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Research article

Determinants of field edge habitat restoration on farms in California's Sacramento Valley

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ABSTRACT

Degradation and loss of biodiversity and ecosystem services pose major challenges in simplified agricultural landscapes. Consequently, best management practices to create or restore habitat areas on field edges and other marginal areas have received a great deal of recent attention and policy support. Despite this, remarkably little is known about how landholders (farmers and landowners) learn about field edge management practices and which factors facilitate, or hinder, adoption of field edge plantings. We surveyed 109 landholders in California's Sacramento Valley to determine drivers of adoption of field edge plantings. The results show the important influence of landholders' communication networks, which included two key roles: agencies that provide technical support and fellow landholders. The networks of landholders that adopted field edge plantings included both fellow landholders and agencies, whereas networks of non-adopters included either landholders or agencies. This pattern documents that social learning through peer-to-peer information exchange can serve as a complementary and reinforcing pathway with technical learning that is stimulated by traditional outreach and extension programs. Landholder experience with benefits and concerns associated with field edge plantings were also significant predictors of adoption. Our results suggest that technical learning, stimulated by outreach and extension, may provide critical and necessary support for broad-scale adoption of field-edge plantings, but that this alone may not be sufficient. Instead, outreach and extension efforts may need to be strategically expanded to incorporate peer-to-peer communication, which can provide critical information on benefits and concerns.

1. Introduction

Simplified agricultural landscapes maximize crop yields, but these large-scale monoculture cropping systems lead to a loss in habitat, biodiversity, and associated ecosystem services (MEA, 2005). As a result, there is wide spread concern that our farming systems have experienced a reduction or loss of critical ecosystem services and ability to sustain food production (Tilman, 1999; MEA, 2005; Foley et al., 2011; Rusch et al., 2016). Best management practices (BMPs) designed to voluntarily restore or conserve habitat on farms are emerging as a strategy to enhance biodiversity on farmlands, and have significant policy support both internationally (European Commission, 2016) and nationally through the United States Department of Agriculture (USDA), Agricultural Act of 2014, best known as the Farm Bill. The Farm Bill includes support for a number of BMPs through the Conservation Stewardship Program, State Acres for Wildlife, and the Environmental Quality Incentives Program (USDA, 2015). These programs aim to inform and engage private landholders (farmers and landowners) with technical and financial support, using an approach that bridges private interests of landholders and the public benefits of on-farm conservation practices.

Field edge habitat plantings have received a great deal of attention as a BMP that can enhance biodiversity and ecosystem services in simplified agricultural landscapes (NRCS, 2010; USDA, 2015). These strips of permanent vegetation are planted along field edges, farm borders, and marginal areas; thus, no cropland is taken out of production. Plants include native shrubs, wildflowers, and perennial bunch grasses that generally do not compete with adjacent crops for resources (Long and Anderson, 2010; Williams et al., 2015). Potential benefits of field edge habitat plantings include water quality protection, increased biodiversity, and habitat

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for native bees and natural enemies that enhance pollination and pest control in adjacent crops (Zhang et al., 2010; Fahrig et al., 2011; Kremen and Miles, 2012; Morandin et al., 2016).

Despite the potential benefits, there has been low adoption of BMPs, and field edge habitat plantings in particular (Brodt et al., 2009), suggesting constraints in the process (Burton et al., 2008; Griffiths et al., 2008; Carvalheiro et al., 2011; Mckenzie et al., 2013). Decision-making studies emphasize the importance of farmers' environmental knowledge and attitudes on influencing behavior (Brodt et al., 2009; Farmer et al., 2011). While these characteristics are hypothesized to have a positive relationship on BMP adoption, a recent review found mixed signals for each category (Prokopy et al., 2008). There is considerable debate surrounding which factors can best be used to describe and predict adoption of on-farm conservation practices, hampering efforts to strategically increase their use (Griffiths et al., 2008; Brodt et al., 2009).

Investigating how landholders learn about management practices and use the pathways that support decision-making—including social, experiential, and technical learning—is critical to understanding patterns of adoption of new practices (Lubell et al., 2014). Social learning refers to peer-to-peer interactions whereby landholders (farmers and landowners) learn directly from each other as well as knowledgeable people in the farming community. Technical learning refers to obtaining information through traditional extension programs and their support resources, including websites, books, and online resources. Experiential learning is the process of learning through “hands-on” experience and trial and error. These pathways can inform management decision-making (Lubell et al., 2014) by providing information on the benefits and concerns associated with innovative practices, and shaping patterns of adoption of these innovations (Rogers, 2003). Landholders often use multiple learning pathways, which can be complementary and mutually reinforcing (Lubell et al., 2014), as landholders draw on their own personal experience and beliefs on management practices.

