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Applications of behavioral science to biodiversity management in agricultural landscapes: conceptual mapping and a California case study

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Abstract The plot-level decisions of land managers (i.e., farmers, ranchers, and forest owners) influence landscape-scale environmental outcomes for biodiversity in agricultural landscapes. The impacts of their decisions often develop in complex, non-additive ways that unfold over time and space. Behavioral science offers insights into ways decision-makers manage complexity, uncertainty, choice over time, and social influence. We review such insights to understand the plot-level conservation actions of farmers that impact biodiversity. To make these connections concrete, we provide a case study of the decision to adopt biodiversity management practices in the heavily cultivated region of the Central Valley, California, USA. We use results from a survey of 122 farmers in the region to test whether adoption is related to farm tenure arrangements or peer influence. We find farmers who are more sensitive to peer influence are three times more likely to adopt practices that support biodiversity, including wildflowers, native grasses, cover crops, hedgerows, and wetlands. This relationship could have important implications for how plot-level decisions aggregate to landscape-scale outcomes. Finally, we suggest priorities for future research and program design to integrate behavioral science into biodiversity conservation in agricultural landscapes. By considering land managers' plot-level conservation decisions with the lens of behavioral science, we identify barriers and opportunities to promote environmental benefits.

Keywords Behavioral science · Biodiversity conservation · Farmer decision-making · Working landscapes

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Introduction

The loss of biodiversity and the services it provides have been highlighted by the European Union and the USA as among the most pressing concerns facing agricultural landscapes (European Commission 2017; IPBES 2018).

This trend is largely the result of habitat loss and fragmentation, and compounded by chemical inputs, invasive species, and climate change (Butchart et al. 2010).

Strategies to improve biodiversity in intensively farmed areas include encouraging natural or improved uncultivated areas along fields and riparian zones, altering the timing and techniques of cropping and tilling, and reducing pesticide use (Bommarco et al. 2013; Kovács-Hostyánszki et al. 2017). If these actions also support populations of beneficial organisms, then a farm may experience yield gains due to provision of ecosystem services, such as pest control, soil retention, and pollination (Garibaldi et al. 2014). Such benefits may extend to nearby farms and contribute to broader landscape multifunctionality (Kremen and Merenlender 2018).

Despite potential private and public benefits, many farmers do not adopt practices that boost biodiversity (Lovell and Sullivan 2006; Wade et al. 2015). Providing habitat often comes at an opportunity cost to farmers: land that would otherwise generate profits may need to be managed less intensively. As a result, both the United States Department of Agriculture and the European Union's Common Agricultural Policy have enlisted a suite of policies and programs, spanning regulatory, incentive-based, and educational approaches, to intervene and encourage farm-level biodiversity management. Desired activities include keeping or taking land out of production, improving uncultivated land by planting native species, and participating in government or nonprofit programs that provide information or financial incentives for such practices (Vaughan and Skinner 2008; Stubbs 2018).

Decisions to engage in these activities, however, are rarely straightforward. A review of 35 years of research found few factors that consistently predict farmers' adoption of conservation practices (Prokopy et al. 2019). Farmers must evaluate complex and uncertain tradeoffs between private and social costs and benefits, now and into the future. A farmer deciding to provide patches of semi-natural habitat must weigh potential crop losses against the unknown probability of increasing bird and bee populations, and the services they can provide, sometime in the future. The farmer must incur upfront costs in time and money in hope of generating benefits that may accrue privately or to others who live nearby or even thousands of miles away.

Behavioral science offers insights into ways decision-makers manage complexity, risk and uncertainty, and changes over time. The field of behavioral science integrates theory and empirical evidence from economics, psychology, and other social sciences to understand the causes of human behavior and decision-making. For example, rather than acting with unlimited cognitive capacity, people often rely on mental shortcuts, biases, and contextual cues to guide their decision-making (Kahneman 2003). People also tend to be sensitive to the ways their behavior impacts and is perceived by others, so-called social preferences (Fehr and Fischbacher 2002). Importantly, these insights demonstrate how simple changes to the decision environment can influence behavior (Thaler 2018). Governments and multilateral institutions have recognized the importance of incorporating insights from behavioral science into program and policy design (e.g., Obama 2015; World Bank 2015; United Nations 2016; OECD 2017).

