Not Just a Label:
synergies and tradeoffs between social and ecological resilience in organic and conventional Michigan apple orchards

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A thesis submitted
in partial fulfillment of the requirements
for the degree of Master of Science
(Natural Resources and Environment)
in the University of Michigan
April 2017

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ABSTRACT

Resilience is an important consideration that enriches the sustainability discourse surrounding farming. Certified organic farm management has been shown to confer resilience to insect pest outbreaks but debate surrounding this issue continues due to lack of context specific ecological knowledge and social data. To explore this, a conceptual model linking organic management, natural enemy communities, resilience to insect pest outbreaks, perceptions of ecological resilience, forms and extent of social resilience, and farmer behavior in a feedback loop was created and tested in apple orchards in Michigan. The model was tested by measuring indicators of ecological and social resilience in field surveys and experiments and long-form interviews with apple farmers. Specifically, ecological resilience was addressed by comparing ant community composition and predatory function in 2 certified organic and 2 conventional apple orchards in southern Michigan using baiting methods and by simulating a pest outbreak using moth larva. Social resilience and feedbacks between ecological resilience and farm management were assessed in long-form interviews conducted with 10 orchard owners/mangers across the Midwest that focused on farmer perceptions of insects and past experiences adapting to insect outbreaks. Ant abundance, species richness, and predation on moth larva were significantly higher in organic than conventional orchards. This indicates that organic apple orchards are more ecologically resilient to insect pest outbreaks. Similarly, interviews indicated that organic apple farmers' sources of social capital were more abundant and uniquely characterized by trust and reciprocity, suggesting greater social resilience. Overall, the results confirmed the conceptual model and demonstrated that robust social capital and predatory insect communities interact synergistically in certified organic apple orchards and provide farmers with high resilience, while in conventional apple orchards, farmers trade social capital and predatory insects for a single form of resilience, synthetic agrochemicals.

ACKNOWLEDGEMENTS

To food – the ecosystems from which it comes and the farmers that tend them.

To women – my mom, who taught me to go outside and be amazed

my role models, the women scientists, environmentalists, and poets who taught me to ask questions and to tell stories

my mentors, Ivette and Jennifer, and lab mates, who taught me to be awake to the possibilities of my research, my life, our food system, and our common future.

> **“Another world is not only possible, she is on her way. On a quiet day, I can hear her breathing.”**
>
> Arundhati Roy

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INTRODUCTION

Increasingly, both food systems and natural resource management regimes are defined and assessed in terms of their resilience, or the resilience they confer (Pingali et al. 2005, Folke 2006, Brown and Williams 2015, Tendall et al. 2015, Himanen et al. 2016). From produce supply chains to populations of endangered species living in national parks, capacity to respond to change, shocks, and/or stressors by maintaining, or even improving, function is a widespread priority in response to actual and anticipated environmental and socio-political volatility (Adger 2006, Nelson et al. 2007). At the intersection of these areas of inquiry is the evaluation of management's impacts, at various scales, on farm level resilience with the goals of addressing food security, sustainability, and agroecosystem provision of ecosystem services in the face of future disturbances of many kinds (Tscharntke et al. 2005, Kinzig 2006, Pretty 2008, Lin et al. 2008). In the past decade, evaluations of farm resilience have largely relied on long-standing frameworks for social-ecological systems that focus on human impacts on the vulnerability or stability of desired ecological states and have centered around the relatively newer concept of biodiversity as an "insurance policy" against ecosystem state changes (Holling 1973, Folke et al. 2004; Wittman et al. 2016).

In particular, a farm's autonomous, ecological ability to suppress herbivores and sustain productivity in the face of new or more abundant insect pests has been linked to aspects of management (Vandermeer et al. 2010; Lin 2011). It is well documented that management that increases planned diversity of many kinds corresponds to increased richness and/or abundance of natural enemies, increased predation, and associated farm resilience to insect pests (Altieri and Niclols 2004, Bianchi et al. 2006, Lin 2011). Identifying management that confers this type of resilience is especially important because of the implications for sustained food production and grower livelihoods in the face of increased pest pressure due to climate change and for improved public health and environmental conservation associated with decreased pesticide use (Pimentel 2005, IPCC 2014).

Though more debated, evidence continues to mount that broader management categories can also be linked to farm level resilience to insect pests. Notably, certified organic farms and non-certified organic farms, referred to as conventional in this paper, have been shown to correspond to capacity for autonomous pest suppression in much the same way that farms with high and low diversity do (Bengtsson et al. 2005, Crowder et al. 2010). Organic farms are similarly associated with more species rich and abundant communities of natural enemies and high levels of autonomous pest control characteristic of resilience (Crowder et al. 2010). However, the effect of such broad management categories on resilience is often criticized as highly context dependent and not reflective of the actual spectrum of management strategies represented on both conventional and organic farms (Ponisio et al. 2015, Seufert and Ramankutty 2017). Nor do broad management categories alone illustrate ecological mechanisms useful in understanding management. Given the status of these categories as the main management paradigms officially recognized in most industrial countries, more exploration is warranted to better establish the effects, or lack there of, of these two modes of management on farm-level resilience to insect pests in a variety of geographical and crop contexts.

Additionally, despite these bodies of entomological work linking management to ecological resilience to pests, little work has addressed the corresponding social resilience to insect pressure and made the critical leap from broad theoretical frameworks of social-ecological resilience to farm-level conceptual models that map the relationships between management and both kinds of resilience to insect disturbance (Fiskel 2006, Folke 2006, Walker et al. 2006, Darnhofer et al. 2010, Cote and Nightingale 2011, Vandermeer and Perfecto 2012, McGinnis and Ostrom 2014). This is a critical step to take in order to avoid cultural assumptions and better characterize and compare organic and conventional farming, predict farm-level responses to socio-political and environmental change, and to identify areas of needed support or best places for intervention to promote farming that aligns with current information on protecting both public health and environmental integrity (Pimentel 2005, Seufert and Ramankutty 2017). For these purposes it is important to explore the ways the broad management categories "certified organic" and "conventional" are able to capture ecological and social resilience and to better understand how these management syndromes align with other characterizations of modes of farming.

For example, Jan Douwe van der Ploeg has identified 3 modes of farming globally, including industrial, entrepreneurial, and peasant agriculture (van der Ploeg 2008). A defining characteristic of peasant farming is its autonomy from empire, the dominant, hegemonic food production and consumption regime globally, attained largely through labor and reliance on nature (van der Ploeg 2008). Peasant labor characterized as non-wage labor that is based not solely in capitalist mechanics, but also in culture, perceptions, and a moral economy (van der Ploeg 2013). In balances identified originally by Chayanov, macro level economic processes are mediated through these micro level considerations resulting in different rational decision making surrounding labor in peasant and capitalist farming (van der Ploeg 2013). It is possible that the categories of organic and conventional farming represent similar distinctions, with organic farming relying more heavily on non-wage labor and collaboration with nature, and that differential resilience to insect pests will be based in different decision making and associated with different levels of autonomy but these questions are largely unexplored.

Such an understanding of the effects of organic and conventional management on farm-level resilience to pests is especially relevant to fruit production. Specifically, orchards are sensitive to insect damage and high use of agrochemicals per acre, which can have relatively large public health implications based on un-mechanized harvest and high annual consumption per capita (PAN 2007, Fantke and Jolliet 2015). It is the purpose of this study to build a model to describe the relationship between organic versus conventional management and social-ecological resilience and to test and refine this model by measuring indicators of social and ecological resilience to pest outbreaks in conventional and certified organic apple orchards in southern Michigan where they are the dominant crop on an acreage basis. The conceptual model developed considers resilience to pests in social-ecological systems to be an equally social-ecological phenomenon itself and includes both the effects of organic versus conventional management on farm-level resilience and the grower-mediated feedbacks of this perceived and experienced resilience on management strategy (Fig. 1). Using a dialectical relationship between social and ecological forces to model farm-level dynamics is based on the precedent set by Vandermeer and Perfecto to describe dynamics of coffee production in Mexico (Vandermeer and Perfecto 2012). Specifically, the model describes mechanistic relationships at the level of the farm by combining key elements of resilience frameworks in social-ecological systems, including Folke's theory relating ecosystems and management via environmental knowledge and McGinnis and Ostrom's actor and outcome based approaches, with causal relationships based in biocontrol concepts from ecology and entomology and socio-psychological models of behavior and decision making used in rural sociology (Burton 2004, Folke 2006, McGinnis and Ostrom 2014, Lamarque et al. 2014, Offenberg 2015).

In order to test this conceptual model, the research questions this work addresses are:

1. Are natural enemy communities compositionally and functionally different in certified organic and conventional orchards?
2. Are perceptions of ecological resilience and experiences using social resilience to adapt to insect pest outbreaks different in certified organic and conventional apple growers?
3. Based on the results from questions 1 and 2, is the observed relationship between chemical management and farm resilience to pest outbreaks consistent with the conceptual model (Fig. 1)?

METHODS

Orchard Surveys

Ants were surveyed at 4 apple orchards in southern Michigan. Ants were chosen for their widely recognized capacity to provide biological control (Perfecto and Castiñeiras 1998 , Philpott and Armbrecht 2006) and based on evidence supporting ant predation on larva of coddling moth and plum circulio, apple's most economically impactful pests (Lacey and Unruh 2005, Jenkins et al. 2006, Offenberg 2015). Two study sites were certified organic and two were conventionally managed. Sites were chosen based on similarities in latitude, planted acreage, and having at least one block of the Red Delicious varietal. All sampling was conducted in Red Delicious to control for effects of fruit sugar content, which is varietal specific. Both organic orchards had once been conventional and had been certified organic for 10 years and both conventional orchards had been managed conventionally from the outset, roughly 50 and 100 years ago respectively. Records including all agrochemicals used for the growing seasons and results from previous soil tests were obtained from all participating farmers. Each study site was sampled once in June, once in July, and once in August, 2016.

Ant community composition surveys were completed using baiting methods. Ant community composition was determined by measuring proportion of baits with ants present as a metric of abundance and counting ant species richness by transect. Baits were laid in transects in the grassy alleys between rows of trees and two transects were laid per alley. Transect placement was always in the exact middle of the alley and in alleys that were in the middle of the Red Delicious block in order to avoid edge effects. Baits within a transect were 1 meter apart and transects in the same alley were 2 meters apart. One-hundred baits were laid at each sampling and transect length and number varied by orchard based on block size. In three of the orchards it was possible to use 2 transects with 50 baits in each and in 1 organic orchard it was necessary to lay 10 transects with 10 baits in each due to the layout of its Red Delicious block. Baits consisted of 1 teaspoon of a crushed Pecan Sandie cookie and 1 teaspoon of tuna packed in oil placed on an index card. Baits were sampled by identifying ant species present at each 2 hours after the bait had been laid. Specimens were conducted and identified in the lab when field identification was not possible. All samplings were carried out in the morning, when the temperature was as close to 60 degrees Fahrenheit as possible, to control for effects of temperature on foraging behavior.