The goal of this study was to investigate drivers of adoption of field edge habitat plantings in California's Sacramento Valley. The region ranks among the nation's top leading producers of almonds, walnuts, and tomatoes (NASS, 2016) and exemplifies primary challenges of conserving ecosystem services in working farmlands: the opportunity costs of encroaching on cultivated areas in high-value, large-acreage specialty crops may affect field edge management decisions, regardless of farm demographics.

To understand patterns of adoption of field edge habitat plantings, we conducted a survey of landholders in California's Sacramento Valley in 2013. Our investigation included landholders' information sharing along two learning pathways: technical learning (e.g., extension and outreach agencies) and social learning (e.g., landholder-to-landholder). It also evaluated the influence of landholder experience with potential benefits and concerns associated with the plantings, and engagement with agencies that provide technical support and cost-share funding. This study provides an approach to bridge a critical knowledge and action gap by documenting potential barriers and facilitators to the adoption of field edge habitat plantings, a BMP that aims to enhance ecosystem services in simplified agricultural landscapes.

2. Methods

We surveyed landholders in California's Sacramento Valley in 2013. The study area comprised Yolo, Solano, Sacramento, Colusa, Sutter, Yuba, and Glenn Counties. This area was chosen to cover the diversity of farming practices and crop types including field, row, and orchard crops, organic and conventional production, and large and small scale cropping systems. The study area reflects the range of farm sizes and grower demographics, including age, income, and gender diversity that occur in the Sacramento Valley (Table 1).

Our survey investigated field edge management practices based on the following themes: farm demographics, including acreage, conventional versus organic farming; information sources accessed by landholders; personal contacts with whom they exchanged information; experience with and perceptions of benefits and concerns; and agencies and partner organizations with whom landholders work. Taken together, these variables provided an overview of potential drivers of adoption of field edge habitat plantings. We focused on landholders to ensure we reached those who make management decisions on the farm. Landholders is a common term used in previous research (Cocklin et al., 2007) as both farmers and landowners play a significant role in crop production (Nickerson et al., 2012). Our survey included 29 questions with most of the responses a yes/no or on 4-point Likert scales, including an option for “Don't Know.” Landholders that had field edge plantings received several additional questions about these plantings. The survey can be found online at: http://ceyolo.ucanr.edu/Custom_Program/Hedgerows/. Prior to distribution, we tested the survey with a small group of growers to help assure relevance and clarity of survey questions.

To reach the agricultural community, we used mailing lists provided by local Resource Conservation Districts (RCDs), University of California Cooperative Extension (UCCE), and Audubon California. We used a modification of Dillman's tailored design method (Dillman et al., 2014), following the introduction letter and initial mailing with two follow-up reminders. Our survey questionnaire was mailed to 300 landholders with self-addressed stamped return envelopes. We distributed the same survey electronically to 2840 landholders by emailing them an electronic link to the survey hosted on the website listed above. While we recognized that the landholder sample was not truly random, we expected that coverage was increased and non-response errors were reduced through the multi-modal nature of the survey and the contacts reached through stakeholder organizations and the extensive outreach of UCCE (Roberts, 2007). Returned surveys were coded into an electronic database and quantitative data were analyzed using R statistical software version 3.0.2 (R Core Development Team, 2013).

First we divided respondents into two groups, those who adopted and currently use field edge plantings and those who did not, hereafter referred to as adopters and non-adopters. We summarized responses, using Welch's t -test to evaluate differences in responses between the two groups. We used logistic regression to evaluate adoption and use of field edge plantings, including hedgerows of native shrubs, trees and strips of native wildflower and/or native grass plantings, in practices currently used by adopters. Our model included fixed effects for grower experience, social learning, technical learning, as well as farm capital characteristics and production practices. We also included a random effect for county. Grower experience with, and perception of, field edge plantings were indicated by two variables, the percent of potential benefits (of 14 total) that landholders ranked as high benefits and the percent of potential concerns (of 11 total) ranked as high concern (range = 0–1).

We investigated social learning in two ways. To understand the composition of contacts within information sharing networks—which describe who interacts with whom (Wasserman and Faust 1994)—we asked landholders to name five contacts with whom they exchange information about field edge management. Since we were particularly interested in social information sharing between landholders, we also considered the rating of “personal communication with other landholders” as an information source

Table 1
Farm characteristics and demographics of the Sacramento Valley and field edge survey respondents.

