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SOCIAL ECOLOGICAL FOOD SYSTEMS: SUSTAINABILITY LESSONS FROM MAINE DAIRY NETWORKS

By

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B.S. University of Maine, 2006

A DISSERTATION

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(in Ecology and Environmental Sciences)

The Graduate School

The University of Maine

August 2016

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Dissertation Co-Advisors: Dr. Xuan Chen and Dr. Laura Lindenfeld

An Abstract of the Dissertation Presented

in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

(in Ecology and Environmental Sciences)

August 2016

Milk production has played an integral role in the culture, landscape, and economy of Maine's agriculture. Maine dairy farmers have faced numerous sustainability challenges to economic, environmental, and social aspects of their industry. Like many other complex social ecological systems, the Maine dairy industry faces a gap between scientific knowledge and actionable management or policy. A cultural dichotomy exists between conventional and organic farming. Shifting the focus from this binary, metrics such as social capital may play a key role in solving sustainability issues. Difficulties arise in the governance of complex social ecological systems when the scales of assessment, management, and policy do not match principal challenges. Despite efforts by many, Maine dairy challenges may be fueled by a state political system that is restricted by term limits and short legislative sessions. Piecemeal policy-making leads to assessment and policy outcomes that do not take the complexities of the system into consideration.

In the case of the Maine dairy industry, using mental modeling and social network analysis: 1) we seek to explore a method that may improve understanding in cases of disintegration between sustainability policy and action; 2) we test whether social capital, measured using Maine dairy farmers' information networks, spans perceived boundaries between conventional and organic management and between different farm sizes, and; 3) we investigate the scale problemscape for long-term success of the Maine dairy industry.

We found no significant difference in the importance of the economic, environmental, or social factors that dairy farmers considered to be the most challenging to industry sustainability. Social capital, rather than farm management practice or size, is a critical variable for better understanding industry sustainability. We found gaps between the current industry policy structure and the management and assessment scales required to address sustainability challenges. The barriers to effective long-term management, assessment, and policy are numerous for the Maine dairy industry. Our findings suggest that solutions concentrating on only one sustainability factor are unlikely to work in the long-term. Solutions may lie in a more holistic evaluation process, and inclusion of social capital and scale assessments to effectively link science and policy.

ACKNOWLEDGEMENTS

This research was supported by the NSF Graduate Research Fellowship Program: Grant DGE 1442085. I would first like to extend my gratitude and respect to the Maine dairy farmers and the industry community, and Cooperative Extension Specialists Gary Anderson, Dave Marcinkowski, and Rick Kersbergen. Your generosity with your time, expertise, and insight is what made this dissertation possible. Writing a dissertation is truly a collaborative process, and I could not have done it without my inspiring, smart, and fun community of friends and family. Last and certainly not least are a few thank you haikus:

Guiding Committee,
I value your wisdom and
many perspectives

Corianne, kindred
spirit, writing buddy in
science adventures

Eric the Hubster,
partner extraordinaire, ace
postpartum edits

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LIST OF ABBREVIATIONS

ANOVA: Analysis of Variance

GLM: Generalized Linear Model

MDIA: Maine Dairy Industry Association

MMC: Maine Milk Commission

MOFGA: Maine Organic Farmers and Gardeners Association

SES: Social Ecological System

SRBE: Short Run Break Even

WCED: World Commission on Environment and Development

INTRODUCTION

The U.S. dairy industry has seen increased consolidation—fewer, larger, and more technologically efficient farms (Shields, 2010; Von Keyserlingk et al., 2013). This trend has occurred across agricultural sectors since the industrialization of agriculture, beginning in the middle of the 20th Century. Federal milk marketing orders, federal milk price stabilization programs, and import quotas were established to decrease power discrepancies between producers and processors, to ensure sufficient milk access for consumers, and to protect farmers from foreign market competition, respectively (Shields, 2010). While these federal programs have helped the dairy industry over the years since their inception, rapidly changing global markets, increasingly volatile environmental conditions, and increasingly complicated social and technological changes have affected the federal dairy landscape to the detriment of farm families. Competition for shelf space threatens dairy's former dominance as Americans' beverage of choice as markets expand and demand increases for alternative milks (Dharmasena & Capps, 2014). Drought has pushed up costs for the large farms in California as well as for the smaller farms in New England, as purchased feed becomes more expensive (Farm Credit East, 2012; Shields, 2010). Well-publicized concerns about industrial agricultural practices and genetically modified foods have thrust conventional and organic farmers into social media and political firestorms, with which they may be ill equipped to handle. Dairying is no longer a business that can succeed solely with hard work and generational knowledge. It is a mercurial landscape with complex challenges.

Solutions to any complex problem are difficult to discover and implement without adaptive assessment of the issues and clear communication to policy makers. Dynamic and complex problems require equally dynamic and adaptive assessment, management, and

policy, which include alignment of the scales of the problems and their solutions. Having worked in human-environmental policy, consulting, advocacy, and planning, I saw first-hand the need for both qualitative and quantitative data, clear communication of relevant results to policy makers, and ongoing assessment that is built-in to management and policy to ensure an adaptive means for addressing problems. A strong and harrowing narrative moves people, but without data to support a story, policy makers from local to federal levels would be reluctant to propose new policies.

Applying the importance of scale and data to the dairy system, federal milk pricing impacts all dairy farmers in states across the country, but not all states will have equal influence on federal dairy policy. New England states make up a smaller proportion of total U.S. milk produced when compared to the dairy-dominant Wisconsin or California (USDA ERS, 2015). While pay price impacts all farmers, in Maine where dairy makes up 0.29% of the U.S. market (USDA ERS, 2016), farmers have very little political leverage to impact the federal pricing structure. There are interesting and complex questions to be asked about all U.S. dairy, but because Maine has so little influence at this scale, I have focused on trying to understand assessment, management, and policy that the Maine dairy industry can impact and improve for the future.

In trying to understand what kind of future the dairy industry can hope for, it's important to understand Maine dairy's past and its present. Milk production has played an integral role in the culture, landscape, and economy of Maine's agriculture. I make the assumption that dairy is an important industry for the future of Maine and the region. Despite its small percent of the national milk production, Maine dairy in 2014 contributed nearly one fifth of all agricultural cash receipts, and it is regularly one of the state's top agricultural commodities (USDA ERS, 2015). Annually, dairy contributes more than 570 million dollors to Maine's economy and over 25 million dollars in taxes (Kersbergen et al.,

2013). Dairy provides a key component of the integrated rural Maine landscape in the form of 700,000 acres of open space (Kersbergen et al., 2013). The dairy industry supports not only farmers, but also thousands of other jobs such as grain suppliers, veterinarians, processors, and scientists (Kersbergen et al., 2013). In 2007, Maine's organic dairy sector made up more than half of revenue from all organic products in the state (Beach, 2010). In 2015[1], the majority of the 260 Maine dairy farms were concentrated in central Maine, and over three-quarters of these farms produced conventional milk. Maine dairy is made up of predominantly small farms, but the largest farms, which in 2015 made up only 7% of the industry, contributed nearly half of the total milk produced. The state's two remaining large processing plants—Oakhurst and Hood—are located in Portland, ME. Farms not affiliated with these plants may haul their milk out of state to other milk companies or cooperatives, participate in smaller processing operations, or process their own milk.

The problems facing the Maine dairy industry are similar to those facing other agricultural sectors in the sixty years since the Green Revolution. Industries have scaled-up and have been able to do so because of technological advances. This has resulted in fewer dairy farms with greater production per farm, a slight decrease in the total number of cows, and fairly steady milk production overall. The scaling up of the dairy industry and the loss of farms has also reduced the infrastructure that supports milk producers such as parts suppliers and processors. In the context of the challenges to the dairy business, the loudest industry voices have focused on costs of production and pay price. The narrative of the criticality of economic issues has led to policy action within this narrow focus. Under the assumption that Maine dairy is important for the future of the state's agriculture, in this rapidly changing world the process toward sustainability will require a more holistic, and dynamic approach to address challenges.

[1] January 2015 data, Maine Milk Quality Lab, Department of Agriculture, Conservation and Forestry

I took time to work at a number of organizations between undergraduate and graduate school. The lessons that I learned working with a consortium of healthy housing and tenant rights organizations propelled me to pursue research-driven graduate work. This passionate collective of empowered tenants shared their stories week after week with the city council, but their harrowing anecdotes rarely moved the council to vote in their favor. Why? At first I struggled to understand why the councilors were unmoved by these brave and mistreated people. Session after session, I saw a pattern unfold. Landlords came with statistics—regardless of the relevance of the statistics. Money and power were also motivators. Vote after vote, councilors listened to testimony, and sided with slumlords, like the infamous Donald Sterling (Zirin, 2014). The organizations that I worked with brought testimony, but very few statistics. I realized that I wanted to return to school to be able to tell a story with data, and tell that story well. I wanted to understand how a system is working or failing, and be able to translate that data to policy makers to help constituents or stakeholders to solve sustainability problems impacting their lives and livelihoods.

This brings me back to this dissertation as the culmination of my doctoral research, and the underlying desire to link scientific knowledge and action to move toward better assessment, management, and policy. Scientists can help bridge these gaps between science and policy by better communicating results for policy makers, and by employing methods that go beyond a narrative-sans-data or data-sans-narrative. To do this in my own work, I have employed mixed methods—qualitative and quantitative analyses, mental modeling, and social network analysis. Using the case of Maine's struggling dairy industry, I have analyzed farmers' perceptions of sustainability challenges to 1) better link scientific knowledge and policy action for sustainable social ecological systems; 2) go beyond the organic and conventional binary common in agricultural literature to solve sustainability

challenges; and 3) evaluate the systemic scale challenges associated with sustainability problems.

Chapter 1 explores the gaps between science and policy in the Maine dairy industry by mapping farmers' mental models of industry sustainability challenges. Based on farmer and industry observations, we expected that Maine dairy farmers would consider economic factors to be the most important to industry sustainability. We found no significant difference in the importance of economic, environmental, or social sustainability challenges. This suggests that farmers face numerous interconnected sustainability challenges and that solutions concentrating on only one sustainability factor are unlikely to work in the long-term. The Maine policy context has created an environment of short-term fixes for long-term problems. To move toward a more sustainable industry for present and future dairy farmers, policy makers and industry stakeholders should diversify evaluation and policy to capture the complete spectrum of challenges.

Due to a cultural dichotomy between conventional and organic farming, many studies have focused on the distinctions between the two management practices. The objective of Chapter 2 was to test with mental modeling and information network analysis whether management practice, farm size, or social capital better explain an integrated or balanced view of Maine dairy industry sustainability. Social ecological systems governance literature has made the case for inclusion of social capital in natural resource management and resilience work (Adger et al., 2005; Folke et al., 2005; Ostrom & Ahn, 2003). The results of this study suggest that neither management practice nor farm size is a primary factor contributing to differences in farmers' mental models of sustainability. These findings demonstrate the value of social capital metrics as variables in evaluating sustainability of agricultural systems, and suggest that there is a benefit to questioning the conventional-organic binary focus of many agricultural studies.

Chapter 3 is an exploratory causation analysis of farmers' mental models of primary sustainability challenges, which investigates the scale problemscape for the long-term success of the Maine dairy industry. We hypothesize that the Maine dairy industry faces management, assessment, and policy challenges that are cross-scale and cross-level, which have led to situations of scale ignorance, mismatch, and plurality. Studies have used mental model networks to research sustainability problems (Hoffman, Lubell, & Hillis, 2014), but combining mental model and information networks and scale analyses for an agricultural system is an innovative approach that may lead to policy solutions. We found that Maine dairy's top sustainability challenges are cross-scale and cross-level. There are gaps between the current policy structure of jurisdictional or organizational players and the management and assessment scales required to address primary sustainability challenges. Management and assessment have focused on dividing the industry by groups, such as conventional versus organic farms or tiered farm sizes, which may not be effective in addressing multi-scale sustainability challenges. Traditional institutions such as industry groups and Cooperative Extension continue to be vital, but challenges have grown in scale, and our results suggest that we may need to rethink how these institutions function, collaborate, and adapt.

This dissertation contributes insight to the use of mental model network analysis in 1) linking knowledge and action in sustainability assessment, management, and policy; 2) moving beyond the conventional-organic binary to discover better metrics for evaluating sustainability challenges; and 3) exploring cross-scale and cross-level problems associated with mismatches between current assessment, management, and policy and that which is needed for solving sustainability challenges.

CHAPTER 1

BEYOND SPLINTERED SUSTAINABILITY POLICY: MENTAL MODEL NETWORKS BRIDGE A PERSISTENT SUSTAINABILITY SCIENCE GAP

Introduction

Sustainability must be cultivated as a dynamic process rather than a static goal if we are to address challenges and vulnerabilities in complex social ecological systems (SESs) (Clark & Dickson, 2003; Kates et al., 2001; Kates & Parris, 2003). Moving toward sustainability requires actions that are evidence-driven with purposeful, adaptive feedback loops between scientific knowledge and policy (Kates et al., 2001). Sustainability science is an integrated cross-disciplinary field defined by its intention to solve complex problems rather than just to understand them (e.g., Clark, 2007; Clark & Dickson, 2003; Kates et al., 2001; Lindenfeld et al., 2012; McGreavy et al., 2013; Speth, 1992). Though sustainability science is intended to produce dynamic knowledge and solutions, gaps remain in the splintered bridge between "useful knowledge and informed action" (Clark, 2007, 1737-1738). A primary gap in the sustainability science vision is the boundary between scientific knowledge and actionable management or policy (Cash, Borck, & Patt, 2006; Cash et al., 2003; Gorczyca et al., 2012; Lyons et al., 2014; van Kerkhoff & Lebel, 2006). "…[A]ctors on different sides of a boundary rely on such different core sets of assumptions that they cannot understand what the other is saying even when speaking the same literal language" (Cash, Borck, & Patt 2006, 469). One of many boundaries in a complex system, policy communication may daunt scientists who are well versed in knowledge production. Historically, scientists maintained a distance between their research and those who would put it into practice; a peer-reviewed publication was seen as the end point of a scientist's public responsibility (van Kerkhoff & Lebel, 2006, 449).

Mental Modeling as a Sustainability Science-Policy Bridging Tool

Within the growing body of sustainability research, a range of perspectives has emerged on how to bridge these boundary problems. Scientists have provided a wealth of critiques and solutions (Cash, Borck, & Patt, 2006; Cash et al., 2003; Gorczyca et al., 2012; Guston, 2001; Rose & Parsons, 2015; van Kerkhoff & Lebel, 2006). Mental modeling is one tool that may help to bridge the boundary between sustainability science and policy. Mental models are used to evaluate and measure human cognitive structure. More simply, this can be thought of a person's internal understanding of an external experience or reality (Jones et al., 2011, 46; Lynam et al., 2012, 23). A combination of mental modeling and social network analysis, mental model network analysis (Hoffman, Lubell, & Hillis, 2014) is an underexplored and underutilized tool with potential for direct sustainability policy application. Researchers have used mental models to produce knowledge and link knowledge and action, but a more concrete stakeholder-directed policy application is missing from the literature (Hoffman, Lubell, & Hillis, 2014; Lynam et al. 2012). Lynam and Brown (2012) state a need for more mental models research with applications for policy. The bridging power of mental models lies is in their capacity to capture stakeholders' understanding of an issue.