Surveys of ant predatory behavior consisted of exactly the same protocol as community composition sampling but with the substitution of dead waxworm larva for baits to simulate a pest outbreak. Sampling of larval baits was completed by both identifying ant species and ranking behavior. Behavior was ranked on a scale of increasing aggression from 0-5 of with 0 representing no ants present at the note card, 1 indicating ants on the notecard but not in contact with the larva, 2 representing ant contact with larva but not using mandibles, 3 representing ant contact with larva using mandibles, 4 representing ant removal of the larva from the notecard, and 5 indicating that larva had been from the notecard but could not be found so the removal could not be attributed to ants.

Grower Interviews

In person, long-form interviews were conducted with all owners of the four orchards where ant community and predatory behavioral surveys took place. Additionally, long-form interviews were conducted over the phone with six additional apple growers across the Midwest, including three certified organic and three conventional orchard owners. All interviews were recorded and consisted of the same five questions. Interview questions asked farmers to describe the insects at their orchard, to outline their management strategy this past season, to recall a time they experienced a particularly damaging insect outbreak, to describe their process responding to this outbreak, and to explain their considerations when picking a new insecticide (Appendix). These questions were based around pre-determined themes relevant to the initial research question and based on the theories used to construct the conceptual model (Fig. 1). These themes included perception of insects, past experiences adapting to new pests, and insecticide choice choice.

Statistical Analysis

In the software package R, generalized linear mixed models were used to analyze all ant survey data and address the effect of organic and conventional management on ant abundance, species richness, and predatory behavior. Predictors of ant abundance, species richness, and predatory behavior used in the model building process included management category (conventional or organic), soil type, herbicide usage, month, temperature, orchard, and transect (Table 1). The process was the same for each test, beginning with model building based on exploratory analysis of error distribution, then selecting a model based on lowest AIC score/AIC score most different from the null model, and lastly model interpretation using beta coefficients, confidence intervals, and p-values. In the case of proportion data, including ant presence and ant removal of larva at baits, logistic regressions with bionomial distributions and logit link functions were used. Richness data was in the form of count data and thus logistic regressions with negative-bionomial distributions and logit link functions were used instead for these models. In all cases, significance was determined using Wald Z tests.

Qualitative Analysis

Thematic and theory guided analysis was used to analyze interview data (Titscher et al. 2002, Kohlbacher 2006). First all interviews were transcribed verbatim. Next, each was coded based on the previously established, theory based themes: perception of insects, past experiences adapting to new pests, and product choice. Interviews were then sorted by how similarly their content expressed each theme. Once grouped, expression of themes was analyzed for consistency with the hypothesized conceptual frameworks and adherence to additional sociological theories, including social capital theory and van der Ploeg's frameworks describing the new peasantry, was also addressed where unforeseen patterns and relationships were apparent in the data (van der Ploeg 2007, van der Ploeg 2008).

RESULTS

Ant Survey

Abundance

The effects of organic versus conventional management, month, soil type, and herbicide usage best predicted the proportion of tuna/cookie baits occupied by ants during summer orchard samplings (Table 2). The GLMM containing these predictors had the lowest AIC score and the greatest difference in AIC score from the null model including random effects only (Table 2). A significantly higher percentage of tuna/cookie baits were occupied at organic orchards and organic management was associated with a 4% increase in ant presence at baits in the best fitting model (z = 7.546, p = 4.50E-14, Table 3, Fig. 2a). Month, soil type, and herbicide use also had significant effects on the proportion of baits occupied by ants (Table 3, Fig. 2b). The proportion of baits occupied in June was significantly lower than in July and August (z = -5.146, p = 2.66E-07, Table 3, Fig. 2b). Sandy loam soil was also associated with a significant decrease in ant presence at baits (z= -2.553, p 1.07E-02, Table 3, Fig. 2c). The herbicide Paraquat was associated with a significantly lower proportion of baits occupied by ants, with its usage corresponding to a 4% decrease in ant presence at baits in the best fitting model (z =-4.174, p = 2.99E-05, Table 2, Fig. 2d). Similarly, these same effects best described *P. imparis* presence at baits when this species was considered independently in a GLMM (Table 4). However, the effect of treatment was not significant (Table 5). Month, soil type, and herbicide remained significant predictors of *P.imparis* abundance when this species was considered independently (Table 5).

Richness

Over the course of summer samplings only four ant species were found: *Prenolepis imparis, Aphenogaster rudis, Myrmica obscura*, and *Campontus pennsylvanicus*. Of these species, only *P. imparis* was sampled at conventionally managed orchards (Table 6). Both *P. imparis* and *A. rudis* were identified at Organic Orchard 2 and at Organic Orchard 1 all 4 species were sampled (Table 6).

Organic management and month of sampling best predicted ant species richness per transect (Table 7). Including both month and management as predictors generated a lower AIC score than either predictor alone and resulted in the greatest difference in AIC score from the null model including only random effects (Table 7).

Organic orchards had significantly greater ant species richness (z =2.554, p = 1.06E-02, Table 8, Fig. 3a). Overall, ant species richness was significantly lower in June than in July and August (z =-2.135, p = 3.28E-02, Table 8, Fig. 3b).

Predation

The percent of larval baits removed by ants was best predicted by organic versus conventional management and month of sampling (Table 9). Including both month and management as predictors generated the lowest AIC score and the AIC score most different from the null model including only random effects (Table 9).

The proportion of larval baits removed by ants was significantly higher in organic orchards, with organic management associated with 45% more ant predation on larva (z =3.474, p = 0.000512, Table 10, Fig. 4a). Across management types, bait removal was significantly lower in June and significantly higher in July (z =-7.774, p =7.63E-15, z =4.025, p = 5.71E-05, Table 10, Fig. 4b).

Only the species *A. ruids* and *P. imparis* were observed at larval baits. Efficiency of removal (larva removed per larva discovered in each transect) was not significantly different between the two species (*A. ruids* and *P. imparis)* with the null model having the best fit to this data (Table 11). Management type did not significantly affect discovery of larva or efficiency of removal for *P. imparis* (Table 12, Table 13, Table 14).

Grower Interviews

Themes

All 10 interviews, with five organic and five conventional growers, reflected the same recurring themes. These included, 1) subjective perceptions of insects, 2) values that shape pest management strategies, 3) social resilience to insect management, and 4) potential drivers of management regime shift (Table 15). These themes were consistently expressed distinctly by organic and conventional growers with all 5 organic farmers and all 5 conventional farmers yielding the same suite of responses, respectively (Table 15). This consistency points to a relationship between perceptions, values, social resilience, thresholds for regime shift, and mode of management (organic *versus* conventional) in agricultural systems.

Decision making

One such consistent characteristic of organic and conventional growers were the relationships between components of their resilience to insect pests and their decision to manage either organically or conventionally (Fig. 5). Important feedback from components of orchard resilience included the sources of social capital growers rely on to adapt to new insect pests and the way they perceive the insect community at their orchard (Fig. 5). Specifically, organic growers rely on extension services and social support networks for pest management information while conventional growers utilize extension services and chemical producers/distributors (Fig. 5). These different sources of social capital/resilience then feedback on what kind of management decisions these groups of farmers make. Additionally, the insect community present at an orchard is an important component of the farm's ecological resilience to pests oubtreaks. Organic growers perceive this component of their ecological resilience, distinguishing the insects in their orchard as pests or predators (Fig. 5). Conversely, when asked to describe the insects at their orchard, no conventional grower described insects using any other words except "pest" or "problem" (Fig. 5). These findings support the hypothesized socio-psychological framework linking environmental perceptions and sources of social support and influence to behavior and decision-making (Fig. 5).

Interview results also revealed that personal values needed to be added to this hypothesized socio-psychological framework (Fig. 5). Organic and conventional growers described consistently different, but equally value based, decision-making process used to pick a particular insecticide to include in their program (Fig. 5). Organic growers always described making this decision based on choosing the product that is narrowest in its mode of action, affecting only the target pest, and least harmful environmentally (Fig. 5). For example, an organic farmer from Michigan explained that when picking an insecticide they choose: "the one that is the most effective on that particular pest with minimum negative impact to the rest of the environment, so it's a balance, there's no freebies in this world, you want to get something, you want to put something there, you've got to pay for it someplace else". Similarly, additional orchard owners in Michigan and Illinois echoed these same product selection criteria with the responses that: "it really comes down to, what is the least impactful most effective product I can find" and "I would base it on trying to find the least toxic thing", respectively. Conventional growers always described making the same decision based instead on choosing the product with the broadest mode of action, affecting as many pests as possible, and for the lowest price (Fig. 5). For instance, one conventional orchard owner in Michigan explained that, when selecting insecticides,: "you try to get something that's going to be good on multiples at the same time without having to use several different products". This focus on broad mode of action was mentioned repeatedly with another conventional orchard owner in Michigan responding that:

> "I probably have a quarter of my total year's costs into one or two of these products, all this new stuff is enormously expensive because it's not in its patent yet, it's like the newest drugs, you're paying the big bucks, that's why I like the old stuff, you stick with the old stuff until you have a problem, then you look for something new, but this new stuff is very narrow in its mode of action".

In most cases conventional growers also mentioned considering harm their bees, primarily kept in hives on the property and used both for pollination services and for honey production (Table 14). This consideration was described by various Michigan conventional apple farmers and one conventional apple farmer in Missouri who explained their insecticide decision making processes by concluding that: "the other input would be related to beekeeping and doing whatever it takes to not kill bees or harm our bees in any way".

In both conventional and organic growers' decision making process, new insecticides are selected based on balancing product cost and efficiency (Fig. 5). However, organic and conventional growers' personal values dictate different definitions of both efficacy and cost in such a way that, by conventional growers' standards, organic growers choices are poor economic decisions (Fig. 6). Specifically, when an organic grower chooses a relatively high-priced organic product with a narrow mode of action, conventional farmers would perceive a poor choice in which the costs outweigh the benefits (Fig. 6). However, this same product becomes a logical choice in which benefits outweigh costs when efficacy is redefined as a narrow mode of action and cost is instead framed as reduced environmental harm (Fig. 6). By prioritizing narrow modes of action and environmental protection organic growers invest in natural enemies and autonomous pest control, a beneficial externality. This relationship between perception and economically impactful decision-making is consistent with van der Ploegs' interpretation of Chayanovian balances that explain how economic rationality does not capture the way perceptions and moral economics effect rationality (Fig. 6)(van der Ploeg, 2013).