County	Study area demographics[a]					Survey response					
	Number of farms	Farm size, mean acres	Market value of products sold, mean	Age, mean yrs	% Male	Number of farms	Number of farms w/field edge plantings	Farm size acres, mean acres (range)	Gross income, mean	Age, mean yrs	% Male
Colusa	782	579	$738,251	56.6	91%	15	8	923.5 (2–5322)	$100,000–499,999	56–65	71%
Glenn	1311	510	$486,165	57.8	87%	7	2	917.5 (40–2500)	$100,000–499,999	56–65	100%
Sacramento	1352	183	$241,559	57.8	78%	14	4	1199.3 (10–7500)	$100,000–499,999	56–65	100%
Solano	860	473	$357,463	60.8	76%	16	8	1493.8 (2.5–10,000)	$100,000–499,999	56–65	88%
Sutter	1358	275	$374,209	58.2	84%	6	2	510 (30–1500)	$100,000–499,999	56–65	100%
Yolo	1011	456	$555,134	57.7	81%	51	30	840.6 (1–10,000)	$100,000–499,999	56–65	88%
Yuba	795	236	$243,332	58.8	77%	0	0	NA	NA	NA	NA
TOTAL	7469	404	$428,016	58.24	82%	109	54	985.9 (2–10,000)	$100,000–499,999	56–65	85%

[a] (NASS, 2016).

(range = 0–4). We investigated technical learning by evaluating whether landholders worked with agencies that provided information, hands-on extension, or outreach related to field edge habitat plantings (agency partnership = 1, no partnership = 0). Several agencies also engage in providing financial assistance, thus we investigated the relationship between agency partnership and access of financial assistance using Pearson's correlation coefficient (0.45, $p < 0.05$); given this significant correlation, we selected agency partnership as the variable to represent technical learning in our model to avoid multi-collinearity among variables (see Gelman and Hill, 2006 for discussion on methods).

Taken together, these variables allowed us to better explore how local knowledge and context affected the decision-making processes in establishing field edge habitat on farms. We also included farm size and farming practice (conventional vs. organic) in our model as indicators of farm capital and farming approach, respectively. We did not find significant correlation among any of the other variables and thus retained them in the model. We did not include land ownership (versus leasing land), nor personal landholder demographics variables (e.g., age or education) in our analyses. Land ownership and personal demographics were not the main focus of our inquiry and often have complex and conflicting signals with adoption of conservation practices (Burton, 2014). We distributed the survey via both mail and email in an effort to reach the broadest possible audience; preliminary analyses did not reveal significant relationships between response mode (mail vs. email), thus responses were grouped for further analysis. Prior to modelling, we assured that the assumptions of logistic regression were satisfied. Results are summarized by arithmetic means ± standard error (SE), and significance is reported at the 95% confidence level, unless otherwise noted.

3. Results

3.1. Demographics

A total of 167 respondents filled out and returned the survey, a 14% response rate to the paper survey and 4% response to the online survey. Of these, 109 were from landholders within the Sacramento Valley, identified by the zip code of the land they manage; our analyses focused on these data. Respondents were 85% male, 11% female, 4% undisclosed. The average age was 56–65, with the category <35-years the smallest age demographic (n = 4 respondents, 3.5% of total), which is representative of the farmer age demographics of the study area. The mean farm size of respondents was 986 acres (median 500 acres), which is larger than the average farm size in the study area. However, the mean gross income was $100,000–499,999 in our survey and encompassed the county average for market value of products sold (Table 1).

In our survey, 58% of respondents owned their land, 36% both owned and rented ground, and 7% rented ground. Crops primarily grown were walnuts, almonds, tomatoes, sunflowers, wheat, and alfalfa, all typical for the Sacramento Valley area (NASS, 2016). Of the respondents that reported a production style, 72% identified as conventional, 10% certified organic, and 16% both. Survey respondents represented approximately 1.5% of the farming operations in the study area, which is similar to previous coverage at a single county scale (Brodt et al., 2009); this sample was sufficient in both size and variation of practices to pursue the study goals (Dillman et al., 2014) of investigating key determinants of field edge management practices by landholders.

There was a range of field edge management practices (Fig. 1). The most commonly used current practices on one or more field edge were mowing (74%), herbicides (70%), and disking (55%) primarily to keep borders vegetation free for crop production needs, such as field access. Some landholders currently managed field edges through burning (26%), which is notably lower than the past likely due to increased air quality restrictions (e.g., http://www.ysaqmd.org/burn/ag.php). Others (23%) currently did not use any field edge management.

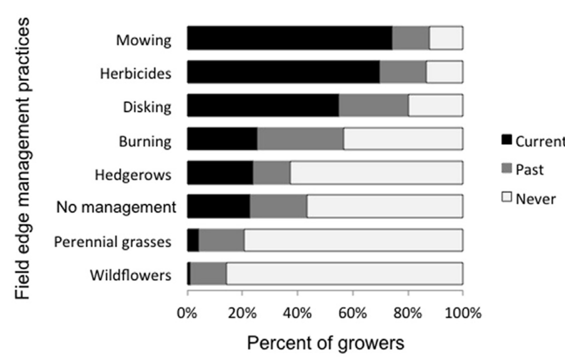

Fig. 1. Field edge management practices currently used by landholders.

