial farmers, future research will need to focus on the diversity of transitioning farmers' systems to understand how farmer systems move from industrial to regenerative.

# Chapter 6 – Conclusions

Climate change, environmental degradation, and a growing human population have put sustainability research at the forefront of science in the last two decades. Identifying approaches to not only balance the competing needs of both human and natural systems, but to, as a start, understand the feedbacks between these systems has become of the utmost importance for the future of our planet. Sustainability science emerged in the early 2000s, distinguishing itself from prior sustainability research approaches by engaging in a systems approach (Clark & Dickson, 2003; Spangenberg, 2011), combining both theoretical and applied sciences (Bettencourt & Kaur, 2011; Clark, 2007), working to coproduce knowledge through transdisciplinary research including the collaboration of scientists, stake-holders, and practitioners (Clark & Dickson, 2003), and engaging these research goals over time and space (Kates et al., 2001; Spangenberg, 2011). However, this approach to sustainability issues is by no means straightforward. It is messy and complex, and it acknowledges that sustainability issues cannot be 'solved' as systems are dynamic, but that we can still try to better understand coupled human-natural systems and improve their ability to exist and endure over the long-term.

Sustainability issues can be understood as wicked problems, problems that do not have a clear, singular solution and require the problem to be addressed from multiple perspectives (Churchman, 1967; Rittel & Webber, 1973), again requiring a multidisciplinary, interdisciplinary, or transdisciplinary research approach. These approaches, in their simplest form, require the bringing together of research from several disciplines on a single research project through the collaboration of scientists in varying fields, and at their most complex they require the integration of data, methods, theory, and concepts from multiple disciplines but in such a way that it generates new paradigms and ideas, and even promotes the development and

emergence of new fields of study (National Council Research, 2014). However, even the seemingly most achievable of these approaches is still challenging for researchers in academia, let alone for a doctoral student conducting dissertation research that must be completed independently, aside from the advisory committee. Regardless of the challenges, though, wicked sustainability issues need the dedicated attention of the scientific community, requiring the training and expertise of interdisciplinary and eventually, hopefully, transdiscinplinary scientists.

This dissertation was an attempt to engage the level of scientific diversity required of sustainability science, focusing specifically on issues within agriculture and rural sustainability. Through leveraging interdisciplinary training, by seeking mentors of diverse academic backgrounds, and drawing on research and methods from various disciplines, the research in this dissertation took a step toward the interdisciplinary approach called for in complex, coupled human-natural systems, such as those found in agricultural and rural sustainability research. The research in this dissertation engaged science *for* sustainability, the approach within sustainability science that recognizes the limitations of academic institutions, by conducting three independent research projects that fell under the umbrella of agricultural and rural sustainability, each employing distinct methods, drawing theory from various disciplines, and analyzing at problems at different scales, ultimately contributing to our broader knowledge of sustainability issues, while not fullying engaging in the inter- and transdisciplinary approach called for in sustainability science.

## 6.1 Summary of key findings

Below is a summarization of key findings and conclusions from each of the unique research projects presented in this dissertation.

### 6.1.1 Key findings in Chapter 3

In chapter three, we investigated how the physical water environment shapes water conservation norms among farmers in the High Plains-Ogallala Aquifer, the largest source of groundwater in the United States. These questions were approached in terms of cultural adaptation to the physical environment, comparing irrigators with dryland farmers using survey and environmental data. We employed grouped simultaneous equations models using the values-beliefs-norms (VBN) framework to develop a conceptual model to integrate the physical water context as an exogenous explanation of water conservation norms. A dataset that linked physical environment data with social data derived from a region-wide survey was used for analysis. The measures used to represent the physical water context for this study were the Palmer Drought Severity Index (PDSI) (Palmer, 1965) and well capacity. The social data included data on values, worldviews, climate change beliefs, and water conservation norms.

Findings demonstrated that the physical water context influences water conservation norms among farmers in the High Plains-Ogallala aquifer region, and that the effects of the physical water context vary between dryland operators and irrigators, who perceive, and are motivated to conserve water in different ways. Dryland operators and irrigators hold stronger water conservation norms in wetter contexts, and weaker water conservation norms in more arid contexts. However, while this was a mostly a direct effect from the physical water context to water conservation norms for dryland operators, for irrigators the effects were indirect and mediated. Irrigators in more arid regions held more eco-centric worldviews, which implied stronger adaptive capacities, that in turn, translated into stronger water conservation norms. This indicated limited cultural adaption as irrigators more strongly believe that water should be saved as they have less water. However, as farmers felt more strongly compelled to conserve water

where there was more water to conserve, and they felt less compelled to conserve water where there was less water to conserve, these findings could be considered evidence of mal-adaptation. If water is vital for survival, as it is for all biological organisms, then it should be expected that humans would conserve water in more arid contexts and that conservation would be weaker in wetter contexts.

This research project integrated environmental and social data to investigate the relationship between the environment and culture, ultimately demonstrating that the ways environment influences culture among farmers in the High Plains- Ogallala aquifer region, adding to our knowledge of coupled human-natural systems. Given the importance of the High Plains-Ogallala aquifer for agriculture in the United States, understanding the complex web of relationships between the physical environment and water conservation norms, or natural and human systems, improves our ability to address agriculture sustainability issues in the region.

### 6.1.2 Key findings in Chapter 4

In chapter four, to better understand the consistency, or lack thereof, across different quantitative rural measures, we compared four common measures applied at the county level for the contiguous United States. Much research in rural sustainability has highlighted many of the unique challenges faced by rural places. Recognizing these unique challenges, federal and state governments have employed a variety of policies and programs to improve rural sustainability. However, many measures of "rural" exist but often these measures emphasize different dimensions associated with how we perceive rurality (Long et al., 2021). This has left politicians, policymakers, and researchers inundated with a wide array of measures that define what and where "rural" is very differently and often with significantly different results. To illustrate and better understand the inconsistencies associated with using different measures of rurality, this

study employs four common measures or approaches from both government agencies and the literature to identify rural counties in the contiguous United States. Our purpose was to (1) quantify and map the degree of rural agreement among these selected rural measures and (2) describe key characteristics of counties classified as rural through urban.

The results showed that the selected rural measures varied widely in their classifications of rural counties. In terms of population, 54.3 million lived in rural counties based on the Urban Rural Density Typology measure while only half a million people were in rural counties according to Index of Relative Rurality. Further, different measures yielded little agreement on rural places with consensus of only 114 of 3,108 counties. The counties that were classified as rural by all measures were characterized by low population density, a high percentage of the population aged 65 years or older, and a high percentage of the population employed in agriculture, forestry, hunting, or fishing as compared to manufacturing. The landscape of these counties included minimal urban development with predominant mixtures of agricultural landuses and grassland, but limited forested landcover. Lastly, when conducting pairwise comparisons, the consistency in classification even when only comparing two of the four measures at a time was generally low. These findings not only emphasize the lack of consistency and agreement between measures' classifications of rural counties, but also demonstrate, through the pairwise comparisons, that the limited agreement among the four measures is not the result of a single measure skewing the results as there is limited persistence in pairwise comparisons as well.

As discussed in Chapter 2, rural sustainability suffers from a lack of consensus among researchers as to what defines rural sustainability, stemming from a lack of consensus surrounding both the definition of 'rural' and 'sustainability' (Nelson et al., 2023). This work

added to our knowledge of how quantitative measures of rural, which bring with them implicit definitions of rurality, vary in where and who is counted as 'rural' or not. As such, this work calls attention to the importance of researchers coming to a consensus regarding the definition of rural, or at the very least, explicitly and intentionally stating their definition of rurality, aiding our ability to compare research in rural sustainability and more easily measure progress in the field.

### 6.1.3 Key findings in Chapter 5

In chapter five, the process of regenerative agriculture adoption was examined. To address the negative environmental impact of industrial agricultural practices, research has been dedicated to the adoption of regenerative agriculture (RA) as it has been shown to reduce agriculture's overall contribution to climate change and prepare farms for future changes in climate. The adoption of RA practices has been linked to systems thinking, with farmers employing regenerative farming practices reporting higher engagement with systems thinking. This study interrogates this relationship further by examining how farmers industrial and regenerative farmers demonstrate systems thinking skills. To do this, we collected sixteen cognitive maps of individual farm systems through qualitative interviews with farmers in central Kansas. We then used these cognitive maps to compare systems thinking skills across farmers employing practices along the spectrum of industrial to regenerative.

The findings showed regenerative farmers demonstrated more developed systems thinking skills when compared to industrial farmers, as indicated through a higher average Complexity Index score, lower average Flow Hierarchy Index score, and greater presence of feedback loops within their farm system cognitive maps. Further, regenerative farmers' cognitive maps prioritized internal and ecological farm factors, particularly soil health, as demonstrated

both by the centrality of soil health in their cognitive maps and feedback loops, but also in their discussion of their maps, frequently citing the importance of soil as the foundation of their farms. Alternatively, industrial farmers' cognitive maps prioritized external and human driven farm factors, often centralizing profit, markets, and labor. This was expressed explicitly in their drawn maps and implicitly through conversations surrounding the motivation behind using various sustainable agriculture practices.

As the scientific community works toward addressing issues of agriculture sustainability, understanding the how and why farmers adopt sustainable practices is extremely relevant. This research project investigated the process of regenerative agriculture adoption, adding to our knowledge of agriculture sustainability, but it also did so through a systems lens. By leveraging cognitive maps to examine systems thinking in farmers, not only did we learn about the differences in how industrial and regenerative farmers demonstrate systems thinking skills, but we also gained insight as to how farmers view their farm systems and how they view their farms in the broader agriculture system.

## 6.2 Future directions

### 6.2.1 Agricultural and rural sustainability

The research presented in this dissertation has practical applications for outreach. This research can be leveraged to improve communication and collaboration efforts with farmers, rural community members, and other agricultural and rural stakeholders. Many academic disciplines contribute to agricultural and rural sustainability issues, each desiring to offer potential solutions using the skillsets unique to their fields of study. However, difficulties when transferring the results or outputs of such research to real world settings are common, with issues often arising when attempting to get these groups to adopt new technologies or approaches. The

research presented in this dissertation emphasizes the need to understand the context in which farmers are making decisions, both the physical context of the environment but also the context of their farm systems. The results of this research suggest we need to challenge our underlying assumptions about what farmers and rural community members need from research by speaking to these groups before we conduct our research, not just after the research is completed. By doing so, we can create a collaborative environment that prioritizes the voices of the people and communities we seek to help while also improving the ability of our research to actually be implemented and adopted into real world settings. Further, this work emphasizes the need for a diversity of voices and perspectives from these communities to be present for these conversations, as this research demonstrates that different groups of farmers thinking differently about resource use and agricultural practices.

### 6.2.2 Interdisciplinary science

The research presented in this dissertation centered around agriculture and rural sustainability, areas of research under sustainability science. Sustainability science requires inter- and transdisciplinary work that draws together theory and methods from various fields of study to better understand sustainability issues within the human-nature systems that make up our planet, attempting to learn the interconnections and feedbacks between various parts of the system instead of only isolated relationships (Clark & Dickson, 2003). The call for sustainability science research is aimed at not only accepting but embracing the messy complexity of sustainability issues by working to understanding a system as a whole, ultimately in hopes that through knowledge of feedbacks and system connections, consequences of proposed solutions can be more appropriately evaluated, getting us closer to a system that can be sustained over the long-term (Spangenberg, 2011).

However, this goal is ambitious at best, and seemingly impossible at worst. Given that the historic structure of academic institutions has prioritized isolated research within one's discipline, a science founded on inter- and transdisciplinary work is exceedingly difficult to achieve (Siedlok & Hibbert, 2014). While progress has been made in this regard as increases in multidisciplinary and interdisciplinary research have been observed (Porter & Rafols, 2009), this challenge remains for graduate students seeking to be sustainability scientists. Graduate students must complete the research for their degrees independently, aside from their advisory committees, often making collaborative work with other graduate students or researchers not eligible for inclusion in their dissertations. As graduate students usually have funding for a limited amount of time, engaging in research that does not contribute to their dissertations and takes time away from research that moves them closer to graduation, there is a clear disincentive to participate in interdisciplinary research.

The research presented in this dissertation was science *for* sustainability, an approach to sustainability science that recognizes many researchers are limited in their ability to participate in inter- and transdisciplinary work. The research was completed within a single discipline but drew on methods and theory from multiple areas of study, investigated different topics, and examined phenomena at various scales. However, even this small attempt at working toward a more interdisciplinary-adjacent dissertation was only achievable under specific circumstances. This dissertation took over five years to complete. This was for many reasons, but a major contributing factor was that accumulating and integrating knowledge from different disciplines to the point of understanding sufficient for a doctoral researcher takes a significant amount of time and energy. Being able to take the time needed to conduct three very different research projects was a privilege afforded to me by having five years of funding available. Many graduate

students have only three or four years of funding available, and while they can seek additional sources of funding, the uncertainty of their finances is an added stress to the already stressful experience of graduate education. Engaging research that may extend their time in a graduate program is a risk many students cannot afford to take.

This dissertation was also made possible by my specific mentors and educational opportunities. My supervisory committee is comprised of researchers with widely varying research backgrounds, providing access to both the breadth and depth required to conducted research in disciplines outside my own. Further, my committee was supportive of my desire to construct my dissertation of three unique research projects. Both of these circumstances, while not unheard of, are arguably not the norm.

Throughout my doctoral education, I was also afforded the opportunity to participate in the KSU Rural Resource Resiliency NSF Research Training program which offered training and practice participating in interdisciplinary and systems-based research. I also mentored an interdisciplinary group of undergraduate students as part of my graduate fellowship for the Natural Resources and Environmental Sciences program, allowing me to employ my interdisciplinary training in the role of an advisor instead of a student.