Social capital

All organic growers and all conventional growers cited the same sources of social capital when describing past adoption to insect pests management strategies (Fig. 7). Organic growers relied on online grower groups, collaboration with neighbors, connection to consumers, and close relationships with extension agents (Fig. 7). These connections were repeatedly characterized by trust and reciprocity, describing social capital using the words *belonging* and *sharing* and describing sources of capital as *friends,* traits associated with robust social capital in social capital theory (Fig. 7). Conversely, conventional growers relied consistently and primarily on chemical producers/distributors and occasionally extension agents as their only sources of social capital when describing past responses to insect pest pressure (Fig. 7). Overall, conventional farmers conveyed industry support with mistrust and described interactions with industry as negative past experiences, relationships with extension agents were not described as reciprocal, relationships with neighbors and other growers were characterized by distrust and competition, and frustration with consumers, especially when dealt with directly as part of u-pick, was often mentioned. When probed directly for details on connections to other apple growers one conventional farmer from Michigan related that: “well if I see other growers, everybody does everything sort of their own way, you share your insights and your ideas if people ask you, but everybody is a little afraid of being accused of misusing or using too much insecticide, they would like to let people think that they are using the minimum insecticides and fungicides, I guess we don’t really, like if I went to the Hort. show they’d probably be talking about the latest think and you’d talk to guys that were there but we’re in competition a little bit”. Distrust of information from chemical producers and distributors was often alluded to, with one farmer clarifying that, while he doesn’t pay for the chemical distributor to scout for insects: “I mean I’m sure we’re paying for it, but we’re not directly paying for it”. Distrust was also more directly linked to bad past experiences like those of one conventional farmer in Michigan who described the effects of a certain herbicide’s drift as “the biggest, craziest mess” they had ever seen. This farmer recounted that: “we were pretty scared, the neighbor, he wouldn’t let people into his raspberries and he wanted to sue the company and we said fine and then he wanted us to join in and our insurance company said no the manufacturer is on your side, you don’t take an adversarial position, they’ll defend you, he should sue if he’s got a loss and they’ll settle, and it was kind of a mess, we were sort of lied to”. Based on these perceptions and experiences, organic growers conveyed greater breadth and depth of social capital, and as a result they may experience greater social resilience in accordance with established social capital theory (Fig. 7).

Organic growers’ experiences with social capital were consistent with van der Ploeg’s assertion that there are important flows that occur between resistance to empire (the dominant, hegemonic food production and consumption regime globally), autonomy from empire, and sustainability in peasant modes of production (Fig. 8; van der Ploeg, 2007). In the case of this study, sustainability can be conceptualized as resilience (from pests outbreaks) and with the focal mode of production as organic management (Fig. 8). The aforementioned differences in organic grower decision making from conventional growers illustrate the dominant paradigm that organic growing resists. Organic growers routinely described this resistance to currently conventional norms in agriculture as linked to choices that allow them autonomy from industrial agriculture’s empire (Fig. 8). For example, organic growers prioritize autonomous pest control using natural enemies over use of industrial agrochemicals, often choose to produce their own natural products when additional pest control is needed, sell to consumers directly to avoid oppressive aesthetic standards and receive a fair price, collaborate with neighbors to share equipment, and seek information outside of empire to avoid ulterior motives in the advice they receive (Fig. 8). In an example that highlights this convergence of social capital and attitudes of resistance to gain autonomy, an organic apple farmer in Michigan explained that:

> “hot pepper oil at that time, in a 2 ½ gallon jug was about $250, now what I’ve ended up doing is I grow my own hot peppers and I have a friend who has a licensed [organic] kitchen and so I make my own hot pepper oil from peppers I grow myself so it’s a lot more economical and the good thing about the hot pepper is it doesn’t necessarily kill the bugs, it does kill off a few, but it’s an extremely good deterrent, because with their little insect senses, they do not find your crop appealing to them, and they just fly over it and move on.”

This autonomy from empire is then directly related to both social and ecological resilience conferred by predatory insects, like ants, and by robust social capital and relative independence from the pressures of empire to sell a cheap but perfect product all while investing in expensive agrochemical inputs (Fig. 8).

Regime shifts

The consistent divergence in organic and conventional growers' expression of the above themes can be interpreted as a system with two alternative stable states with path dependency (Vandermeer and Perfecto 2012). This hysteresis is suggested by lack of intermediate responses both in interviews and ecological data and the presence of two highly distinct management modes under the same socio-political and environmental conditions (Fig. 9). This potential hysteresis has implications for both policy interventions and ecological predictions of global warming's effects on our food systems. Based on the results of this study alone, it is unclear whether climate change, and the associated shifts in both environmental variables and socio-political systems, will shift farms toward the organic or conventional stable state. All growers expressed concerns around future adaptive capacity to insect pests and these serve as potential thresholds for regime shifts between stable states (Fig. 9). Organic growers primarily expressed concerns over changes in natural enemy predatory capacity while conventional growers were worried about increases in insecticide prices, rapid pest evolution of resistance to insecticides, and occasionally about loss of ecosystem services associated with bees (Fig. 9). These thresholds could also serve as intervention points addressed by policy and extension to shift conventional farming to organic certification or to support organic farms continued presence.

DISCUSSION

Surveys of ant community composition and behavior

Non target effects of pesticides on predatory arthropods

The significant, positive effects of organic management on both ant abundance and species richness suggest a lethal effect of synthetic pesticides on ants that is species specific (Fig. 2 & Fig. 3). A lethal effect of synthetic insecticides on non-target, beneficial arthropods has been broadly demonstrated in the literature and this study adds support to that body of work spanning decades (Ripper 1956, Croft 1990). In particular, these results align with evidence that insecticides are lethal to some ant species while not impacting the establishment and persistence of others, creating different community structures in organic and conventional agriculture (Perfecto 1990, Pereira et al. 2005, Sonoda 2011, Motzke 2013). The differences in ant community composition observed in this study were driven by the prevalence of *A. rudis* in certified organic orchards and the complete absence of this species in conventional orchards (Table 6). This suggests that *A. rudis* is sensitive to the synthetic insecticides used under conventional management while *P. imparis,* a species equally prevalent across management type, experiences no lethal effects from insecticides (Table 5). However, the herbicide Paraquat was used in one conventional orchard and the usage of this product did have a significant negative impact on *P. imparis* abundance (Table 5).

Species-specific nesting strategy may explain these trends. *P. imparis* nests are typically located deep in the soil while *A. rudis* nests are shallower in soil or even located above the soil under cover objects like rocks or logs (Lynch et al. 1980). This difference in nests may expose *A. rudis* colonies more directly to spray of insecticides and may explain why direct ground spraying, as in the case of herbicides, is required to cause mortality and decreases in *P. imparis* colonies. Direct mortality based on herbicide exposure has been shown in laboratory studies of common arthropod pests and predators in Korean apple orchards and herbicides impacted insect biodiversity in peach orchards more negatively than even insecticides (Ahn et al. 2001, Sonoda et al. 2011). It is also possible that *A. rudis* and *P. imparis* abundance was decreased based on herbicide use due to associated decreases in cover and food associated with decreased vegetative complexity (Altieri et al. 1977, Bendixen et al. 1981). In fact, in several studies ranging from long leaf pine plantations to wheat fields to apple orchards, ant community composition and foraging behavior has been shown to be more impacted by management of ground vegetation than by chemical used (Altieri and Schmidt 1984, Yadim and Edwards 2002, Badji et al. 2006, Minarro et al. 2009, Greenslade et al. 2010, Sells et al. 2015).

Sub-lethal effects of pesticides, such as changes in behavior, on non-target insects have also been shown in wide ranging works (Desneux et al. 2007). Although the proportion of larval baits removed was significantly higher in organic orchards, this increased removal was based on *A. rudis* presence and did not correspond to significantly more larval discovery or more efficient removal behavior (number of larva removed/number of baits occupied) of *P. imparis* in organic as compared to conventional orchards (Table 12 & Table 14). Therefore, sub-lethal effects of synthetic insecticides or herbicides on foraging/predatory behavior of particular species were not demonstrated in this study. However, sub-lethal effects of synthetic pesticides may offer an alterative explanation for *A. rudis* absence in conventional orchards if, for example, this species instead suffered reproductive damage rather than direct mortality as posited above (Desneaux et al. 2007).

Ant potential as a biological control

Prenolepis imparis and *A. rudis* removal of larva in this study confirm ant potential as a form of biological control. This aligns with many past studies that have routinely demonstrated robust ant control of insect pests (Perfecto and Castineiras 1998; Philpott and Armbrecht 2006, Morris et al. 2015, Offenberg 2015). In organic orchards, ants removed up to 80% of larval baits, suggesting that the differences in community composition associated with organic and conventional management do lead to important functional differences (Fig. 2a). The significant increase in larval remove in organic orchards suggests that this type of chemical management did consistently confer resilience to the simulated outbreaks. Importantly, larva used in this study were dead and therefore do not perfectly represent predation on living pests. However, it is reasonable to link ant removal of the dead wax worm larva to ant predation on key apple pests and meaningful orchard biocontrol, given the life cycles of these main pests. Michigan State University's extension service cites coddling moth and plum circulio as the two most economically significant insect pests in apple orchards, with resistance to synthetic pesticides becoming increasingly problematic in the former ("Crop Profile for Apples in Michigan" 2004). Both coddling moth and plum circulio spend their larval stage in the fruit but then must enter the soil of the orchard floor to pupate ("Ecological Management of Key Arthropod Pests in Northeast Apple Orchards" 2015). Populations, particularly as the climate has warmed, can undergo multiple life cycles per season. Importantly, ants have been observed predating these living larva (Lacey and Unruh 2005, Jenkins et al. 2006). Therefore, ant predation on the larval stage of these pests could confer resilience both within and between growing seasons.

Robustness of this control may vary seasonally, with ant presence, species richness, and removal of larva all significantly lower in June than in July and August samplings (Fig. 2b, Fig. 3b, Fig. 4b). This variation is likely due to cooler temperatures in June, and the proceeding months, that can reduce foraging activity of ant species including *A. rudis* (Lynch et al. 1980). Relatively low ant presence at baits in June could also be attributable to coincidence with management activities early in the growing season (Braman and Pendley 1993). Resilience of apple orchards to pest outbreaks will additionally depend on presence and activity of other predatory or parasitoid insects, particularly because ants were not found to forage on the trees in this study and in other surveys of ants in Californian apple orchards (Altieri and Schmidt 1984). There is mixed evidence on the impact of organic and conventional management on these additional natural enemies and the effects may not be easily generalizable to other species beyond ants. For example, organic management has been shown to have inconsistent effects on parasitoid wasp and carabid beetle richness and abundance but has demonstrably increased hunting spider abundance and activity in studies in the UK (Mates et al. 2012, Feber et al. 2015).