Current use of field edge habitat plantings by landholders was modest relative to chemical or mechanical control. In total, 49% of landholders (n = 54) surveyed currently used some type of field edge planting. In general, these plantings comprised fewer than 5% of external property edges (estimated from total farm size), ranging in length from 10.5 to 1600 m in length. Hedgerows were used more frequently (27% of respondents) than riparian and other plantings, or plantings primarily comprised of remnant trees, planted perennial grasses, or native wildflowers (respectively, 22%, 6%, 4% and 1%). Of the hedgerow plantings reported (n = 30), most were concentrated in Yolo County (n = 20), reflecting a previous study (Brodt et al., 2009) and Natural Resource Conservation Service (NRCS) study reporting with 28% of the total hedgerow feet planted in California in the last 6 years were in Yolo County (P. Hogan, Personal Communication). The plantings dominated by native wildflowers and perennial grasses were also located within Yolo County (n = 1 wildflowers, n = 4 grasses). We noted that Yolo County respondents comprised 46% of the overall survey response; the potential effects were accounted for by including county as a random effect in our regression models. The proportion of landholders reporting adoption of field edge plantings by surveyed counties was: 15% in Colusa, 4% in Glenn, 7% in Sacramento, 15% in Solano, 4% in Sutter, and 55% in Yolo.

3.2. Information sources

Adopters that currently used field edge plantings accessed information from more sources (7.08 ± 0.21) compared with non-adopters (4.49 ± 0.37) out of a list of nine possible ($p < 0.01$). On the whole, landholders rated personal observation and personal communication with other landholders as the most useful source of information on managing field edges, reflecting the importance of social learning in support of personal experience. The sources that received the next highest ratings were information from agencies, print resources, meetings (e.g. workshops), and online, reflecting resources comprising the technical learning pathway. The lowest ratings were for commercial suppliers, membership organizations, and commodity boards, with this trend holding for both adopters and non-adopters. The greatest difference in usefulness ratings between landholders that had adopted field edge plantings and non-adopters was for communication with agencies, respectively (3.4 ± 0.23) and (2.6 ± 0.16, $p < 0.0001$ Fig. 2). Overall, landholders that adopted field edge plantings reported usefulness ratings of information sources that were higher, on average, than non-adopters for all sources except for commercial suppliers and commodity boards.

3.3. Potential benefits and concerns

Adopters that currently use field edge plantings rated many benefits more highly than non-adopters (Fig. 3a), including increasing the presence of native bees and honey bees ($p < 0.001$), attracting natural enemies of crop pests ($p < 0.0001$), improving farm aesthetics ($p < 0.0001$), increasing weed control ($p < 0.001$), and increasing water infiltration ($p = 0.05$, 90% confidence). The remainder of the benefits, including soil and water quality protection, received similar ratings across adopters and non-adopters. In addition, 25% of adopters assigned a monetary value to the plantings' benefits; the remainder emphasized the difficulty of estimating a dollar value for field edge restoration. For off-farm benefits, 70% of adopters reported that the plantings had broader

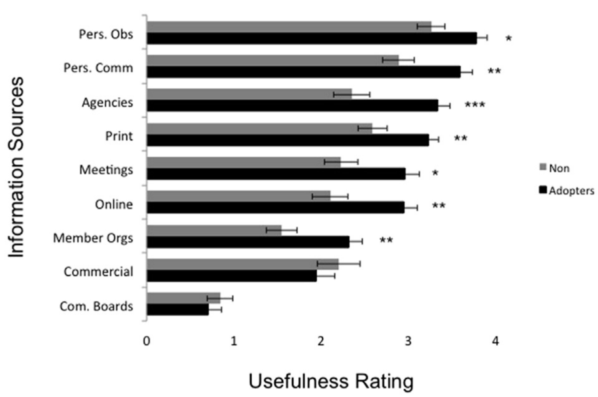

Fig. 2. Landholder ratings of information sources on field edge management (0 = never used, 4 = most useful) including: Personal observation (Pers. Obs), personal communication (Pers. Comm) with other landholder, partnership with agencies (Agencies), use of print resources (Print), meetings, use of online resources (Online), membership organizations (Member orgs), commercial suppliers of farm inputs (Commercial), and crop commodity boards (Com. Boards). *Adopters* reflect ratings for growers that currently use field edge plantings; *Non* reflects ratings for growers that do not use field edge plantings. Usefulness ratings that are significantly different between adopters and non-adopters are indicated as follows: ***$p < 0.0001$, **$p < 0.001$, *$0.01 \le p \le 0.05$.