Taking into account the importance of stakeholder engagement in sustainability science research (e.g., Anderson, Teisl & Noblet, 2012; Bell et al., 2013; Bieluch et al., 2016; Cash et al., 2003; Lindenfeld et al., 2012; van Kerkof & Lebel, 2006), mental models provide a pathway from the co-production of knowledge to policy action. Stakeholders communicate in a language often more familiar to the public and policy makers than scientific discussions or articles full of jargon and analyses (Cash, Borck, & Patt, 2006). As constituents, stakeholders provide perspectives that are directly relevant to the policy decisions that affect their interests. Combining sustainability science theory, mental

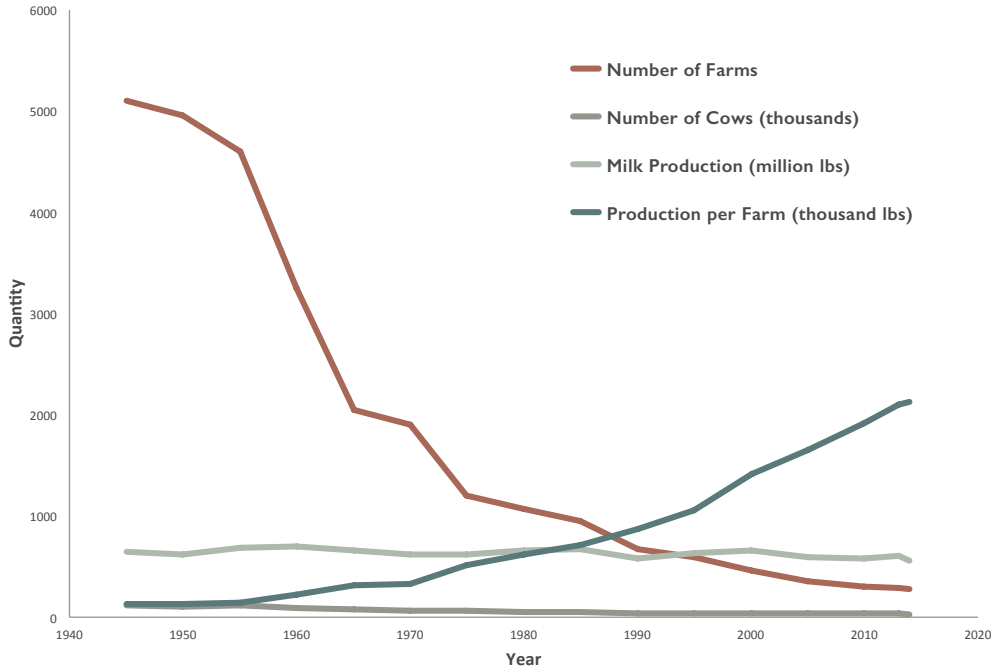
modeling, and social network analysis, scientists can map these perspectives in a network (Hoffman, Lubell, & Hillis, 2014), and use stakeholders' language to frame issues for sustainability policy (Lynam et al. 2012).

We aim to explore the gaps between science and policy in the Maine dairy industry by mapping farmers' mental models of industry sustainability challenges. Using social network analysis and statistical analysis, we will evaluate the relative importance of these challenges. Differences between the current policy focus and the problems that farmers perceive to be the most important may provide a bridge to opportunities for better assessment and policies that lead toward sustainability of the Maine dairy industry. First we will present an overview of the Maine dairy industry and discuss why it is a model location to study sustainability challenges. We will discuss the policy context for Maine dairy industry sustainability challenges, and explore how this policy landscape influences sustainability science-policy gaps. We will explain our construction and evaluation of farmers' mental model networks of sustainability challenges, and discuss the implications of these results for Maine dairy industry sustainability assessment and policy.

The Maine Dairy Industry

Maine has predominantly small and medium-sized dairies, and even the state's largest dairies would be considered small when compared to high production regions of the U.S. (Maine Milk Quality Database, 2014; Shields, 2010). Over the sixty years since the Green Revolution, the number of Maine dairy farms has steeply declined, the production per farm has increased, total cows have decreased slightly, and overall milk production has remained fairly steady (Figure 1).

Figure 1. Maine Dairy Farm Trends Since the Green Revolution



Maine is a model location for studying sustainability problems because of its small size and isolation (leading to small insular networks), and its part-time citizen legislature[1]. To understand hugely complex systems, we need to first look at systems on a more manageable scale, and then we can attempt to address larger-scale challenges. Maine dairy is complex, but its scale makes it tractable for application and testing of sustainability solutions. As a SES, milk production has played an integral role in the culture, landscape, and economy of Maine's agriculture. While Maine is known nationally and internationally for its lobster and blueberries, dairy is also one of the state's most important food commodities. In 2013, dairy products were the second largest agricultural commodity in Maine (USDA ERS, 2015). Annually, dairy contributes more than 570 million dollors to Maine's economy and over 25 million dollars in taxes (Kersbergen et al., 2013). Dairy provides a key component of the integrated rural Maine landscape in the form of 700,000

[1] The Maine Legislature is a part-time, citizen, bicameral law-making body made up of the 154 member House of Representatives and the 34 member Senate.

acres of open space (Kersbergen et al., 2013). The dairy industry supports not only farmers, but also thousands of other jobs such as grain suppliers, veterinarians, processors, and scientists (Kersbergen et al., 2013). In 2007, Maine's organic dairy sector made up more than half of revenue from all organic products in the state (Beach, 2010).

The complexities of agriculture in a rapidly changing post-Green Revolution world are especially relevant to sustainability science problems across SESs. Globally, smaller dairies have experienced the brunt of challenges from scaled-up industrial agriculture, which focuses primarily on the economic efficiencies of size and scale, and frequently ignores the importance of environmental and social factors (Mosheim & Lovell, 2009). Dairy industries worldwide have faced interrelated economic, environmental, and social losses. For Maine dairy farmers, profit margins occasionally support a farm for a short period of strong pay price, but frequently, the costs of production are higher than the price that a farmer receives for milk produced (G. Anderson & D. Marcinkowski, personal communication, February, 2 2015; Kersbergen, 2013). Milk production is vulnerable to the increasing frequency of drought conditions, which impact feed prices (Farm Credit East, 2012). Dairy support systems in Maine, including human and physical infrastructure, are rapidly declining with farm loss, leaving farmers isolated.

The Maine Legislature and other dairy industry stakeholders have worked hard to support an industry facing infrastructure loss, a declining work force, and dwindling interest in a younger generation. Despite efforts by many, dairy challenges may be fueled by a state political system that is restricted by term limits and short Legislative sessions. Piecemeal policy-making leads to assessment and policy outcomes that do not take the complexities of the system into consideration (Cash et al., 2006). Using the case of the Maine dairy industry, we seek to explore a method that may improve understanding in cases of disintegration between sustainability policy and action.

Alignment or Misalignment? Sustainability and Maine Dairy Policy

While the federal government sets milk pricing, the Maine Legislature set forth a unique program to support Maine conventional dairy farmers when federal milk prices drop below a state-established cost of production threshold (Kersbergen et al., 2013). The program was established in 2004 by *An Act to Encourage the Future of Maine's Dairy Industry* (Chapter 648 H.P. 1445-L.D. 1945), and updated in 2010 Legislative Act *MRSA, Title 7, Section 2952-A*, or *An Act to Implement the Recommendations of the Task Force on the Sustainability of the Dairy Industry in Maine* (Kersbergen et al. 2013). The preamble of *An Act to Encourage the Future of Maine's Dairy Industry* states that,

> …volatility of prices paid to milk producers jeopardizes the viability of the Maine dairy industry; and…the Maine dairy industry is essential to the State's rural economy and communities and generates business activity and preserves open space; and…the stabilization of the dairy industry during temporary price drops constitutes a public purpose and an appropriate expenditure of state revenues (Chapter 648 H.P. 1445-L.D. 1945).

Every three years the Maine Milk Commission (MMC) is required to evaluate the cost of production for a sample of conventional farms at four milk production levels, called tiers, to determine support for farmers (Chapter 648 H.P. 1445-L.D. 1945) (Table 1).

Table 1. Maine Dairy Farm Size by Milk Production Tiers

Size category	Tier	Annual milk production levels (cwt)*	Number of farms **
Small	1	<16,790	189
Medium	2	16,791-49,079	47
Large	3	49,080-76,803	5
Very Large	4	>76,803	18

* Chapter 648 H.P. 1445-L.D. 1945

** January 2015 data, Maine Milk Quality Lab, Department of Agriculture, Conservation and Forestry

Cost of production is evaluated as the Short Run Break Even (SRBE) cost of producing a yearly quantity of milk, and the most recent study defines SRBE as adjusted cash operating costs (Chen et al., 2016). Though the titles and language of the Acts speak to supporting the industry in the long-term, the Legislature's directive and the state's application of the rules

conflict with both the timeframe and the scale of influence that the acts suggest are needed. The legislative language used is "sustainability" and "future of," and the preamble of L.D. 1945 speaks to the economic, environmental, and social importance of the industry. However, the mandated metric to evaluate the industry is short term and limited to a narrowly defined economic measure. Misalignment between knowledge and action emerges in the relationship among the challenges farmers face, sustainability evaluation, and state policy. The Maine Legislature passed acts to address the sustainability challenges facing the industry, yet the narrow execution of the policies diverge from that aim, and the industry continues to struggle.

From foundational ethnographic work, it became clear that the narrative of challenges to the Maine dairy industry frequently focused on cost of production and pay price. Understandably, if the voices at these industry meetings repeatedly spoke to economic issues, industry leaders would push for policy action on this narrow focus. Data are critical for making policy decisions. Although economic metrics provide the clear results often required by policymakers, alone, they have little utility in addressing sustainability problems (Nowak & Cabot, 2004). Considering Maine dairy legislative actions and industry voices we would expect that Maine dairy farmers would consider economic factors to be the most important to industry sustainability. To test this hypothesis, we mapped a representative mental model network of the challenges that farmers perceive to be the most important to Maine dairy industry sustainability.

Methods

In 2014, we sent a mail survey to the entire Maine dairy industry population in conjunction with a three-year Maine Milk Commission (MMC) Cost of Production study. We anticipated that this would increase our survey response rates, as the MMC study historically had high response rates. We followed a modified Dillman (2007) approach and

sent a second round of surveys, followed by a reminder mail from University of Maine Cooperative Extension and the Maine Dairy Industry Association (MDIA). The survey was designed to capture farmers' perceptions of challenges to the sustainability, or long-term success of the Maine dairy industry. Though surveys are one of the most prevalent methods for collecting network data (Marsden, 1990; Marsden, 2011; Scott & Carrington, 2011; Wasserman & Faust, 1994; Žnidaršič, Ferligoj, & Doreian, 2012), mail surveys typically have lower response rates (Bernard et al., 1984). Farmers' lack of consistent access to phones and the Internet necessitated a mail survey (G. Anderson & D. Marcinkowski, personal communication, March 21, 2014).

Framing of survey questions and careful selection of language is important when working with an industry with diverse ideologies. Anecdotally, the dairy industry in New England, including Maine dairy farmers, is divided ideologically, and sometimes contentiously, between conventional and organic practices (D. Marcinkowski & P. Erickson, personal communication, January 7, 2014). While the term organic is not synonymous with sustainable, they are more closely linked in popular culture than the terms conventional and sustainable (Hansen, 1996). Evidence from literature, farmer observations, expert input, and industry demographics suggest that framing sustainability appropriately is important for research with the Maine dairy farming population. With this in mind we have chosen to use the term "long-term success" to prevent bias and polarization (Hinrichs, 2000). Though more work should be done to understand optimal framing for agricultural sustainability research in a variety of contexts, "long-term success" provided a more neutral framing without losing meaning.

To prompt survey recall and reduce error, we employed a hybrid name generator format with dairy system categories (Henry, Lubell, and McCoy, 2012). We collected farmer perceptions of sustainability of the Maine dairy industry with the survey question, "What do

you think the challenges and issues are for long-term success of the Maine dairy industry?" and delineated categories in the hybrid name generator with the question "For each category please list the specific issues: Crop Production, Milk Production, Processing, Packaging, Transport/Distribution, Retail, Profit, and Other." We further refined the categories with the following questions: 1) "Out of the issues that you listed above, please circle ONE that is the most important for the long-term success of Maine's dairy industry" and 2) "Please describe why the issue that you circled is the most important." Out of the 260 farms listed in the MMC database in January 2015, farmers completed 63 surveys for a 24% response rate. Of these 63 surveys, 58 farmer responses were complete and could be used in our analyses. We deemed respondents proportionally representative of the industry based on the similar proportions of farmers by milk production levels (farm size by tier, 1-4: small to large, respectively) and management practice (conventional or organic) (Tables 2 and 3).

Table 2. Proportion of Maine Milk Industry Survey Respondents and Total Farms by Milk Production Level (Tier), January 2015 Data

	Milk Production Level	
Tier	Survey Respondents (%)	Industry Total (%)
1	62	73
2	24	18
3	3	2
4	10	7

Table 3. Proportion of Maine Milk Industry Survey Respondents and Total Farms by Management Practice (Conventional Or Organic), January 2015 Data

	Management Practice	
Management Practice	Survey Respondents (%)	Industry Total (%)
Conventional	78	78
Organic	22	22

We used a modified grounded theory process and NVivo qualitative data analysis software to define unique concepts of farmer-identified industry challenges (Bazeley & Jackson, 2007; Corbin & Strauss, 2014; Hoffman, Lubell & Hillis, 2014; Saldaña, 2013).

Multiple coders analyzed a random sample of 10 farmer responses to ensure consistency and reliability, and the result was 96% agreement overall. Using the unique challenge concepts that came out of the qualitative analysis, we constructed a mental model concept network (Hoffman, Lubell & Hillis, 2014). To generate a mental model concept network, we created a weighted, non-directional adjacency matrix with the unique concepts as nodes and the associations between these concepts as ties (Wasserman & Faust, 1994). Associations between concepts are the co-occurrences across all responses (Hoffman, Lubell & Hillis, 2014). For example, in these 58 usable farmer responses climate occurred 16 times, cost occurred 33 times, and they co-occurred 11 times. The weight of the tie between the climate and cost nodes is 11. In addition to farmer-identified industry challenges, we also coded for the primary sustainability category into which each challenge falls (economic, environmental, or social). The objective of this coding was to place each challenge into its primary sustainability category. For example, farmers may discuss milk production as an economic or biological process. For consistency, we had multiple reliability coders categorize all the challenges into their primary sustainability groupings. With the few challenges, like milk production, that could have ambiguous primary categories, we used farmer responses to determine into which sustainability category the challenge most frequently fell.