Again, these circumstances, while available to me, are not accessible to many graduate students, and when considering the many privileges and opportunities I have had throughout my time as a doctoral researcher, it is clear to see how my research has benefited from these opportunities in ways that could be difficult to replicate for other students. So while interdisciplinary work is already challenging for graduate students to participate in, even in cases where interdisciplinary-adjacent work can be achieved, it requires a substantial amount of

support through mentorship and education that is not consistently or widely available (e.g. specialized programs such as the NRT).

These barriers to engaging in interdisciplinary work while a graduate student may seem peripheral to achieving broader scientific goals, but this issue is central to sustainability science efforts. Sustainability science seeks to find balance between the needs and values of society and the environmental limitations of the planet over the long-term, using a systems approach to better understand coupled human-natural systems as a whole instead of individual component parts (Clark & Dickson, 2003; Spangenberg, 2011). This understanding of sustainability science not only emphasizes the way social and natural systems are inextricably intertwined, but it also acknowledges that sustainability efforts must be continuous as systems are constantly changing, making sustainability issues impossible to be truly solved.

These aspects of sustainability science highlight the importance of addressing the limitations of graduate research. When studying human-natural systems, we as researchers are not on the outside of the system looking in – we are a part of the system, and academia is a part of the system. Further, as sustainability research will always be needed, as systems are everchanging, there will always be a need for sustainability scientists to conduct such research. In this sense, the ability to foster and train the next generation of interdisciplinary sustainability scientists and sustain this area of scientific research is a vital part of the future of sustainability science as a discipline and consequently, the future of our planet.

Academic institutions will have to address the barriers to taking part in interdisciplinary research at the graduate level. This could potentially be done through increased educational programs and departments centered around interdisciplinary research and training, and by rethinking the requirements and qualifications of dissertation research. However, as graduate

students will need mentors to guide them through interdisciplinary work, barriers to collaborative work that professors face will also have to be addressed. The work in this dissertation demonstrates how with unique opportunities and excellent mentors we can work toward interdisciplinary research even at the graduate level, but also makes clear that we have a long ways to go.

# References


Adger, W. N., & Vincent, K. (2005). Uncertainty in adaptive capacity. *Comptes Rendus - Geoscience*, *337*(4), 399–410. https://doi.org/10.1016/j.crte.2004.11.004

Aeschbach-Hertig, W., & Gleeson, T. (2012). Regional strategies for the accelerating global problem of groundwater depletion. *Nature Geoscience*, *5*(12), 853–861. https://doi.org/10.1038/ngeo1617

Albert, J. S., Carnaval, A. C., Flantua, S. G. A., Lohmann, L. G., Ribas, C. C., Riff, D., Carrillo, J. D., Fan, Y., Figueiredo, J. J. P., Guayasamin, J. M., Hoorn, C., De Melo, G. H., Nascimento, N., Quesada, C. A., Ulloa, C. U., Val, P., Arieira, J., Encalada, A. C., & Nobre, C. A. (2023). Human impacts outpace natural processes in the Amazon. *Science*, *379*. https://doi.org/10.1126/science.abo5003

Alhaddi, H. (2015). Triple bottom line and sustainability: A literature review. *Business and Management Studies*, *1*(2), 6–10.

Angel, J., Swanston, C., Boustead, B. M., Conlon, K. C., Hall, K. R., Jorns, J. L., Kunkel, K. E., Lemos, M. C., Lofgren, B., Ontl, T. A., Posey, J., Stone, K., Takle, G., & Todey, D. (2018). Midwest: Impacts, Risks, and Adaptation in the United States. *Fourth National Climate Assessment, Volume II*, *II*, 872–940. https://doi.org/10.7930/NCA4.2018.CH21

Arbuckle, J G, & Roesch-Mcnally, G. (2015). Cover crop adoption in Iowa: The role of perceived practice characteristics. *Journal of Soil and Water Conservation*, *70*(6), 418–429. https://doi.org/10.2489/jswc.70.6.418

Arbuckle, J Gordon, Hobbs, J., Loy, A., Morton, L. W., Prokopy, L. S., & Tyndall, J. (2014). Understanding Corn Belt farmer perspectives on climate change to inform engagement strategies for adaptation and mitigation. *Journal of Soil and Water Conservation*, *69*(6), 505–516. https://doi.org/10.2489/jswc.69.6.505

Arbuckle, J Gordon, Tyndall, J. C., Morton, L. W., & Hobbs, J. (2017). Climate change typologies and audience segmentation among Corn Belt farmers. *Journal of Soil and Water Conservation*, *72*(3), 205–214. https://doi.org/10.2489/jswc.72.3.205

Arbuckle Jr, J. G., Prokopy, L. S., Haigh, T., Hobbs, J., Knoot, T., Knutson, C., Loy, A., Mase, A. S., McGuire, J., Morton, L. W., Tyndall, J., & Widhalm, M. (2013). Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. *Climatic Change*, *117*, 943–950. https://doi.org/10.1007/s10584-013-0707-6

Arcipowski, E., Schwartz, J., Davenport, L., Hayes, M., & Nolan, T. (2017). Clean Water, Clean Life: Promoting Healthier, Accessible Water in Rural Appalachia. *Journal of Contemporary Water Research & Education*, *161*(1), 1–18. https://doi.org/10.1111/j.1936-704x.2017.3248.x

Arnold, R. D., & Wade, J. (2015). A Definition of Systems Thinking: A Systems Approach. *Procedia Computer Science*, *44*, 669–678. https://doi.org/10.1016/j.procs.2015.03.050

Averbuch, B., Martin, ·, Thorsøe, H., & Kjeldsen, C. (2022). *Using fuzzy cognitive mapping and social capital to explain differences in sustainability perceptions between farmers in the northeast US and Denmark*. *39*, 435–453. https://doi.org/10.1007/s10460-021-10264-4

Barbier, E. B. (1987). The concept of sustainable economic development. *Environmental Conservation*, *14*(2), 101–110.

Barnes, A. P., & Toma, L. (2012). A typology of dairy farmer perceptions towards climate change. *Climatic Change*, *112*(2), 507–522. https://doi.org/10.1007/s10584-011-0226-2

Beddoe, R., Costanza, R., Farley, J., Garza, E., Kent, J., Kubiszewski, I., Martinez, L., Mccowen, T., Murphy, K., Myers, N., Ogden, Z., Stapleton, K., & Woodward, J. (2009). Overcoming systemic roadblocks to sustainability: the evolutionary redesign of worldviews, institutions, and technologies. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(8), 2483–2489.

Beeson, E., & Strange, M. (2003). Why Rural Matters, 2003: The Continuing Need for Every State To Take Action on Rural Education. *Journal of Research in Rural Education*, *18*(1), 3–16.

Bell, M. M. (2004). *Farming for Us All: Practical Agriculture and the Cultivation of Sustainability*. Pennsylvania State University Press.

Bennett, D. E. (2013). Geography and the emergence of sustainability science: missed opportunities and enduring possibilities. *THe Geographical Bulletin*, *54*, 99–112.

Bennett, K. J., Borders, T. F., Holmes, G. M., Kozhimannil, K. B., & Ziller, E. (2019). What Is Rural? Challenges And Implications Of Definitions That Inadequately Encompass Rural People And Places. *Health Affairs*, *38*(12), 1985–1992. https://doi.org/10.1377/hlthaff.2019.00910

Bessire, L. (2021). *Running Out: In Search of Water on the High Plains*. Princeton University Press.

Bettencourt, L. M. A., & Kaur, J. (2011). Evolution and structure of sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(49), 19540–19545. https://doi.org/10.1073/PNAS.1102712108/-/DCSUPPLEMENTAL/PNAS.1102712108_SI.PDF

Bierkens, M. F. P., & Wada, Y. (2019). Non-renewable groundwater use and groundwater depletion: a review. *Environmental Research Letters*, *14*, 063002. https://doi.org/10.1088/1748-9326/ab1a5f

Blaikie, P., & Brookfield, H. (1987). Land degradation and society. In *Land degradation and society.* Methuen. https://doi.org/10.2307/633496

Bogdanov, N., Meredith, D., & Efstratoglou, S. (2008). A typology of rural areas in Serbia. *Economic Annals*, *53*(177), 7–29. https://doi.org/10.2298/EKA0877007B

Bollen, K. A. (1989). *Structural equations with latent variables*. Wiley.

Boonstra, W. J., Ahnström, J., & Hallgren, L. (2011). Swedish farmers talking about nature - A study of the interrelations between farmers' values and the sociocultural notion of naturintresse. *Sociologia Ruralis*, *51*(4), 420–435. https://doi.org/10.1111/j.1467-9523.2011.00547.x

Bossange, A. V, Knudson, K. M., Shrestha, A., Harben, R., & Mitchell, J. P. (2016). The Potential for Conservation Tillage Adoption in the San Joaquin Valley, California: A Qualitative Study of Farmer Perspectives and Opportunities for Extension. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0167612

Bouman, T., Verschoor, M., Albers, C. J., Böhm, G., Fisher, S. D., Poortinga, W., Whitmarsh, L., & Steg, L. (2020). When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. *Global Environmental Change*, *62*. https://doi.org/10.1016/j.gloenvcha.2020.102061

Bourdieu, P. (1990). Structures, habitus, practices. In *The Logic of Practice* (pp. 52–65). Stanford Univserity Press.

Bradford, N. K., Caffery, L. J., & Smith, A. C. (2016). Telehealth services in rural and remote Australia: a systematic review of models of care and factors influencing success and sustainability. *Rural and Remote Health*, *16*(4), 1–23. https://doi.org/10.3316/INFORMIT.206937797420021

Brock, C., Jackson-Smith, D., Culman, S., Doohan, D., & Herms, C. (2021). Soil balancing within organic farming: negotiating meanings and boundaries in an alternative agricultural community of practice. *Agriculture and Human Values*, *38*, 449–465.

Brooks, J. S., Waring, T. M., Borgerhoff Mulder, M., & Richerson, P. J. (2018). Applying cultural evolution to sustainability challenges: an introduction to the special issue. In *Sustainability Science* (Vol. 13, pp. 1–8). Springer Tokyo. https://doi.org/10.1007/s11625-017-0516-3

Brooks, M. M. (2021). Countering Depopulation in Kansas: An Assessment of the Rural Opportunity Zone Program. *Population Research and Policy Review*, *40*(2), 137–148. https://doi.org/10.1007/s11113-020-09572-0

Brown, G. (2018). *Dirt to Soil: One Family's Journey into Regenerative Agriculture*.

Brummel, R. F., & Nelson, K. C. (2014). Does multifunctionality matter to US farmers? Farmer motivations and conceptions of multifunctionality in dairy systems. *Journal of Environmental Management*, *146*, 451–462. https://doi.org/10.1016/j.jenvman.2014.07.034

Brundtland, G. (1987). Our common future: report of the World Commission on Environment

and Development. In *International Affairs* (Vol. 64, Issue 1, pp. 126–126). https://doi.org/10.2307/2621529

Burton, R. J. F. (2004a). Seeing through the "good farmer's" eyes: Towards developing an understanding of the social symbolic value of "productivist" behaviour. *Sociologia Ruralis*, *44*(2), 195–215. https://doi.org/10.1111/j.1467-9523.2004.00270.x

Burton, R. J. F. (2004b). Reconceptualising the "behavioural approach" in agricultural studies: A socio-psychological perspective. *Journal of Rural Studies*, *20*(3), 359–371. https://doi.org/10.1016/j.jrurstud.2003.12.001

Burton, R. J. F., Forney, J., Stock, P., & Sutherland, L. A. (2020). *The good farmer: Culture and identity in food and agriculture*. Routledge. https://doi.org/10.4324/9781315190655

Burton, R. J. F., Kuczera, C., & Schwarz, G. (2008). Exploring farmers' cultural resistance to voluntary agri-environmental schemes. *Sociologia Ruralis*, *48*(1), 16–37. https://doi.org/10.1111/j.1467-9523.2008.00452.x

Burton, R. J. F., & Wilson, G. A. (2006). Injecting social psychology theory into conceptualisations of agricultural agency: Towards a post-productivist farmer self-identity? *Journal of Rural Studies*, *22*(1), 95–115. https://doi.org/10.1016/j.jrurstud.2005.07.004

Butzer, K. W. (1989). Cultural Ecology. In *Geography in America* (pp. 192–208).

Butzer, K. W. (1990). The realm of cultural–human ecology: adapta- tion and change in historical perspective. In *The earth as transformed by human action* (pp. 685–701).

Caldas, M. M., Sanderson, M. R., Mather, M., Danielsd, M. D., Bergtolde, J. S., Aistrup, J., Stamm, J. L. H., Haukos, D., Douglas-Mankin, K., Sheshukov, A. Y., & Lopez-Carr, D. (2015). Opinion: Endogenizing culture in sustainability science research and policy. In *Proceedings of the National Academy of Sciences of the United States of America* (Vol. 112, Issue 27, pp. 8157–8159). National Academy of Sciences. https://doi.org/10.1073/pnas.1510010112

Caporali, F., Mancinelli, R., & Campiglia, E. (2003). Indicators of Cropping System Diversity in Organic and Conventional Farms in Central Italy. *International Journal of Agricultural Sustainability*, *1*(1), 67–72. https://doi.org/10.3763/IJAS.2003.0107

Carlisle, L. (2016). Factors influencing farmer adoption of soil health practices in the United States: a narrative review. *Agroecology and Sustainable Food Systems*, *40*(6), 583–613. https://doi.org/10.1080/21683565.2016.1156596

Caschili, S., De Montis, A., & Trogu, D. (2015). Accessibility and rurality indicators for regional development. *Computers, Environment and Urban Systems*, *49*, 98–114. https://doi.org/10.1016/j.compenvurbsys.2014.05.005

Cash, D. W., Neil Adger, W., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., & Young, O. (2006). *Scale and Cross-Scale Dynamics: Governance and Information in a*

*Multilevel World* (Vol. 11, Issue 2). and Society.