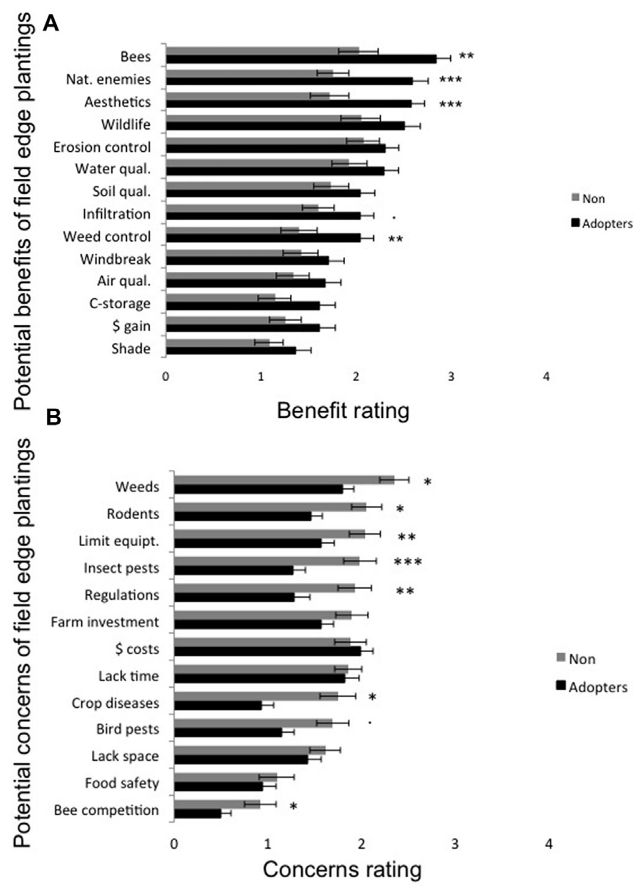

Fig. 3. a. Landholder ratings of potential benefits of field edge management (0 = never used, 4 = most useful). *Adopters* reflects ratings for growers that currently use field edge plantings; *Non* reflects ratings for growers that do not use field edge plantings. Benefits ratings that are significantly different are indicated as follows: ***$p < 0.0001$, **$p < 0.001$, *$0.01 \le p \le 0.05$, "." $p < 0.10$. b. Landholder ratings of potential concerns of field edge management (0 = never used, 4 = most useful). *Adopters* reflects ratings for growers that currently use field edge plantings; *Non* reflects ratings for growers that do not use field edge plantings. Concerns ratings that are significantly different are indicated as follows: ***$p < 0.0001$, **$p < 0.001$, *$0.01 \le p \le 0.05$, "." $p < 0.10$.

societal benefits, comprising recreational and cultural benefits, such as providing hunting areas for game birds. Aesthetics and enhanced public perception of their farms also emerged as top considerations.

Both adopters and non-adopters had significant concerns related to field edge habitat, plantings including the potential for more weeds, increased time to manage them, and associated financial costs. Overall, non-adopters had higher concern ratings relative to adopters, including the potential for increased weeds ($p < 0.05$), rodent pests ($p < 0.05$), limiting operation of farm equipment ($p < 0.001$), increased insect pests ($p < 0.001$), potential for increased regulation ($p < 0.001$), increased bird pests ($p = 0.09$, 90% confidence), crop diseases ($p < 0.001$), and competition with honey bees ($p < 0.05$, Fig. 3b). The suite of potential concerns that received similar ratings from adopters and non-adopters included those related to costs, lack of time for field edge plantings, lack of space, and food safety. Food safety was a lower concern, likely due to the fact that most of the crops grown in the Sacramento Valley, and reported in the survey, are processed after harvest. The lowest concern for both adopters and non-adopters was potential floral resource competition with honey bees. This likely reflects that a majority of responding landholders grow crops that do not rely on pollination; less than 5% of responding landholders grew exclusively pollinator dependent crops (e.g., sunflowers, almonds).

3.4. Predictors of adoption

A subset of 35 respondents within the study area listed the network of contacts with whom they shared information about field edge management. This network data is sufficient for analysis; it included the contacts' roles in terms of the type of position they held. Landholders networked most frequently with contacts in agencies that provide technical and financial support (28%), including the USDA-NRCS, Resource Conservation Districts (RCDs), Agricultural Commissioner and other agencies; other landholders (27%); extension and research (16%); commercial suppliers (12%); non-government organizations, NGOs (9%); Pest Control Advisors (PCAs, 3%); crop commodity boards (1%), and other roles (5%), such as the Farm Bureau (Fig. 4).