To understand which concepts are the most important to farmers, we calculated three measures of centrality for each of the 43 challenge concepts—average occurrence probability, network centrality, and prominence (de Nooy, Mrvar & Batagelj, 2005; Hoffman, Lubell & Hillis, 2014). Average occurrence probability is the number of times that a challenge was mentioned out of the total farmer survey responses (n=58). Network centrality, calculated using eigenvector centrality, measures the association between concepts in the network (Bonacich, 2007; de Nooy, Mrvar & Batagelj, 2005; Hoffman, Lubell,

and Hillis, 2014). When a concept has more ties or ties with higher weights, it is more important in the network. A concept that is linked to other highly central ties is more important in the network. Prominence is the mean of occurrence and centrality (Hoffman, Lubell, and Hillis 2014). To compile the three sustainability categories, we averaged the challenge values for each network analysis measure. To test whether there was a significant difference between the sustainability categories for the network measure of prominence, we ran an analysis of variance (ANOVA) (Bodin & Prell 2011; Vaske, 2008).

Results

Preliminary ethnographic work with Maine dairy stakeholders suggested that economic issues were most critical to industry survival. We hypothesized that in Maine dairy farmers' mental models of sustainability challenges, economic factors would be the most important. We constructed our mental model based on our survey responses. To illustrate the connections between farmers, Figure 2 shows a network graph of the top ten most prominent challenges to industry sustainability. The circles, or nodes, represent the farmer-described challenges and the lines between the nodes, or ties, represent the strength of the relationship between the two linked challenges. A thicker line between two challenges indicates that more farmers responded that they were important to Maine dairy sustainability. The most important challenges have strong connections to other important challenges. For example, cropping is clearly more prominent in the network than climate, and it has strong ties to important challenges, like costs and profit. Table 4 shows the values that correspond with each challenge's importance in the network, sorted by most prominent challenge. Prominence is the mean of occurrence and centrality values. Occurrence probability is the number of times that each challenge was mentioned out of the total survey responses (n=58), and network centrality measures the associations between concepts in the network. We found that cropping (for feed production) and costs (i.e. of

production, hauling, and maintenance) were the most important sustainability challenges in farmers' mental model networks (0.836 and 0.835, prominence values respectively). We also included in Table 4 the sustainability category (economic, environmental, or social) for each challenge.

Figure 2. Network Graph of Top Ten Sustainability Challenges for The Maine Dairy Industry

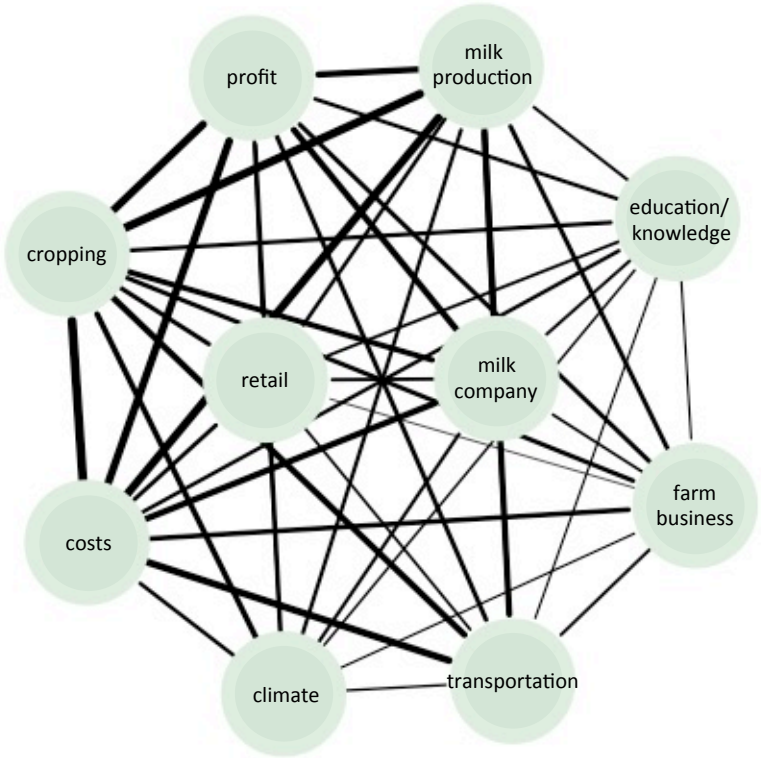


Table 4. Sustainability Challenges for the Maine Dairy Industry (by Descending Average Prominence Value)

Challenge	Sustainability category[1]	Average of occurrence probability[2]	Average of network centrality[3]	Average of prominence[4]
cropping	N	0.672	1.000	0.836
costs	E	0.672	0.997	0.835
milk production	N	0.672	0.921	0.797
profit	E	0.690	0.895	0.792
milk company	E	0.672	0.770	0.721
transportation	E	0.655	0.729	0.692
farm business	E	0.690	0.595	0.642
climate	N	0.638	0.586	0.612
retail	E	0.638	0.533	0.586
education/knowledge	S	0.638	0.519	0.578
cow care	N	0.621	0.527	0.574
pay price	E	0.621	0.527	0.574
generational	S	0.690	0.428	0.559
markets	E	0.655	0.427	0.541
government	S	0.603	0.465	0.534
labor	E	0.569	0.496	0.533
equipment	E	0.603	0.448	0.526
farm life	S	0.655	0.360	0.508
geography	N	0.569	0.437	0.503
land	N	0.569	0.417	0.493
consumer	S	0.569	0.376	0.473
fuel	E	0.569	0.353	0.461
tier	S	0.621	0.268	0.444
packaging	E	0.603	0.253	0.428
facilities	E	0.552	0.255	0.404
innovation	E	0.586	0.191	0.389
infrastructure	E	0.500	0.247	0.374
debt	E	0.517	0.182	0.349
genetic modification	N	0.483	0.201	0.342
organic	S	0.517	0.166	0.342
seed	N	0.483	0.167	0.325
capital	E	0.483	0.153	0.318
fertilizer	N	0.483	0.138	0.310
energy	N	0.431	0.180	0.306
risk	E	0.448	0.161	0.304
health	S	0.466	0.140	0.303
number of farms	S	0.448	0.115	0.281
spray	N	0.345	0.055	0.200
other employment	E	0.259	0.046	0.152
equity	E	0.224	0.044	0.134
supplies	E	0.103	0.014	0.059
research	S	0.069	0.012	0.041
conventional	S	0.069	0.008	0.039

[1] E = Economic, N = Environmental, S = Social

[2] Occurrence probability: number of times a challenge is mentioned in total responses (n=58)

[3] Network centrality: (using eigenvector centrality) measures the association between concepts

[4] Prominence: mean of occurrence and centrality

We compiled challenges into their respective sustainability categories (economic, environmental, or social), and found that environmental challenges were the most prominent in the network (0.482), closely followed by economic challenges (0.467) (Table 5). Social challenges were the least prominent (0.373). However, none of these differences were significant (Table 6).[2]

Table 5. Network Measures for Sustainability Challenge Categories (by Descending Average Prominence Value)

Network Analysis Measures for Sustainability Categories (E, N, and S)			
Sustainability Category	Average of occurrence probability	Average of network centrality	Average of prominence
Environmental	0.542	0.421	0.482
Economic	0.539	0.396	0.467
Social	0.486	0.260	0.373

Table 6. ANOVA Test of Prominence of Sustainability Challenge Categories

Prominence of Sustainability Challenge Categories					
Df	Sum Sq.	Mean Sq.	F value	Pr(>F)	Significance Level
2	0.082	0.041	0.972	0.387	n.s.

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

Discussion and Conclusions

Many researchers have demonstrated the importance of bridging science and policy with integrated and co-produced solutions that are designed to be dynamic over time (Cash, Borck, & Patt, 2006; Cash et al., 2003; Clark, 2007; Clark & Dickson, 2003; Rose & Parsons, 2015; van Kerkhoff & Lebel, 2006). Sustainability science needs metrics to evaluate and repair the splintered bridge between knowledge production and policy application. There is also a need for adaptive tools to synthesize knowledge of the economic, environmental, and social aspects of a system. A tool never provides standalone answers to all scientific questions, but we highlight the potential for mental model networks to be a dynamic and

[2] When reliability coding revealed ambiguous sustainability categories (i.e. milk production as an economic process rather than a biological process), the alternative options were tested statistically with an ANOVA. The results showed no statistical difference between the prominence means.

adaptive bridging tool with capacity for direct policy application. (Hoffman, Lubell, and Hillis, 2014; Lynam et al. 2012).

In the case of Maine dairy, mental model network analysis provides qualitative and quantitative insight into an ongoing cycle of sustainability science and policy problems. Maine dairy industry policies and stakeholders have invested considerable resources into addressing economic issues for conventional farms (Chapter 648 H.P. 1445-L.D. 1945). Though our network prominence calculations suggested that farmers considered environmental challenges most important to industry sustainability, we found no significant difference in the prominence of each sustainability category. This suggests that solutions concentrating on only one sustainability factor are unlikely to work in the long-term. These statistical results could indicate a need for a larger sample. However, with a proportionally representative sample of Maine dairy farms with respect to farm management practice and farm size, coupled with robust qualitative evidence, our results present a strong case for incorporating more diverse sustainability measures into industry evaluation and policy. Farmers live this complexity and many understand the diversity of dairying challenges. As seen in the mental model network, many farmers articulate a need for the integration of both environmental and social systems to ensure a healthy dairy economy and livelihood. If included into policy decisions, this complexity of challenges can provide valuable lessons that lead to concrete and more effective policy. Mental models are not a perfect representation of the "real" state of sustainability issues for the industry. They do, however, provide a key stakeholder perspective that is important and under-represented in the assessment and establishment of Maine dairy policy.

Sustainability Solutions Through Mental Models Network Analysis

Our results suggest that farmers face numerous interconnected sustainability challenges. Dairy is a complex system that includes interactions between economic,

environmental, *and* social factors. The Maine policy context has created an environment of short-term fixes for long-term problems. To move toward a more sustainable industry for present and future dairy farmers, policy makers and industry stakeholders should diversify evaluation and policy to capture the complete spectrum of challenges. Focusing solely on economic issues decreases the likelihood of successful sustainability solutions. Likewise, policy that stipulates evaluation of one sub-sector of an industry, like the assessment and support of conventional dairies (to the exclusion of other sectors), risks missing challenges that are common across management practice and farm size. A holistic approach may have a broad impact on industry success.

Commonalities across management practices and farm size may be important to the dairy industry as a whole. Conventional and organic producers of all sizes must balance their costs of production with the pay prices that they receive. Though the language of *An Act to Implement the Recommendations of the Task Force on the Sustainability of the Dairy Industry in Maine* and *An Act to Encourage the Future of Maine's Dairy Industry* imply action on behalf of the whole industry, these acts only support conventional producers (Chapter 648 H.P. 1445-L.D. 1945; Kersbergen et al. 2013). These policies have created further separation between conventional and organic, and small and large producers. Our mental model network revealed sustainability challenges that impact farmers across these groups. Cropping, costs of production, geographic isolation, lack of infrastructure, and climate change affect all producers. We recommend that future studies expand the industry's economically focused policies, and for all categories of Maine dairy producer, measure sustainability factors over time.

While mental models are useful for capturing a snapshot of stakeholder perspectives, sustainability is a dynamic and long-term process. One solution is to implement longitudinal mental models as an adaptive evaluation tool that could be used to

inform better sustainability policies. Like the MMC's cost of production study, a mental model network could be conducted every few years. This would require a different recruiting process. Instead of recruiting different participants each cycle, we recommend recruiting a representative sample of farmers who are compensated for their participation for the entirety of the long-term study. This type of research, in order to be effective, requires a transparent science-policy feedback process. It may be useful to compare mental models of industry leaders, policy makers, and Cooperative Extension specialists with farmers' mental models to determine where misalignment is occurring. This will aid in creating a dynamic process of needs evaluation and adaptive policies to address challenges that may change over time. A more holistic approach to sustainability assessment and policy may lead to a better understanding of the challenges facing the Maine dairy industry, and reveal avenues for effective policies and support.

Sustainability Science and Policy Applications for Mental Model Networks

For any natural resource system that wants to move toward sustainability—linking knowledge and action at the interface of economic, environmental, and social contexts for present and future generations—we need tools to assess the dynamic complex around which these interactions occur. Here we look through a sustainability science lens to explicitly bridge the sustainability science-policy gap—a chasm that other researchers may further address with future application of mental model networks.

CHAPTER 2

BEYOND CONVENTIONAL VS. ORGANIC: THE IMPORTANCE OF SOCIAL CAPITAL IN SUSTAINABLE AGRICULTURE RESEARCH

Introduction

In agriculture, the term sustainability has arisen primarily in contrast to industrial management practices (Pretty, 1995). Post World War II, commercial ammonium synthesis made available nitrogen fertilizer that had previously limited global agricultural production (Smil, 1997; Smil, 1999). The effects of widely available nitrogen fertilizer were vast, and the intensity and scale of agriculture increased—as did the use of industrial agricultural technologies such as irrigation, fossil fuel use, and chemical pesticides and herbicides (Erisman et al., 2008; Galloway et al., 2008; Ramankutty, Foley, & Olejniczak 2002; Smil, 1997; Smil, 2002). Population growth followed close behind this agricultural intensification (Smil, 1997). United States policy began to scale up as well. As the famous philosopher-farmer Wendell Berry (1999) recalls, "In the 1950s, Secretary of Agriculture Ezra Taft Benson said to the farmers, 'Get big or get out.' Twenty years later, Secretary of Agriculture Earl Butz was telling them, 'Adapt or die' – and he meant that they must adapt to the economics of agribusiness" (1). Cochrane (1979) explains that from 1935 to 1970 the number of farms in America fell by half, and during the same period the size of farms and intensity of production grew. Industrial agriculture fundamentally changed agroecosystems, and the social and economic cultures of farming in the United States and around the world, bringing about both benefits and unforeseen consequences. These negative externalities of industrial agriculture led to demand for a scaled-down alternative and a more holistic method of farming (Horrigan, Lawrence, & Walker, 2002; Pretty et al., 2001).