Childers, D. L., Corman, J., & Elser, J. J. (2011). Sustainability Challenges of Phosphorus and Food: Solutions for Closing the Human Phosphorus Cycle. *BioScience*, *61*(2), 117–124. https://doi.org/10.1525/bio.2011.61.2.6

Church, S. P., Lu, J., Ranjan, P., Reimer, A. P., & Prokopy, L. S. (2020). The role of systems thinking in cover crop adoption: Implications for conservation communication. *Land Use Policy*, *94*. https://doi.org/10.1016/j.landusepol.2020.104508

Churchman, G. E. C. W. (1967). Guest Editorial: Wicked Problems. In *MANAGEMENT SCIENCE* (Vol. 14, Issue 4).

Clark, W. C. (2007). Sustainability science: A room of its own. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(6), 1737–1738. https://doi.org/10.1073/PNAS.0611291104/ASSET/54120A34-4AC7-4672-B595-CDB74DD0F745/ASSETS/GRAPHIC/ZPQ0060751490001.JPEG

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: The emerging research program. *Proceedings of the National Academy of Sciences*, *100*(14), 8059–8061. https://doi.org/10.1073/PNAS.1231333100

Cohen, S. A., Cook, S. K., Kelley, L., Foutz, J. D., & Sando, T. A. (2017). A Closer Look at Rural-Urban Health Disparities: Associations Between Obesity and Rurality Vary by Geospatial and Sociodemographic Factors. *Journal of Rural Health*, *33*(2), 167–179. https://doi.org/10.1111/jrh.12207

Conant, R. T., Anderson, M., Badger, A., Boustead, B. M., Derner, J., Farris, L., Hayes, M., Livneh, B., McNeeley, S., Peck, D., Shulski, M., & Small, V. (2018). Northern Great Plains. In D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, & B. C. Stewart (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Vol. II* (pp. 941–986). U.S. Global Change Research Program. https://doi.org/10.1891/9780826129857.0015

Cooley, S. W., Ryan, J. C., & Smith, L. C. (2021). Human alteration of global surface water storage variability. *Nature*, *591*, 78–81. https://doi.org/10.1038/s41586-021-03262-3

Cope, M. A., McLafferty, S., & Rhoads, B. L. (2011). Farmer attitudes toward production of perennial energy grasses in east central Illinois: Implications for community-based decision making. *Annals of the Association of American Geographers*, *101*(4), 852–862. https://doi.org/10.1080/00045608.2011.575320

Croasdell, D. T., Freeman, L. A., Urbaczewski, A., Croasdell, D. T., Freeman, L. A., & Urbaczewski, A. (2003). Communications of the Association for Information Systems Communications of the Association for Information Systems Concept Maps for Teaching and Assessment Concept Maps for Teaching and Assessment Concept Maps for Teaching and Assessment by CONCEPT MAPS FOR TEACHING AND ASSESSMENT. *Communications of the Association for Information Systems*, *12*, 396–405.

https://doi.org/10.17705/1CAIS.01224

Cromartie, J., Nulph, D., Hart, G., & Dobis, E. (2013). Defining frontier areas in the United States. *Journal of Maps*, *9*(2), 149–153. https://doi.org/10.1080/17445647.2013.773569/SUPPL_FILE/TJOM_A_773569_SM4889.PDF

Crouch, M., & Nguyen, T. D. (2021). Examining teacher characteristics, school conditions, and attrition rates at the intersection of school choice and rural education. *Journal of School Choice*, *15*(2), 268–294.

Crutzen, P. J. (2006). The "Anthropocene." In E. Ehlers & T. Krafft (Eds.), *Earth System Science in the Anthropocene* (pp. 13–18). Springer, Berlin, Heidelberg.

Curran, V., & Rourke, J. (2004). The role of medical education in the recruitment and retention of rural physicians. *Medical Teacher*, *26*(3), 265–272. https://doi.org/10.1080/0142159042000192055

Cusworth, G. (2020). Falling short of being the 'good farmer': Losses of social and cultural capital incurred through environmental mismanagement, and the long-term impacts agri-environment scheme participation. *Journal of Rural Studies*, *75*, 164–173. https://doi.org/10.1016/j.jrurstud.2020.01.021

Dai, A. (2019). *The Climate Data Guide: Palmer Drought Severity Index (PDSI)*. National Center for Atmospheric Research. https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi

Dale, V. H., & Polasky, S. (2007). *Measures of the effects of agricultural practices on ecosystem services*. https://doi.org/10.1016/j.ecolecon.2007.05.009

Daverkosen, L., Holzknecht, A., Friedel, J. K., Keller, T., Strobel, B. W., Wendeberg, A., & Jordan, S. (2022). The potential of regenerative agriculture to improve soil health on Gotland, Sweden. *Journal of Plant Nutrition and Soil Science*, *185*, 901–914. https://doi.org/10.1002/jpln.202200200

David Tilman, Kenneth G. Cassman, Pamela A. Matson, Rosamond Naylor, & Stephen Polasky. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(August), 671–677.

de Groot, J. I. M., & Steg, L. (2008). Value orientations to explain beliefs related to environmental significant behavior. *Environment and Behavior*, *40*(3), 330–354. https://doi.org/10.1177/0013916506297831

DeLonge, M. S., Miles, A., & Carlisle, L. (2016). Investing in the transition to sustainable agriculture. *Environmental Science and Policy*, *55*, 266–273. https://doi.org/10.1016/j.envsci.2015.09.013

Derpsch, R., Friedrich, T., Kassam, A., & Li, H. (2010). Current status of adoption of no-till

farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*, *3*(1), 1–25. https://doi.org/10.3965/J.ISSN.1934-6344.2010.01.0-0

Diamond, J. (2005). *Collapse: How Societies Choose to Fail or Succeed*. Penguin Books.

Diaz, R. J., & Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. *Science*, *321*(5891), 926–929. https://doi.org/10.1126/science.1156401

Dietz, T. (2020). Under the influence: Putting peer pressure to work. *Nature*, *577*(7791), 468–469.

Dietz, T., Dan, A., & Shwom, R. (2007). Support for climate change policy: Social Psychological and social structural influences. *Rural Sociology*, *72*(2), 185–214. https://doi.org/10.1526/003601107781170026

Dietz, T., Fitzgerald, A., & Shwom, R. (2005). Environmental values. *Annual Review of Environment and Resources*, *30*, 335–372. https://doi.org/10.1146/annurev.energy.30.050504.144444

Dietz, T., Shwom, R. L., & Whitley, C. T. (2020). Climate change and society. *Annual Review of Sociology*, *46*(1), 135–158. https://doi.org/10.1146/annurev-soc-121919-054614

Dietz, T., Stern, P. C., & Guagnano, G. A. (1998). Social structural and social psychological bases of environmental concern. *Environment and Behavior*, *30*(4), 450–471. https://doi.org/10.1177/001391659803000402

Dietz, T., & Whitley, C. T. (2018). Environmentalism, norms, and identity. In *Proceedings of the National Academy of Sciences of the United States of America* (Vol. 115, Issue 49, pp. 12334–12336). National Academy of Sciences. https://doi.org/10.1073/pnas.1817487115

Diggs, D. M. (1991). Drought experience and perception of climatic change among Great Plains farmers. *Plains Research*, *1*(1), 114–132.

DiMaggio, P. (1997). Culture and Cognition. *Annual Review of Sociology*, *23*, 263–287.

Douglas, E. M., Wheeler, S. A., Smith, D. J., Overton, I. C., Gray, S. A., Doody, T. M., & Crossman, N. D. (2016). Using mental-modelling to explore how irrigators in the Murray-Darling Basin make water-use decisions. *Journal of Hydrology: Regional Studies*, *6*, 1–12. https://doi.org/10.1016/j.ejrh.2016.01.035

Doukas, H., Papadopoulou, A., Savvakis, N., Tsoutsos, T., & Psarras, J. (2012). Assessing energy sustainability of rural communities using Principal Component Analysis. *Renewable and Sustainable Energy Reviews*, *16*, 1949–1957. https://doi.org/10.1016/j.rser.2012.01.018

Douthit, N., Kiv, S., Dwolatzky, T., & Biswas, S. (2015). Exposing some important barriers to health care access in the rural USA. *Public Health*, *129*(6), 611–620. https://doi.org/10.1016/j.puhe.2015.04.001

Draper, F. (1993). A proposed sequence for developing systems thinking in grades 4-12 curriculum. *System Dynamics Review*, *9*(2), 207–214.

Dudley, N., & Alexander, S. (2017). Agriculture and biodiversity: a review. *Biodiversity*, *18*(2–3), 45–49. https://doi.org/10.1080/14888386.2017.1351892

Dugan, K. E., Mosyjowski, E. A., Daly, S. R., & Lattuca, L. R. (2022). Systems thinking assessments in engineering: A systematic literature review. *Systems Research and Behavioral Science*, *39*(4), 840–866. https://doi.org/10.1002/sres.2808

Dunlap, R. E., Van Liere, K. D., Mertig, A. G., & Jones, R. E. (2000). Measuring endorsement of the new ecological paradigm: A revised NEP scale. *Journal of Social Issues*, *56*(3), 425–442. https://doi.org/10.1111/0022-4537.00176

Eaton, W. M., Eanes, F. R., Ulrich-Schad, J. D., Burnham, M., Church, S. P., Arbuckle, J. G., & Cross, J. E. (2019). Trouble with sense of place in working landscapes. *Society and Natural Resources*, *32*(7), 827–840. https://doi.org/10.1080/08941920.2019.1568653

Eden, C. (1992). On the Nature of Cognitive Maps. *Journal of Management Studies*, *29*(3), 261–265. https://doi.org/10.1111/j.1467-6486.1992.tb00664.x

Eden, C., Ackermann, F., & Cropper, S. (1992). The Analysis of Cause Maps. *Journal of Management Studies*, *29*(3), 309–324. https://doi.org/10.1111/j.1467-6486.1992.tb00667.x

Ellen, R. F. (1982). *Environmental determinism and causal correlation in Environment, subsistence and system: the ecology of small-scale social formations*. Cambridge University Press.

Elshafei, Y., Tonts, M., Sivapalan, M., & Hipsey, M. R. (2016). Sensitivity of emergent sociohydrologic dynamics to internal system properties and external sociopolitical factors: Implications for water management. *Water Resources Research*, *52*(6), 4944–4966. https://doi.org/10.1002/2015WR017944

Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, *21*(2), 647–656. https://doi.org/10.1016/j.gloenvcha.2011.01.019

Eva, H. D., Mayaux, P., Stibig, H.-J., Belward, A., Cairns, 18 M A, Brown, S., Helmer, E. H., & Baumgardner, G. A. (2012). Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. *Science*, *336*(2), 9899. https://doi.org/10.1126/science.1217962

Evans, A. E., Mateo-Sagasta, J., Qadir, M., Boelee, E., & Ippolito, A. (2019). Agricultural water pollution: key knowledge gaps and research needs. *Current Opinion in Environmental Sustainability*, *36*, 20–27. https://doi.org/10.1016/j.cosust.2018.10.003

Fairweather, J. R., & Hunt, L. M. (2011). Can farmers map their farm system? Causal mapping and the sustainability of sheep/beef farms in New Zealand. *Agriculture and Human Values*, *28*, 55–66. https://doi.org/10.1007/s10460-009-9252-3

Farmer, J., Prior, M., & Taylor, J. (2012). A theory of how rural health services contribute to community sustainability. *Social Science & Medicine*, *75*(10), 1903–1911. https://doi.org/10.1016/J.SOCSCIMED.2012.06.035

Fenster, T. L. D., LaCanne, C. E., Pecenka, J. R., Schmid, R. B., Bredeson, M. M., Busenitz, K. M., Michels, A. M., Welch, K. D., & Lundgren, J. G. (2021). Defining and validating regenerative farm systems using a composite of ranked agricultural practices. *F1000Research*, *10*, 115. https://doi.org/10.12688/f1000research.28450.1

Ferguson, R. S., & Lovell, S. T. (2014). Permaculture for agroecology: Design, movement, practice, and worldview. A review. *Agronomy for Sustainable Development*, *34*(2), 251–274. https://doi.org/10.1007/s13593-013-0181-6

Fisher, J., & Rucki, K. (2016). *Re-conceptualizing the Science of Sustainability: A Dynamical Systems Approach to Understanding the Nexus of Conflict, Development and the Environment*. https://doi.org/10.1002/sd.1656

Floress, K., García de Jalón, S., Church, S. P., Babin, N., Ulrich-Schad, J. D., & Prokopy, L. S. (2017). Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality. *Journal of Environmental Psychology*, *53*, 73–80. https://doi.org/10.1016/j.jenvp.2017.06.009

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., … Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, *478*(7369), 337–342. https://doi.org/10.1038/nature10452

Gale, R. P., & Cordray, S. M. (1994). Making Sense of Sustainability: Nine Answers to 'What Should Be Sustained?''.' *Rural Sociology*, *59*(2), 311–332. https://doi.org/10.1111/J.1549-0831.1994.TB00535.X

Garcia, M., Portney, K., & Islam, S. (2016). A question driven socio-hydrological modeling process. *Hydrology and Earth System Sciences*, *20*, 73–92. https://doi.org/10.5194/hess-20-73-2016

Gardezi, M., & Arbuckle, J. G. (2020). Techno-optimism and farmers' attitudes toward climate change adaptation. *Environment and Behavior*, *52*(1), 82–105. https://doi.org/10.1177/0013916518793482

Ghaly, A. E., & Ramakrishnan, V. V. (2015). Nitrogen Sources and Cycling In the Ecosystem and its Role in Air, Water and Soil Pollution: A Critical Review. *Pollution Effects and Control*, *3*(2). https://doi.org/10.4172/2375-4397.1000136

Gibson, C. C., Ostrom, E., & Ahn, T. K. (2000). The concept of scale and the human dimensions of global change; a survey. *Ecological Economics*, *32*, 217–239.