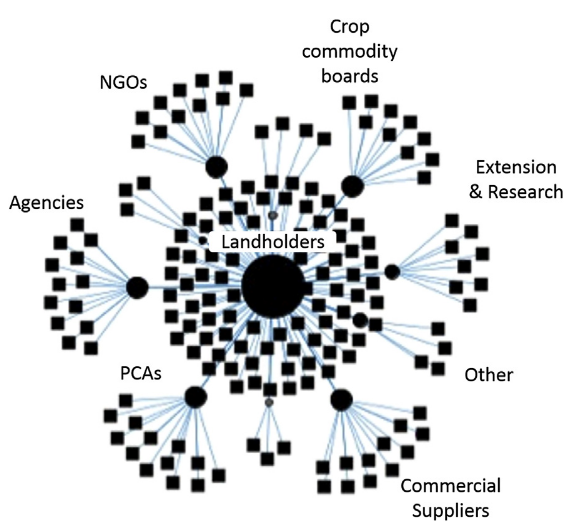

Fig. 4. Key roles in landholder knowledge networks on field edge management: squares represent contacts of individual landholders and circles represent key roles, with circle size proportional to number of contacts. Landholders networked most frequently with contacts in agencies that provide technical and/or financial support (28%), including the NRCS, RCDs, Agricultural Commissioner, other agencies; and landholders (27%). Other key roles include extension (16%); commercial suppliers (12%); Non-government organizations (NGOs, 9%); Pest Control Advisors (PCAs, 3%); commodity groups (1%) and other roles (5%). Network data, n = 48 respondents.

Landholders and agencies were both reflected nearly equally in landholder communication networks. However, two interesting characteristics distinguished the networks of adopters. First, all adopters that reported communication network data ($n = 25$) included both landholders and one or more agencies that promote field edge plantings. This suggests that networks of adopters have the capacity for complementary and mutually reinforcing social and technical learning pathways. The networks of non-adopters ($n = 10$) included either agency contacts or landholder contacts, but only one of the non-adopters' networks included both organizations and landholders. Second, a majority of adopters' networks ($n = 17$) included a connection to another landholder with field edge plantings or a local commercial supplier of native plants that has been locally active in promoting hedgerows and other field edge habitat plantings. This characteristic of adopters' communication networks suggests a strong capacity to exchange primary information, such as personal observations about field edge management, which can support implementing new practices.

Next we modeled factors that help predict characteristics of landholders that are likely to adopt field edge plantings. This model compared adopters with the baseline category of non-adopters. We included experience with potential benefits associated with field edge plantings, and experience with potential concerns associated with field edge plantings. The model included: respondents' ratings of personal communications with other landholders; agency collaboration; and it controlled for production style (comparing organic to conventional production) and farm size (a measure of farm capital suggested by diffusion of innovation theory; Table 2). Including personal perceptions as well as communication with both social contacts and agencies allowed us to estimate the effects of key social and technical learning pathways. The modelling approach accounted for personal perceptions and capital characteristics that have been identified by diffusion theory as factors with strong potential to influence practice adoption.

We found that personal experience with both benefits and concerns were important considerations in field edge management; as ratings of benefits increased, so did the probability of adopting field edge habitat plantings. On average, adopters rated 41% of benefits highly; in contrast, non-adopters rated only 20% of benefits highly. As ratings of concerns increased, the probability of adopting field edge plantings decreased (Table 2). On average, adopters rated 18% of concerns highly and 22% of non-adopters rated concerns highly. Importantly, higher ratings of personal communication with other landholders had a significant positive relationship with adoption of field edge plantings, as did partnership with agencies (90% confidence level, Table 2). We found that farm capital was also an important consideration, with landholders on larger farms significantly less likely to adopt field edge habitat plantings than landholders on smaller acreage. Landholders with organic production were more likely to adopt field edge plantings (90% confidence level, Table 2).

4. Discussion

Taken together, the survey results demonstrated significant relationships between the adoption of field-edge plantings and both social and technical learning pathways, as well as landholder experience with potential benefits and concerns, and farm characteristics. Building understanding of the experience and learning pathways is critical to developing strategic outreach and extension efforts designed to enhance on-farm biodiversity. Typically, outreach efforts do not aim to change farm capital factors such as farm size and type of operation rather, they aim to support shifts in

Table 2
Predictors of adoption of field edge plantings by landholders in California's Sacramento Valley.

Variable	Description	Estimate	Std. Error	z-value	
Intercept	Non-adopters	0.257	1.633	0.158	
County	County reported	−0.145	0.584	−0.261	
Benefits	Benefits highly rated, %	2.884	1.217	2.369	*
Concerns	Concerns highly rated, %	−2.337	1.153	−2.028	*
Landholders	Rating of personal communication with landholders	0.3055	0.204	1.494	*
Agencies	Current or past collaboration	1.077	0.582	1.852	.
Farm size	log acres	−0.416	0.210	−1.984	*
Conventional	Conventional crop production	−1.0456	0.7847	−1.332	
Organic	Organic crop production	1.9658	1.0916	1.801	.