Sustainable agriculture has been used to describe a diverse array of ideologies, strategies, and goals, and it is often used synonymously to describe organic management (Hansen, 1996; Pretty, 1995). The 1987 Report of the World Commission on Environment and Development (WCED)—the Brundtland Commission Report—famously defined sustainability as, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, 15). Though this report was written from a global development perspective nearly three decades ago, there is a salient need to understand and address present and long-term economic, environmental, and social challenges within agriculture. Due to a cultural dichotomy between conventional and organic farming, many studies have focused on the distinctions between the two management practices. Across a diversity of disciplines, researchers have compared biophysical and economic measures for conventional and organic management systems and found differences in yield, technological efficiency, and biodiversity (de Ponti, Rijk, & Van Ittersum, 2012; Gabriel et al., 2010; Gomiero, Pimentel, & Paoletti, 2011; Seufert, Ramankutty, & Foley, 2012). Behavioral economic literature and organic management adoption literature have examined social aspects of management choices (Best, 2010; Läpple, & Van Rensburg, 2011; Mzoughi, 2011). Others have utilized mental models and social network analysis to study organic or sustainable farmers (Hoffman, Lubell, & Hillis 2014; Milestad et al., 2010). Scale of production plays a role in discussion about conventional, or industrial, versus sustainable agriculture discussion. Horrigan et al. (2002) describe the industrial agriculture focus on capturing the financial benefits of economies of size and scale and high yields, and argue that from a human health perspective, full cost accounting of the costs associated with agriculture need to include environmental, cultural, and social benefits of scaled-down agriculture.

The objective of this chapter is to explore the case of the Maine dairy industry to test whether there are social metrics that better explain an integrated or balanced view of sustainability. The social metrics that we will use to test our objective include management practice, farm size, and social capital. Consistent with many of the studies described above, the Maine dairy industry is often divided in both culture and policy by management practice and farm size. We will first present background about the Maine dairy industry, which will help illustrate why we include management practice and farm size variables. We will then discuss why social capital may be a critical variable to include in sustainability analyses, and we will explain our evaluation of farmers' views of industry sustainability.

Management Practice, Farm Size, and Social Capital

Maine dairy contributes only 0.29% of total U.S. milk production (USDA ERS, 2016). Despite its small percent of the national milk production, Maine dairy in 2014 contributed nearly one fifth of all agricultural cash receipts, and it is regularly one of the state's top agricultural commodities (USDA ERS, 2015). The majority of the 260[1] Maine dairy farms are concentrated in central Maine, and over three-quarters of farms produce conventional milk (Figure 3 and Table 3). Maine dairy is made up of predominantly small farms, but the largest farms, which make up only 7% of the industry, contribute nearly half of the total milk produced in the industry (Table 2). The state's two remaining large processing plants—Oakhurst and Hood—are located in Portland, ME. Farms not affiliated with these plants may haul their milk out of state to other milk companies or cooperatives, participate in smaller processing operations, or process their own milk.

Some Maine dairy farmers and industry professionals have expressed that differences between conventional and organic management and large and small farms are so disparate that each should be considered a different industry. Maine dairy assessment

[1] 2014 data compiled from the Maine Department of Agriculture Milk Quality Lab database.

and policy follow the common cultural dichotomy between conventional and organic management and the perceived difference in agricultural production scales. A conventional dairy stabilization program, colloquially called the Tier Program, is a policy example that requires evaluation of and financial support for one segment of the industry, and differentiates the level of support by farm size. This Maine Legislature under *An Act to Encourage the Future of Maine's Dairy Industry* (Chapter 648 H.P. 1445-L.D. 1945) established this program in 2004, which supports conventional farms when federal milk prices drop below a state-established cost of production threshold (Kersbergen et al., 2013). We are interested in exploring whether these commonly employed metrics—farm management practice and farm size—are useful for evaluating sustainability of the Maine dairy industry. What other metrics may be insightful for the assessment agricultural sustainability? Agriculture is inherently a social ecological system, and a variety of social metrics may play a key role in sustainability. Social ecological systems governance literature has made a strong case for the inclusion of social capital in natural resource management and resilience work (Adger et al., 2005; Folke et al., 2005; Ostrom & Ahn, 2003). Moving toward sustainability in agricultural systems will be difficult without these same considerations. In a small dairy industry with limited infrastructure, Maine dairy farmers' information networks may span perceived boundaries between conventional and organic management and between tiers, or categories of farm size. We found that robust social capital is a critical variable for better understanding industry sustainability challenges. We acknowledge that social capital is a comprehensive idea, and it can be defined and measured in many ways. In this paper, the specific social capital that we measure is farmers' trusted information networks.

Measurement of Sustainability Challenges: Mental Model Networks

Mental models are useful in the evaluation of farmers' perspectives of the sustainability of their industry. Mental models are used to evaluate and measure human cognitive structure, or more simply, a person's internal understanding of an external experience or reality (Jones et al. 2011, 46; Lynam et al. 2012, 23). In the case of Maine dairy sustainability, farmers are experts who intimately understand the challenges facing their livelihoods. Through a sustainability science lens, mental model network analysis provides insight into the important sustainability challenges facing farmers. There are examples of studies that employ mental models and social network analysis to study organic or sustainable farmers (Hoffman et al., 2014; Milestad et al., 2010). In addition to total challenges in each farmer's response, we evaluate the challenges by sustainability category—economic (E), environmental (N), and social (S)—which will be described in depth in the Methods section of this paper. We use mental model network analysis to study an industry that faces cultural and policy divisions, which are based on perceived differences between management practices and between farm sizes. We use results from a social network analysis to evaluate the most prominent sustainability challenges in Maine dairy farmers' mental models. We can test statistically whether dominant industry variables, management practice and farm size, are as influential to sustainability challenge metrics as social capital.

We hypothesize that for Maine dairy 1) social capital, or the size of farmers' information networks, will be more strongly related to economic, social, and environmental sustainability challenge metrics than management practice or farm size, and 2) a farmer with greater social capital will have a more integrated and a more balanced awareness of sustainability challenges. Integrated in this context is defined as richness, or the combined total of sustainability challenges—economic plus environmental plus social. Richness is an

ecological concept used to describe the number of species in a community (Smith & Smith, 2001). A more integrated mental model will have a greater richness, or a greater number of total sustainability challenges. We define balanced as a more even array of economic, environmental, and social challenges in a farmer's mental model. Evenness, which is also an ecological concept, is the relative abundance of species where, "the more equitable the distribution, the greater the evenness" (Smith & Smith, 2001, 389). A farmer who has described a more equal distribution of economic, environmental, and social challenges will have a more balanced mental model in regard to sustainability challenges.

Methods

Explanatory Variables: Management Practice, Farm Size, and Social Capital

Age, sex, and education are often employed as explanatory variables, or predictors of sustainable management behavior (Best, 2010; Läpple, & Van Rensburg, 2011; Mzoughi, 2011). For our case study, these variables are not applicable. While farm ownership data for the Maine dairy industry exists, it is not representative of actual on-farm management. In foundational ethnographic work, we verified that ownership structures of Maine dairy farms are often more complex than the Maine Department of Agriculture Milk Quality Lab's ownership database suggests. We will employ management practice, farm size, and information network size as more applicable variables to evaluate integrated or balanced mental models of sustainability. We use two farm size variables—tiers (continuous) and milk production (categorical)—in statistical tests. A farm's tier designation is determined by its annual milk production. Maine Department of Agriculture Milk Quality Lab provided farm ownership, milk company affiliation, and milk production data, which we compiled for the variables of management practice (conventional or organic) and farm size (tiers 1, 2, 3, and 4, small to large, respectively).

In 2014, we sent a two-page mail survey to the entire Maine dairy industry population of 260 farms. We employed a hybrid name generator format with dairy system categories, as is recommended to prompt recall and reduce error (Henry, Lubell, & McCoy, 2012). On the first page of our survey, we collected social capital data with a social network survey of farmers trusted information networks. On the second page of the survey, we collected data for the sustainability mental model network, which we will describe in the following section. The survey was distributed in conjunction with a three-year Maine Milk Commission (MMC) Cost of Production study. This collaboration was intended to increase response rates, as the Cost of Production survey has been conducted for over a decade and historically, it has had high response rates. We followed a modified Dillman (2007) approach and sent a second round of surveys, followed by a reminder mail from University of Maine Cooperative Extension and the Maine Dairy Industry Association (MDIA). From the industry-wide mailing to the 260 dairy farms listed in the MMC database, 63 surveys were completed for a 24% response rate. Though surveys are one of the most prevalent forms for collecting network data (Marsden, 1990; Marsden, 2011; Scott & Carrington, 2011; Wasserman & Faust, 1994; Žnidaršič, Ferligoj, & Doreian, 2012), mail surveys typically have lower response rates (Bernard et al. 1984). Farmers' lack of consistent access to phones and the Internet necessitated a mail survey (personal communication, Anderson & Marcinkowski, March 21, 2014). Respondents were, however, proportionally representative of the industry in regard to milk production levels (farm size by tier) and management practice (conventional and organic) (Tables 2 and 3). To understand the extent of farmers' social network of trusted information sources, on the first page of the survey we asked, "Who do you talk to or go to for information about the dairy industry? For each category below please list the names of organizations or individuals in the spaces provided: Federal,

State, Local, University/College, Non-governmental Organizations, Individuals, or Other Organizations." We organized and analyzed each farmer's total information sources.

Measurement of Sustainability Challenges: Mental Models and Information Networks

Acknowledging the relationship between the word sustainability and organic management, we utilized a context-specific definition of sustainability. Maine dairy is an industry defined more often by differences than commonalities, and farmers are evaluated and supported based on their management practices and farm size (Chapter 1; Chen et al., 2016; D. Marcinkowski & P. Erickson, personal communication, January 7, 2014). In this divisive environment, to employ a term that has been historically used to identify "good," or organic farming, versus "bad," or conventional farming, would likely create a perceived negative bias toward conventional farming (Hinrichs, 2000; Sutherland & Darnhofer, 2012). With input from industry experts and from farmer observations, we addressed this problem of bias with the term "sustainable," and reframed it as "long-term success" of the industry. We collected farmer perceptions of sustainability of the Maine dairy industry with the survey question, "What do you think the challenges and issues are for long-term success of the Maine dairy industry?" and focused with a hybrid name generator "For each category please list the specific issues: Crop Production, Milk Production, Processing, Packaging, Transport/Distribution, Retail, Profit, and Other." These categories were followed by the refining statements 1) "Out of the issues that you listed above, please circle ONE that is the most important for the long-term success of Maine's dairy industry" and 2) "Please describe why the issue that you circled is the most important." We used grounded theory process and NVivo qualitative data analysis software to define unique concepts of farmer-identified industry challenges (Bazeley, 2007; Hoffman, et al. 2014; Saldaña, 2013). To ensure consistency and reliability across sustainability challenge categorization two coders analyzed two random samples of 10 farmer responses.

In addition to farmer-identified industry challenges, we also coded for the primary sustainability category into which each challenge falls—economic (E), environmental (N), or social (S). The objective of this coding was to place each challenge into its primary sustainability category. For example, farmers may discuss milk production as an economic or biological process. For consistency, we had an independent reliability coder categorize a sample of ten responses into primary sustainability challenge categories, and the result was 96% agreement overall. With the few challenges, like milk production, that could have ambiguous primary categories, we used farmer responses to determine into which sustainability category the challenge most frequently fell.

Using the individual sustainability challenge categories (E, N, and S), we created two compiled metrics to evaluate sustainability challenges: integrated awareness score and balanced awareness score. To capture the richness of farmer views of sustainability challenges to Maine dairy, we summed the categories in each farmer's response: economic challenges (E) + environmental challenges (N) + social challenges (S). We will refer to this metric as the integrated awareness score for sustainability challenges. For example, Farmer A described 3 economic challenges, 3 environmental challenges, and 3 social challenges and Farmer B's response included 11 economic challenges, 4 environmental challenges, and 1 social challenge. We would consider Farmer A to have a less integrated awareness of sustainability with (E + N + S): 3 +3 +3 = 9 compared to Farmer B's (E + N + S): 11 + 4 + 1 = 16.

The second compiled metric calculates the evenness of farmers' responses, where a farmer has a more balanced awareness of sustainability challenges if he or she described each category equitably across the total challenges. To calculate the balance of responses we took the difference between each of the three sustainability categories, and summed that difference: [|E – N| + |E – S| + |N – S|]. The smaller the value the more balanced the farmer's

response. We call this metric the balanced awareness score for sustainability challenges. For example, if Farmer A described 3 economic challenges, 3 environmental challenges, and 3 social challenges, it is a more balanced response than Farmer B's:

Farmer A: 3 – 3 = 0, 3 – 3 = 0, 3 – 3 = 0;
0 + 0 + 0 = 0, score is perfectly balanced
Farmer B: 11 – 4 = 7, 11 – 1 = 10, 4 – 1 = 3;
7 + 10 + 3 = 20, score is less balanced than Farmer A's

Descriptive and Statistical Analyses

We compiled descriptive statistics and conducted a variety of statistical analyses to test our hypotheses. To provide perspective on farmers' management type and mental model sustainability challenge categories, we compiled the percent of conventional and organic responses by sustainability challenge category. We employed several statistical analyses to test our first hypothesis. We are interested in the relationship between our explanatory variables—management practice, farm size, and social capital (information network size)—and individual sustainability categories as well as our compiled sustainability metrics of integrated awareness score and balanced awareness score. The inclusion of both individual and compiled sustainability metrics provides a more holistic evaluation of the robustness of farmers' mental model networks.

We conducted non-parametric Mann-Whitney-Wilcoxon tests for management practice and individual and compiled sustainability metrics: Do the number of economic (or environmental or social) sustainability challenge categories significantly differ by management practice?; and Does the integrated awareness score (E + N + S) and balanced awareness score [|E – N| + |E – S| + |N – S|] significantly differ by management practice? We employed the non-parametric Kruskal-Wallis test to explore the same questions for farm size and the individual and compiled sustainability metrics. For the continuous variable information network size, we performed generalized linear models (GLMs) to determine whether there is a correlation between social capital (information network size) and

individual (E, N, and S) and compiled (E + N + S and [|E – N| + |E – S| + |N – S|]) sustainability challenge metrics. For our second hypothesis, we were interested in evaluating the direction of the relationship between a farmer's information network and integrated awareness score and balanced awareness score. The GLM results provided the direction of the correlation with the sign of the estimated coefficient. *P*-values less than 0.05 were considered significant for all statistical tests.

Results

We hypothesized that for Maine dairy 1) social capital, or the size of farmers' information networks, would be more strongly related to economic, social, and environmental sustainability challenge metrics than management practice or farm size, and 2) a farmer with greater social capital would have a more integrated and a more balanced awareness of sustainability. Our Chapter 1 analysis of farmer responses suggested that the most important Maine dairy challenges span management practices, and our results here add statistical support. Maine conventional and organic dairy farmers' responses included similar proportions of sustainability challenge categories, as represented in their mental models (Table 7). We employed a number of statistical analyses to determine if information networks are a better explanatory variable for evaluating sustainability metrics when compared to management practice or farm size.

Table 7. Percent of Conventional and Organic Dairy Farmer Responses by Sustainability Challenge Category.