Giddings, B., Hopwood, B., & O'Brien, G. (2002). Environment, economy and society: Fitting

them together into sustainable development. *Sustainable Development*, *10*(4), 187–196. https://doi.org/10.1002/SD.199

Gober, P., White, D. D., Quay, R., Sampson, D. A., & Kirkwood, C. W. (2017). Socio-hydrology modelling for an uncertain future, with examples from the USA and Canada. *Geological Society Special Publication*, *408*(1), 183–199. https://doi.org/10.1144/SP408.2

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(5969), 812–818. https://doi.org/10.1126/science.1185383

Goetz, S. J., Partridge, M., Deller, S. C., & Fleming, D. A. (2010). Evaluating U.S. Rural Entrepreneurship Policy. *Journal of Regional Analysis and Policy*, *40*(1), 20–33.

Gomiero, T., Paoletti, M. G., & Pimentel, D. (2008). Critical Reviews in Plant Sciences Energy and Environmental Issues in Organic and Conventional Agriculture Energy and Environmental Issues in Organic and Conventional Agriculture. *Critical Reviews in Plant Sciences*, *27*, 239–254. https://doi.org/10.1080/07352680802225456

Gordon, E., Davila, F., & Riedy, C. (2022). *Transforming landscapes and mindscapes through regenerative agriculture*. *39*, 809–826. https://doi.org/10.1007/s10460-021-10276-0

Gosnell, H. (2022). Regenerating soil, regenerating soul: an integral approach to understanding agricultural transformation. *Sustainability Science*, *17*, 603–620. https://doi.org/10.1007/s11625-021-00993-0

Gosnell, H., Gill, N., & Voyer, M. (2019). Transformational adaptation on the farm: Processes of change and persistence in transitions to 'climate-smart' regenerative agriculture. *Global Environmental Change*, *59*, 101965. https://doi.org/10.1016/j.gloenvcha.2019.101965

Gowda, P. H., Steiner, J. ., Farrigan, T., Grusak, M. A., & Boggess, M. (2018). Agriculture and Rural Communities. Impacts, Risks, and Adaptation in the United States. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, *2*, 391–437. https://doi.org/10.7930/NCA4.2018.CH10

Gramig, B. M., Barnard, J. M., & Prokopy, L. S. (2013). Farmer beliefs about climate change and carbon sequestration incentives. *Climate Research*, *56*, 157–167. https://doi.org/10.3354/cr01142

Gray, S., Sterling, E. J., Aminpour, P., Goralnik, L., Singer, A., Wei, C., Akabas, S., Jordan, R. C., Giabbanelli, P. J., Hodbod, J., Betley, E., & Norris, P. (2019). Assessing (social-ecological) systems thinking by evaluating cognitive maps. *Sustainability (Switzerland)*, *11*(20), 1–11. https://doi.org/10.3390/su11205753

Green, Gary P. (2007). *Workforce development networks in rural areas: Building the high road*. Edward Elgar Publishing.

Green, Gary Paul. (2001). Amenities and community economic development: Strategies for sustainability. *Journal of Regional Analysis and Policy*, *31*(2), 61–76.

Green, Gary Paul. (2014). Sustainability and Rural Communities. *Kansas Journal of Law & Public Policy*, *23*(3), 421–436.

Griggs, B. W. (2017). The political cultures of irrigation and the proxy battles of interstate water litigation. *Natural Resources Journal*, *57*(1), 1–73.

Griggs, B. W. (2019). Interstate litigation, state reaction, and federalism in the age of groundwater. *Rocky Mountain Mineral Law Institute*, 65.

Guttman, N. B., & Quayle, R. G. (1996). A historical perspective of U.S. climate divisions. *Bulletin of the American Meteorological Society*, *77*(2), 293–303. https://doi.org/10.1175/1520-0477(1996)077<0293:AHPOUC>2.0.CO;2

Haacker, E. M. K., Kendall, A. D., & Hyndman, D. W. (2016). Water level declines in the High Plains Aquifer: Predevelopment to resource senescence. *Groundwater*, *54*(2), 231–242. https://doi.org/10.1111/gwat.12350

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V, Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., P Madin, E. M., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., & Watson, R. (2008). A Global Map of Human Impact on Marine Ecosystems. *Science*, *319*, 948–952. https://doi.org/10.1126/science.1151084

Han, G., Schoolman, E. D., Arbuckle, J. G., & Morton, L. W. (2021). Weather, values, capacity and concern: Toward a social-cognitive model of specialty crop farmers' perceptions of climate change risk. *Environment and Behavior*, *54*(2), 327–362. https://doi.org/10.1177/00139165211026607

Harden, C. P. (2012). Framing and Reframing Questions of Human–Environment Interactions. *Annals of the Association of American Geographers*, *102*(4), 737–747. https://doi.org/10.1080/00045608.2012.678035

Harrington, L. M. B. (2016). Sustainability Theory and Conceptual Considerations: A Review of Key Ideas for Sustainability, and the Rural Context. *Papers in Applied Geography*, *2*(4), 365–382. https://doi.org/10.1080/23754931.2016.1239222

Harwood, R. (1990). A history of sustainable agriculture. In *Sustainable Agriculture Systems* (pp. 3–19).

Head, L., Atchison, J., Gates, A., & Muir, P. (2011). A fine-grained study of the experience of drought, risk and climate change among Australian wheat farming households. *Annals of the Association of American Geographers*, *101*(5), 1089–1108. https://doi.org/10.1080/00045608.2011.579533

Hedlund, M. (2016). Mapping the Socioeconomic Landscape of Rural Sweden: Towards a

Typology of Rural Areas. *Regional Studies*, *50*(3), 460–474. https://doi.org/10.1080/00343404.2014.924618

Hoffman, M., Lubell, M., & Hillis, V. (2014). Linking knowledge and action through mental models of sustainable agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(36), 13016–13021. https://doi.org/10.1073/pnas.1400435111

Horrigan, L., Lawrence, R. S., & Walker, P. (2002). How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture. In *Environmental Health Perspectives* • (Vol. 110, Issue 5).

Houghton, R. A., House, J. I., Pongratz, J., Van Der Werf, G. R., Defries, R. S., Hansen, M. C., Le Quéré, C., & Ramankutty, N. (2012). Carbon emissions from land use and land-cover change. *Biogeosciences*, *9*, 5125–5142. https://doi.org/10.5194/bg-9-5125-2012

Howell, J., & Elliott, J. R. (2019). Damages Done: The Longitudinal Impacts of Natural Hazards on Wealth Inequality in the United States. *Social Problems*, *66*, 448–467. https://doi.org/10.1093/socpro/spy016

Hyland, J. J., Jones, D. L., Parkhill, K. A., Barnes, A. P., & Williams, A. P. (2016). Farmers' perceptions of climate change: identifying types. *Agriculture and Human Values*, *33*(2), 323–339. https://doi.org/10.1007/s10460-015-9608-9

Ikerd, J. E. (1993). The need for a systems approach to sustainable agriculture. In *Ecosystems and Environment* (Vol. 46).

Inagami, S., Gao, S., Karimi, H., Shendge, M. M., Probst, J. C., & Stone, R. A. (2016). Adapting the Index of Relative Rurality (IRR) to Estimate Rurality at the ZIP Code Level: A Rural Classification System in Health Services Research. *Journal of Rural Health*, *32*(2), 219–227. https://doi.org/10.1111/jrh.12148

Institute of Medicine. (2005). Facilitating Interdisciplinary Research. In *Facilitating Interdisciplinary Research*. The National Academies Press. https://doi.org/10.17226/11153

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (R. K. Pachauri & L. A. Meyer (eds.)).

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, Y. Chen, L. Goldfarb, M. I. Gomis, J. B. R. Matthews, S. Berger, M. Huang, O. Yelekçi, R. Yu, B. Zhou, E. Lonnoy, T. K. Maycock, T. Waterfield, K. Leitzell, & N. Caud (eds.)). Cambridge University Press. https://doi.org/10.1017/9781009157896

Isaac, M. E., Dawoe, E., & Sieciechowicz, K. (2009). Assessing Local Knowledge Use in Agroforestry Management with Cognitive Maps. *Environmental Management*, *43*, 1321–1329. https://doi.org/10.1007/s00267-008-9201-8

Isserman, A. M. (2005). In the national interest: Defining rural and urban correctly in research and public policy. *International Regional Science Review*, *28*(4), 465–499. https://doi.org/10.1177/0160017605279000

Jones, N. A., Ross, H., Lynam, T., Perez, P., & Leitch, A. (2011). *Mental Models: An Interdisciplinary Synthesis of Theory and Methods* (Vol. 16, Issue 1). and Society.

Judkins, G., Smith, M., & Keys, E. (2008). Determinism within human–environment research and the rediscovery of environmental causation. *The Geographical Journal*, *174*(1), 17–29. https://doi.org/10.1111/j.1475-4959.2008.00265.x

Kajikawa, Y. (2008). Research core and framework of sustainability science. *Sustainability Science*, *3*(2), 215–239. https://doi.org/10.1007/s11625-008-0053-1

Kajikawa, Y., Ohno, J., Takeda, Y., Matsushima, K., & Komiyama, H. (2007). Creating an academic landscape of sustainability science: An analysis of the citation network. *Sustainability Science*, *2*(2), 221–231. https://doi.org/10.1007/s11625-007-0027-8

Kajikawa, Y., Tacoa, F., & Yamaguchi, K. (2014). Sustainability science: the changing landscape of sustainability research. *Sustainability Science*, *9*(4), 431–438. https://doi.org/10.1007/s11625-014-0244-x

Kandilov, I. T., & Renkow, M. (2010). Infrastructure Investment and rural economic development: An Evaluation Of USDA's broadband loan program. *Growth and Change*, *41*(2), 165–191. https://doi.org/10.1111/j.1468-2257.2010.00524.x

Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of conservation agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability*, *7*(4), 292–320. https://doi.org/10.3763/ijas.2009.0477

Kates, R. W. (2011). What kind of a science is sustainability science? *Proceedings of the National Academy of Sciences*, *108*(49), 19449–19450. https://doi.org/10.1073/pnas.1116097108

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., Mccarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grubler, A., Huntley, B., Jager, J., Jodha, N. S., Kasperson, R. E., Maboguje, A., Matson, P., … Svedin, U. (2001). Sustainability Science. *Science*, *292*, 641–642.

Kates, R. W., & Dasgupta, P. (2007). African poverty: A grand challenge for sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(43), 16747–16750. https://doi.org/10.1073/PNAS.0708566104

Kennedy, S. M., Burbach, M. E., & Sliwinski, M. S. (2016). Sustainable Grassland Management: An Exploratory Study of Progressive Ranchers in Nebraska. *Sustainable Agriculture Research*, *5*(2), 103. https://doi.org/10.5539/sar.v5n2p103

Kenny, D. C., & Castilla-Rho, J. (2022). What Prevents the Adoption of Regenerative

Agriculture and What Can We Do about It? Lessons and Narratives from a Participatory Modelling Exercise in Australia. *Land*, *11*, 1383. https://doi.org/10.3390/land11091383

Khangura, R., Ferris, D., Wagg, C., & Bowyer, J. (2023). *Regenerative Agriculture-A Literature Review on the Practices and Mechanisms Used to Improve Soil Health*. https://doi.org/10.3390/su15032338

Kim, G., Kang, W., & Lee, J. (2020). Knowledge Structures and Components of Rural Resilience in the 2010s: Conceptual Development and Implications. *Sustainability*, *12*(9769). https://doi.org/10.3390/su12229769

Kinzig, A. P., Ehrlich, P. R., Alston, L. J., Arrow, K., Barrett, S., Buchman, T. G., Daily, G. C., Levin, B., Levin, S., Oppenheimer, M., Ostrom, E., & Saari, D. (2013). Social Norms and Global Environmental Challenges: The Complex Interaction of Behaviors, Values, and Policy. *BioScience*, *63*(3), 164–175. https://doi.org/10.1525/bio.2013.63.3.5

Klein, R. J. T., Nicholls, R. J., & Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? *Global Environmental Change Part B: Environmental Hazards*, *5*(1), 35–45. https://doi.org/10.1016/J.HAZARDS.2004.02.001

Kline, R. B. (1998). Software review: Software programs for structural equation modeling: Amos, EQS, and LISREL. *Journal of Psychoeducational Assessment*, *16*(4), 343–364. https://doi.org/10.1177/073428299801600407

Knickel, K., Redman, M., Darnhofer, I., Ashkenazy, A., Calvão Chebach, T., Šūmane, S., Tisenkopfs, T., Zemeckis, R., Atkociuniene, V., Rivera, M., Strauss, A., Kristensen, L. S., Schiller, S., Koopmans, M. E., & Rogge, E. (2018). Between aspirations and reality: Making farming, food systems and rural areas more resilient, sustainable and equitable. *Journal of Rural Studies*, *59*, 197–210. https://doi.org/10.1016/J.JRURSTUD.2017.04.012