Significance levels indicated as follows: $^{*}0.01 \leq p \leq 0.05$; "." $p < 0.1$.

landholder opinion by understanding motivations behind the decision-making process. This information is important for identifying opportunities to strengthen outreach programs that aim to increase use of BMPs for on-farm conservation, and the local and international programs designed to do so.

Taken together, the communication networks of landholders related to information on field edge management (as specified in the survey questionnaire) included two key roles, each comprising about one third of the total network contacts: agencies that provide technical support and fellow landholders. However, the networks of adopters included both fellow landholders and agencies, whereas networks of non-adopters included either landholders or agencies. This pattern echoes previous work describing that social learning through peer-to-peer information exchange serves as a complementary and reinforcing pathway with technical learning that is stimulated by traditional outreach and extension programs (Garbach et al., 2012; Lubell et al., 2014). In contrast, the communication networks of non-adopters did not reflect the same mutually reinforcing social and technical learning pathways. As the number of communication networks described in this study was modest, we did not attempt to model additive or synergistic effects of social and technical learning pathways, but note this is an area of interest for further investigation.

Adopters' communication networks also suggest the potential importance of thought leaders in promoting adoption of new practices. For example, fellow landholders that have adopted field edge plantings, may act as "champions" (Risgaard et al., 2007), by demonstrating field edge planting practices and potentially assisting their contacts in doing the same. Another key role is played by "ambassadors," comprising organizational representatives that facilitate and support work of champions (Risgaard et al., 2007). In this study, a majority of adopters' communication networks (17 of 25) included either a champion or ambassador. A key ambassador in this study was a commercial supplier of native plants that also hosts workshops and tours at the business; the importance of this ambassador's role has been documented in adoption and use of hedgerow plantings in Yolo County (Brodt et al., 2009). Previous work has emphasized the potential for farm advisors to serve as ambassadors (Risgaard et al., 2007), serving in the traditional capacity of outreach and extension. Our results highlight that ambassadors are not limited to individuals serving in formal outreach and extension roles.

The survey results also emphasize the need to investigate the use of information sources within the broader context of communication networks to gain a more complete picture of how learning pathways articulate. For example, among the nine categories of information sources presented on the survey, commercial suppliers were rated as one of the least useful, along with commodity board groups. This underscores the potential to use communication network data to better understand the roles of organizations, individuals, and activities comprised by different types of information sources.

With respect to potential benefits associated with field edge practices, landholder ratings suggested the importance of both economic considerations and personal orientation toward stewardship (e.g., enhanced aesthetics; wildlife habitat) both of which have been shown to influence adoption of conservation practices (Stonehouse, 1996). Interestingly, survey responses suggest that, even among adopters, the potential economic benefits of field edge plantings are not yet well understood. Specifically, the number of adopters that responded that field edge plantings were expected to have societal benefits was nearly 3-fold higher than adopters that expect field edge plantings to have a monetary benefit (e.g., increasing availability of ecosystem services directly supporting on-farm productivity). This may reflect that the study of the economic benefits of attracting bees and natural enemies, which can enhance yield and pest control in adjacent crops is relatively recent (e.g., Morandin et al., 2016), and may be primarily limited to scientific literature. As such, there is a pressing need to share data on economic influence of field edge plantings with landholders and agencies that support technical learning. In contrast, outreach and extension literature has emphasized establishment requirements and highlighted general environmental benefits (e.g., Long and Anderson, 2010).

Landholders may recognize general environmental benefits of field edge plantings, as indicated by top-rated benefits comprising cultural services, enhancing farm aesthetics, and attracting wildlife. The scientific literature has emphasized that farm-scale benefits of field edge plantings can provide food resources and critical habitat for beneficial insects and pollinators (Long et al., 1998; Kremen et al., 2002), reduce crop pests, and limit presence of weedy plants (Ehler et al., 2002). Across these benefits, enhancing habitat for bees and natural enemies of crop pests were among the most recognized and highly rated by adopters of field edge plantings. However, the potential for weed control was rated lower, reflecting variation in perceptions across potential benefits, regardless of scientific study. Identifying this variation can inform research, extension, and agencies that emphasize management of critical ecosystem services.

Landholder responses also highlighted near-term ease of use and future considerations, including anticipated changes in policy. One grower summarized, "While disking is fast and the cleanest [for] weed control, hedgerows [and] filter strips may be best (especially the downslope side), due to pending agricultural irrigation waiver regulation changes." This information suggests that in addition to technical information that emphasizes potential economic benefits, benefits that accrue at broader scales, such as cultural services, should also be included in outreach efforts that aim to increase adoption of on-farm conservation practices.