Insights from behavioral science may help explain farmers' plot-level decisions to support biodiversity. Observational studies of farmer behavior indicate that social norms and time horizons are associated with environmental actions on farms in the USA (Prokopy et al. 2008; Niles et al. 2016). Reviews of and research agendas for farmer behavior call for integration of behavioral science approaches to understand conservation actions (Reimer et al. 2014; Groeneveld et al. 2017). A number of survey papers apply behavioral science to environmental and conservation issues (e.g., Brekke and Johansson-Stenman 2008; Shogren and Taylor 2008; Gsottbauer and van den Bergh 2010; Croson and Treich 2014; Cinner 2018), though none explicitly focuses on decision-making around land management to improve outcomes for biodiversity.

This paper adds to the existing literature by mapping insights from the field of behavioral science to the challenge of increasing biodiversity in agricultural landscapes. The next section examines how four factors of influence in decision-making—complexity and context-dependence, uncertainty and risk, time discounting, and social preferences—may help explain farmers' biodiversity management behavior. Then, we present a case study that explores the role of these factors in the adoption of biodiversity management practices by farmers in central California, USA. Finally, we discuss how integrating behavioral science into future research might improve our understanding of farmer behavior and inform more effective landscape-scale conservation. While we focus on behaviors that encourage farm-level structural changes for biodiversity and the services it provides in high-income countries, we expect the discussion herein to be useful to other land management decisions and landscape-scale challenges.

Behavioral science and biodiversity management in agricultural landscapes

In the following subsections, we consider how farmers' actions that impact biodiversity may be explained or influenced by insights from the field of behavioral science. This paper adapts the frameworks offered by Camerer et al. (2004) and Just (2014), organizing these insights into four factors of influence: (1) complexity and context-dependence; (2) uncertainty and risk; (3) time discounting; and (4) social preferences (Table 1). For each, we explain the behavioral factor and its components, make connections to farmers' plot-level management decisions, and discuss implications for biodiversity outcomes. This conceptual mapping is not meant to provide an exhaustive review of the literature, but rather to connect evidence from behavioral science with research on farmer behavior and biodiversity management. It is our hope that this review facilitates ways of thinking about farmers' conservation behavior in the context of key insights gleaned over the past few decades of inquiry into human decision-making.

Complexity and context-dependence

Rather than being able to seamlessly navigate the complexity of the world, humans have limited cognitive capacity, or "bounded rationality" (Simon 1955). As a result, peoples' decisions often vary according to the context in which they are made. For example, the reference point from which one makes a guess or a bid can influence its value (Kahneman et al. 1991). As can the order in which options are presented and the ways in which they are framed (Tversky and Kahneman 1981; Shu et al. 2012). People often become attached to a status quo and evaluate changes relative to that baseline, rather than considering absolute gains and losses. These "supposedly irrelevant factors" have shown to influence a range of important decisions, including saving for retirement and organ donation (Thaler 2016).

Farmers make numerous management decisions amidst dynamic market, policy, social, and climatic conditions, such that the range of options and potential tradeoffs are large and complex. Farmers' decisions to change management or enroll in programs that subsidize conservation practices can require considerable time and energy to search for information, evaluate alternatives, and estimate costs and benefits. These real and perceived transaction costs have shown to inhibit program participation in the E.U. and the USA (Mettepenningen et al. 2009; McCann and Claassen 2016; Palm-Forster et al. 2016). Habits and preferences for status quos are likely to influence management, but little is known about their importance in conservation practice adoption (Reimer and Prokopy 2014; Dayer et al. 2017). Farm-level decisions can also be sensitive to the context in which they are presented. Narrowly framing crop insurance as an investment (with a premium) that may produce a gain (the indemnity) can reduce purchasing compared to broadly framing insurance costs and payouts over all farm assets if some event occurs (Babcock 2015).