Percent of Conventional and Organic Dairy Farmer Responses by Sustainability Challenge Category		
Sustainability Challenge Category	Conventional (%)	Organic (%)
Environmental	52	57
Economic	31	25
Social	17	19

Hypothesis 1 Test Results

We used a Mann-Whitney-Wilcoxon test to determine if there is a difference between conventional and organic farmers' sustainability metrics— sustainability challenge categories, integrated awareness score, and balanced awareness score (Tables 8 and 9). We found no significant differences between conventional and organic farmers' responses in terms of the economic, environmental, or social sustainability challenge categories in their mental models (*P*=0.329, *P*=0.689, and *P*=0.759, respectively). We also found no significant differences between management practice (organic versus conventional) for the compiled sustainability metrics: integrated awareness score (sum of E, S, and N); and balanced awareness score (evenness of E, S, and N), (*P*=0.149 and *P*=0.153, respectively). In our Kruskal-Wallis tests (Tables 10 and 11), we found that across all farm sizes, farmers' responses were not different in terms of their sustainability metrics (economic: *P*=0.510, environmental: *P*=0.513, and social: *P*=0.510; integrated awareness score: *P*=0.149 and balanced awareness score: *P*=0.153).

Table 8. Mann-Whitney-Wilcoxon Test of Sustainability Challenge Categories for Conventional and Organic Farmers

Sustainability Challenge Category	W	*P*-value	Significance Level
Economic	378	0.329	n.s.
Environmental	424	0.689	n.s.
Social	340	0.759	n.s.

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

Table 9. Mann-Whitney-Wilcoxon Test of Integrated Awareness Score and Balanced Awareness Score for Conventional and Organic Farmers

Integrated Awareness Score (E + N + S)

W	*P*-value	Significance Level
404	0.149	n.s.

Balanced Awareness Score [|E – N| + |E – S| + |N – S|]

W	*P*-value	Significance Level
403	0.153	n.s.

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

Table 10. Kruskal-Wallis Test of Sustainability Challenge Categories and Farm Size by Tier

Sustainability Challenge Category	$\chi 2$	df	*P*-value	Significance level
Economic	2.3124	3	0.510	n.s.
Environmental	2.2987	3	0.513	n.s.
Social	2.3129	3	0.510	n.s.

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

Table 11. Kruskal-Wallis Test of Integrated Awareness Score and Balanced Awareness Score for Farm Size by Tier

Integrated Awareness Score (E + N + S)

$\chi 2$	df	*P*-value	Significance Level
2.2237	3	0.527	n.s.

Balanced Awareness Score [|E – N| + |E – S| + |N – S|]

$\chi 2$	df	*P*-value	Significance Level
2.0608	3	0.560	n.s.

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

Information network size is a continuous variable, so we used a GLM to test the correlation between the number of sustainability categories (economic, environmental, or social) in farmer's responses, and the size of farmers' information networks. We found that the size of information networks was correlated with economic, environmental, and social challenges ($P<0.0001$, $P<0.0001$, and $P=0.006$, respectively) (Table 12). We also tested the correlations between farmers' information network sizes, and both integrated awareness score (E + N + S), and balanced awareness score [|E – N| + |E – S| + |N – S|] (Table 13). We found that information network size was positively correlated with both integrated awareness score and balanced awareness score ($P<0.0001$ and $P=0.005$, respectively).

Table 12. GLM: Correlation Between Farmers' Sustainability Categories and Social Capital (Size of Information Network: info)

Economic Challenges (E)

Explanatory Variable	Estimate	Std. Error	t value	Pr(>|t|)	Significance Level
(Intercept)	2.69851	0.507	5.325	0.000	***
info	0.29229	0.066	4.460	0.000	***

Environmental Challenges (N)

Explanatory Variable	Estimate	Std. Error	t value	Pr(>|t|)	Significance level
(Intercept)	1.21008	0.312	3.881	0.000	***
info	0.21986	0.040	5.451	0.000	***

Social Challenges (S)

Explanatory Variable	Estimate	Std. Error	t value	Pr(>|t|)	Significance level
(Intercept)	0.83794	0.265	3.167	0.003	**
info	0.09712	0.034	2.838	0.006	**

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

Table 13. GLM: Correlation Between Farmers' Compiled Sustainability Metrics (Integrated Awareness Score and Balanced Awareness Score) and Social Capital (Size of Information Network: info)

Integrated Awareness Score (E + N + S)

Explanatory Variable	Estimate	Std. Error	t value	Pr(>|t|)	Significance Level
(Intercept)	4.7465	0.873	5.436	0.000	***
info	0.6093	0.113	5.395	0.000	***

Balanced Awareness Score [|E – N| + |E – S| + |N – S|]

Explanatory Variable	Estimate	Std. Error	t value	Pr(>|t|)	Significance Level
(Intercept)	5.505	0.774	7.114	0.000	***
info	0.2962	0.100	2.959	0.005	**

n.s. = not significant, . = 90%, * = 95%, ** = 99%, and *** = 99.9%

<u>Hypothesis 2 Test Results</u>

We are interested in whether farmers with a larger information network have a more integrated and more balanced awareness of sustainability challenges. We performed a GLM to determine the direction of influence between farmers' information network size, and both integrated awareness score (E + N + S), and balanced awareness score [|E-N| + |E – S| + |N – S|]. Integrated awareness score and balanced awareness score were both positively

related to farmers' information network sizes (Table 13). This indicates that farmers with larger information networks discussed a greater number of sustainability challenges (e.g., cropping, costs, milk production) of any type (economic, environmental, or social). Interestingly, farmers with larger information networks were more likely to focus on a single sustainability category.

Discussion and Conclusions

A cultural dichotomy between conventional and organic farming has led to a binary focus in agricultural literature on conventional versus organic management practices (Best, 2010; de Ponti, Rijk, & Van Ittersum, 2012; Gabriel et al., 2010; Gomiero, Pimentel, & Paoletti, 2011; Mzoughi, 2011; Seufert, Ramankutty, & Foley, 2012). Social ecological systems governance literature has made the case for inclusion of social capital in natural resource management and resilience work (Adger et al., 2005; Folke et al., 2005; Ostrom & Ahn, 2003). Robust social capital may also be critical for social ecological agricultural systems, and there is a need for increased evaluation of social metrics that influence sustainability perspectives and decisions. Across disciplines, the default focus on the differences between conventional and organic farming and the use of traditional farmer demographics of age, sex, and education level may limit studies interested in exploring sustainability challenges. The central focus of this article is to test how well management practice, farm size, and access to social capital explain an integrated and balanced view of farm sustainability. We used mental model network analysis, information network analysis, and statistical analyses to test our hypotheses that for Maine dairy, 1) social capital, or the size of information networks, will be more strongly related to economic, social, and environmental sustainability challenge metrics than management practice or farm size, and 2) a farmer with greater social capital will have a more integrated and a more balanced awareness of sustainability challenges.

Based on previous findings that showed that the most important farmer sustainability challenges cross conventional and organic lines (Chapter 1), we expected to find that management practice would not explain farmers' views of sustainability challenges. Contrary to the focus on differences between conventional and organic management in the literature, our results suggested that neither management practice nor farm size is a primary factor contributing to differences in farmers' mental models of challenges to sustainability. These findings provide novel evidence that current agricultural policy along conventional versus organic lines may be misguided. There was significant correlation between the size of a farmer's information network and economic, environmental, and social sustainability challenges, total sustainability categories, and sustainability balance score. This empirical evidence supports our first hypothesis, suggesting that social capital is more strongly related to our sustainability metrics than farm management practice or farm size.

We found a positive correlation between the size of a farmer's information network and integrated awareness score, meaning that larger information networks correspond with more integrated views of sustainability. We defined integrated views of sustainability in terms of the abundance of sustainability challenge terms in farmer's responses. These results may indicate that farmers with smaller networks are more socially isolated, which means decreased information access and a less robust understanding of sustainability issues. It follows that a larger information network may increase access to more sustainability perspectives and problems. This access to information may allow farmers to develop a more extensive mental model of the sustainability challenges for their industry.

Larger information networks, however, do not equate with more balanced mental models of sustainability. We expected to find an inverse relationship between social capital and sustainability balance score. We found the opposite effect where larger information

networks corresponded with a less even view of sustainability, and smaller information networks were correlated with a more balanced perspective of sustainability, or a lower score. We anticipated that more extensive social capital would provide farmers with a broader, more even perspective of sustainability issues. This is not what we found. One reason for this unexpected result may lie in quantity versus quality of social capital. In this chapter, our analyses included the quantity of social capital, or the size of information networks, but not the details of that capital. For example, farmers with extensive networks may have a plethora of information sources that focus primarily on economic issues rather than a more even distribution of sustainability challenges. A positive relationship may indicate that farmers with greater social capital have a concentration of a particular type of information source, leading to a less balanced view of sustainability. This work would benefit from a more nuanced look at the makeup of farmer's information networks, and the relationship between their network connections and both individual and compiled sustainability metrics. Further research may benefit from the development of other metrics to evaluate sustainability that could be employed across a diversity of agricultural systems.

What might seem to be contradictory results in the findings of our second hypothesis actually provide a better understanding of the role that social capital plays in farmers' views of sustainability. A farmer with a larger information network discussed a greater number of sustainability challenges perhaps due to greater access to information. Those challenges were more likely to fall under the same sustainability category perhaps due to homogeneity of the farmer's numerous network connections. What this could imply is that across the Maine dairy information network there is a focus on singular issues. The industry could benefit in terms of sustainability progress by increasing education, assessment, and policy that is more diverse, that spans sustainability issues, and that is targeted to address the most important sustainability challenges.

Our findings have policy implications for the Maine dairy industry. Our results suggest that robust social capital, measured by the size of Maine dairy farmers' information networks, is one useful metric to evaluate farmer sustainability perspectives. Considering our findings, that social capital is more strongly related to our dependent variables than organic versus conventional dichotomies, assessment of social capital may give policy makers, the Maine Milk Commission, industry associations, and Cooperative Extension a better means to evaluate and inform sustainability policies. Increased access to a more extensive network of information sources may promote a better understanding of sustainability by facilitating shared learning and increasing awareness of issues common across the industry. In addition to our finding that more extensive information networks are correlated with a more integrated view of sustainability, social capital is a metric that is unifying rather than divisive. It provides an opportunity for critical education or support such as additional capacity building for farmers to network. An important outcome of the significance of social capital in sustainability research is the opportunity to assess Maine dairy farms based on commonalities rather than differences. Maine dairy industry policies have reinforced the differences between conventional and organic farms and between small and large farms, which may be hindering efforts to find solutions to some of the biggest issues affecting all farmers.

This paper provides support for the value of social capital metrics as variables in evaluating sustainability of agricultural systems. We have demonstrated that for Maine dairy there may be a benefit to questioning the binary focus of many agricultural studies to find more robust metrics for measuring sustainability. Thinking broadly, the implications of increasing the use of social capital metrics in sustainability research for agricultural systems could be a shift in perspective. Agricultural research may be stuck in a binary, but a focus on social capital metrics rather than traditional, yet divisive variables could help shift

the culture of agricultural production away from negative comparisons toward more productive sustainability progress.

CHAPTER 3

SCALE MISMATCHES IN SUSTAINABLE AGRICULTURE MANAGEMENT AND POLICY: THE MAINE DAIRY INDUSTRY PROBLEMSCAPE

Introduction

Difficulties arise in the governance of complex social ecological systems when scale of management and governance does not match resource characteristics and principal challenges (Cash et al., 2006; Termeer, Dewulf, & van Lieshout, 2010). A wealth of literature explains the complex and challenging nature of common pool and open access management for the governance of marine systems (Acheson, 2015; Bodin & Crona, 2009; Dietz, Ostrom, & Stern, 2003; Ostrom, 2010). In this paper we broaden the scope to include the formal and informal management of agricultural systems. Though agriculture can provide public resources such as open space and a picturesque agricultural landscape, it is primarily a system that produces private goods. There are examples of common pool disputes over irrigation and groundwater management and access for agriculture (Ostrom, 2010), but compared with marine systems, analysis of scale challenges are rare in modern industrial agriculture. The management and assessment of common pool and private goods face different challenges, but there are commonalities in the utility of scale analysis to understand and address complex problems. There are many barriers to implementation of policies for sustainable social ecological systems—regardless of whether they provide common pool resources or private goods. With social ecological systems governance challenges, solutions may require a nested approach with adaptive cross-scale and cross-level policies (Anderies, Janssen, & Ostrom, 2004; Ostrom, 2007; Ostrom, 2012).

In an exploration of scale challenges, it is common across disciplines to focus on spatial (geographic space), temporal (time frame), and jurisdictional (formal political unit)

scales (Cash et al., 2006; Termeer et al., 2010). Each of these three common scales is made up of different levels. For example, spatial levels in an agricultural system could include a farm's acreage, a local agricultural area, a statewide agricultural landscape, and global agricultural production. Levels are the units in a scale as it relates to a specific system. Critical problems arise when a system of governance emerges with a structure that drives policy, evaluation, and management at levels that may not be in line with the needs of a dynamic system—we employ the terms scale ignorance, mismatch and plurality defined by Cash et al. (2006) to describe these circumstances (11). Cash et al. (2006) describe (1) ignorance, (2) mismatch, and (3) plurality as:

> (1) the failure to recognize important scale and level interactions altogether, (2) the persistence of mismatches between levels and scales in human-environment systems, and (3) the failure to recognize heterogeneity in the way that scales are perceived and valued by different actors, even at the same level (11).

We hypothesize that the Maine dairy industry faces management, assessment, and policy challenges that are cross-scale and cross-level, which have led to situations of scale ignorance, mismatch, and plurality. In an exploratory causation analysis of farmers' mental models of primary sustainability challenges, we investigate the scale problemscape for the long-term success of the Maine dairy industry. Mental models provide a farmer perspective on systemic problems that cross spatial, temporal, and jurisdictional scales. Studies have used mental model networks to research sustainability problems (Hoffman, Lubell, & Hillis, 2014), but combining mental model and information networks and scale analyses for an agricultural system is an innovative approach that may lead to policy solutions. The dairy system in Maine is useful as a test case for its size and relative geographic isolation, which could allow for experimentation with solutions and a faster feedback process than a larger and more dispersed system. Larger dairy systems like those in Wisconsin or in New York, likely include bigger producers, vaster networks, and greater scales. It is important to study agricultural systems at both large and small scales, and Maine provides an interesting small-

scale test case for exploring agricultural governance. Spatial, temporal, and jurisdictional scales will be included in the exploratory analysis of the policy, evaluation, and management of the Maine dairy system. In the following sections, we will 1) discuss the governance context and characteristics of the Maine dairy industry, 2) delineate the causation between top challenges to Maine dairy sustainability; 3) illustrate associated spatial, temporal, and jurisdictional scales; and 4) provide a specific example of a policy that runs counter to the scales of Maine dairy sustainability problems and reinforces issues of ignorance, mismatch, and plurality.