Grower Interviews

Farmers' decision-making promotes positive feedbacks between resilience and management

Grower interviews consistently demonstrated that not only does broad chemical management impact the nature and degree of an orchard's social resilience, grower agency and decision-making processes also create positive feedback loops that link experienced resilience back to management. This is because, in the face of new or worsening insect damage, all growers described drawing upon their perceptions of ecological resilience and their sources of social resilience to make management choices and address the issue. Specifically, grower decisions integrate perception of insects (the main source of ecological resilience to pests on a farm), sources of knowledge/information (the main source of social resilience to pests on a farm as told by growers themselves), and personal values to the reinforcement of their initial chemical management paradigm (Fig. 1). The ecological results from this study illustrate that this management paradigm, conventional or organic, in turn continually links grower decisions to ecological consequences that reinforce their perceptions. The consistent differences in organic and conventional growers' interactions with their own resilience, namely how they perceive insects on their orchard and the sources of social capital they draw on when experiencing issues with pests, and the positive feedback loops this creates, confirm the initial conceptual model (Fig. 1). This feedback demonstrates a dynamism between social-ecological resilience and management that expands on the feedbacks between ecosystem and management noted by Folke and confirms models of behavior used in rural sociology, both centering around knowledge and values (Burton 2004, Folke 2006, Lamarque et al. 2014). Though these the existence of these feedbacks, and the stability they confer, are consistent across both management types, it is important to note that stability and resilience are not the same concept. While conventional farmer's are very stable in their preference for conventional management techniques, namely use of broad-spectrum, potent chemistries to adapt to pest outbreaks, this stability was found to actually degrade sources of resilience needed to maintain function in a volatile, dynamic world.

Organic farmer's in the US as part of the "new peasantry"

The way organic apple growers in across the Midwest expressed their perceptions and personal values, described their use of social capital to adapt to insect pests, and the social-ecological resilience indicated by both the quantitative and qualitative results of this study align closely with van der Ploeg's interpretation of the new peasantry in ways that were not anticipated. Namely, organic growers illustrated relationships between van der Ploeg's concepts of resistance, autonomy, and sustainability offer new ways to conceptualize organic farming and rural sociology in general in the United States (Fig. 8)(van der Ploeg 2007). First, qualitative data from organic growers reveals the ways in which social capital can actually lead to autonomy and produce resilience and confirm that reliance and reciprocity at one scale directly facilitate independence at other scales (Ostrom and Ahn 2003). Additionally, interpretation of organic growing through van der Ploeg's framework demonstrates that resistance of dominant, institutionalized paradigms can be directly linked to increased resilience, ecologically and socially, and that, as empires go through crises, resistance may be important for survival of our growers and our food systems. Lastly, van der Ploeg's use of sustainability as the third element of this framework highlights the ability to use indicators of resilience as a functional means of addressing concepts of sustainability in social-ecological systems (Folke 2006, van der Ploeg 2007). This indicates that it would be useful and appropriate to include resilience as a key sustainability metric in future iterations of comprehensive reviews that aim to compare organic and conventional cropping systems (Reganold and Wachter 2016, Seufert and Ramankutty 2017).

Social capital as central to social resilience

When describing their past experiences adapting to insect pest outbreaks, all growers referred exclusively to relying on social capital, but the sources of this type of capital were consistently, markedly different between the certified organic and conventional growers (Fig. 7). Organic growers rely on "bonding and networking" types of social capital while conventional growers rely on institutional support (Fig. 7)(Adger 2003). Perhaps more importantly, not only were sources of social capital different, organic and conventional growers consistently characterized these relationships with different qualities (Ostrom and Ahn 2003). Importantly, organic growers used terms of trust and reciprocity to describe their relationship to extension agents, consumers, and other growers. These are qualities emphasized in social capital theory as indicative of resilience (Ostrom and Ahn 2003). Conventional growers typically used terms denoting caution or wariness when describing the information they receive from their sources of social capital and on several occasions spoke of competition with other growers and secrecy from their neighbors.

Despite this lack of trust, and though not necessarily a characteristic of strong social resilience, it is probable that the institutional support conventional growers receive in the form of access to potent insecticides has allowed them to adapt to herbivore damage exceptionally well over the past century (Cooper and Dobson 2007). However, in the case of apple growers in the Midwest, the results of this study suggests that this type of resilience may come at the expense of robust social networks and ecosystem services that provide adaptive capacity to future scenarios. In fact, the positive feedback between perceptions/experiences and future management continuously degrades resilience in conventional apple farming such that this management syndrome's stability ultimately leads to vulnerability. Such loss of resilience in the pursuit of stability has been noted by Holling himself in his 1973 of the concepts in which he explains that: "the very approach, therefore, that assures a stable maximum sustained yield of a renewable resource might so change these determinis-tic conditions that the resilience is lost or reduced so that a chance and rare event that previously could be absorbed can trigger a sudden dramatic change and loss of structural integrity of the system" (Holling 1973). As public perceptions of the food system continue to deepen and shift, access to labor decreases with isolationist policies, agrochemical input prices increase, and pest resistance rapidly evolves with agrochemical over-use, conventional apple farmer's in Michigan will have few social and ecological options available for adaptation and innovation. Therefore, and expanding on the idea of diversity as an insurance policy, this tradeoff of synthetic chemicals for social capital and arthropod natural enemies is a poor one and likely to only function short term (Folke et al. 2004). In fact, it is possible that this tradeoff is reflected in recent apple production trends, with total acres of apple production in the US decreasing by 25% since peaks in 1990 but acreage of organic apple production doubling since 1997 (Slattery et al. 2011).

Economic resilience is also an important component of social resilience, and one largely not addressed by this work (Ostrom and Ahn 2003). Economic resilience to pests via diverse farm-related income flows was never directly mentioned in interviews but all growers indirectly demonstrated this strategy by engaging in some kind of agrotourism or processing. This did not differ by management type but is only one component of grower financial capacity to adapt to pest damage and does not adequately describe grower ability to remain in business following extreme pest damage. This component of resilience should be added to the model in the future to better understand the ubiquity of the positive effects of organic certification on profitability and to map the relationships between management, social capital, financial capital, ecology, and resilience to insect pests.

LITERATURE CITED

Adger, W.N. 2003. Social capital, collective action, and adaptation to climate change. *Economic Geography* 79(4):387-404.

Adger, W.N. 2006. Vulnerability. *Global Environmental Change* 16:268–281.

Ahn, Y., Y. Kim, and J. Yoo. 2001. Toxicity of the herbicide glufosinate-ammonium to predatory insects and mites of Tetranychus urticae (Acari: Tetranychidae) under laboratory conditions. *Journal of Economic Entomology* 94(1):157-161.

Altieri, M., and C. Nicholls. 2004. *Biodiversity and pest management in agroecosystems*. CRC Press.

Altieri, M., and L. L. Schmidt. 1984. Abundance patterns and foraging activity of ant communities in abandoned, organic, and commercial apple orchards in northern California. *Agriculture, Ecosystems and Environment* 11: 341-352.

Badji, C.A., R.N. Guedes, A.S. Correa, G. H. Ferreira, and I. C. Nascimento. 2006. Deltamethrin-induced impact on ant assemblages in tropical maize fields under conventional and no-tillage cultivation. *Sociobiology* 48(3): 701-715.

Bengtsson, J., J. Ahnström, and A. Weibull. 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of applied ecology* 42(2): 261-269.

Bianchi, F. J., Booij, C. J. H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society of London B: Biological Sciences*, *273*(1595), 1715-1727.

Braman, S.K., and A.F. Pendley. 1993. Relative and seasonal abundance of beneficial arthropods in centipede grass as influenced by management practices. *Journal of Economic Entomology* 86(2): 494-504.

Brown, E.D., and B.K. Williams. 2015. Resilience and Resource Management. *Environmental Management* DOI 10.1007/s00267-015-0582-1.

Burton, R.J.F. 2004. Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective. *Jounral of Rural Studies* 20:359-371.

Cooper, J., and H. Dobson. 2007. The benefits of pesticides to mankind and the environment. *Crop Protection* 26(9): 1337–1348.

Cote, M., and A.J. Nightingale. 2012. Resilience thinking meets social theory: situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4): 475–489.

Croft BA. 1990. *Arthropod Biological Control Agents and Pesticides*. Wiley: New York, NY.

"Crop profile for apples in Michigan." 2005. Michigan State University Extension Service: Lansing, MI.

Crowder, D.W., T. D. Northfield, M. R. Strand, and W. E. Snyder. 2010. Organic agriculture promotes evenness and natural pest control. *Nature* 466:109-113.

Darnhofer1, I., J. Fairweather, and H. Moller. 2010. Assessing a farm's sustainability: insights from resilience thinking. *International Journal of Agricultural Sustainability* 8(3): 186-198.

Desneux, N., A. Decourtye, and J. Delpuech. 2007. The sublethal effects of pesticides on beneficial arthropods. *Annu. Rev. Entomol*. 52:81-106.

"Ecological Management of Key Arthropod Pests in Northeast Apple Orchards." 2015. Sustainable Agriculture Research & Education Technical Bulletin.

Fantke, P. & Jolliet, O. 2016. Life cycle human health impacts of 875 pesticides. *Int J Life Cycle Assess* 21(5):722-733.

Feber, R.E., P. J. Johnson, J. R. Bell, D. E. Chamberlain, L. G. Firbank, R. J. Fuller, W. Manley, F. Mathews, L. R. Norton, M. Townsend, and D. W. Macdonald. 2015. Organic farming: biodiversity impacts can depend on dispersal characteristics and landscape context. *PLoS ONE* 10(8): e0135921.

Fiskel, J. 2006. Sustainability and resilience: toward a systems approach. *Sustainability: Science, Practice, & Policy* 2(2): 14-21.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C.S. Holling. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst*. 35:557–581.

Folke, C. 2006. Resilience: the emergence of a perspective for social-ecological systems analsys.

Greenslade, P.J.M, I. A. Reid, and I. J. Packer. 2010. Herbicides have negligible effects on ants and springtails in an Australian wheat field. *Soil Biology & Biochemistry* 42:1172-1175.

Himanen, S. J., P. Rikkonen, and H. Kahiluoto. 2016. Codesigning a resilient food system. *Ecology and Society* 21(4):41. https://doi.org/10.5751/ES-08878-210441

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1-23.

IPCC, 2014. *Climate Change 2014 Synthesis Report.*

Jenkins, D.A., R. F. Mizell, D. Shapiro-Ilan, T. Cottrell, and D. Horton. 2006. Invertebrate predators and parasitoids of plum circulio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), in Georgia and Florida. *Florida Entomologist* 89(4):435-440.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walker. 2006. Resilience and regime shifts: assessing cascading effects. *Ecology and Society* 11(1): 20.

