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Research article

Grower networks support adoption of innovations in pollination management: The roles of social learning, technical learning, and personal experience

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ABSTRACT

Management decisions underpinning availability of ecosystem services and the organisms that provide them in agroecosystems, such as pollinators and pollination services, have emerged as a foremost consideration for both conservation and crop production goals. There is growing evidence that innovative management practices can support diverse pollinators and increase crop pollination. However, there is also considerable debate regarding factors that support adoption of these innovative practices. This study investigated pollination management practices and related knowledge systems in a major crop producing region of southwest Michigan in the United States, where 367 growers were surveyed to evaluate adoption of three innovative practices that are at various stages of adoption. The goals of this quantitative, social survey were to investigate grower experience with concerns and benefits associated with each practice, as well as the influence of grower networks, which are comprised of contacts that reflect potential pathways for social and technical learning. The results demonstrated that 17% of growers adopted combinations of bees (e.g. honey bees, *Apis mellifera*, with other species), representing an innovation in use by early adopters; 49% of growers adopted flowering cover crops, an innovation in use by the early majority 55% of growers retained permanent habitat for pollinators, an innovation in use by the late majority. Not all growers adopted innovative practices. We found that growers' personal experience with potential benefits and concerns related to the management practices had significant positive and negative relationships, respectively, with adoption of all three innovations. The influence of these communication links likely has different levels of importance, depending on the stage of the adoption that a practice is experiencing in the agricultural community. Social learning was positively associated with adopting the use of combinations of bees, highlighting the potentially critical roles of peer-to-peer networks and social learning in supporting early stages of adoption of innovations. Engaging with grower networks and understanding grower experience with benefits and concerns associated with innovative practices is needed to inform outreach, extension, and policy efforts designed to stimulate management innovations in agroecosystems.

1. Introduction

The Millennium Ecosystem Assessment documented a critical environmental management challenge: global patterns of degradation in ecosystem services (MEA, 2005), including the service of pollination which is needed to sustain plant diversity and crop production. The current crisis in declining pollinator populations illustrates the need to develop approaches to sustain or increase the capacity of social-ecological systems to manage critical ecosystem services (Barthel et al., 2010). Addressing this challenge is critical to agroecosystems, as flows of ecosystem services are directly affected by growers' land management practices, and how practices articulate with the surrounding landscape (Foley et al., 2005; Zhang et al., 2007). There is a growing call to investigate decision-making in coupled human natural systems in general (Díaz et al., 2011), and a pressing need to increase understanding about how

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growers manage ecosystem services needed to support crop production in farmlands.

Sustaining pollinators and pollination services is also a critical economic consideration in agricultural systems. Pollination by managed honey bees (*Apis mellifera*) supports production of food, fiber, and forage crops estimated at $15 billion (Losey and Vaughan, 2006). Unmanaged, wild bee pollination supports an additional $3 billion (Losey and Vaughan, 2006). Demand for pollination of fruits and vegetables is projected to grow as consumption of these foods increases (Aizen et al., 2009; Garibaldi et al., 2009). This trend is evident in the United States, as demonstrated by a 30% increase in bearing acres of fruits and nuts since 1980 (USDA- ERS, 2009). At the same time, the future ability of honey bees to meet crop pollination demands is uncertain (Berenbaum, 2007) as their populations are facing significant challenges, including losses from *Varroa* mites and Colony Collapse Disorder (Ellis et al., 2010; Pettis and Delaplane, 2010). Recent modeling work has emphasized that wild bee abundance is likely to be declining in the same U.S. regions where acreage of pollinator-dependent crops is increasing, suggesting the potential for future mismatches in pollination supply and demand in these regions (Koh et al., 2016).

Thus, management innovations to sustain pollinators and their services are expected to play an imperative role. Yet, few studies have investigated growers' goals, perceptions, and practices related to managing pollinators and pollination services (Isaacs et al., 2012; Garbach, 2016). As a result, there is limited understanding of the considerations that contribute to growers' decisions to adopt (or reject) management innovations such as alternative managed pollinators, or on-farm pollinator habitat. With respect to environmental policy, conserving pollinators and pollination services has emerged as a national priority in the United States (Pollinator Research Action Plan, 2015) and a foremost consideration for sustaining crop production (Losey and Vaughan, 2006) because pollination provided by bees and other insects is required for production of many of the most economically important fruit, nut, and vegetable crops (Delaplane and Mayer, 2000).