Farmers managing for biodiversity must weigh multiple options whose outcomes unfold in complex ways. Efforts to increase biodiversity may interact with other factors, such as farm or regional characteristics, that ultimately determine their effectiveness (Sardiñas and Kremen 2015; Heath et al. 2017). While the farm-level ecosystem service benefits derived from biodiversity can be drivers of farmer adoption of biodiversity-friendly practices (Kross et al. 2018), few studies have quantified these services at the farm scale. Farmers also tend to be time-scarce, further reducing their capacity to systematically assess how choices will play out on the landscape (Reimer and Prokopy 2014). As a result, farmers may avoid making changes in management that could benefit biodiversity when the process and outcomes are not straightforward, or when the status quo fosters inaction. Programs and policies designed to incentivize conservation may fall short if they do not account for the supposedly irrelevant factors that shape decisions.

Uncertainty and risk

Judgments and choices under risk and uncertainty can be subject to systematic errors. Accurate assessments of probabilities are difficult, even among trained statisticians (Tversky and Kahneman 1971). Instead, people often overweight insights from small samples. They tend to use rules-of-thumb, or "heuristics," to match uncertain situations with similar or salient scenarios in

Table 1 Aspects of behavioral science and their connection to farmers' plot-level decisions to improve biodiversity

Behavioral factor	Summary	Related biases, effects, and influences	Barriers to farmers' adoption of biodiversity management	Examples of strategies to intervene and increase conservation behavior
Complexity and context--dependence	People struggle to evaluate complex options and are sensitive to the context (reference state) in which they make decisions.	• Anchoring and adjustment • Status quo bias • Transaction utility • Mental accounting and choice bracketing • Endowment effect • Framing effects	Complex systems and processes may dissuade action, as might a particular reference point or the way behavior change is framed.	Changing the baseline cost-share contribution from 0 to 100% increased the amount farmers were willing to pay for conservation (Messer et al. 2016).
Uncertainty and risk	People use mental shortcuts to judge probabilities and evaluate risk relatively, weighting losses more than gains.	• Law of small numbers • Availability and representativeness heuristics • Confirmation bias • Loss aversion	High uncertainty and even small risks of losses may overwhelm potential benefits from biodiversity, especially if familiar stories serve as cautionary tales.	Translating statistical information on climate risk and uncertainty into concrete experiences increased farmers' understanding (Marx et al. 2007).
Time discounting	People tend to be farsighted when costs and benefits are incurred in the future but tend to overweight those incurred in the present.	• Present bias • Procrastination • Projection and hindsight bias	Upfront costs in time and money may dwarf long-term benefits of biodiversity management, even if farmers want or intend to make changes.	Simple reminder letters increased re-enrollment in the Conservation Reserve Program (Wallander et al. 2017).
Social preferences	People care about the impacts of their actions and how they are perceived, as well as the behavior of others.	• Altruism and impure altruism • Fairness • Reciprocity and cooperation • Messenger effect • Reputation and image • Social norms and influence	Prevailing social norms or missing information about others' contributions to biodiversity may reduce incentives to adopt beneficial management practices.	Information about neighbors' conservation behavior increases spatial coordination of land management (Banerjee et al. 2014)

the mind (the representativeness heuristic and availability heuristic, respectively) (Tversky and Kahneman 1974). This is especially the case in "low-validity environments," which are highly uncertain and unpredictable (Kahneman 2011). Rather than exhibiting consistent risk preferences (i.e., being risk loving or risk averse), people's choices can again be sensitive to a reference point (Kahneman and Tversky 1979). Potential losses below this reference point hurt more than equivalent potential gains, called "loss aversion." As a result, people are often willing to take riskier gambles to avoid losses than they would to achieve gains.