Kohlbacher, F. 2006. The use of qualitative content analysis in case study research. *Forum: Qualitative Social Research* 7(1): 21.

Lacey, L.A., and T.R. Unruh. 2005. Biological control of codling moth (*Cydia pomonella)* and its role in integrated pest management, with emphasis on entomopathogens. *Vedalia* 12(1):33-60.

Lamarque, P., P. Meyfroldt, B. Nettier, and S. Lavorel. 2014. How ecosystem services knowledge and values influence farmers' decision making. *PloS One* 9(9):1-16.

Lin, B.B., I. Perfecto, and J. Vandermeer. 2008. Synergies between agricultural intensification and climate change could create surprising vulnerabilities for crops. *BioScience* 58(9):847-854.

Lin, B.B. 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience* 61(3):183-193.

Lynch, J.F., E.C. Balinsky, and S.G. Vail. 1980. Foraging patterns of three sympatric forest ant species, *Prenolepis imparis, Paratrechina melanderi,* and *Aphaenogaster rudis* (Hymenoptera: Formicidae). *Ecological Entomology* 5:353-371.

Mates, S., I. Perfecto, and C. Badgley. 2012. Parasitoid wasp diversity in apple orchards along a pest-management gradient. *Agriculture Ecosystems & Environment* 156:82–88.

McGinnis, M. D., and E. Ostrom. 2014. Social-ecological system framework: initial changes and continuing challenges. *Ecology and Society* 19(2): 30.

Miñarro, M, X. Espadaler , V. X. Melero, and V. Suárez-Álvarez. 2009. Organic versus conventional management in an apple orchard: effects of fertilization and tree-row management on ground-dwelling predaceous arthropods. *Agricultural and Forest Entomology* 11:133–142.

Morris, J. R., Vandermeer, J., & Perfecto, I. (2015). A keystone ant species provides robust biological control of the coffee berry borer under varying pest densities. *PloS one*, *10*(11), e0142850.

Motzke, I., T. Tscharntke, N. S. Sodhi, A. Klein, and T. C. Wanger. 2013. Ant seed predation, pesticide applications and farmers' income from tropical multi-cropping gardens. *Agricultural and Forest Entomology* 15: 245–254.

Nelson, D.R., W.N. Adger, and K. Brown. 2007. Adaptation to environmental change: contributions of a resilience framework. *Annu. Rev. Environ. Resour.* 32:395–419.

Offenberg, J. 2015. Ants as tools in sustainable agriculture. *Journal of Applied Ecology* 52: 1197–1205.

Ostrom, E. and T.K. Ahn. 2003. *Foundations of social capital.* Edward Elgar Publishing Limited: Cheltenham, U.K.

Pereira, J.L, A. A. da Silva, M. C. PicanÇco, E.C. de Barros, and A. Jakelaitis. 2005. Effects of herbicide and insecticide interaction on soil entomofauna under maize crop. *Journal of Environmental Science and Health* 40(1): 45-54.

Perfecto, I. 1990. Indirect and direct effects in a tropical agroecosystem: the maize-pest-ant system in Nicaragua. *Ecology* 71(6): 2125-2134.

Perfecto, I., and A. Castineiras. 1998. Deployment of the predaceous ants and their conservation in agroecosystems. *Conservation biological control*: 269-289.

Philpott, S. M., and I. Armbrecht. 2006. Biodiversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. *Ecological Entomology*, *31*(4): 369-377.

Pingali, P., L. Alinovi, and J. Sutton. 2005. Food security in complex emergencies: enhancing food systems resilience. *Disasters* 29(51): S5-S24.

Pimentel, D. 2005. Environmental and economic costs of the application of pesticides primarily in the United States. *Environment, Development and Sustainability* 7: 229–252.

Ponisio, L. C., L.K. M'Gonigle, K. C. Mace, J. Palomino, P. de Valpine, and C. Kremen (2015). Diversification practices reduce organic to conventional yield gap. *Proc. R. Soc. B* 282(1799):

Pretty, J. 2008. Agricultural sustainability: concepts, principles and evidence. *Phil. Trans. R. Soc. B* 363:447–465.

Reganold, J.P., and J.M Wachter. 2016. Organic agriculture in the twenty-first century. *Nature Plants* 2:1-8.

Ripper, W.E. 1956. Effect of pesticides on balance of arthropod populations. *Annu. Rev. Entomol*. 1:403-438.

Sells, S.M., D.W. Held, S. F Enloe, N.J. Loewenstein, and L.G. Eckhardt. 2015. Impact of cogongrass management strategies on generalist predators in cogongrass-infested longleaf pine plantations. *Pest Manag Sci* 71: 478–484.

Seufert, V., and N. Ramankutty. Many shades of gray—the context-dependent performance of organic agriculture. *Sci. Adv.* 3: e1602638.

Slattery, J., M. Livingston, C. Greene, and K. Klonsky. 2011. *Characteristics of conventional and organic apple production in the United States. Economic.* Research Service/USDA.

Sonoda, S., Y. Izumi, Y. Kohara, Y. Koshiyama, and H. Yoshida. 2011. Effects of pesticide practices on insect biodiversity in peach orchards. *Appl Entomol Zool* 46:335–342.

Tendall, D.M., J. Joerin, B. Kopainsky, P. Edwards, A. Shreck, Q.B. Le, P. Kruetli, M. Grant, and J. Six. 2015. Food system resilience: defining the concept. *Global Food Security* 6:17–23.

Titscher, S., M. Meyer, R. Wodak, and E. Vetter. 2002. *Methods of text and discourse analysis.* Sage, London.

Tresnik, S., and S. Parente. 2007. State of the art of integrated crop management and organic systems in Europe with particular reference to pest management. *Pesticide Action Network (PAN)*. http://www.pan-europe.info/old/Resources/Reports/Apple_production_review.pdf.

Tscharntke, T., A. M. Klein, A. Kruess, I. Steffan-Dewenter, and C. Thies. 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters* 8: 857–874.

Vandermeer, J., I. Perfecto, and S. Philpott. (2010). Ecological complexity and pest control in organic coffee production: uncovering an autonomous ecosystem service. *BioScience*, *60*(7): 527-537.

Vandermeer, J., and I. Perfecto. (2012). Syndromes of production in agriculture: prospects for social-ecological regime change. *Ecology and Society*, *17*(4).

van der Ploeg, J.D. 2008. *The new peasantries: struggles for autonomy and sustainability in an era of empire and globalization.* Earthscan: New York, NY.

van der Ploeg, J.D. 2007. *Resistance of the third kind and the construction of sustainability.* Paper presented to the ESRS Conference, 23 of August 2007, Wageningen.

Walker, B. H., L. H. Gunderson, A. P. Kinzig, C. Folke, S. R. Carpenter, and L. Schultz. 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society* 11(1): 13.

Wittman, H., Chappell, M. J., Abson, D. J., Kerr, R. B., Blesh, J., Hanspach, J., ... & Fischer, J. (2016). A social–ecological perspective on harmonizing food security and biodiversity conservation. *Regional Environmental Change*, 1-11.

Yardlm, E.N., and C. A. Edwards. 2002. Effects of weed control practices on surface-dwelling arthropod predators in tomato agroecosystems. *Phytoparasitica* 30(4):379-386.

TABLES

TABLE 1. Predictors used in GLMM building. Orchard and Transect were considered a random effect while management type, Month, Herbicide, and Soil Type were included as fixed effects.

Orchard	Transect #	Management Type	Sampling Month	Herbicide	Soil Type
1	1-10	Organic	June, July, August	None	Sandy loam
2	1-4	Organic	June, July, August	None	Clay loam
3	1-4	Conventional	June, July, August	None	Clay loam
4	1-4	Conventional	June, July, August	Paraquat	Sandy loam

Ant Abundance

TABLE 2. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting ant presence at tuna/cookie baits during summer orchard samplings. Models predict ant presence at baits as a binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null	1334.5	
Management Type	1330.8	-3.7
Month	1282.9	-51.6
Soil Type	1333.8	-0.7
Herbicide	1327.7	-6.8
Month+SoilType+Herbicide	1279.7	-54.8
Treatment + Month +SoilType	1276.9	-57.6
Treatment + Month + Herbicide	1272.5	-62
Treatment + Month +SoilType + Herbicide*	1269.1	-65.4

TABLE 3. Effect of GLMM predictors on ant presence at tuna/cookie baits. Statistically significant results ($p<0.05$) are denoted by an asterisk. Beta coefficients represent the relative size and direction of the effect of each predictor on ant abundance. P-values are based on asymptotic Wald tests.

Model Predictor	**β**	2.5% CI	97.5% CI	*z* score	p-value
Management Type (Organic)	4.37234728	2.960468275	6.517200418	7.546	4.50E-14*
Month (June)	-2.395279678	-3.349473924	-1.721060551	-5.146	2.66E-07*
Herbicide (Paraquat)	-4.170350145	-8.404990756	-2.19267772	-4.174	2.99E-05*
Soil Type (Sandy Loam)	-1.979610286	-3.249983027	-1.121346954	-2.553	1.07E-02*

TABLE 4. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting *P. imparis* presence at tuna/cookie baits during summer orchard samplings. Models predict ant presence at baits as a binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null	1487.9	
Management Type	1488.8	.9
Month	1465.5	-22.4
Soil Type	1485.7	-2.2
Herbicide	1480	-7.9
Month+SoilType+Herbicide	1453.5	-34.4
Management Type + Month +SoilType	1461.1	-26.8
Management Type + Month + Herbicide	1459.6	-28.3
Management Type + Month +SoilType + Herbicide*	1453	-34.9

TABLE 5. Effect of GLMM predictors on *P. imparis* presence at tuna/cookie baits at apple orchards. Statistically significant results ($p<0.05$) are denoted by an asterisk. Beta coefficients represent the relative size and direction of the effect of each predictor on ant abundance. P-values are based on asymptotic Wald tests.

Model Predictor	β	2.5% CI	97.5% CI	*z* score	p-value
Management Type (Organic)	1.303300639	-1.068867846	0.5974952	1.584	0.11325
Month (June)	-1.784788641	-2.429386412	-1.314623615	1.227	2.16E-04
Herbicide (Paraquat)	-4.048311983	-6.984077044	-1.95859504	-4.855	1.20E-06
Soil Type (Sandy Loam)	-1.944296082	-3.640314431	-1.369083174	-3.297	9.76E-04

Ant Richness

TABLE 6. Ant species sampled at each study site during summer data collection.