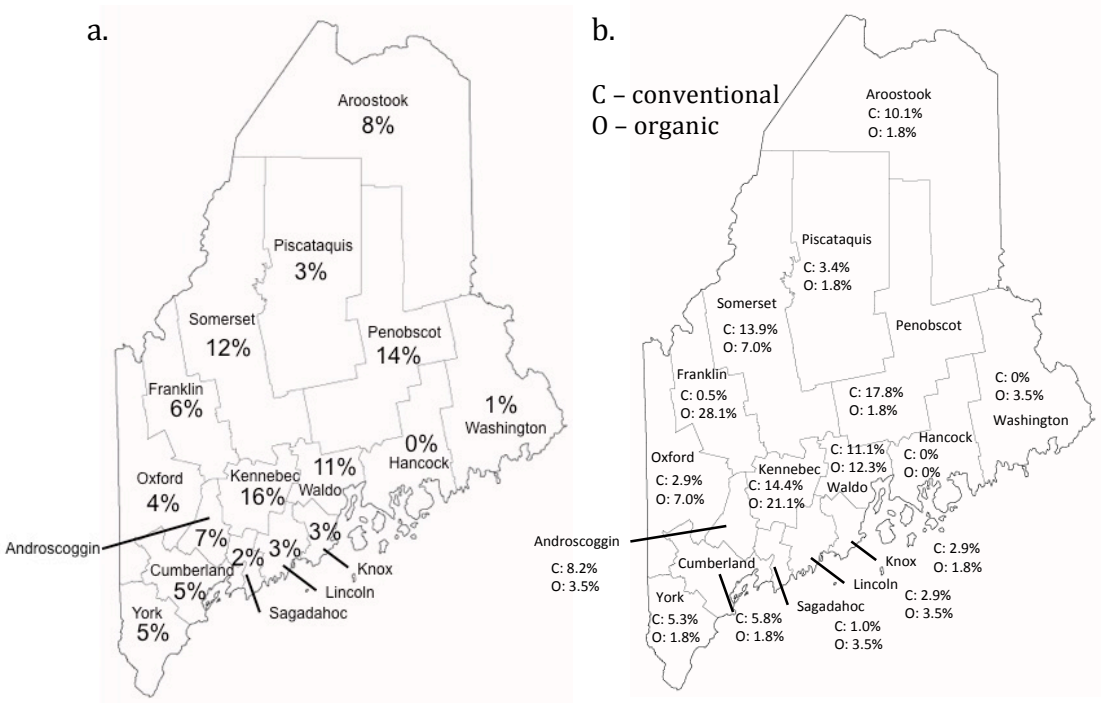
Governance Context and Characteristics of the Maine Dairy Industry

It is important to understand the governance context in which the Maine dairy industry exists. Maine has a part-time, citizen, term-limited legislature. Short-term policy goals evolved from the state-level legislative structure where a short legislative session and term limits drive the temporal scale of policy-making. Piecemeal governance leads to outcomes that do not take into consideration the scales of critical systemic challenges. The political process that guides management of an industry like dairy acts on a different temporal scale than do the major challenges experienced by farmers. In the case of the Maine dairy system, farmers, industry groups, Cooperative Extension, and policy makers have worked hard to address critical problems affecting the system. However, due to spatial, temporal, and jurisdictional scale challenges—ignorance, mismatch, and plurality—serious problems continue to affect the industry. It is important to understand the context of current policy to better understand the scale challenges facing Maine dairy. The U.S. government establishes the price of fluid milk, but due to higher costs of production in Maine, the legislature set forth a unique program in 2004 to support Maine conventional dairy farmers when federal milk prices drop below a state-established cost of production threshold (Kersbergen et al., 2013). Every three years under this program, referred to as the

Tier Program, the Maine Milk Commission (MMC) is required to evaluate the cost of production for a sample of conventional farms at four milk production levels, called tiers, to determine support for farmers (Chapter 648 H.P. 1445-L.D. 1945) (Table 1). Conventional farmers have expressed that the Tier Program has slowed rates of Maine dairy farm loss, but farmers' challenges are diverse (Table 4). This exploration of causes and scales of sustainability challenges may reveal that Maine dairy management, assessment, and policy may be needed beyond a short-term economic assessment and subsidy program for conventional farms.

Dairy distribution in Maine is spread throughout fifteen of the state's sixteen counties. Producers are concentrated in central Maine with a majority of dairies located in Kennebec (16%), Penobscot (14%), Somerset (12%), and Waldo (11%) Counties (Figure 3 a.). When divided by management type (Figure 3.b.), nearly sixty percent of conventional farms are concentrated in central Maine counties—Penobscot (17.8%), Kennebec (14.4%), Somerset (13.9%), and Waldo (11.1%). Over sixty percent of organic farms are located in Franklin (28.1%), Kennebec (21.1%), and Waldo (12.3%) counties. Maine dairies sell their milk to one of eight large milk companies or cooperatives. These companies are predominantly located out of state. Fluid milk processing in Maine is limited to two larger plants in Portland, Maine, two small processers, and several vertically integrated operations.

Figure 3. County-Level Percent Dairy Distribution: (a.) by Total; (b.) by Management Type



Methods

In 2014, we sent a mail survey to the entire Maine dairy industry population in conjunction with a triennial Maine Milk Commission (MMC) cost of production study. We undertook this method to increase response rates, as the Cost of Production survey typically has high response rates. We mailed a second round of surveys, followed by a reminder mail from University of Maine Cooperative Extension and the Maine Dairy Industry Association (MDIA). From the industry-wide mailing to the 260 dairy farms listed in the MMC database, farmers returned 63 completed surveys for a 24% response rate. Though surveys are one of the most prevalent forms for collecting network data (Marsden, 1990; Marsden, 2011; Scott & Carrington, 2011; Wasserman & Faust, 1994), mail surveys typically have lower response rates (Bernard et al. 1984). Farmers' lack of consistent access to phones and the Internet necessitated a mail survey (G. Anderson and D. Marcinkowski, personal communication, March 21, 2014). Respondents were, however, proportionally representative of the industry

in regard to milk production levels (farm size by tier) and management type (conventional and organic) (Tables 2 and 3).

We employed a hybrid name generator format, which is a method that uses a combination of categories and space for open-ended responses. There is evidence that as a network surveying method, it prompts recall and reduces error (Henry, Lubell, & McCoy, 2012). Acknowledging the relationship between the word sustainability and organic management, we utilized a context-specific definition of sustainability. Maine dairy is an industry defined more often by differences than commonalities, and farmers are evaluated and supported based on their management practices and farm size (Chapter 1; Chen et al., *In Press*; D. Marcinkowski & P. Erickson, personal communication, January 7, 2014). In this divisive environment, to employ a term that has been historically used to identify "good," or organic farming, versus "bad," or conventional farming, would likely create a perceived negative bias toward conventional farming (Hinrichs, 2000; Sutherland & Darnhofer, 2012). With input from industry experts and from farmer observations, we addressed this problem of bias with the term "sustainable," and reframed it as "long-term success" of the industry. We collected farmer perceptions of sustainability of the Maine dairy industry with the survey question, "What do you think the challenges and issues are for long-term success of the Maine dairy industry?" and focused with a hybrid name generator "For each category please list the specific issues: Crop Production, Milk Production, Processing, Packaging, Transport/Distribution, Retail, Profit, and Other." These categories were followed by the refining statements 1) "Out of the issues that you listed above, please circle ONE that is the most important for the long-term success of Maine's dairy industry" and 2) "Please describe why the issue that you circled is the most important." We used grounded theory process and NVivo qualitative data analysis software to define unique concepts of farmer-identified industry challenges (Bazeley 2007; Hoffman et al. 2014; Saldaña 2012). To ensure

consistency and reliability two coders analyzed two random samples (using Excel's RAND function) of 10 farmer responses. To generate a mental model concept network, we created a weighted, non-directional adjacency matrix with the unique concepts as nodes and the associations between these concepts as ties (Wasserman & Faust, 1994). Associations between concepts are the co-occurrences across all responses (Hoffman et al. 2014). For example, in the 58 usable farmer responses climate occurred 16 times, cost occurred 33 times, and they co-occurred 11 times. The weight of the tie between the climate and cost nodes is 11.

To understand which concepts are the most important to farmers, we calculated three measures of centrality for each of the 43 challenge concepts—average occurrence probability, network centrality, and prominence (de Nooy, Mrvar & Batagelj 2005; Hoffman et al., 2014). Average occurrence probability is the number of times that a challenge was mentioned out of the total farmer survey responses (n=58). Network centrality, calculated using eigenvector centrality, measures the association between concepts in the network (de Nooy, Mrvar & Batagelj 2005; Hoffman et al., 2014). When a concept has more ties or ties with higher weights, it is more important in the network. A concept that is linked to other highly central ties is more important in the network. Prominence is the mean of occurrence and centrality (Hoffman et al., 2014). To determine the formal and informal government, non-governmental, private, public, and individual sources of information that farmers trust, we asked, "Who do you talk to or go to for information about the dairy industry? For each category below please list the names of organizations or individuals in the spaces provided: Federal, State, Local, University/College, Non-governmental organizations, Individuals or other organizations." We organized and analyzed the categories of information sources listed by each farmer, and the frequency that each category was mentioned.

Causation coding provides a perspective on farmers' mental models beyond primary sustainability challenges. What do dairy farmers believe to be the causes of the sustainability challenges? How do the challenges affect one another and relate to the system of governance? For each sustainability challenge, we analyzed the direction of causation of farmer responses and used these paths of influence between linked challenges to explore causes and outcomes (Munton et al., 1999; Saldaña, 2012). For example, if a farmer responded that crop production is a top sustainability challenge, and that weather variability hinders quality forage production, the general causal direction is that weather variability hinders cropping. We will present a causation and a scale analysis for the two top sustainability challenges—cropping and cost. The causation analysis will delineate the relationships between cropping or cost and associated primary and secondary sustainability challenges. The scale analysis will illustrate associated spatial, temporal, and jurisdictional scales for the challenges. We will use the Tier Program as a specific policy example to demonstrate problems of ignorance, mismatch, and plurality that exist within and across the sustainability problemscapes of cropping and cost.

Maine Dairy Sustainability Problems' Causation and Scale: Cropping and Cost

The grounded theory process and NVivo qualitative data analysis used to define unique concepts of farmer-identified industry challenges resulted in 43 unique challenge concepts most important to Maine dairy sustainability. These are shown in Table 4, organized by prominence value in descending order. Concepts that have a higher prominence value are the challenges that farmers considered the most important in regard to sustainability. These most important challenges are also more highly associated with other important, or prominent concepts. Our causation coding reveals direction of influence and offers descriptive evidence of the relationships between each of the sustainability challenges from farmers' mental models. We will present the causation analysis for

cropping and cost, which are the two most prominent sustainability challenges in farmers' mental model networks. After a discussion of the strength and direction of relationships between cropping and other challenges, we will explore associated spatial, temporal, and jurisdictional scales, and Maine dairy industry governance challenges.

The Cropping Problemscape: Causation and Scale

Cropping was the most prominent, or important, sustainability challenge in farmers' mental model networks. Figure 4 shows the primary causal relationships between cropping and other sustainability challenges, including five most prominent challenges and five less prominent challenges. A primary causal relationship either directly influences or is influenced by cropping. The medium green challenges have higher prominence values, and thus stronger causal relationships with cropping. The pale green challenges have lower prominence values, and have relatively weaker causal relationships with cropping. Causal relationships can occur on secondary or tertiary levels as well. Figure 5 shows examples of secondary and tertiary causal relationships with cropping.

Figure 4. Primary Causal Relationships for Cropping

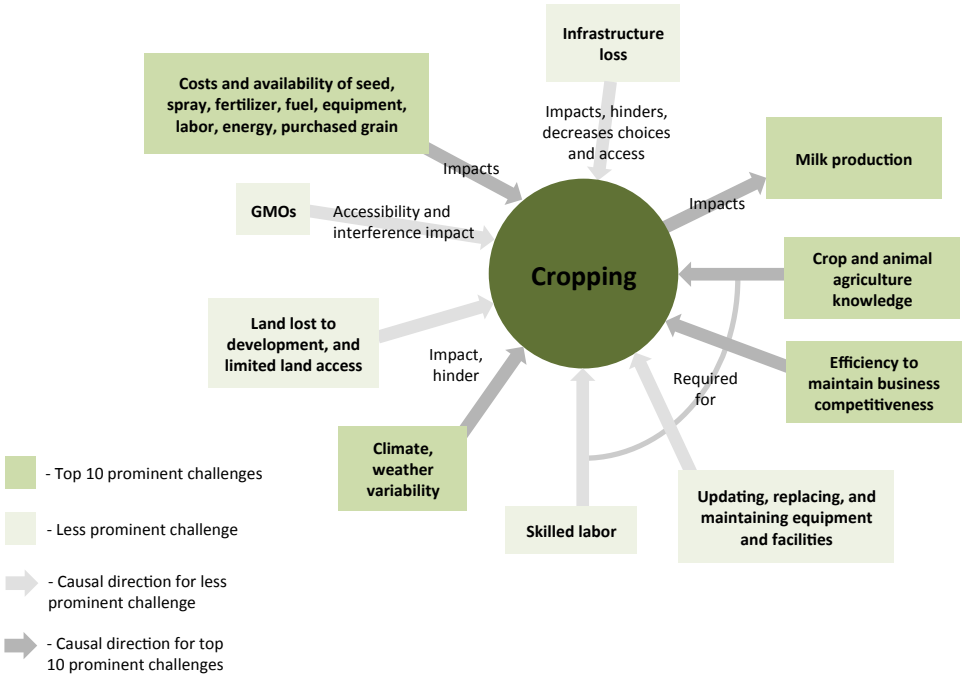
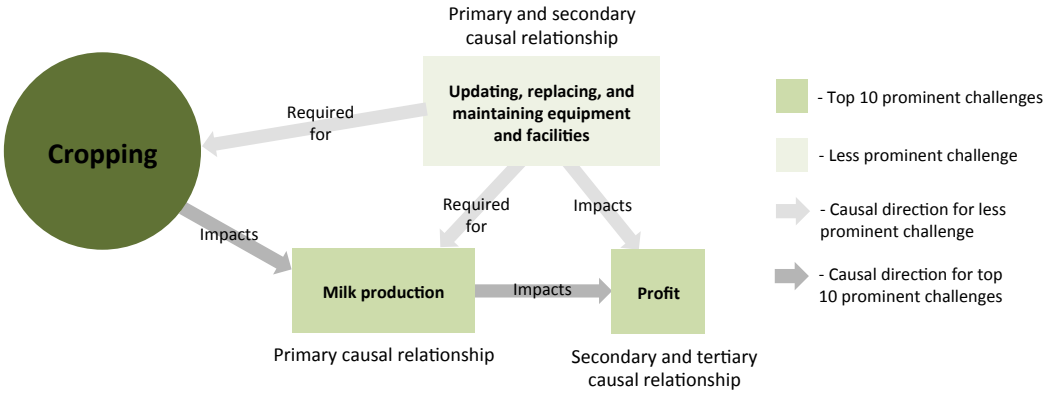