The ratings of concerns related to field edge plantings can be used to identify key themes and areas in which field data have not been as well developed in the scientific community or widely circulated to the agricultural community. For example, highly rated concerns about the potential for plantings to increase crop pests and weeds highlight a pressing need for field investigation. This observation reflects that technical and performance information about many BMPs for on-farm conservation is inadequate in many areas and previous work in the region highlighting the need for primary data on potential barriers to adopting field edge habitat plantings, in particular (Stonehouse, 1996; Brodt et al., 2009). Our survey results emphasize the importance of field data investigating the economic influence of field edge plantings, including the potential benefits for ecosystem services such as pollination and pest control that directly support crop production (Morandin et al., 2016). At the same time, we recognize that the overall response rates to this survey were modest, thus some results should be interpreted with caution. Specifically, the Yolo County respondents comprised nearly half of the sample. This may be due in part to the strong presences of UCCE and the U.C. Davis campus, both located in the county, which could lead to a cultural norm of participating in survey research. Thus, field edge management practices in Yolo County should not be considered representative of all counties in the Sacramento Valley without further investigation. Similarly, field research on other potential constraints, such as bird pests, rodents, and weeds is critically needed to understand how to best address concerns related to field edge plantings on farms.

On average, landholders that adopted field edge plantings accessed approximately three more information sources than non-adopters, of eight potential sources listed on the survey. This is substantial, as additional information sources may help to supply technical information, or provide complementary details (e.g., filling in the gaps between one source and another), as growers triangulate among different sources in the decision-making process. Print material (e.g., newsletters, books, magazines) was slightly more useful than on-line materials (e.g., websites, e-newsletters, blogs). This may reflect the older demographics of the survey population and lower Internet use compared with younger generations (Coleman and McCombs, 2007). Technical information is needed about outcomes of BMPs for on-farm conservation; in order for the information to be effective in supporting their use, it needs to be matched to individual landholders' levels of management skill, economic circumstances, and access to capital (Stonehouse, 1996). Landholders accessing more information sources may effectively be increasing the possibilities of amalgamating evidence and tailoring it to their personal skills and circumstances (Hull et al., 2015). Extending this line of thinking to explore how usefulness ratings differ between adopters and non-adopters may help outreach and extension professionals to identify additional opportunities to build capacity to effectively support technical learning.

This analysis focused on partnerships between landholders and agencies as an indicator of engaging in technical learning, as partnership with agencies and access of funding for field edge plantings were significantly correlated. From a policy perspective, the funding resources available through cost-share for these BMPs can be substantial: through the USDA's, Environmental Quality Incentives Program (EQIP) funding for field edge plantings border practices comprise a 50–75% cost share for qualifying landholders (NRCS, 2016). Given that agency partnerships had a significant positive relationship with adopting field edge habitat plantings, and that both adopters and adopters reported that monetary costs were a consideration, continued funding for field edge plantings is critical. Policy support for practices designed to enhance biodiversity and ecosystem services in marginal areas is particularly important; field edge plantings in the Sacramento Valley exemplify how marginal areas can be used for on-farm conservation practices, including terraces left over from land leveling, old fence lines, and along waterways (canals, streams, and ditches). These areas may be ideal to implement and study the potential benefits and concerns associated with field edge plantings and other conservation practices without encroaching on cropped areas.

5. Conclusion

This study highlights two main knowledge gaps related to landholder experience with, and adoption of, BMPs such as field edge habitat plantings. First, this study builds on existing literature that emphasizes the importance of multiple learning pathways (e.g., Lubell et al., 2014), providing primary data that adopters of field edge plantings draw on both social and technical sources of information, when considering new practices. However, future work and larger datasets describing stakeholder networks is needed to determine the mechanisms through which multiple learning pathways interact, and investigate whether the outcomes include additive effects or perhaps include more complex, synergistic relationships.

A related knowledge gap is that little is known about how the chain of communication among landholders, between landholders and agencies, and landholders and other contacts unfolds. For example, are landholders that are predisposed to adopting field edge plantings more likely to contact agencies, or does contact with agencies stimulate interest in field edge plantings? Working with focus groups and controlled studies may be helpful in untangling these details, which in turn may be useful to supporting approaches to successfully engage the agricultural community. Building understanding of these knowledge gaps have important applications for advancing theory and practice, with wide applicability for educators and policy makers in other regions to identify "network-smart" extension strategies that help target programs that will encourage practices to enhance biodiversity and sustain ecosystem services in intensively farmed landscapes.

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