Orchard	Treatment	*P. imparis*	*A. rudis*	*M. obscura*	*C. Pennsylvanicus*
1	Organic	✓	✓	✓	✓
2	Organic	✓	✓		
3	Conventional	✓			
4	Conventional	✓			

TABLE 7. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting ant species richness per transect at tuna/cookie baits during summer orchard samplings. Models predict ant species richness per transect as a negative binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null	148.5	
Management Type	144.2	-4.3
Month	146.6	-1.9
Treatment + Month*	142.3	-6.2

TABLE 8. Effect of GLMM predictors on ant species richness per transect at tuna/cookie baits. Statistically significant results ($p<0.05$) are denoted by an asterisk. Beta coefficients represent the relative size and direction of the effect of each predictor on ant species richness. P-values are based on asymptotic Wald tests.

Model Predictor	**β**	2.5% CI	97.5% CI	*z* score	p-value
Management Type (Organic)	2.111080707	1.189828525	3.745723653	2.554	1.06E-02
Month (June)	-1.842088533	-3.227957228	-1.051250471	-2.135	3.28E-02

Predation

TABLE 9. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting ant removal of larval baits during summer orchard samplings. Models predict ant removal of larva as a binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null	1048.1	
Management Type	1046.8	-1.3
Month	901.9	-146.2
Management Type + Month	898.3	-149.8

TABLE 10. Effect of GLMM predictors on proportion of larva removed by ants. Statistically significant results ($p<0.05$) are denoted by an asterisk. Beta coefficients represent the relative size and direction of the effect of each predictor on ant species richness. P-values are based on asymptotic Wald tests.

Model Predictor	**β**	2.5% CI	97.5% CI	*z* score	p-value
Management Type (Organic)	45.67266596	3.04025198	1219.599982	3.474	0.000512
Month (July)	2.134857714	1.478409577	3.101180359	4.025	5.71E-05
Month (June)	-6.166922938	-9.88271034	-3.937648824	-7.774	7.63E-15

TABLE 11. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting efficiency of ant removal of larval baits (removal/presence in each transect) during summer orchard samplings. Models predict ant removal of larva as a negative binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null*	100.7	
Species	102.6	1.9
Month	104.5	3.8
Species + Month	106.4	5.7

TABLE 12. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting efficiency of *P. imparis* removal of larval baits (removal/presence in each transect) during summer orchard samplings. Models predict ant removal of larva as a negative binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null*	57.4	
Management Type	60	2.6
Month	60.7	3.3
Management Type + Month	61.6	4.2

TABLE 13. Akaike information criterion (AIC) table for generalized linear mixed models (GLMM) predicting *P.imparis* discovery of larval baits during summer orchard samplings. Models predict ant presence at larva as a binomial distribution using a logit function. The null model includes random effects only. Lower AIC scores and greater differences from the null indicate better model fit to the data and the best model is denoted by an asterisk.

Model Predictor	AIC	Δ AIC from Null
Null	786	
Management Type	786.5	0.5
Month	786.4	0.4
Management Type + Month*	768.8	-17.2

TABLE 14. Effect of GLMM predictors on *P. imparis* discovery of larva baits at apple orchards. Statistically significant results ($p<0.05$) are denoted by an asterisk. Beta coefficients represent the relative size and direction of the effect of each predictor on ant abundance. P-values are based on asymptotic Wald tests.

Model Predictor	β	2.5% CI	97.5% CI	*z* score	p-value
Treatment Organic	6.501936138	-4.927490046	344.427287	1.338	0.180803
Month July	1.620281663	1.062982366	2.488949913	2.252	0.024353
Month June	-1.882310478	-3.192562801	-1.130760483	-2.425	0.015297

Grower Interviews

TABLE 15. Summary of the relationship between management category and various key themes expressed consistently in long-form interviews with apple orchard owners/managers in the Midwest.

Theme	Organic	Conventional
Perception of insects	Pests/predators, problems/beneficials, complex & dynamic communities	Pests, problems
Values that shape pest management strategy	Primarily balancing crop protection with environmental protection, secondarily minimizing costs	Primarily economic efficiency of pest control, secondarily minimizing harm to bees
Social resilience to insect damage	Economic flexibility via product diversity and industry independent pest management Social capital including extension, grower networks, and local community	Economic flexibility via product diversity Social capital including extension and chemical distributors
Potential drivers of management regime shift	Invasives with no natural enemies, natural enemy crashes	Beekeeping/pollination services, pest evolution of resistance, increasing price of products

FIGURES

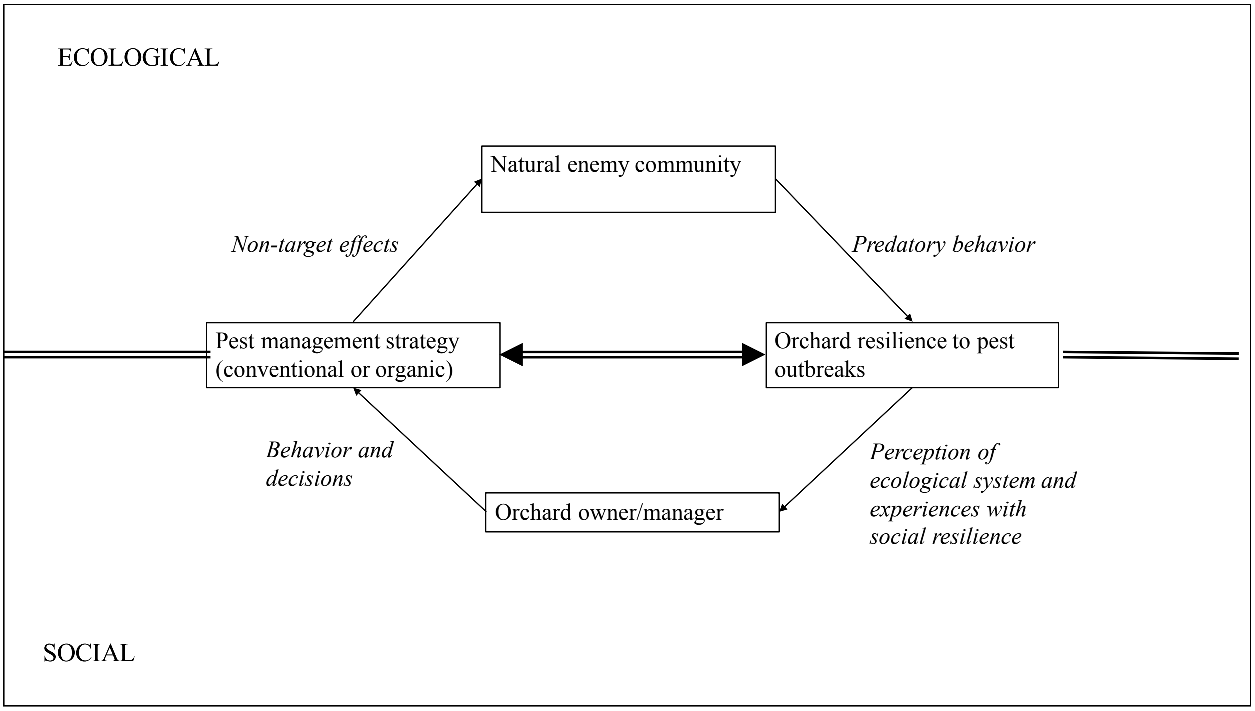

FIG. 1. Conceptual model describing the effect of organic/conventional management on resilience and feedbacks from resilience to mode of management.

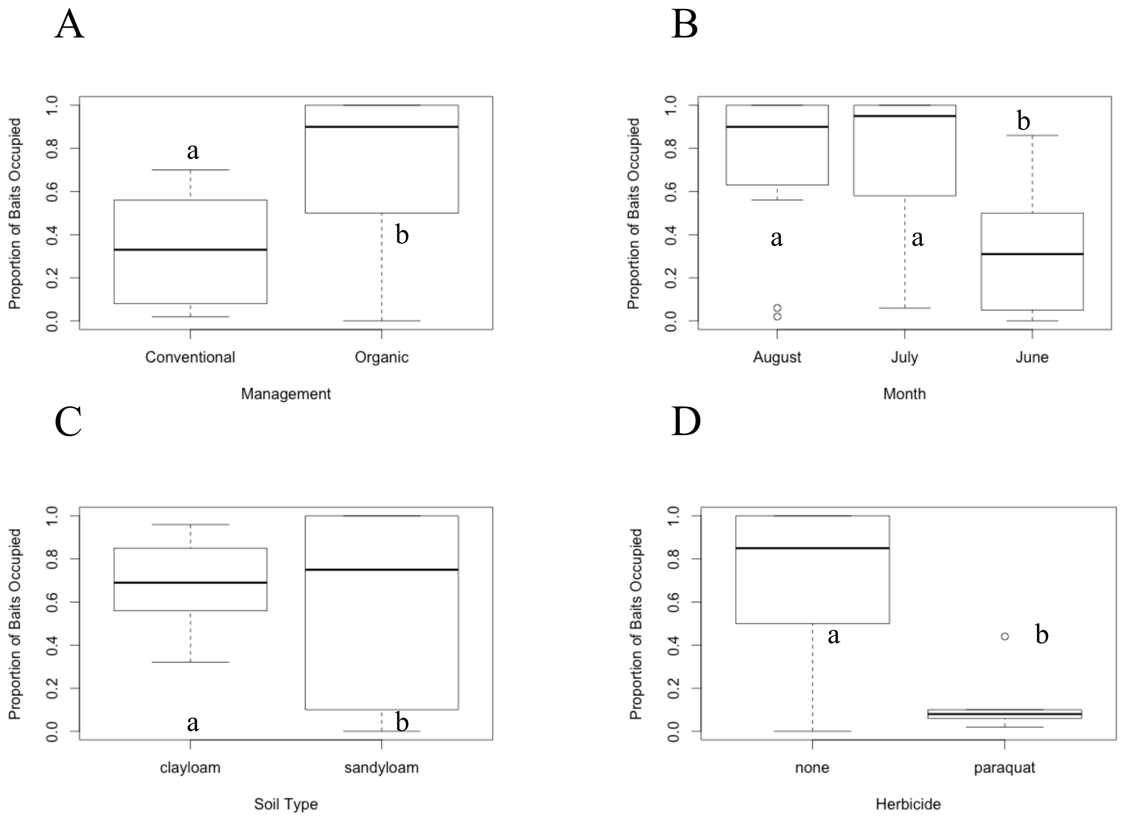

FIG. 2. Effect of management type (A), month (B), soil type (C), and herbicide usage (D) on proportion of tuna/cookie baits occupied by ants during summer apple orchard samplings. Letters denote significant differences as determined by Wald *z* tests from the GLMM detailed in Table 2. Bands the bisect boxes represent the median, the upper and lower bounds of each box represent the 25th and 75th percentiles, respectively. Whiskers denote maximum and minimum values and outliers are given as open circles.