The inherent uncertainty and risk in farming motivated a large body of work studying farmers' responses to changes in yields and prices, which contributed to early foundations of behavioral economics (Carter 2016). More recent studies have focused on risk and uncertainty related to climate change, showing that high levels of uncertainty dissuade farmers from adapting to changing weather patterns (Morton et al. 2017) and that farmers often perceive climate change risk to be greater than potential climate change benefits (Niles et al. 2013). Past experiences or stories about other farmers, such as crop losses from extreme weather events, can serve as influential reference points for evaluating uncertainty and risk (Marx et al. 2007; Tonsor 2018). Loss aversion in risky decisions may help explain the failure of many farmers to adopt technologies that generate higher average profits but may increase losses on occasion (Bougherara et al. 2017; Du et al. 2017).

For farmers deciding how much cost to incur for future or public benefits of biodiversity, they must estimate the risks of changing practices against the likelihood of achieving gains, given varying levels of uncertainty. Yet any change in biodiversity may be perceived as stochastic, since only a fraction of that outcome can be attributed to the actions of one land manager (Hanley et al. 2012). This unpredictability is compounded by scientific uncertainty; even experts do not agree on the most effective strategies for conserving biodiversity in agricultural landscapes (Fischer et al. 2008). Such uncertainty may dissuade farmers from making any changes that could benefit biodiversity. Where outcomes are more probabilistic, farmers may instead rely on recent events or familiar stories to guide their assessments. Increasing biodiversity may increase risks of certain ecosystem disservices, such as crop destruction and disease (Jacobson et al. 2003; Zhang et al. 2007). If potential losses loom large, farmers may fail to adopt biodiversity management practices that have private and social benefits because they are more risk averse over gains than they "should" be.

Time discounting

People tend to discount the future and view time inconsistently. Immediate gains are often worth more than those expected at some future time period. In part, this is because events that are far off in time can be abstract or "psychologically distant" (Trope et al. 2007). Moreover, the difference between receiving some benefit today versus tomorrow has shown to be much greater than that equivalent one-day wait a year in the future (called "hyperbolic discounting") (Laibson 1997). Not only do people tend to value the future less, but that when the future arrives, they often exert less self-control than predicted. This is because people tend to be biased towards the present, causing them to procrastinate costly behavior that will have future benefits, such as studying, dieting, or saving for the future (Madrian 2014). Failing to accurately predict how one will feel at some future time period (projection bias) and misremembering how one arrived at a decision (hindsight bias) have also shown to obscure people's abilities to make consistent choices over time (Christensen-Szalanski and Willham 1991; Loewenstein et al. 2003).

Certain factors are likely to influence the rate at which farmers discount the future, including immediate need, financial or tenure security, and age. For example, farmers who do not own their land and landowners who lease to farmers often must adjust their time horizons to the terms of their contracts, potentially interfering with adoption of conservation practices (Ranjan et al. 2019). Although older farmers are less likely to adopt best management practices, perhaps because of a shorter planning horizon (Baumgart-Getz et al. 2012), those with a successor to maintain farm management into the future were found to be more likely to participate in agri-environmental schemes (Lastra-Bravo et al. 2015). Overall, the literature on farmers' time horizons seems to be inconclusive: a review paper on farmer decision-making conducted by Niles and colleagues (in preparation) found a wide range of discount rates used in models with often arbitrary or missing justification for their selection. Inconsistent time preferences may interfere with farmers acting in their own self-interest. One study found farmers intended to adopt certain management practices, but when the time came to do so, the upfront time costs overwhelmed the highly discounted future benefits of those practices (Duflo et al. 2011). This insight could help explain evidence that farmers' intentions to adopt climate mitigation and adaptation practices differ considerably from actual adoption (Niles et al. 2016).

Like climate change mitigation, the benefits of management changes for biodiversity are often distant in time and space. The impacts of many land management practices unfold over long time scales that conflict with the upfront costs and benefits associated with ecosystem change (Wilson et al. 2016). Planting flower strips and hedgerows to attract native pollinators, for example, requires 4 to 7 years before yield benefits offset establishment costs (Kovács-Hostyánszki et al. 2017). This temporal disconnect between biodiversity actions and impacts may be compounded when farmers do not own the land they cultivate or have a successor to continue a legacy (Lastra-Bravo et al. 2015; Ranjan et al. 2019). Farmers' actions to manage for biodiversity are likely to take time to produce beneficial outcomes. This makes private costs particularly difficult to justify in the present time period, thus discouraging management practices that yield benefits in the long run.