Konar, M., Garcia, M., Sanderson, M. R., Yu, D. J., & Sivapalan, M. (2019). Expanding the scope and foundation of sociohydrology as the science of soupled human-water systems. *Water Resources Research*, *55*(2), 874–887. https://doi.org/10.1029/2018WR024088

Krebs, J., & Bach, S. (2018). Permaculture-Scientific Evidence of Principles for the Agroecological Design of Farming Systems. *Sustainability*, *10*(3218), 1–24. https://doi.org/10.3390/su10093218

Kremen, C., & Miles, A. (2012). *Ecosystem Services in Biologically Diversified versus Conventional Farming Systems: Benefits, Externalities, and Trade-Offs*. *17*(4). https://doi.org/10.5751/ES-05035-170440

Krzywoszynska, A. (2019). Making knowledge and meaning in communities of practice: What role may science play? The case of sustainable soil management in England. *Soil Use and Management*, *35*(1), 160–168. https://doi.org/10.1111/sum.12487

LaCanne, C. E., & Lundgren, J. G. (2018). Regenerative agriculture: Merging farming and natural resource conservation profitably. *PeerJ*, *2018*(2), 1–12.

https://doi.org/10.7717/peerj.4428

Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of Soil and Water Conservation*, *75*(5), 123A-124A. https://doi.org/10.2489/jswc.2020.0620a

Lalani, B., Aminpour, P., Gray, S., Williams, M., Büchi, L., Haggar, J., Grabowski, P., & Dambiro, J. (2021). Mapping farmer perceptions, Conservation Agriculture practices and on-farm measurements: The role of systems thinking in the process of adoption. *Agricultural Systems*, *191*, 103171. https://doi.org/10.1016/j.agsy.2021.103171

Lalani, B., Gray, S., & Mitra-Ganguli, T. (2023). Systems Thinking in an era of climate change: Does cognitive neuroscience hold the key to improving environmental decision making? A perspective on Climate-Smart Agriculture. *Frontiers in Integrative Neuroscience*, *17*(April), 1–15. https://doi.org/10.3389/fnint.2023.1145744

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*(SUPPL. 1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Latruffe, L., Diazabakana, A., Bockstaller, C., Desjeux, Y., Finn, J., Kelly, E., Ryan, M., & Uthes, S. (2016). Measurement of sustainability in agriculture: A review of indicators. *Studies in Agricultural Economics*, *118*(3), 123–130. https://doi.org/10.7896/j.1624

Lauer, S., & Sanderson, M. R. (2020). Producer attitudes toward groundwater conservation in the U.S. Ogallala-High Plains. *Groundwater*, *58*(4), 674–680. https://doi.org/10.1111/gwat.12940

Lauer, S., Sanderson, M. R., Manning, D. T., Suter, J. F., Hrozencik, R. A., Guerrero, B., & Golden, B. (2018). Values and groundwater management in the Ogallala Aquifer region. *Journal of Soil and Water Conservation*, *73*(5), 593–600. https://doi.org/10.2489/jswc.73.5.593

Lavoie, A., & Wardropper, C. B. (2021). Engagement with conservation tillage shaped by "good farmer" identity. *Agriculture and Human Values*, *38*(4), 975–985. https://doi.org/10.1007/s10460-021-10205-1

Lawrie, M., Tonts, M., & Plummer, P. (2011). Boomtowns, resource dependence and socio-economic well-being. *Australian Geographer*, *42*(2), 139–164. https://doi.org/10.1080/00049182.2011.569985

Lebacq, T., Baret, P. V., & Stilmant, D. (2013). Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Development*, *33*(2), 311–327. https://doi.org/10.1007/s13593-012-0121-x

Lehman, R. M., Cambardella, C. A., Stott, D. E., Acosta-Martinez, V., Manter, D. K., Buyer, J. S., Maul, J. E., Smith, J. L., Collins, H. P., Halvorson, J. J., Kremer, R. J., Lundgren, J. G., Ducey, T. F., Jin, V. L., & Karlen, D. L. (2015). *Understanding and Enhancing Soil*

*Biological Health: The Solution for Reversing Soil Degradation*. *7*, 988–1027. https://doi.org/10.3390/su7010988

Levin, S. A., & Clark, W. C. (2010). Toward a Science of Sustainability. *Center for International Development Working Papers*.

Levy, M. A., Lubell, M. N., & Mcroberts, N. (2018). The structure of mental models of sustainable agriculture. *Nature Sustainability*, *1*.

Lichter, D. T., & Brown, D. L. (2011). Rural America in an Urban Society: Changing Spatial and Social Boundaries. *Annual Review of Sociology*, *37*, 565–592. https://doi.org/10.1146/annurev-soc-081309-150208

Lindell, M. K., & Prater, C. S. (2003). Assessing Community Impacts of Natural Disasters. *Natural Hazards Review*, *4*(4), 176–185. https://doi.org/10.1061/ASCE1527-698820034:4176

Long, J. C., Delamater, P. L., & Holmes, G. M. (2021). Which Definition of Rurality Should I Use?: The Relative Performance of 8 Federal Rural Definitions in Identifying Rural-Urban Disparities. *Medical Care*, *59*(10), S413–S419. https://doi.org/10.1097/MLR.0000000000001612

Maani, K. E., & Maharaj, V. (2004). Links between systems thinking and complex decision making. *System Dynamics Review*, *20*(1), 21–48. https://doi.org/10.1002/sdr.281

Magnani, N., & Struffi, L. (2009). Translation sociology and social capital in rural development initiatives. A case study from the Italian Alps. *Journal of Rural Studies*, *25*(2), 231–238. https://doi.org/10.1016/J.JRURSTUD.2008.10.004

Maltzan, T. (2006). *Rurality and higher education: Implications for identity and persistence*. The Ohio State University.

Mann, C., Parkins, J. R., Isaac, M. E., & Sherren, K. (2019). *Do practitioners of holistic management exhibit systems thinking? 24*(3), 19. https://doi.org/10.5751/ES-11092-240319

Manson, S. M. (2008). Does scale exist? An epistemological scale continuum for complex human-environment systems. *Geoforum*, *39*(2), 776–788. https://doi.org/10.1016/j.geoforum.2006.09.010

Mao, L., Stacciarini, J. M. R., Smith, R., & Wiens, B. (2015). An individual-based rurality measure and its health application: A case study of Latino immigrants in North Florida, USA. *Social Science and Medicine*, *147*, 300–308. https://doi.org/10.1016/j.socscimed.2015.10.064

Marshall, N. A., Fenton, D. M., Marshall, P. A., & Sutton, S. G. (2007). How resource dependency can influence social resilience within a primary resource industry. *Rural Sociology*, *72*(3), 359–390. https://doi.org/10.1526/003601107781799254

Martens, P. (2006). Sustainability: science or fiction? *Sustainability: Science, Practice and Policy*, *2*(1), 36–41. https://doi.org/10.1080/15487733.2006.11907976

Martínez-Zarzoso, I., & Maruotti, A. (2011). *The impact of urbanization on CO 2 emissions: Evidence from developing countries ☆*. https://doi.org/10.1016/j.ecolecon.2011.02.009

Mastrandrea, M. D., Mach, K. J., Barros, V. R., Bilir, T. E., Dokken, D. J., Edenhofer, O., Field, C. B., Hiraishi, T., Kadner, S., Krug, T. K., Minx, J. C., Madruga, R. P.-, Plattner, G.-K., Qin, D., Sokona, Y., Stocker, T. F., & Tignor, M. (2015). *IPCC, 2015: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Climate Change, Food, and Agriculture. World Meteorological Organization, Geneva, Switzerland, 68 pp.* (Issue May).

McGuire, J. M., Morton, L. W., Arbuckle, J. G., & Cast, A. D. (2015). Farmer identities and responses to the social-biophysical environment. *Journal of Rural Studies*, *39*, 145–155. https://doi.org/10.1016/j.jrurstud.2015.03.011

Mcguire, J., Morton, L. W., & Cast, A. D. (2013). Reconstructing the good farmer identity: shifts in farmer identities and farm management practices to improve water quality. *Agriculture and Human Values*, *30*, 57–69. https://doi.org/10.1007/s10460-012-9381-y

McManus, P., Walmsley, J., Argent, N., Baum, S., Bourke, L., Martin, J., Pritchard, B., & Sorensen, T. (2012). Rural community and rural resilience: What is important to farmers in keeping their country towns alive? *Journal of Rural Studies*, *28*(1), 20–29. https://doi.org/10.1016/j.jrurstud.2011.09.003

McNicoll, G. (2014). Population and Sustainability. In *Handbook of Sustainable Development* (pp. 291–303). Edward Elgar Publishing.

Meadows, D. H. (2008). *Thinking in Systems: A Primer*. Chelsea Green Publishing.

Mebratu, D. (1998). Sustainability and sustainable development. *Environmental Impact Assessment Review*, *18*(6), 493–520.

Mishra, A., El-Osta, H., & Gillespie, J. M. (2009). Effect of agricultural policy on regional income inequality among farm households. *Journal of Policy Modeling*, *31*(3), 325–340. https://doi.org/10.1016/J.JPOLMOD.2008.12.007

Mitter, H., Larcher, M., Schönhart, M., Stöttinger, M., & Schmid, E. (2019). Exploring farmers' climate change perceptions and adaptation intentions: Empirical evidence from Austria. *Environmental Management*, *63*, 804–821. https://doi.org/10.1007/s00267-019-01158-7

Monat, J. P., & Gannon, T. F. (2015). What is Systems Thinking? A Review of Selected Literature Plus Recommendations. *American Journal of Systems Science*, *2015*(1), 11–26. https://doi.org/10.5923/j.ajss.20150401.02

Montgomery, D. R., Biklé, A., Archuleta, R., Brown, P., & Jordan, J. (2022). Soil health and nutrient density: preliminary comparison of regenerative and conventional farming. *PeerJ*,

*10*, 1–20. https://doi.org/10.7717/peerj.12848

Montgomery, D. R., & Matson, P. A. (2007). Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(33), 13268–13272.

Montgomery, M. A., Bartram, J., & Elimelech, M. (2009). Increasing Functional Sustainability of Water and Sanitation Supplies in Rural Sub-Saharan Africa. *Environmental Engineering Science*, *26*(5), 1017–1023. https://doi.org/10.1089/EES.2008.0388

Morton, L. W., Hobbs, J., Arbuckle, J. G., & Loy, A. (2015). Upper Midwest climate variations: Farmer responses to excess water risks. *Journal of Environmental Quality*, *44*(3), 810–822. https://doi.org/10.2134/jeq2014.08.0352

Morton, L. W., McGuire, J. M., & Cast, A. D. (2017). A good farmer pays attention to the weather. *Climate Risk Management*, *15*, 18–31. https://doi.org/10.1016/j.crm.2016.09.002

Morton, L. W., Roesch-Mcnally, G., & Wilke, A. K. (2017). Upper Midwest farmer perceptions: Too much uncertainty about impacts of climate change to justify changing current agricultural practices. *Journal of Soil and Water Conservation*, *72*(3), 215–225. https://doi.org/10.2489/jswc.72.3.215

Murphy, A. B. (2014). Geography's Crosscutting Themes: Golden Anniversary Reflections on "The Four Traditions of Geography. *Journal of Geography*, *113*(5), 181–188. https://doi.org/10.1080/00221341.2014.918639

National Academies of Sciences, Engineering, and M. (2016). *Rationalizing rural area classifications for the Economic Research Service: A workshop summary*. National Academies Press.

National Centers for Environmental Information. (n.d.). *U.S. Climate Normals*. National Oceanic and Atmospheric Administration. Retrieved February 1, 2022, from https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

National Council Research. (2014). *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond*. The National Academies Press. https://doi.org/10.17226/18722

Nelson, K. S., Nguyen, T. D., Brownstein, N. A., Garcia, D., Walker, H. C., Watson, J. T., & Xin, A. (2021). Definitions, measures, and uses of rurality: A systematic review of the empirical and quantitative literature. *Journal of Rural Studies*, *82*(July 2020), 351–365. https://doi.org/10.1016/j.jrurstud.2021.01.035

Nelson, K. S., Nguyen, T. D., Francois, J. R., & Ojha, S. (2023). Rural sustainability methods, drivers, and outcomes: A systematic review. *Sustainable Development*, *31*, 1226–1249. https://doi.org/10.1002/sd.2471

Newton, P., Civita, N., Frankel-Goldwater, L., Bartel, K., & Johns, C. (2020). What Is

Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. *Frontiers in Sustainable Food Systems*, *4*(October), 1–11. https://doi.org/10.3389/fsufs.2020.577723

Niles, M. T., Lubell, M., & Brown, M. (2015). How limiting factors drive agricultural adaptation to climate change. *Agriculture, Ecosystems and Environment*, *200*, 178–185. https://doi.org/10.1016/j.agee.2014.11.010

Noy, I., & Yonson, R. (2018). Economic Vulnerability and Resilience to Natural Hazards: A Survey of Concepts and Measurements. *Sustainability*, *10*. https://doi.org/10.3390/su10082850

Nyborg, K., Anderies, J. M., Dannenberg, A., Lindahl, T., Schill, C., Schluter, M., Adger, W. N., Arrow, K. J., Barrett, S., Carpenter, S., Chapin III, F. S., Crepin, A.-S., Daily, G., Ehrlich, P., Folke, C., Jager, W., Kautsky, N., Levin, S. A., Madsen, O. J., … de Zeeuw, A. (2016). Social norms as solutions. *Science*, *354*, 42–43. https://doi.org/10.1126/science.aaf8317

Oberč, B. P., & Schnell, A. A. (2020). Approaches to sustainable agriculture: exploring the pathways towards the future of farming. In *International Union for Conservation of Nature*. https://doi.org/10.2305/iucn.ch.2020.07.en

Ophuls, W. (2012). *Immoderate Greatness: Why Civilations Fail*. CreateSpace Independent Publishing Platform.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–15187. https://doi.org/10.1073/PNAS.0702288104/ASSET/EC5B6197-C649-4DE9-97A7-C0416D49CC4A/ASSETS/IMAGES/LARGE/ZPQ03407735300T2.JPG

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people's knowledge: A multi-step fuzzy cognitive mapping approach. *Ecological Modelling*, *176*(1–2), 43–64. https://doi.org/10.1016/j.ecolmodel.2003.10.027

Page, C., & Witt, B. (2022). *A Leap of Faith: Regenerative Agriculture as a Contested Worldview Rather Than as a Practice Change Issue*. https://doi.org/10.3390/su142214803

Palmberg, I., Hofman-Bergholm, M., Jeronen, E., & Yli-Panula, E. (2017). Systems Thinking for Understanding Sustainability? Nordic Student Teachers' Views on the Relationship between Species Identification, Biodiversity and Sustainable Development. *Education Sciences*, *7*(72). https://doi.org/10.3390/educsci7030072

Palmer, W. C. (1965). Meteorological Drought. In *US Department of Commerce, Weather Bureau, Research Paper No. 45*.