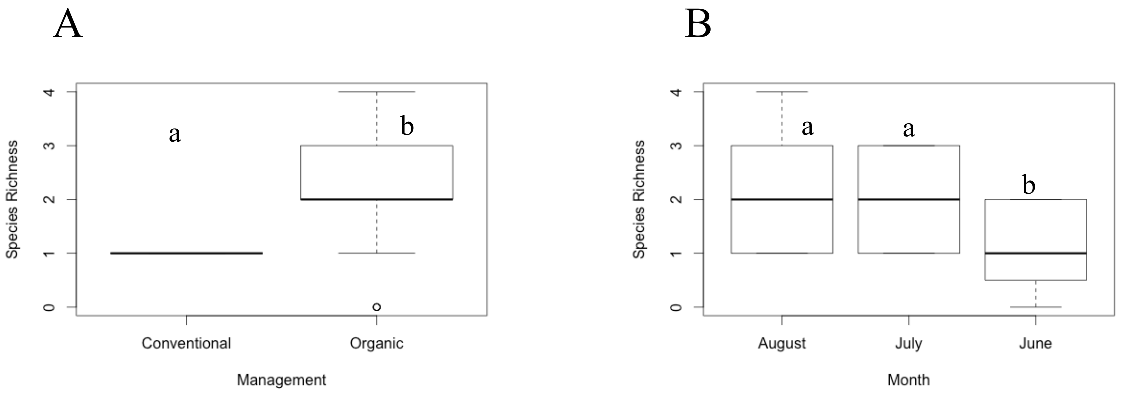

FIG. 3. Effect of management type (A) and month (B) on ant species richness per transect during summer apple orchard samplings. Letters denote significant differences as determined by Wald *z* tests from the GLMM detailed in Table 5. Bands the bisect boxes represent the median, the upper and lower bounds of each box represent the 25th and 75th percentiles, respectively. Whiskers denote maximum and minimum values and outliers are given as open circles.

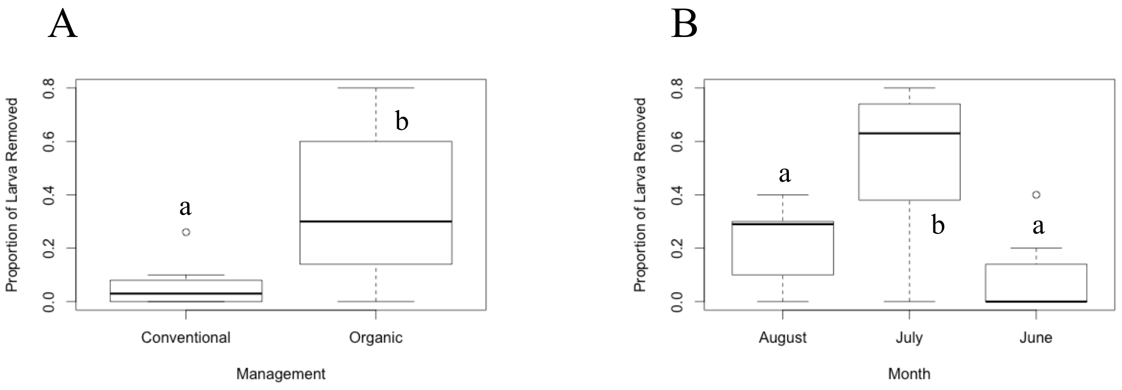

FIG. 4. Effect of management type (A) and month (B) on proportion of larva removed by ants during summer apple orchard samplings. Letters denote significant differences as determined by Wald *z* tests from the GLMM detailed in Table 7. Bands the bisect boxes represent the median, the upper and lower bounds of each box represent the 25th and 75th percentiles, respectively. Whiskers denote maximum and minimum values and outliers are given as open circles.

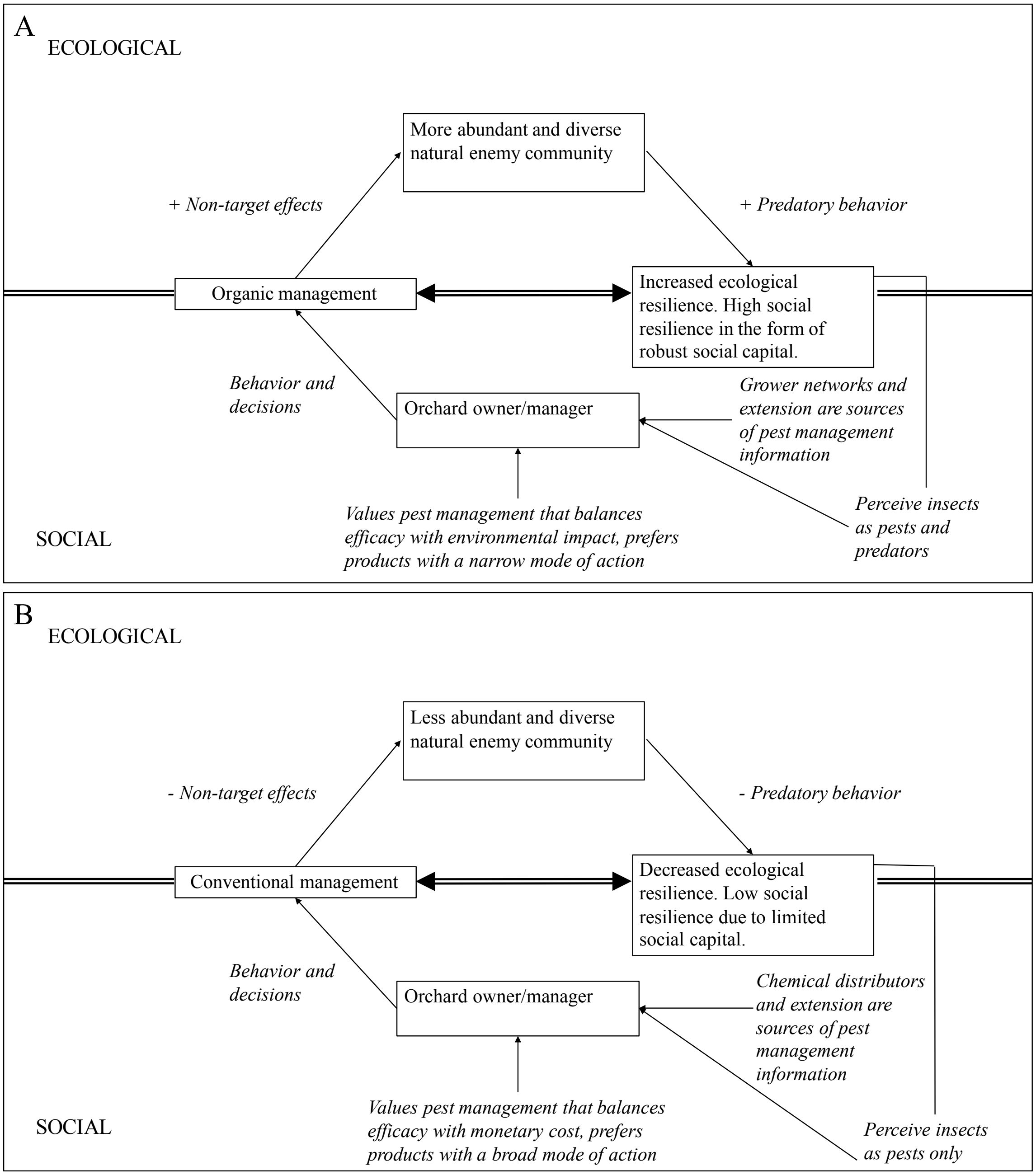

FIG. 5. Conceptual framework describing the relationship between socio-ecological resilience, personal values, and use of an organic (A) or conventional (B) pest management strategy. These relationships are consistent with the hypothesized framework, with the addition of "values" to the model. Qualitative analysis of interview data demonstrated that perception of insects, sources of pest management information, and personal values were both associated with the decision to manage organically (A) or conventionally (B) and used to determine management adaptions to pest outbreaks.

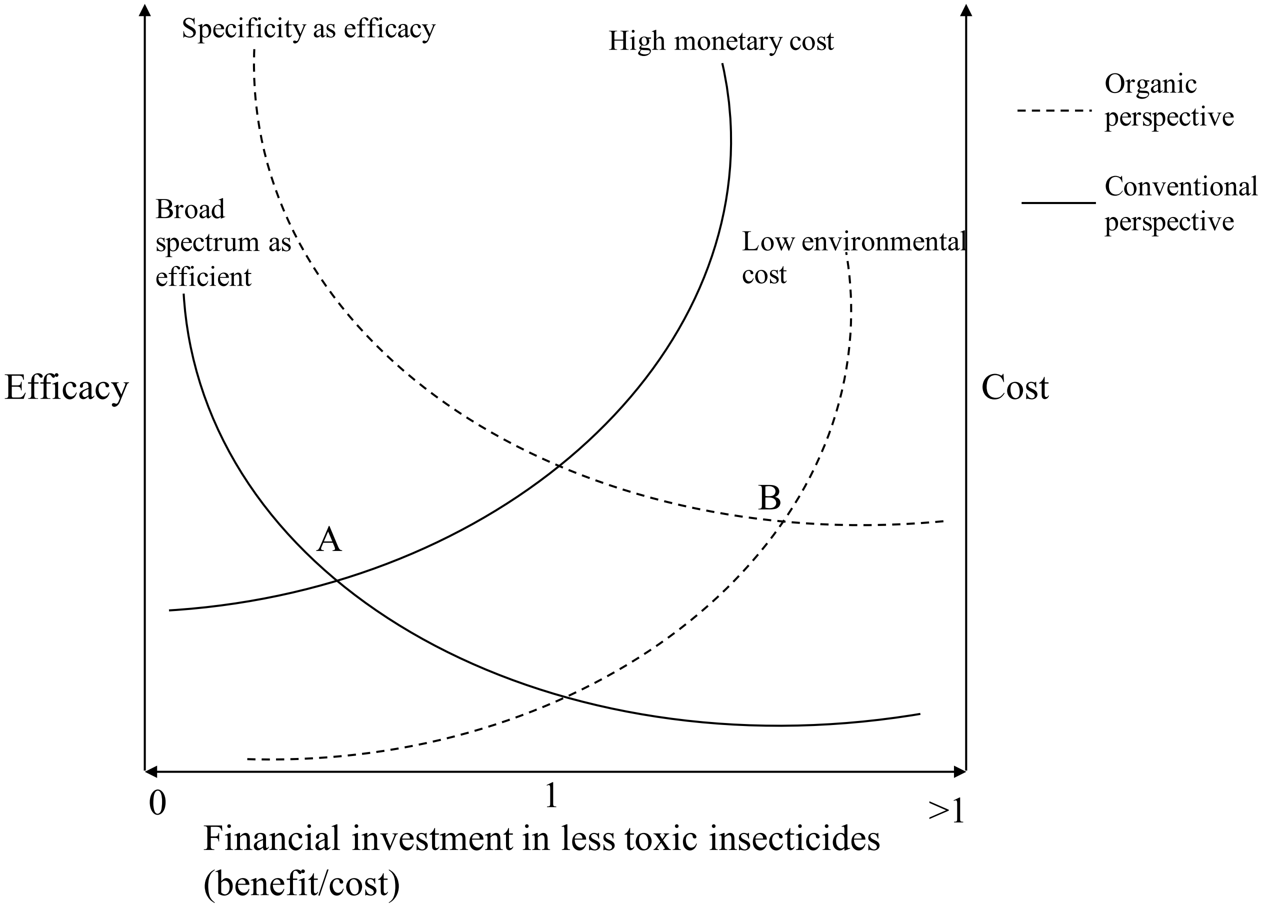

FIG. 6. Balance between insecticide efficacy and cost. Financial investments that are greater than one are beneficial and represent a sound economic decision, with benefit outweighing cost. Financial investments less than one are costly and represent a poor economic decision, with cost outweighing benefit. Given these relationships, it is possible to describe organic apple growers choice of insecticides as both economically sound (B) and economically poor (A) depending upon value-based definitions of efficacy and cost. High-efficacy as a broad mode of action and cost as price of product yield scenario A, while high-efficacy as a narrow mode of action and cost as negative environmental impacts yield B. Adapted from van der Ploeg (2013, p.40).