Social preferences

Social scientists have a long history studying the roles of social norms and cooperation in influencing behavior, including in land management (Hardin 1968; Ostrom 2000). Behavioral economists have incorporated these insights to explain deviations from expectations of self-interest and measured their effects on economic behavior. In doing so, they have identified the contributions of altruism, fairness, reciprocity, and social norms to observed behaviors (Fehr and Fischbacher 2002; Hoff and Stiglitz 2016). Furthermore, this research has used experimental methods to estimate *how much* these social preferences matter in certain decisions and contexts (Abrahamse and Steg 2013). Studies show that providing information about the expectations and behavior of others, making one's behavior observable to others, and selecting specific messengers to deliver information can change the actions people take (Cialdini 2003; Landry et al. 2006; Yoeli et al. 2013). These insights highlight the importance of social norms, image and reputation, and trust in influencing behavior.

Social norms have shown to be associated with the management practices farmers use and their willingness to adopt alternatives (Garbach and Morgan 2017; Hillis et al. 2017). The absence of widespread support for climate change policies among farmers may influence perceptions of norms and cooperation, suggesting, "If no one else is supporting this, why should I?" (Niles et al. 2016). This social influence, or sensitivity to the views and behavior of others, has also been associated with the adoption and persistence of conservation activities (Prokopy et al. 2008; Dayer et al. 2017). Offering reputational benefits, such as publicizing good stewardship, may be important for conservation program participation (Atari et al. 2009; Banerjee and Shogren 2012). Land managers have been willing to coordinate on conservation action when group performance is rewarded (Parkhurst et al. 2002), although perceptions of fairness may matter (Drechsler 2017). Conversely, empathy for others is associated with some farmers' decisions to adopt conservation practices and share access to private land (Sheeder and Lynne 2011; Czap et al. 2015; Niles et al. 2017).

As with other land management decisions, changes in on-farm biodiversity can influence costs and benefits incurred by neighboring parcels and communities near and far. This implies that there is an inherent social aspect to these decisions, both impacted by and impacting others (Sonter et al. 2017). In some regions, prevailing social norms may conflict with biodiversity goals, such as esthetic preferences for manicured farms over the "messy" look of natural areas (Dayer et al. 2017). Because biodiversity is maintained at large spatial scales, effectively increasing biodiversity in agricultural landscapes requires the action of many individual landowners, which can lead to free-riding and concerns about fairness. While altruistic land managers may be willing to supply biodiversity without incentives, others will likely require reciprocity or recognition for their behavior. Yet biodiversity is a public good, contributions towards which may not be easily observed or measured. Where management actions are difficult to observe or take time to produce benefits, these social rewards will be challenging to provide.

Farmers' social preferences, as well as their time discounting, evaluation of risk and uncertainty, and reactions to complexity and context, have clear links to decisions about managing for biodiversity. Evidence from behavioral science and research on farmer decision-making suggests these factors can be barriers to adopting practices that encourage biodiversity and, ultimately, improving biodiversity outcomes on the landscape. To illustrate these ideas, we offer a case study of farm-level biodiversity management. We explore whether farmer attributes related to two behavioral factors—time discounting and social preferences—are associated with adoption of practices that provide habitat and forage for pollinators and other wildlife.

Tenure arrangements, peer information, and biodiversity management in California

The Central Valley of California, USA, is an intensively farmed region that is critically important for food production and to the state and national economies. More than 400 crops are grown in California, worth more than $50 billion in 2017, and contributing 13% of all US agricultural value (CDFA 2018). In this largely agricultural landscape, the biodiversity management of individual farmers can provide refuge and habitat for birds, bats, bees, and other species. Creating hedgerows along fields, for example, increases bird abundance and diversity (Heath et al. 2017). Other actions, such as retaining existing tree lines and riparian corridors, planting wildflower strips, and providing habitat for cavity-nesting species, increase landscape complexity and have positive effects on biodiversity and the services they provide (Kross et al. 2016).