This study aims to bridge this critical knowledge and action gap by evaluating growers' pollination management practices and their related knowledge systems in a major fruit-producing region of the United States, southwest Michigan. In particular, it evaluates growers' communication networks relevant to pollination management, which describe who-speaks-with-whom (Scott, 1988), investigating which characteristics can be used to understand adoption and use of management innovations designed to support pollinators and enhance crop pollination.

Management innovations include using honey bees in combination with other pollinators, and creating, restoring, or retaining habitat with the aim of attracting and retaining diverse pollinators. The study used a quantitative survey to investigate grower knowledge systems, communication networks, and demographic characteristics to build understanding about key actors and information sources through which growers share information about pollination management. Taken together, these elements form a useful context for actualizing diffusion of innovation theory, which describes how information about innovative practices spreads throughout a community of practitioners (Rogers, 2010). The survey of specialty crop growers that produce blueberry, apple, and cherry (e.g. high-value, pollinator dependent crops) in Michigan pursued two main goals.

The first goal was to evaluate growers' pollination management practices, communication networks, and knowledge systems related to pollination management. Knowledge systems comprise the actors, organizations, and resources that link information and know-how with action (Buizer et al., 2016; Kalafatis et al., 2015). At the heart of knowledge systems are individual belief systems that encode people's knowledge and perceptions and form the proximate basis for decision-making (Lubell et al., 2014). To understand how growers manage the ecosystem service of pollination, this study explicitly investigates growers' management goals and experience with benefits and concerns of pollination management strategies. These individual considerations help shape belief systems and inform decisions (Stern et al., 1999; Lubell et al., 2014).

The second goal of the study was to investigate the characteristics of growers, their knowledge systems, and communication networks to understand patterns of adoption and use of several key management innovations: planting flowering cover crops and other floral resources, retaining areas of permanent habitat (i.e., wooded patches, old-fields, marshes) to support pollinators, and using combinations of pollinators. Flowering cover crops and other floral enhancements, such as plantings along field margins that provide nectar and pollen resources, have resulted in increased pollinator species richness and higher crop yield in Michigan blueberry production (Blaauw and Isaacs, 2014). Retaining areas of semi-natural habitat (e.g. wooded areas, meadows within the farm or at the periphery) can result in greater pollinator species richness and higher fruit set (Garibaldi et al., 2011). Additionally, combinations of different pollinator species (e.g. honey bees plus wild bees, or honey bees plus an alternative managed bee (e.g. *Osmia* spp. or *Bombus* spp.)) can be used to diversify pollination strategies. Combinations of pollinators have been shown to be more effective than honey bees alone in some crops by causing more variable flight patterns, which supported outcrossing among varietals in the same orchard (Brittain et al., 2013). All of these practices are associated with integrated crop pollination, defined as the combined use of different pollinator species, habitat augmentation, and farm management practices to provide reliable and economical crop pollination (Isaacs et al., 2012).

Existing research on innovative management in agricultural ecosystems highlights the importance of communication networks in facilitating both technical and social learning. Technical learning encompasses participating in extension and outreach programs, such as those offered through Cooperative Extension, which is a traditional means of knowledge transfer to farmers and agricultural organizations (Lubell et al., 2014). With respect to pollination of specialty crops, extension specialists are expected to play an important role of communicating research findings to growers. However, contemporary agricultural knowledge systems incorporate diverse experts, including producer associations, government agencies, non-profit organizations, and other groups that offer programs that can support technical learning (Lubell et al., 2014).

Within this body of research diffusion of innovations (Rogers, 2010) can also be supported by social learning, which refers to how growers learn from each other as well as actors with different roles and is supported by social capital (Foster and Rosenzweig, 1995) and networks among farmers and other stakeholders (Warner, 2007). Formation of communication networks can be sparked through participation in outreach and extension programs, which provide opportunities for social interaction (Lubell and Fulton, 2008). At the same time, existing networks can spread awareness about programs and provide means of encouraging participation. In particular, understanding communication patterns can provide insights into the connections that support social learning (Bandura and McClelland, 1977). Thus, we also use communication data surrounding pollination management to evaluate networks, which describe actors—growers in this case—and their contacts (people, organizations) as “nodes” that are connected by “links,” which can support information exchange and can be analyzed using social network analysis (Wasserman and Faust, 1994). Networks of growers and other experts have long been important to agriculture (Warner, 2007), and information