Figure 5. Example of Secondary and Tertiary Causal Relationships for Cropping



The most prominent challenges associated with cropping span spatial and temporal levels (Figure 7). Cost drivers range from prices charged by local mechanics to global oil prices that impact fuel, fertilizer, and other energy costs that farmers pay. While climate systems are known to operate at a global, long-term scale, the impacts of anthropogenic climate change are increasingly felt locally in increased seasonal volatility and extreme weather events (Wheeler & von Braun, 2013). Weather systems, influenced by climatic systems, are experienced locally but they often have regional, or in rare cases, national effects. A recent example is the historic 2012 drought in the central and western U.S., which dramatically increased feed prices for Northeastern dairy farmers (Farm Credit East, 2012). The time and experience needed to develop knowledge of both crop and animal agriculture can take generations. Technology can quickly change the way in which people farm, and some knowledge must be developed over a shorter time scale. Farmers use of social media, nutritional tracking software, and even robotic milking equipment has dramatically changed dairying in less than one generation. Crop production, milk production, and business efficiency are closely linked, and experienced at the farm level over shorter time periods. If a farmer has a poor forage year, it will impact both the quality and quantity of milk that the cows produce, which can result in decreased efficiency for the business. The

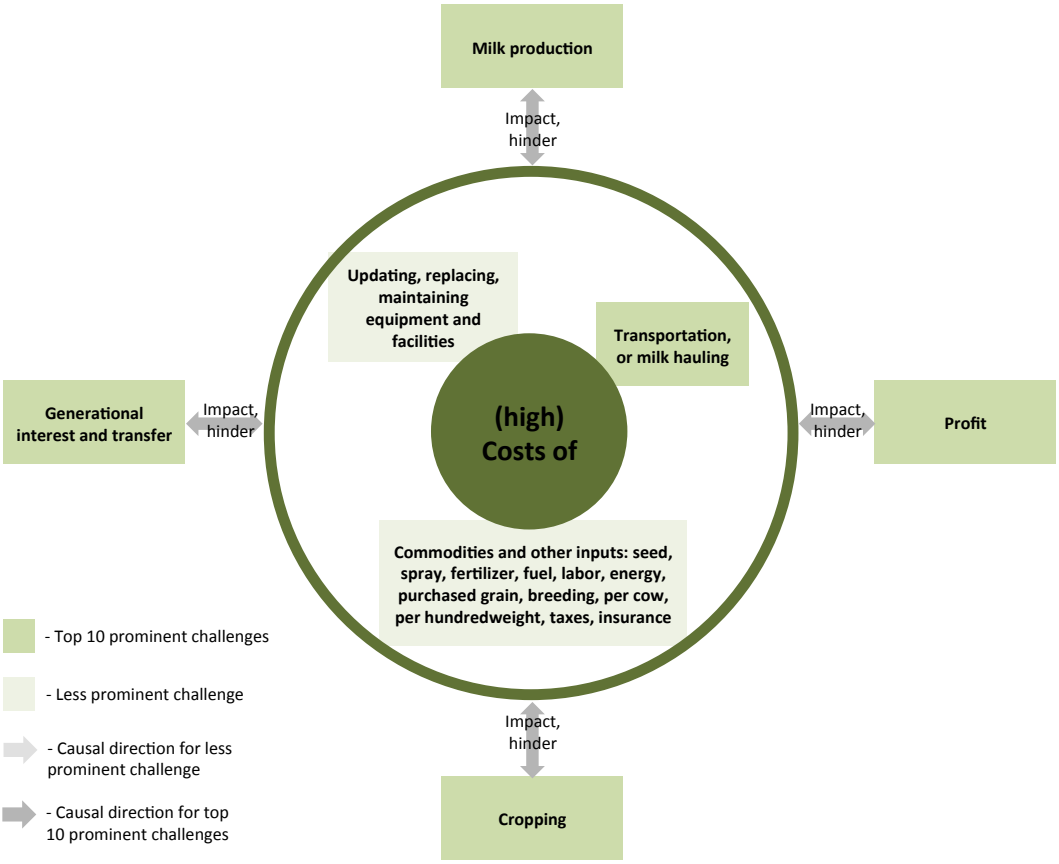
secondary impact of these challenges on profit can occur over longer time periods especially when costs rise, and efficiency falls.

The less prominent challenges associated with cropping are clustered in the longer time periods and concerns are more local than those associated with the more prominent challenges (Figure 8). Farmers expressed concerns about genetically modified crops (GMOs) that range from maintaining access to fears of organic crop contamination. While genetic modification is a less prominent issue for Maine farmers, these concerns reflect an ongoing debate at regional and national levels about the technology being critical to or dangerous and problematic for the future of agriculture (Leyser, 2014). Farmers' concerns about land and infrastructure loss and skilled labor are expressed at the state and local levels. There is a shortage of affordable land for dairying in central and southern Maine, milk processing plants have gone out of business, and the remaining two large processors are located in southern Maine. These challenges are felt on a monthly basis, and become more challenging over time as more land is developed and supporting infrastructure is lost. Part of this loss in infrastructure extends to specialized farm equipment maintenance and repair. As the number of dairy farms decrease, the demand for these services have decreased and farmers have seen equipment repair and retail go out of business or move to servicing lawn mowers rather than tractors. This contributes to the amount of labor needed to keep a farm in business. Farmers not only need to know about cow care and cropping, but they also often need to maintain and repair their own equipment. Lack of access to skilled labor can hinder a farm's productivity in the short term, but it also has longer-term consequences. Knowledge takes time to develop, and while demand for skilled labor is high, supply is low, as interest in entering the dairy industry has decreased in favor of other off-farm job opportunities.

The Cost Problemscape: Causation and Scale

Cost was the second most prominent, or important, sustainability challenge in farmers' mental model network. Figure 6 shows the primary and secondary causal relationships between cost and other sustainability challenges. As in the cropping figure, the medium green challenges have higher prominence values, and thus stronger causal relationships with cost. The pale green challenges have lower prominence values, and have relatively weaker causal relationships with cost.

Figure 6. Primary and Secondary Causal Relationships for Cost



The challenges associated with costs span spatial and temporal levels (Figures 9 and 10). High costs associated with transportation and hauling, equipment and facilities, commodities and other inputs impact and hinder the secondary challenges of milk production, profit, cropping, and generational interest and transfer. Transportation is a

relatively short-term regional challenge in its impact on the secondary challenges—production, profit, cropping, and generational transfer—which are predominantly local and have cross-temporal effects. Dairy farmers may haul their own milk to a plant or the milk company may be responsible for transport. For farmers that live far from the processing plant costs fall directly on them if they personally haul milk, or if the company hauls for them, they can still face indirect costs. The story of the twelve Maine's Own Organic Milk, or MOO Milk, farms demonstrates the impact that transportation costs can have on a dairy. Hood did not renew the farms' contracts due to the start of the recession in 2008 and the increased cost of hauling small quantities of milk from relatively isolated farms (Zezima, 2011). The farms formed an independent company called MOO Milk, and after a number of insurmountable problems, the company went out of business (Fishell, 2014). Costs of equipment and facilities updates, replacement, and maintenance occur at a local level and at the temporal scale of months to decades. While equipment and facilities maintenance should be ongoing to keep a farm running smoothly, when farmers face numerous other costs important updates are often put off. The costs of commodities and other inputs are shorter-term challenges and span local to global spatial effects. Gas prices are globally determined. Equipment repairs may be conducted locally, but parts may come from another country. Higher costs cut into the bottom line and leave less profit for the farmer. The primary and secondary challenges are in a feedback cycle where greater costs mean less profit, which impacts farmers' ability to fix, maintain, or replace machinery and facilities, pay for milk hauling, or purchase needed inputs. When a farmer is unable to purchase necessary inputs or keep machinery working well, cropping and milk production can suffer. The longer this cycle continues, the less incentive and fewer options the next generation has for transfer. An exploration of the primary and secondary challenges associated with cost illustrates the integrated and complex nature of the challenges that farmers face.

Governance Scales: Maine Dairy Jurisdictional and Organizational Players

Dairy farmers rely on formal and informal information networks for knowledge and support. These networks span spatial, temporal and jurisdictional scales and levels (Table 14).

Table 14. Sources of Information for Maine Dairy Farmers, by Most Frequently Mentioned

Sources of Information	Frequency	Examples
Farm consultants/other services	86	Farm Credit, feed companies, haulers, and vets
Farmers	62	Names unavailable due to confidentiality
UMaine Cooperative Extension	32	Gary Anderson, Rick Kersbergen, Dave Marcinkowski
Federal government	28	U.S. Dept. of Ag. (USDA), Farm Service Agency (FSA)
Farm magazines (print and Web)	21	Hoard's Dairyman, Progressive Dairyman, Country Folks
Milk company or cooperative	18	AgriMark, Oakhurst, National Farmers Organization (NFO), Dairy Farmers of America (DFA), Stonyfield Farm
National or regional farm associations or cooperatives	17	National Milk Producers Association, National Organic Dairy Producers Association, Holstein Association
State-level farm associations	17	Maine Organic Farmers and Gardeners Association (MOFGA), Maine Dairy Industry Association (MDIA)
State government	15	Maine Milk Commission (MMC), Maine Dept. of Agriculture, Conservation, and Forestry
Other	<10	Local government and farm associations, UMaine (other than Extension), Cornell Cooperative Extension

Jurisdictional and organizational players, which are farmers' primary information sources, are clustered between state and local spatial scales, and their ranges of influence are temporally clustered between months and years (Figures 7, 8, 9, and 10). Magazines that farmers trust are predominantly national, but some do provide regional information. Federal government entities, like the USDA, NRCS, or FSA, span several spatial levels as their policies affect state level regulations and access to services. Milk companies and cooperatives span spatial scales, and farmers express frustration with the large distances that their milk needs to travel from farm to plant. Farm associations and cooperatives are national or regionally focused, but the knowledge or support that they provide can impact farmers at a local level. Likewise, farm consultants and services, like Farm Credit East, may also have a regional or local influence depending on the reach of the business or service. State government entities, Cooperative Extension, MDIA, and MOFGA provide management,

assessment, and policy that impact state and local levels. Spatially, farmers are local, but many of the farmers who are considered trusted sources of information are involved in state-level organizations as dairy representatives. It is clear from the causation and scale analyses for cropping and cost that the associated challenges cross spatial and temporal scales and levels. Formal and informal jurisdictional and organizational players are spread from local to national spatial levels, and there is clustering at the state and local levels. Problems of ignorance, mismatch, or plurality exist between the spatial and temporal scales of the sustainability challenges associated with cropping and current management, assessment, or policies of the jurisdictional and organizational players. In the following section, we will provide an in-depth comparison of the Tier Program and the cropping and cost problemscapes to explore, for a specific example, ignorance, mismatch, and plurality governance problems.

Figure 7. Spatial, Temporal, and Jurisdictional Scales for Most Prominent Challenges Associated With Cropping

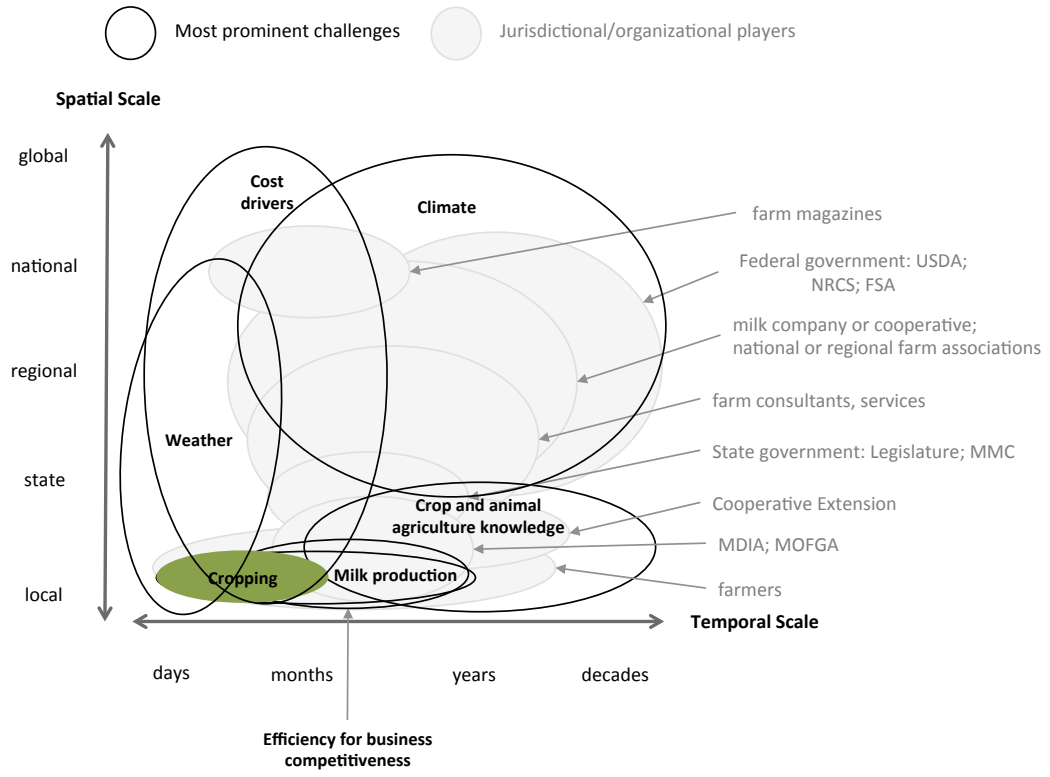


Figure 8. Spatial, Temporal, and Jurisdictional Scales for Less Prominent Challenges Associated With Cropping