We examined farmers' biodiversity management in the Central Valley and the farm-level factors associated with that outcome. Specifically, we used results from a survey of farmers to test whether farm role (manager and/or owner) or peer influence is associated with adoption of on-farm practices that benefit biodiversity.

Farmers' tenure arrangements may influence their time horizons. Farmers who own the land they cultivate have incentive to invest in practices that may not show returns in the near term, thus lowering their discount rate (Soule et al. 2000). This position contrasts with that of renters and non-operating owners looking for returns over the short time frame of farmland leases (Ranjan et al. 2019). These lease terms, which are often only 1 year in the USA, create insecurity for both parties, thus reducing incentives to invest in biodiversity practices that may disrupt the current year's revenue.

Farmers' responses to information from their peers can reflect their social preferences. For one, valuing information from or about others indicates a sensitivity to social influence (Abrahamse and Steg 2013). Since managing for biodiversity is a contribution to a public good, engaging with peers and trusting them for information may also facilitate cooperation and reciprocity (Fehr and Fischbacher 2002). Biodiversity tends to increase when beneficial agricultural practices extend across farm boundaries, meaning coordination with nearby farmers can improve also outcomes.

We hypothesized that farmers who own and operate their farms (*owner-operators*) and farmers who highly value information from other farmers (*peer influence*) are more likely to adopt biodiversity management practices. To test these relationships, we used data from a survey of California farmers that assessed management practices and opinions of wildlife (see Table 2). A detailed description of the survey can be found in Kross et al. (2018), who found that farmers' perceptions of bats and birds were correlated with the management practices they used to attract or deter wildlife. On average, women had more favorable opinions of wildlife than men, and organic farmers viewed wildlife more positively than conventional farmers (Kross et al. 2018). A copy of the survey can be found in Supplemental Material (Online Resource 1).

Methods

The survey was mailed to 500 farmers randomly selected from the County Agricultural Commissioner's Office registers in each of five counties in central California (Butte, Sacramento, Solano, Sutter, and Yolo). An identical online version was also made available and post hoc analysis showed no significant difference in responses between the two outreach methods (Kross et al. 2018).

The survey asked farmers to report on their perceptions of the ecosystem services and disservices on the farm from perching birds, bats, and birds of prey. Farmers also reported on the use of common biodiversity management practices, as well as their source of information about such practices, their interest in having wildlife on their farm, and whether they had ever participated in five major conservation programs: Environmental Quality Incentives Program (EQIP), Conservation Reserve Program (CRP), Conservation Stewardship Program (CSP), Wetlands Reserve Easements (WRE), and Organic Certification. Farmers provided demographic information, including age, gender, education, percent income from farm, and farm role.

The survey also included questions related to farmers' tenure arrangements and information sources

Table 2 Description of variables in California case study

Variable	Description	Values	Percent	Total respondents
Biodiversity management	Number of practices adopted[a]	Native grasses	47	118
		Cover crops	43	
		Wildflowers	39	
		Hedgerows	38	
		Wetlands	19	
		Other	11	
		None	22	
Owner-operator	Whether the farmer owns and operates her/his farm	Farmer is both owner and manager	76	122
		Farmer is either owner or manager	24	
Peer influence	Whether the farmer highly values information from peers about wildlife and wildlife management	Information from other landowners and growers is very useful in decision-making	36	120
		Information from other landowners and growers is not useful, useful, or not used	64	
Program participation	Currently or previously participated in government programs (EQIP, CRP, CSP, WRE, and organic certification)	Yes	48	122
		No	52	
Wildlife interest	Level of interest in having wildlife habitat on land	Very interested	49	120
		Somewhat/not interested or unsure	51	
Age	Age of farmer	60 years old and older	51	121
		Under 60 years old	49	
Gender	Gender of farmer	Female	26	113
		Male	74	
Education	Level of education received	High school	9	117
		College	68	
		Graduate school	23	
Farm dependence	Percent of income that comes from farm		65 (40)[†]	120