Pande, S, & Ertsen, M. (2014). Endogenous change: on cooperation and water availability in two ancient societies. *Hydrol. Earth Syst. Sci*, *18*, 1745–1760. https://doi.org/10.5194/hess-18-1745-2014

Pande, Saket, Haeffner, M., Blöschl, G., Alam, M. F., Castro, C., Di Baldassarre, G., Frick-Trzebitzky, F., Hogeboom, R., Kreibich, H., Mukherjee, J., Mukherji, A., Nardi, F., Nüsser, M., Tian, F., van Oel, P., & Sivapalan, M. (2022). Never ask for a lighter rain but a stronger umbrella. *Frontiers in Water*, *3*. https://doi.org/10.3389/frwa.2021.822334

Pande, Saket, & Sivapalan, M. (2017). Progress in socio-hydrology: a meta-analysis of challenges and opportunities. *WIREs Water*, *4*, 1193. https://doi.org/10.1002/wat2.1193

Partridge, M. D., Olfert, M. R., & Ali, K. (2009). Towards a rural development policy: Lessons from the United States and Canada. *Journal of Regional Analysis and Policy*, *39*(2), 109–125.

Pattison, W. D. (1990). The four traditions of geography. *Journal of Geography*, *89*(5), 202–206. https://doi.org/10.1080/00221349008979196

Pauleit, S., Ennos, R., & Golding, Y. (2005). Modeling the environmental impacts of urban land use and land cover change-a study in Merseyside, UK. *Landscape and Urban Planning*, *71*, 295–310. https://doi.org/10.1016/j.landurbplan.2004.03.009

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, *11*, 1633–1644. https://doi.org/10.1002/ppp.421

Peet, R. (1985). The Social Origins of Environmental Determinism. *Annals of the Association of American Geographers*, *75*(3), 309–333.

Pittelkow, C. M., Liang, X., Linquist, B. A., Van Groenigen, L. J., Lee, J., Lundy, M. E., Van Gestel, N., Six, J., Venterea, R. T., & Van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365–368. https://doi.org/10.1038/nature13809

Pontius, R. G., & Millones, M. (2011). Death to Kappa: birth of quantity disagreement and allocation disagreement for accuracy assessment. *International Journal of Remote Sensing*, *32*(15), 4407–4429. https://doi.org/10.1080/01431161.2011.552923

Pontius, R. G., & Santacruz, A. (2014). Quantity, exchange, and shift components of difference in a square contingency table. *International Journal of Remote Sensing*, *35*(21), 7543–7554. https://doi.org/10.1080/2150704X.2014.969814

Poortinga, W., Steg, L., & Vlek, C. (2004). Values, environmental concern, and environmental behavior. *Environment and Behavior*, *36*(1), 70–93. https://doi.org/10.1177/0013916503251466

Porter, A. L., & Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, *81*(3), 719–745. https://doi.org/10.1007/S11192-008-2197-2

Power, A. G. (2010a). Ecosystem services and agriculture: tradeoffs and synergies.

*Philosophical Transactions of the Royal Society B*, *365*, 2959–2971. https://doi.org/10.1098/rstb.2010.0143

Power, A. G. (2010b). Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2959–2971. https://doi.org/10.1098/RSTB.2010.0143

Pretty, J. (2008). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447–465. https://doi.org/10.1098/RSTB.2007.2163

Pretty, J. N., Ball, A. S., Lang, T., & Morison, J. I. L. (2005). Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food Policy*, *30*(1), 1–19. https://doi.org/10.1016/j.foodpol.2005.02.001

Princen, T. (2003). Principles for Sustainability: From Cooperation and Efficiency to Sufficiency. *Global Environmental Politics*, *3*(1), 33–50. https://doi.org/10.1162/152638003763336374

Prokopy, L. S., Floress, K., Arbuckle, J. G., Church, S. P., Eanes, F. R., Gao, Y., Gramig, B. M., Ranjan, P., & Singh, A. S. (2019). Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature. *Journal of Soil and Water Conservation*, *74*(5), 520–534. https://doi.org/10.2489/jswc.74.5.520

Prokopy, Linda S, Arbuckle, J. G., Barnes, A. P., Haden, V. R., Hogan, A., Niles, M. T., & Tyndall, J. (2015). Farmers and climate change: A cross-national comparison of beliefs and risk perceptions in high-income countries. *Environmental Management*, *56*, 492–504. https://doi.org/10.1007/s00267-015-0504-2

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, *14*(3), 681–695. https://doi.org/10.1007/s11625-018-0627-5

Qi, S. (2010). Digital map of the aquifer boundary for the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. In *U.S. Geological Survey Data Series*. https://doi.org/10.3133/DS543

Quinton, J. N., Govers, G., Van Oost, K., & Bardgett, R. D. (2010). The impact of agricultural soil erosion on biogeochemical cycling. *Nature Geoscience 2010 3:5*, *3*(5), 311–314. https://doi.org/10.1038/ngeo838

Ranjan, P., Church, S. P., Floress, K., & Prokopy, L. S. (2019). *Synthesizing Conservation Motivations and Barriers: What Have We Learned from Qualitative Studies of Farmers' Behaviors in the United States?* https://doi.org/10.1080/08941920.2019.1648710

Rasmussen, K., & Arler, F. (2010). Interdisciplinarity at the Human-Environment interface. *Geografisk Tidsskrift-Danish Journal of Geography*, *110*(1), 37–45. https://doi.org/10.1080/00167223.2010.10669495

Reidsma, P., Tekelenburg, T., Van Den Berg, M., & Alkemade, R. (2006). *Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union*. https://doi.org/10.1016/j.agee.2005.11.026

Rhodes, C. J. (2017). The imperative for regenerative agriculture. *Science Progress*, *100*(1), 80–129. https://doi.org/10.3184/003685017X14876775256165

Riley, M. (2016). Still being the "good farmer": (Non-)retirement and the preservation of farming identities in older age. *Sociologia Ruralis*, *56*(1), 96–115. https://doi.org/10.1111/soru.12063

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a General Theory of Planning. In *Sciences* (Vol. 4, Issue 2).

Roberts, E., Anderson, B. A., Skerratt, S., & Farrington, J. (2017). A review of the rural-digital policy agenda from a community resilience perspective. *Journal of Rural Studies*, *54*, 372–385. https://doi.org/10.1016/J.JRURSTUD.2016.03.001

Roesch-McNally, G., Arbuckle, J. G., & Tyndall, J. C. (2018). Soil as social-ecological feedback: Examining the "ethic" of soil stewardship among Corn Belt farmers. *Rural Sociology*, *83*(1), 145–173. https://doi.org/10.1111/ruso.12167

Roesch-Mcnally, G. E., Basche, A. D., Arbuckle, J. G., Tyndall, J. C., Miguez, F. E., Bowman, T., & Clay, R. (2017). The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. *Renewable Agriculture and Food Systems*, *33*(4), 322–333. https://doi.org/10.1017/S1742170517000096

Roesch-Mcnally, G. E., Gordon Arbuckle, J., & Tyndall, J. C. (2017). What would farmers do? Adaptation intentions under a Corn Belt climate change scenario. *Agriculture and Human Values*, *34*, 333–346. https://doi.org/10.1007/s10460-016-9719-y

Running, K., Burke, J., & Shipley, K. (2017). Perceptions of environmental change and climate concern among Idaho's farmers. *Society and Natural Resources*, *30*(6), 659–673. https://doi.org/10.1080/08941920.2016.1239151

Running, K., Burnham, M., Wardropper, C., Ma, Z., Hawes, J., & Du Bray, M. V. (2019). Farmer adaptation to reduced groundwater availability. *Environmental Research Letters*, *14*, 115010. https://doi.org/10.1088/1748-9326/ab4ccc

Saak, A. E., Wang, T., Xu, Z., Kolady, D., Ulrich-Schad, J. D., & Clay, D. (2021). Duration of usage and farmer reported benefits of conservation tillage. *Journal of Soil and Water Conservation*, *76*(1), 65–75. https://doi.org/10.2489/jswc.2021.00187

Sanderson, M. R., Bergtold, J. S., Heier Stamm, J. L., Caldas, M. M., & Ramsey, S. M. (2017). Bringing the "social" into sociohydrology: Conservation policy support in the Central Great Plains of Kansas, USA. *Water Resources Research*, *53*(8), 6725–6743. https://doi.org/10.1002/2017WR020659

Sanderson, M. R., Bergtold, J. S., Heier Stamm, J. L., Caldas, M. M., Ramsey, S. M., & Aistrup, J. (2018). Climate change beliefs in an agricultural context: what is the role of values held by farming and non-farming groups? *Climatic Change*, *150*(3–4), 259–272. https://doi.org/10.1007/s10584-018-2283-2

Sanderson, M. R., & Curtis, A. L. (2016). Culture, climate change and farm-level groundwater management: An Australian case study. *Journal of Hydrology*, *536*, 284–292. https://doi.org/10.1016/j.jhydrol.2016.02.032

Sanderson, M. R., & Curtis, A. L. (2017). Are irrigators different from dryland operators? Insights from a comparative study in Australia. *Journal of the American Water Resources Association*, *53*(6), 1453–1466. https://doi.org/10.1111/1752-1688.12584

Sanderson, M. R., & Frey, R. S. (2015). Structural impediments to sustainable groundwater management in the High Plains Aquifer of western Kansas. *Agriculture and Human Values*, *32*(3), 401–417. https://doi.org/10.1007/s10460-014-9567-6

Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. M., McGuire, V. L., & McMahon, P. B. (2012). Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(24), 9320–9325. https://doi.org/10.1073/pnas.1200311109

Schulte-Uebbing, L. F., Beusen, A. H. W., Bouwman, A. F., & de Vries, W. (2022). From planetary to regional boundaries for agricultural nitrogen pollution. *Nature*, *610*(7932), 507–512. https://doi.org/10.1038/s41586-022-05158-2

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. *Advances in Experimental Social Psychology*, *25*(C), 1–65. https://doi.org/10.1016/S0065-2601(08)60281-6

Scott, M. (2013). Resilience: a Conceptual Lens for Rural Studies? *Geography Compass*, *7*(9), 597–610. https://doi.org/10.1111/GEC3.12066

Seidl, C., Wheeler, S. A., & Zuo, A. (2021). The drivers associated with Murray-Darling Basin irrigators' future farm adaptation strategies. *Journal of Rural Studies*, *83*(January), 187–200. https://doi.org/10.1016/j.jrurstud.2020.10.048

Semple, E. C. (1911). *Influences of the geographic environment on the basis of Ratzel's system of antro-geography*. Henry Holt and Company.

Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, *485*(7397), 229–232. https://doi.org/10.1038/nature11069

Sewell, W. H. (1992). A theory of structure: duality, agency, and transformation. *American Journal of Sociology*, *98*, 1–29.

Sher, J. P. (2019). *Education in rural America: A reassessment of conventional wisdom.* Routledge.

Shucksmith, M., & Rønningen, K. (2011). The Uplands after neoliberalism? e The role of the small farm in rural sustainability. *Journal of Rural Studies*, *27*, 275–287. https://doi.org/10.1016/j.jrurstud.2011.03.003

Siedlok, F., & Hibbert, P. (2014). The organization of interdisciplinary research: Modes, drivers and barriers. *International Journal of Management Reviews*, *16*(2), 194–210. https://doi.org/10.1111/IJMR.12016

Sivapalan, M., Savenije, H. H. G., & Bloschl, G. (2011). Socio-hydrology: A new science of people and water. *Hydrological Processes*, *26*(8), 1270–1276.

Sivapalan, M., Savenije, H. H. G., & Blöschl, G. (2011). Socio-hydrology: A new science of people and water. *Hydrological Processes*, *26*(8), 1270–1276. https://doi.org/10.1002/hyp.8426

Slimak, M. W., & Dietz, T. (2006). Personal values, beliefs, and ecological risk perception. *Risk Analysis*, *26*(6), 1689–1705. https://doi.org/10.1111/j.1539-6924.2006.00832.x

Smidt, S. J., Haacker, E. M. K., Kendall, A. D., Deines, J. M., Pei, L., Cotterman, K. A., Li, H., Liu, X., Basso, B., & Hyndman, D. W. (2016). Complex water management in modern agriculture: Trends in the water-energy-food nexus over the High Plains Aquifer. *Science of the Total Environment*, *566–567*, 988–1001. https://doi.org/10.1016/j.scitotenv.2016.05.127

Sobczyk, W. (2014). Sustainable development of rural areas Zrównoważony rozwój obszarów wiejskich Wiktoria Sobczyk Department of Environmental Engineering and Mineral Processing ,. *Problems of Sustainable Development*, *9*(1), 119–126.