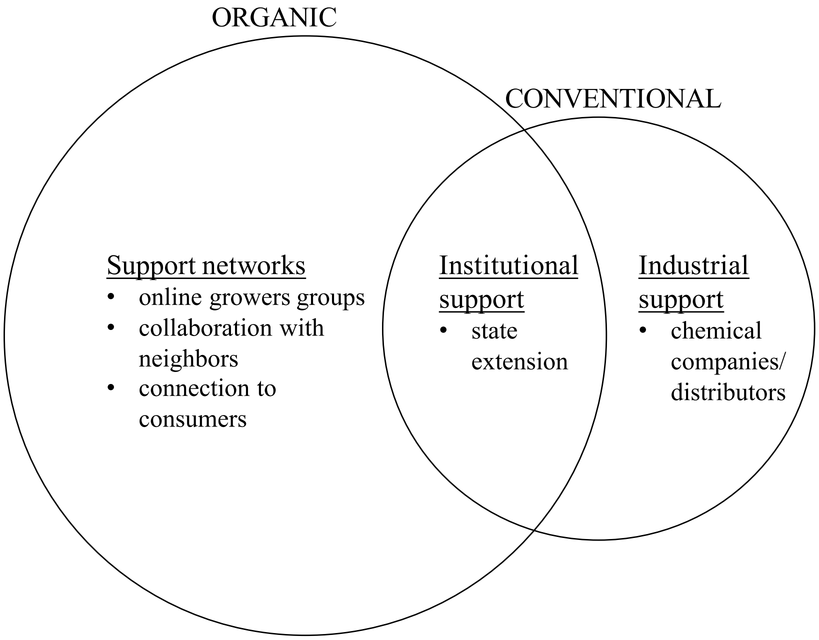

FIG. 7. Types of social capital relied upon by apple growers in the Midwest to adapt to new insect pests identified in interviews. The left circle represents sources of social capital used by organic growers and the circle on the right illustrates sources used by conventional growers. The area contained by both circles denotes source of social capital used by both organic and conventional growers. The circle representing social capital of organic growers is larger because the extent and nature of their sources are more robust than conventional growers.

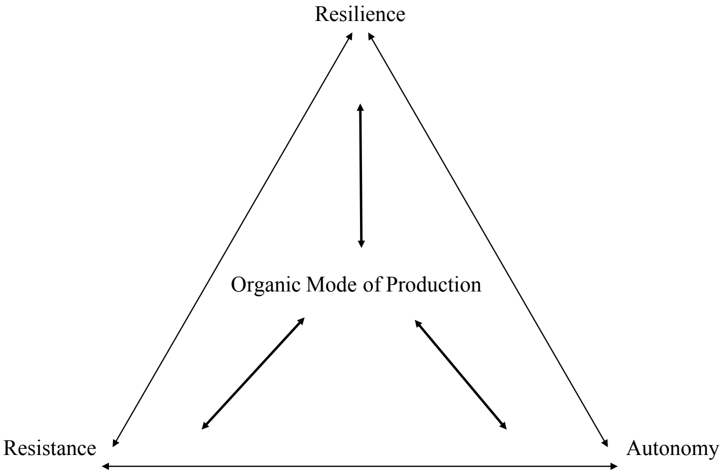

FIG. 8. Links between organic orchard resistance to empire, autonomy from empire, and resilience demonstrated by characteristics of organic apple growers in interviews. Adapted from van der Ploeg (2007).

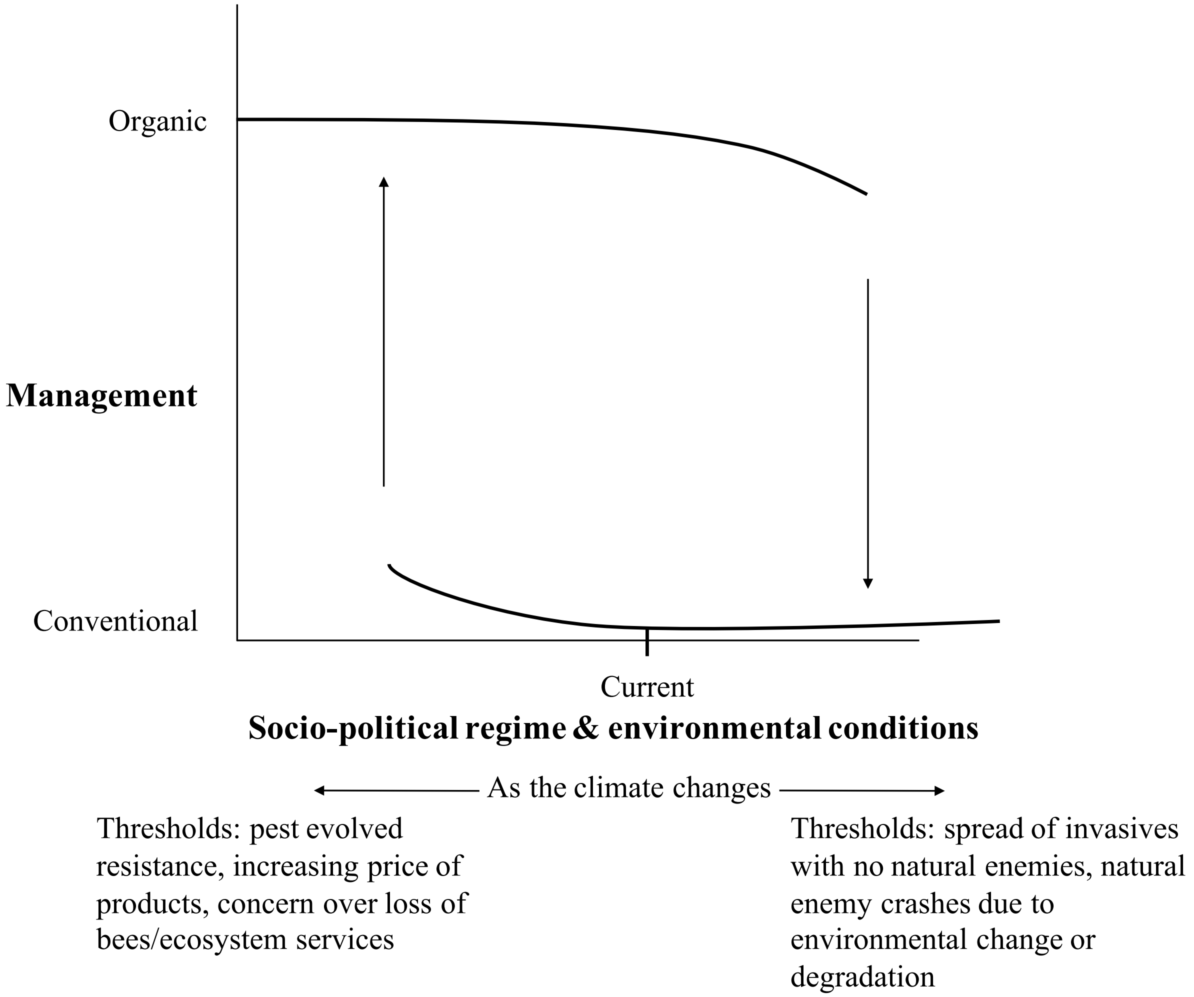

FIG. 9. Organic and conventional Midwestern apple orchard systems as alternative stable states with path dependency. Co-existence of both states (y-axis) under the same socio-political and environmental conditions (x-axis) and lack of intermediate social or ecological conditions are consistent with the hysteresis shown. Both current conditions and potential thresholds for regime shift as the climate changes identified in interviews are given on the x-axis.

Interview Guide

1. **Broadly, how would you describe the insects at this orchard?** ***(determine present opinion to assess farmer awareness and concern surrounding insects)***
    - ***Probes***
        - What kinds?
        - How many?
        - Are they predictable each season?
        - Do you notice any particular relationships between them?
2. **What I'm hearing is that *summarize general farmer view of insects*. Is that right?**
    - ***If yes, move forward***
    - ***If no, ask respondent to if they could give me some information that would help me understand, then move forward***
3. **Could you walk me through your insect management this season?** ***(background management information, connecting insect perception to insect management)***
    - ***Probes***
        - What are you using?
        - How much of it are you using?
        - When is it applied?
            - How and by whom?
        - What is the goal/priority?
        - Are there particular insects that your management strategy focuses on or is it more general?
4. **Thanks for walking me through that. Now that we've discussed how you're currently managing, I'd like to talk about your past experiences with insects. Can you give me any examples that stand out to you as times throughout your career when insects have placed your orchard at risk?** ***(understanding the types of risk and the magnitude of risk farmers associate with insects)***
    - ***Probes***
        - For example, tell me about a time insects impacted your yields or made your job particularly hard.
        - How would you characterize the damage?
        - What was the magnitude of the damage?
        - What was going through your head at the time?
        - Has your management for this pest been effective since then?

5. **For my last question, I want to learn more about your response to the past challenges presented by some insects. You mentioned that *summarize a past experience dealing with insect threats.* What process did you use to respond to the new challenge? (*if no past experience comes up, go to future tense/theoretical new pest outbreak)(understanding social resilience)*)**
    - ***Probes***
        - From the moment you noticed a new pest or increasing damage, what steps did you take?
        - What helped you respond?

  - What constrained your response?

6. **That's all of my questions. Anything you think I missed? Anyone else you recommend I talk to?**