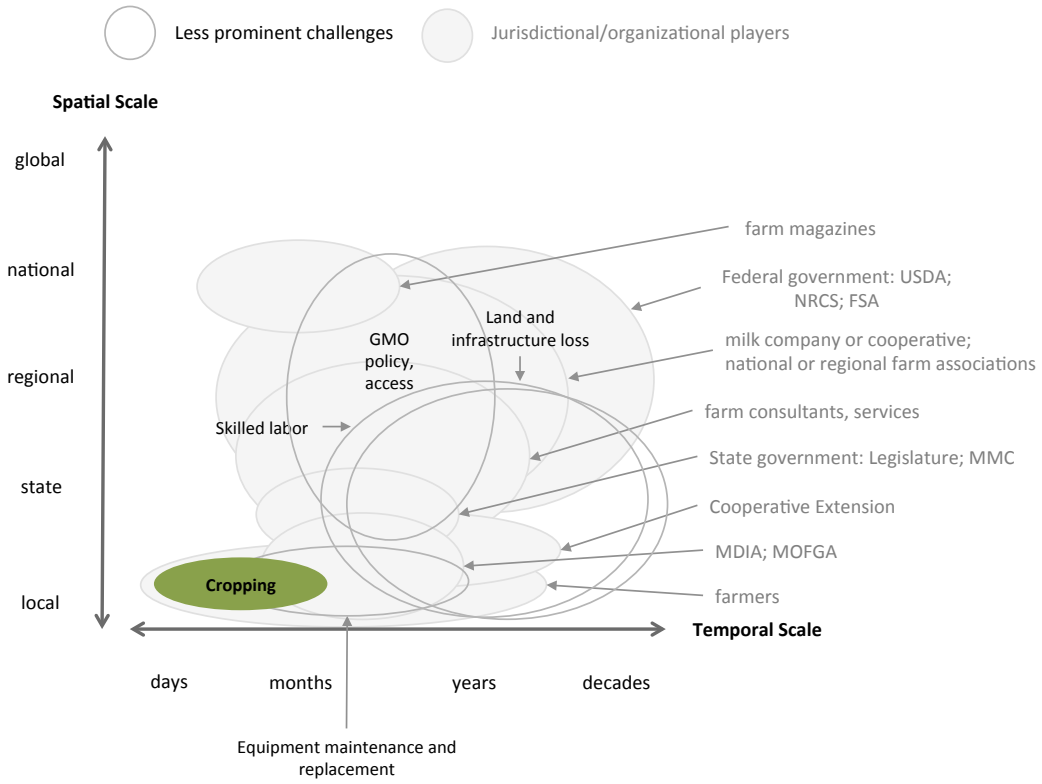


Figure 9. Spatial, Temporal, and Jurisdictional Scales for Most Prominent Challenges Associated With Costs

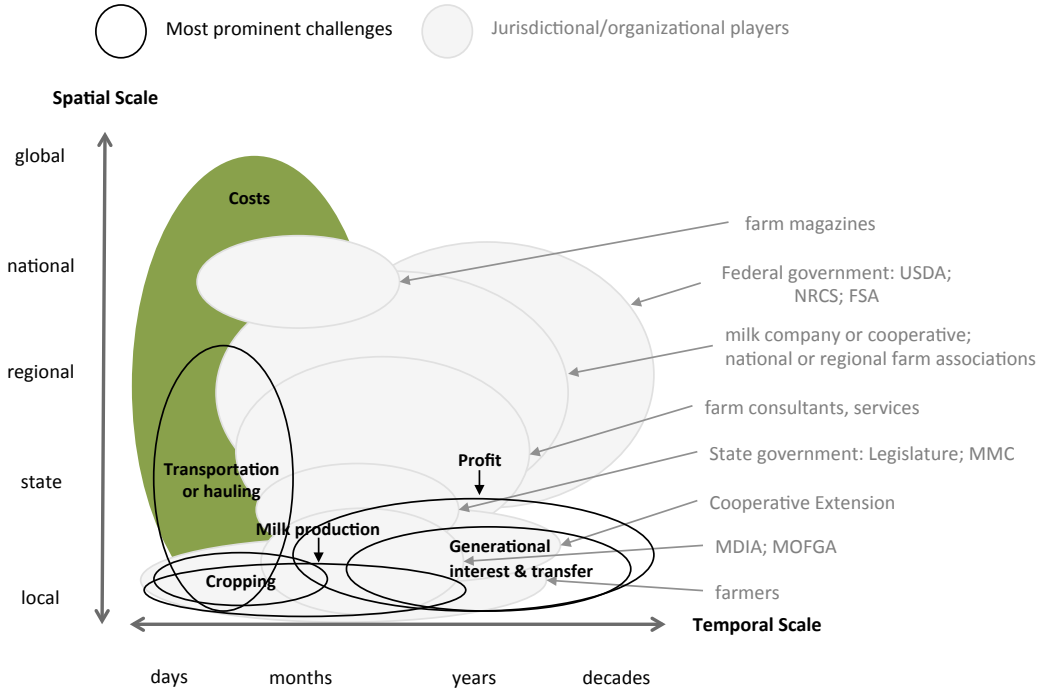
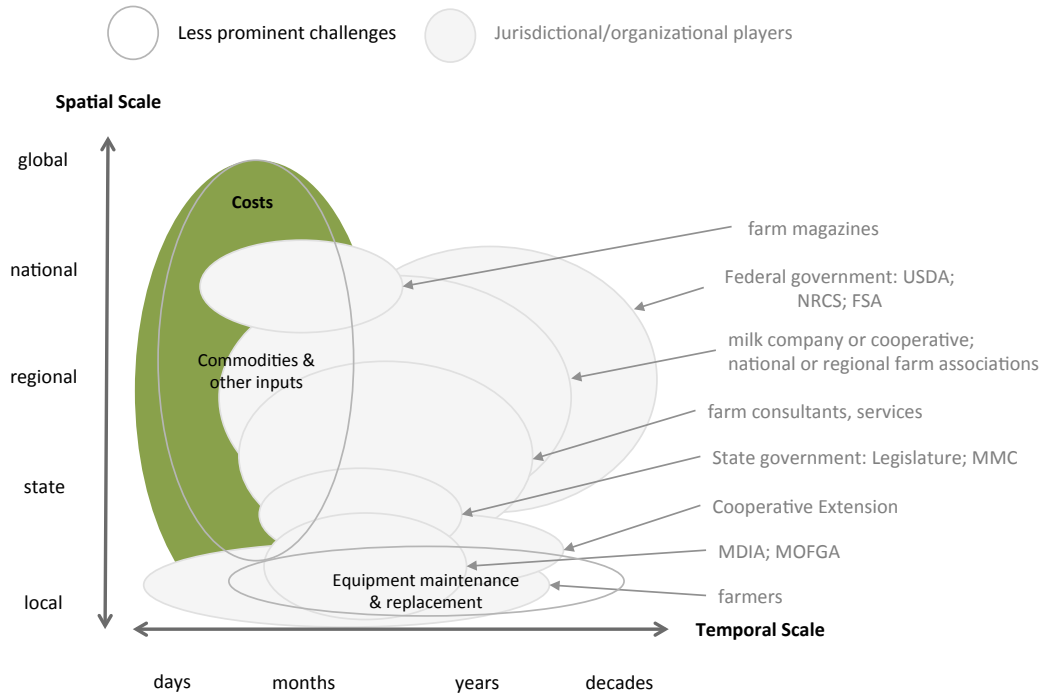


Figure 10. Spatial, Temporal, and Jurisdictional Scales for Less Prominent Challenges Associated With Costs



Misalignment in Maine Dairy Governance: The Tier Program

There are many cases where management, assessment, and policy do not address the problems in a social ecological system. Cash et al. (2006) attribute these challenges to, "the failure to take into proper account the scale and cross-scale dynamics in human-environment systems" (8). As illustrated above in the causation analysis of the two top challenges for Maine dairy farmers, it is clear that the scales involved are complex. Problems facing farmers cross scales and levels, but policy in Maine is often constrained by the short-term focus of elected officials due to term limits and short legislative sessions. The Maine dairy industry's Tier Program provides an example of a short-term solution attempting to address long-term, industry-wide problems, which leads to scale challenges of ignorance, mismatch, and plurality.

The Tier Program assessment is designed to determine the cost of production for a sample of Maine's conventional farmers every three years with short-run breakeven, or

adjusted cash operating costs over a one-year period (Chen et al., 2016). The results of the triennial study inform a kick-in milk price for each tier, or milk production level, which is set by the Maine Legislature (Chen et al., 2016). When the federal milk price drops below the tier-specific kick-in prices, farmers receive payments intended to counteract milk price volatility and lend stability to the industry (Chapter 648 H.P. 1445-L.D. 1945).

Ignorance, or the lack of recognition of scalar problems and interactions, is a common problem in social ecological systems management. In the Maine dairy industry, perhaps due in part to short-term legislative action, and a narrowly focused Tier Program assessment, there is ignorance around common challenges that dairy farmers are facing, and the scales at which these problems occur. There is a pervasive narrative that focuses on the differences between groups of Maine dairy farmers, which often pits small farms against large and conventional farms against organic in assessment and in policy. We found that many of the most prominent challenges affect a majority of farmers, but farmers are situated in a governance context where assessment and policies are separated by management practice and farm size, as evidenced by the Tier Program. From the causation and scale analysis for cropping and cost, we saw that the associated challenges span spatial and temporal scales, and are influenced by other cross-scale and cross-level challenges. There is a mismatch between the Tier Program's single year assessment of farmers' costs of production and the time-scales and levels that impact cropping and costs that farmers described as prominent. Farmers have expressed that the monetary support has been helpful, but the implementation of a short-term economic solution misses the interactions between multiple long-term problems, which may compound over time. In the case of Maine dairy, rather than a problem of management and assessment at a single level, as described by Cash et al. (2006) plurality problems may exist in policies that are focused on binary management type or tiered farm sizes, but ignore the diverse spatial and temporal

scales of prominent challenges. Multiple scales and levels of management, assessment, and policy may be needed to combat problems of ignorance, mismatch, and plurality.

Conclusions

Agricultural systems could benefit from increased exploration of scalar problems and their relationship to sustainability policy. The barriers to effective long-term management, assessment, and policy are numerous, and solutions may lie in better understanding the scales at which challenges and jurisdictional resources intersect. There are gaps between the current policy structure of jurisdictional or organizational players and the management and assessment scales required to address primary sustainability challenges. The Maine Legislature faces the temporal restrictions of short legislative sessions and term limits, which creates a context of ignorance and mismatch when legislators are faced with long-term sustainability problems. Management and assessment has focused on dividing the industry by groups, such as conventional versus organic farms or tiered farm sizes, which may not be effective in addressing multi-scale sustainability challenges. Adaptive approaches may need to be nested within existing governance structures—both formal and informal—and modified to address cross-scale and cross-level problems. Institutions like Cooperative Extension that were created over a century ago effectively addressed problems at state and local levels in a different agricultural, political, and global context. These institutions continue to be vital, but our challenges have grown in scale, and we may need to rethink about how these institutions function, collaborate, and adapt. Further studies of causation between top agricultural challenges and their spatial, temporal, and jurisdictional scales may provide insight for better sustainability governance in the future. Mental model and information networks provide one perspective of sustainability challenges, and while insightful, they represent farmers' view of these problems for a particular period in time. To capture the dynamics of a changing system,

these tools need to be iterative. More of these types of studies combining network and scale analysis may reveal patterns that are relevant across agricultural systems, and lead to solutions that would otherwise be obscured.

CONCLUSION

Maine dairy farmers described 43 critical challenges to their industry's sustainability. The results of this dissertation research suggest that Maine dairy farms face numerous interconnected economic, environmental, and social challenges that cross management practices and farm sizes. Our causation analysis of challenges associated with cropping and cost, the top challenges to Maine dairy sustainability, showed that they span spatial, temporal, and jurisdictional scales and levels. There is a misalignment between the current industry assessment, management, and policy and what is needed to address sustainability challenges.

Researchers exploring sustainability at the intersection of human and environmental systems have demonstrated the importance of bridging scientific knowledge and policy action to find solutions to long-term challenges (Cash, Borck, & Patt, 2006; Cash et al., 2003; Clark, 2007; Clark & Dickson, 2003; Rose & Parsons, 2015; van Kerkhoff & Lebel, 2006). Contrary to the dominant industry narrative focusing on economic factors as the most critical issues facing the Maine dairy industry, we found a complex and strongly interrelated network of economic, environmental, and social sustainability challenges facing Maine dairy farmers.

State-level policy has separated dairy farmers by management practice—conventional or organic. This binary is common in the literature (Best, 2010; de Ponti, Läpple, & Van Rensburg, 2011; Mzoughi, 2011; Rijk, & Van Ittersum, 2012; Gabriel et al., 2010; Gomiero, Pimentel, & Paoletti, 2011; Seufert, Ramankutty, & Foley, 2012). Social ecological systems governance literature has made a strong case for the inclusion of social capital in natural resource management and resilience work (Adger et al., 2005; Folke et al., 2005; Ostrom & Ahn, 2003). Evaluation of sustainability challenges for agricultural systems

may also benefit from use of social capital as a variable. We utilized size of farmers' information networks as a social capital variable and compared it to farm size and management practice variables. While the literature frequently focuses on the differences between conventional and organic management, we found that neither management practice nor farm size is a primary factor contributing to differences in farmers' mental models of sustainability challenges. These findings suggest that current agricultural assessment, management, and policy divided along conventional versus organic lines may be misguided.

Agricultural systems could benefit from increased exploration of scalar problems to overcome barriers to effective long-term management, assessment, and policy. There are gaps between the Maine dairy system's current policy structure and the management and assessment scales required to address farmers' primary sustainability challenges. Solutions may lie in better understanding the scales that intersect both challenges and policies. The Maine Legislature faces the temporal restrictions of short legislative sessions and term limits, which leads to a misalignment when legislators are faced with long-term sustainability problems. Critical institutions like Cooperative Extension were created over a century ago to address problems in a different agricultural, political, and global context. Challenges have grown in scale and complexity, and we may need to reevaluate how these institutions function, collaborate, and adapt. Further causation studies of the relationships between top agricultural challenges and their spatial, temporal, and jurisdictional scales may provide a path toward sustainability.

Recommendations

Evidenced by our mental model network analysis, information network analysis, and causation analysis, to address long-term challenges to Maine dairy sustainability assessment, management, and policy must extend beyond the short-term economic

measures and supports for conventional farms. A more holistic approach is needed to address the many economic, environmental, and social challenges facing dairy farmers—conventional and organic, alike. We recommend that future studies expand the industry's economically focused policies, and for all categories of Maine dairy producer, measure sustainability factors over time.

Longitudinal mental models are one example of an adaptive evaluation tool that could be used to inform better sustainability policies. Like the triennial MMC's cost of production study that informs the dairy stabilization program for conventional farmers, a mental model network could be conducted every few years. A representative sample of farmers would be recruited at the start of the study, and they would be compensated for their participation for the entirety of the long-term study. This type of research, in order to be effective, requires a transparent science-policy feedback process. A longitudinal study has the potential to better inform policy in dynamic systems. Expansion of this dissertation research to include assessment of industry leaders, policy makers, and Cooperative Extension specialists may be useful. It would allow a comparison of other dairy industry groups' mental models of with farmers' mental models to determine if and where misalignment is occurring. This will aid in creating a dynamic process of needs evaluation and adaptive policies to address challenges that may change over time. In this globalized, industrialized, and fast-paced technological world, we often expect immediate fixes to problems. However, sustainability is an ongoing goal and requires looking to both the past and the future for solutions. Without assessment, management, and policy that align with the scale of challenges facing an agricultural system, long-term success may remain elusive.

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