Sonnino, R., Kanemasu, Y., & Marsden, T. (2008). Sustainability and Rural Development. In *Unfolding Webs* (pp. 29–53).

Soto, L., Padilla, M. C., Rivera Méndez, M., Pinto-Correia, T., Boix-Fayos, C., De, J., Soto, R. L., Padilla, M. C., Rivera Méndez, M., Pinto-Correia, T., Boix-Fayos, C., & De Vente, J. (2021a). Participatory monitoring and evaluation to enable social learning, adoption, and out-scaling of regenerative agriculture. *Ecology and Society*, *26*(4), 29. https://doi.org/10.5751/ES-12796-260429

Soto, L. R., Martínez-Mena, M., Cuéllar Padilla, M., & de Vente, J. (2021). Restoring soil quality of woody agroecosystems in Mediterranean drylands through regenerative agriculture. *Agriculture, Ecosystems and Environment*, *306*, 107191. https://doi.org/10.1016/j.agee.2020.107191

Spangenberg, J. H. (2011). Sustainability science: a review, an analysis and some empirical lessons. *Environmental Conservation*, *38*(3), 275–287. https://doi.org/10.1017/S0376892911000270

Speth, J. G. (2008). *The Bridge at the Edge of the World: Capitalism, the Environment, and Crossing from Crisis to Sustainability*. Yale University Press. https://doi.org/10.12987/9780300145304

Stave, K., & Hopper, M. (2007). What Constitutes Systems Thinking? A Proposed Taxonomy. *Proceedings of the 25th International Conference of the System Dynamics Society*.

Stedman, R. C., Parkins, J. R., & Beckley, T. M. (2004). Resource dependence and community well-being in rural Canada. *Rural Sociology*, *69*(2), 213–234. https://doi.org/10.1526/003601104323087589

Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The anthropocene: are aumans now overwhelming the great forces of nature. *AMBIO: A Journal of the Human Environment*, *36*(8), 614–621. https://doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2

Steg, L. (2016). Values, Norms, and Intrinsic Motivation to Act Proenvironmentally. *Annual Review of Environment and Resources*, *41*, 277–292. https://doi.org/10.1146/annurev-environ-110615-085947

Steg, L., Dreijerink, L., & Abrahamse, W. (2005). Factors influencing the acceptability of energy policies: A test of VBN theory. *Journal of Environmental Psychology*, *25*(4), 415–425. https://doi.org/10.1016/j.jenvp.2005.08.003

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology*, *29*(3), 309–317. https://doi.org/10.1016/j.jenvp.2008.10.004

Stern, P. C. (1993). A Second Environmental Science: Human-Environment Interactions. *New Series*, *260*(5116), 1897–1899.

Stern, P. C. (2000). Psychology and the science of human-environment interactions. *American Psychologist*, *55*(5), 523.

Stern, P. C., & Dietz, T. (1994). The value basis of environmental concern. *Journal of Social Issues*, *50*(3), 65–84.

Stern, P. C., Dietz, T., Abel, T. D., Guagnano, G., & Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Human Ecology Review*, *6*(2), 81–97.

Stern, P. C., Kalof, L., Dietz, T., & Guagnano, G. A. (1995). Values, beliefs, and proenvironmental action: Attitude formation toward emergent attitude objects. *Journal of Applied Social Psychology*, *25*(18), 1611–1636. https://doi.org/10.1111/j.1559-1816.1995.tb02636.x

Stock, P., & Burton, R. J. F. (2011). Defining Terms for Integrated (Multi-Inter-Trans-Disciplinary) Sustainability Research. *Sustainability*, *3*(8), 1090–1113. https://doi.org/10.3390/su3081090

Stuart, D., Schewe, R. L., & McDermott, M. (2012). Responding to climate change: Barriers to reflexive modernization in U.S. agriculture. *Organization & Environment*, *25*(3), 308–327. https://doi.org/10.1177/1086026612456536

Sutherland, L. A., & Calo, A. (2020). Assemblage and the 'good farmer': New entrants to crofting in scotland. *Journal of Rural Studies*, *80*, 532–542. https://doi.org/10.1016/j.jrurstud.2020.10.038

Swidler, A. (1986). Culture in action: symbols and strategies. *American Sociological Review*, *51*, 273–286.

Switzer, D., & Vedlitz, A. (2017). Green Colored Lenses: Worldviews and Motivated Reasoning in the Case of Local Water Scarcity. *Environment and Behavior*, *49*(7), 719–744. https://doi.org/10.1177/0013916516669391

Syvitski, J., Ángel, J. R., Saito, Y., Overeem, I., Vörösmarty, C. J., Wang, H., & Olago, D. (2022). Earth's sediment cycle during the Anthropocene. In *Nature Reviews Earth and Environment* (Vol. 3, pp. 179–196). Springer Nature. https://doi.org/10.1038/s43017-021-00253-w

Tainter, J. A. (1988). *The Collapse of Complex Societies*. Cambridge University Press.

Taylor, G. (1921). The Evolution and Distribution of Race, Culture, and Language. *Geographical Review*, *11*(1), 54. https://doi.org/10.2307/207857

Teague, R., & Kreuter, U. (2020). Managing Grazing to Restore Soil Health, Ecosystem Function, and Ecosystem Services. *Frontiers in Sustainable Food Systems*, *4*(September), 1–13. https://doi.org/10.3389/fsufs.2020.534187

Tegtmeier, E. M., & Duffy, M. D. (2004). External Costs of Agricultural Production in the United States. *International Journal of Agricultural Sustainability*, *2*(1), 1–21.

Tessier, L., Bijttebier, J., Marchand, F., & Baret, P. V. (2021). Cognitive mapping, flemish beef farmers' perspectives and farm functioning: a critical methodological reflection. *Agriculture and Human Values*, *0123456789*.

Thomas, D. R. (2006). A General Inductive Approach for Analyzing Qualitative Evaluation Data. *American Journal of Evaluation*, *27*(2), 237–246.

Thompson, A. W., Reimer, A., & Prokopy, L. S. (2015). Farmers' views of the environment: the influence of competing attitude frames on landscape conservation efforts. *Agriculture and Human Values*, *32*(3), 385–399. https://doi.org/10.1007/s10460-014-9555-x

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(50), 20260–20264. https://doi.org/10.1073/pnas.1116437108

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*, *515*. https://doi.org/10.1038/nature13959

Toensmeier, E. (2016). *The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture Practices for Climate Change Mitigation and Food Security*.

Chelsea Green Publishing.

Ullah, N., Hossain, I., Dayarathna, V. L., Nagahi, M., & Jaradat, R. (2020). Systems Thinking: A Review and Bibliometric Analysis. *Systems*, *8*(23), 1–26. https://doi.org/10.3390/systems8030023

Van Winsen, F., de Mey, Y., Lauwers, L., Van Passel, S., Vancauteren, M., & Wauters, E. (2013). Cognitive mapping: A method to elucidate and present farmers' risk perception. *Agricultural Systems*, *122*, 42–52. https://doi.org/10.1016/j.agsy.2013.08.003

Vayda, A. P., & McCay, B. J. (1975). New Directions in Ecology and Ecological Anthropology. *Annual Review of Anthropology*, *4*(1), 293–306. https://doi.org/10.1146/ANNUREV.AN.04.100175.001453

Velten, S., Leventon, J., Jager, N., & Newig, J. (2015). *What Is Sustainable Agriculture? A Systematic Review*. *7*, 7833–7865. https://doi.org/10.3390/su7067833

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2012). Climate Change and Food Systems. *Annual Review of Environment and Resources*, *37*, 195–222. https://doi.org/10.1146/annurev-environ-020411-130608

Vilsack, T. J. (2016). United States rural policy : Increasing opportunities and improving the quality of life of rural communities. In *OECD Regional Outlook 2016: Productive regions for inclusive societies* (pp. 267–279).

Vörösmarty, B. C. J., Hoekstra, A. Y., & Bunn, S. E. (2015). What scale for water governance? *Science*, *349*(6247), 478. https://doi.org/10.1126/science.349.6247.478-a

Vose, R. S., Applequist, S., Squires, M., Durre, I., Menne, M. J., Williams Jr., C. N., Fenimore, C., Gleason, K., & Arndt, D. (2014). *NOAA Monthly U.S. Climate Divisional Database (NClimDiv)*. NOAA National Climatic Data Center. https://doi.org/10.7289/V5M32STR

Vuillot, C., Coron, N., Calatayud, F., Sirami, C., Mathevet, R., & Gibon, A. (2016). Ways of farming and ways of thinking: do farmers' mental models of the landscape relate to their land management practices? *Ecology and Society*, *21*(1), 35. https://doi.org/10.5751/ES-08281-210135

Waldorf, B., & Kim, A. (2015). Defining and Measuring Rurality in the US: From Typologies to Continuous Indices. *Workshop on Rationalizing Rural Area Classifications*, 1–15.

Waldorf, B. S. (2006). A Continuous Multi-dimensional Measure of Rurality: Moving beyong the threshold measures. *Annual Meeting, Long Island, California, July 24-27*, 1–29.

Ward, F. A., & Pulido-Velazquez, M. (2008). Water conservation in irrigation can increase water use. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(47), 18215–18220. https://doi.org/10.1073/pnas.0805554105

Wardropper, C. B., Mase, A. S., Qiu, J., Kohl, P., Booth, E. G., & Rissman, A. R. (2020).

Ecological worldview, agricultural or natural resource-based activities, and geography affect perceived importance of ecosystem services. *Landscape and Urban Planning*, *197*, 103768. https://doi.org/10.1016/j.landurbplan.2020.103768

Waring, T. M., Kline, M. A., Brooks, J. S., Goff, S. H., Gowdy, J., Janssen, M. A., Smaldino, P. E., & Jacquet, J. (2015). A multilevel evolutionary framework for sustainability analysis. *Ecology and Society*, *20*(2), 34. https://doi.org/10.5751/ES-07634-200234

Weber, E. U., & Stern, P. C. (2011). Public understanding of climate change in the United States. *American Psychologist*, *66*(4), 315–328. https://doi.org/10.1037/a0023253

Wei, J., Wei, Y., & Western, A. (2017). Evolution of the societal value of water resources for economic development versus environmental sustainability in Australia from 1843 to 2011. *Global Environmental Change*, *42*, 82–92. https://doi.org/10.1016/j.gloenvcha.2016.12.005

Weinstein, M. P. (2010). Sustainability science: the emerging paradigm and the ecology of cities. *Sustainability: Science, Practice and Policy*, *6*(1), 1–5. https://doi.org/10.1080/15487733.2010.11908037

Wheeler, S. A., Nauges, C., & Zuo, A. (2021). How stable are Australian farmers' climate change risk perceptions? New evidence of the feedback loop between risk perceptions and behaviour. *Global Environmental Change*, *68*(March). https://doi.org/10.1016/j.gloenvcha.2021.102274

Wheeler, S., Zuo, A., & Bjornlund, H. (2013). Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. *Global Environmental Change*, *23*(2), 537–547. https://doi.org/10.1016/j.gloenvcha.2012.11.008

White, S. E. (1994). Ogallala oases: Water use, population redistribution, and policy implications in the High Plains of Western Kansas, 1980-1990. *Annals of the Association of American Geographers*, *84*(1), 29–45.

Wilbanks, T. J. (2007). Scale and sustainability. *Climate Policy*, *7*, 278–287.

Wilbanks, T. J. (2015). Putting "'Place'" in a multiscale context: Perspectives from the sustainability sciences. *Environmental Science and Policy*, *53*, 70–79. https://doi.org/10.1016/j.envsci.2015.04.009

Williams, A., Kennedy, S., Philipp, F., & Whiteman, G. (2017). Systems thinking: A review of sustainability management research. *Journal of Cleaner Production*, *148*, 866–881. https://doi.org/10.1016/j.jclepro.2017.02.002

Woods, M. (2009). Rural geography: blurring boundaries and making connections. *Progress in Human Geography*, *33*(6), 849–858. https://doi.org/10.1177/0309132508105001

Wooldridge, J. M. (2013). *Introductory Econometrics: A Modern Approah* (5th ed.). Cengage Learning.

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., Jackson, J. B. C., Lotze, H. K., Micheli, F., Palumbi, S. R., Sala, E., Selkoe, K. A., Stachowicz, J. J., & Watson, R. (2006). Impacts of Biodiversity Loss on Ocean Ecosystem Services. *Science*, *314*.

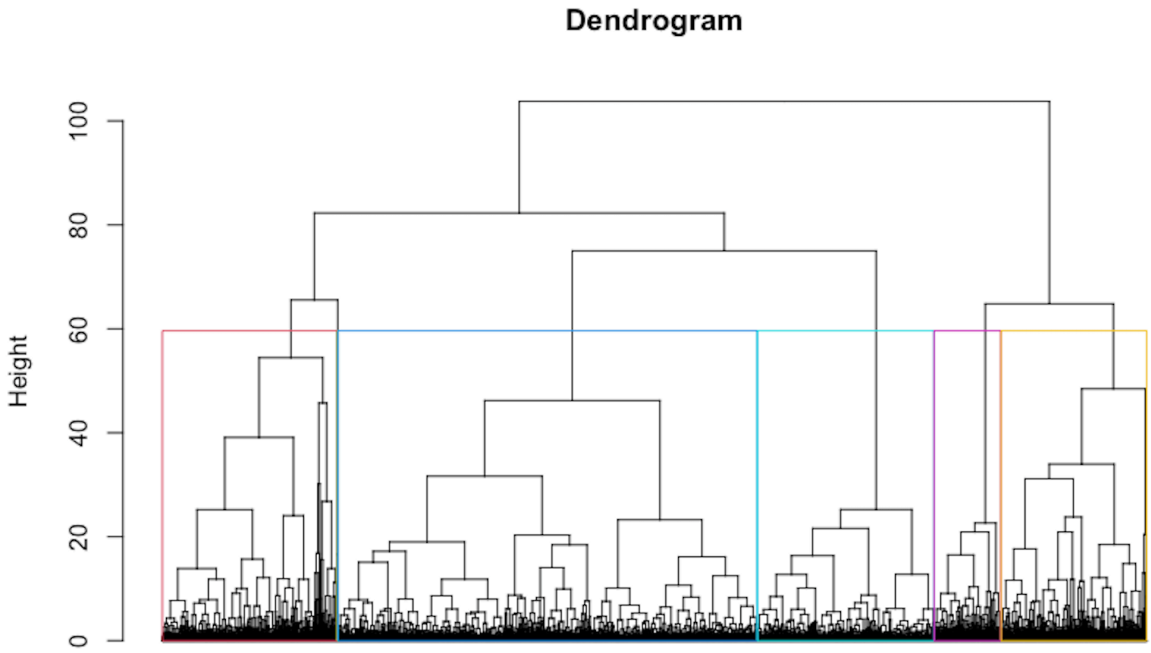
Wu, H., & Li, Z.-L. (2009). Scale Issues in Remote Sensing: A Review on Analysis, Processing and Modeling. *Sensors*, *9*, 1768–1793. https://doi.org/10.3390/s90301768

Zhao, J., Ameratunga, S., Lee, A., Browne, M., & Exeter, D. J. (2019). Developing a New Index of Rurality for Exploring Variations in Health Outcomes in Auckland and Northland. *Social Indicators Research*, *144*(2), 955–980. https://doi.org/10.1007/S11205-019-02076-1/METRICS

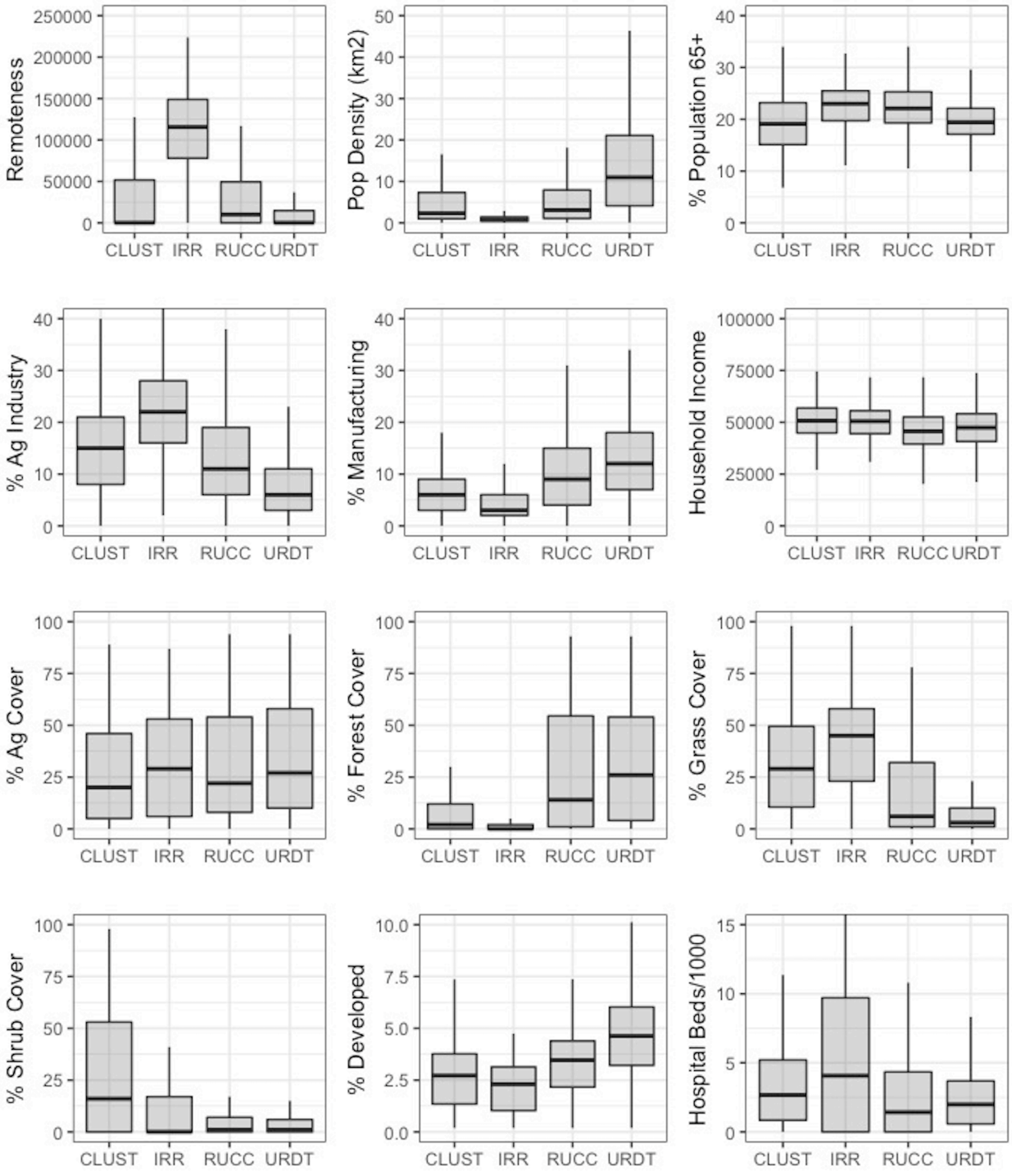
Zucaro, A., Ripa, M., Mellino, S., Ascione, M., & Ulgiati, S. (2014). Urban resource use and environmental performance indicators. An application of decomposition analysis. *Ecological Indicators*, *47*, 16–25. https://doi.org/10.1016/j.ecolind.2014.04.022

Zuo, A., Wheeler, S. A., & Xu, Y. (2022). Expanders, diversifiers or downsizers? Identifying clusters of irrigators' water trade and farm management strategies in Australia. *Agricultural Water Management*, *264*, 107495. https://doi.org/10.1016/j.agwat.2022.107495

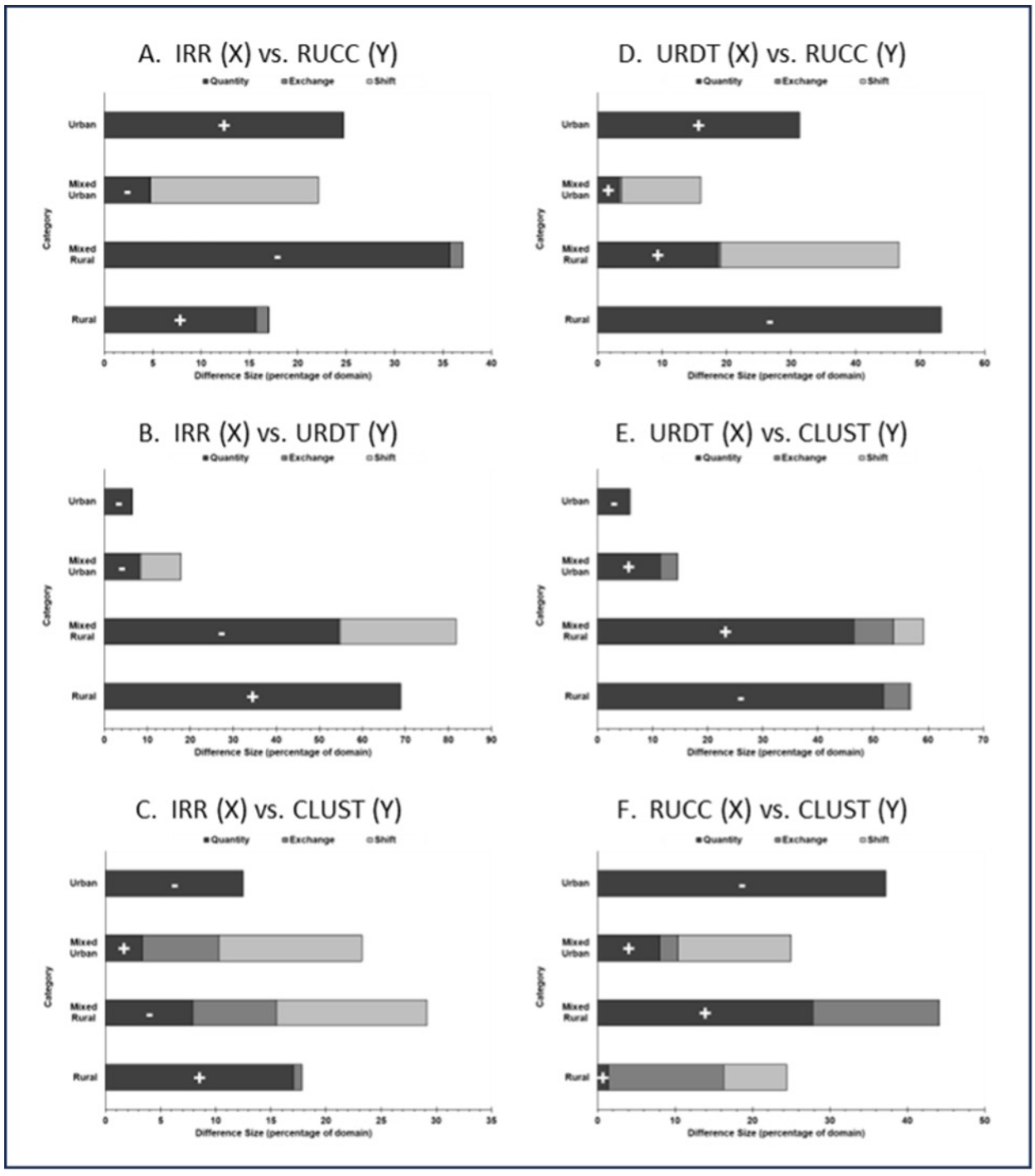
# Appendix A Supplementary materials for Chapter 4




Appendix A Figure A.1 Agglomerative clustering dendrogram for counties and twelve rural-relevant variables used in the "Cluster" measure. Colored boxes represent the six resulting clusters. The urban cluster is too small to be visible but is located between the first and second boxes on the left.




Appendix A Figure A.2 The distribution of key rural variable values (y-axes) for counties identified as rural by the original rural measures (x-axes). Outliers in the boxplots have been omitted for clarity.




Appendix A Figure A.3 Quantity, exchange, and shift difference components for each county category for all pairwise comparisons of reclassified rural definitions. Positive (+) and negative

(-) labels in the quantity component indicate the X definition map saw a net gain or loss of a category after accounting for persistence.

Appendix A Table A.1 Descriptive statistics for the six (6) clusters and their assigned detailed classification and simplified classification. SD = standard deviation.

| | | Cluster Classification (simplified / Detailed) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rural | | Mixed Rural | | Mixed Urban | Urban |
| Variable | Statistic | Extreme Rural | Rural | Mixed Rural - Forested | Mixed Rural - Agricultural | Mixed Urban | Extreme Urban |
| Total Population | mean | 32,796 | 53,896 | 47,302 | 37,342 | 386,670 | 1,967,660 |
| | SD | 98,526 | 133,344 | 83,901 | 40,625 | 699,534 | 674,627 |
| Population Density | mean | 10 | 11 | 30 | 26 | 380 | 17,317 |
| | SD | 27 | 33 | 40 | 28 | 756 | 5,398 |
| % Employed in Agriculture Industry | mean | 16 | 14 | 4 | 7 | 2 | 0 |
| | SD | 10 | 10 | 3 | 4 | 2 | 0 |
| % Employed in Manufacturing | mean | 7 | 6 | 15 | 17 | 10 | 3 |
| | SD | 5 | 4 | 7 | 7 | 4 | 0 |
| % Agriculture landcover | mean | 36 | 8 | 22 | 74 | 22 | 0 |
| | SD | 23 | 10 | 17 | 12 | 19 | 0 |
| % Forested | mean | 6 | 10 | 51 | 9 | 32 | 4 |
| | SD | 10 | 12 | 20 | 8 | 20 | 2 |
| % Grassland | mean | 42 | 11 | 4 | 2 | 3 | 1 |
| | SD | 23 | 9 | 5 | 4 | 6 | 0.58 |
| % Shrubland | mean | 10 | 66 | 4 | 0.2 | 4 | 0.33 |
| | SD | 14 | 15 | 7 | 1 | 10 | 0.58 |
| % Developed land | mean | 3 | 2 | 7 | 6 | 25 | 85 |
| | SD | 3 | 2 | 4 | 3 | 22 | 9 |
| Median Household Income | mean | 51,571 | 51,507 | 45,175 | 52,634 | 64,845 | 58,853 |
| | SD | 9,464 | 13,105 | 8,890 | 10,440 | 18,017 | 22,323 |
| Hospital Beds/1000 people | mean | 6 | 3 | 2 | 3 | 3 | 4 |
| | SD | 10 | 3 | 2 | 2 | 3 | 2 |
| % Population 65+ | mean | 20 | 19 | 21 | 18 | 15 | 14 |
| | SD | 5 | 6 | 4 | 3 | 3 | 2 |