[a] The values of specific biodiversity management practices are shown here to provide descriptive statistics; the variable itself is simply the count of practices. Because farmers have adopted multiple practices, the percentages do not sum to 100

[†] Mean (standard deviation)

for making decisions about wildlife management. Farmers reported their role on the farm: *owner-operators* are those who both own and manage their farms, rather than either owning or managing the farm. Those who placed a high value on information from peers about wildlife and wildlife management (rating this information as "Very Useful") were considered sensitive to *peer influence*.

The outcome measure was the number of biodiversity management practices that farmers reported adopting, which included cover crops, hedgerows, native grasses, wetlands, wildflowers, or "other." These practices can provide habitat and connectivity for a variety of species and have shown to increase biodiversity in agricultural systems (Kremen and Merenlender 2018).

To test whether biodiversity management was more likely among farmers who are owner-operators or influenced by their peers, we used the nonparametric Mann-Whitney *U* test, which accounts for the nonnormality of our outcome distribution and smaller sizes of our subgroups. We modeled the decision to adopt biodiversity management practices using ordinal logistic regression to better estimate this relationship and account for other factors. We included as covariates participation in government programs, interest in having wildlife on farm, proportion of income from farm, and farmers' gender and level of education. We also conducted a sensitivity analysis for an alternative classification of *peer influence* that included both respondents who found peer information "Very Useful" and those who found it "Useful."

Results

Our survey received 122 responses from farmers who are majority male (74%), at least 60 years old (51%), have a college education (68%), and who rely on their farm for most of their income (mean = 65%, sd = 40%). About half of the sample have participated in at least one of the five major conservation programs listed in the survey (48%) and are very interested in having wildlife on their farm (49%). Table 2 provides a complete list of variables and their distribution in the sample.

Native grasses are the most commonly adopted biodiversity management practice, followed by cover crops, wildflowers, hedgerows, wetlands, and "other." Those who selected "other" indicated they adopted riparian buffers, ponds, conservation tillage, and rotational grazing. On average, farmers have adopted two biodiversity management practices (Fig. 1), although 22% of all respondents have not adopted any practices.

Among respondents, 76% were categorized as owner-operators and 36% were considered influenced by peers. Figure 1 shows the distributions and median values of biodiversity management practices according to these factors. Mann-Whitney tests indicate farmers who are more influenced by their peers also adopt more biodiversity management practices ($W = 1007$, $p < 0.01$), but we find no difference in management according to farmers' role on the farm ($W = 1216$, $p = 0.64$).

An ordinal logistic regression model estimates that peer influence, participation in government programs, and interest in wildlife all predict the adoption of biodiversity management practices (Table 3). Farmers who highly value information from peers are three times more likely to manage for biodiversity than those who do not, given that all other values in the model are held constant (OR = 3.11, $p = 0.01$, 95% CI of OR 1.36–7.22). We do not observe a relationship between a farmer's role as owner-operator and biodiversity management ($p = 0.74$, 95% CI of OR 0.37–2.06).

A sensitivity analysis of the cutoff for peer influence suggests a positive but not statistically significant relationship between biodiversity management and rating peer information as "Useful" or "Very Useful" ($W = 880$, $p = 0.18$; OR = 2.05, $p = 0.13$, 95% CI of OR 0.82–5.24).

Discussion

These results show that farmers who highly value information from their peers are more likely to use practices that benefit biodiversity. The direction of the relationship is supported by behavioral science research on social preferences: as farmers communicate with each other they can share information about their contributions to a public good, which may increase cooperation (Banerjee et al. 2017), and improve reputation within groups that value those contributions (Banerjee and Shogren 2012). Other research in this region has also found peers to be an important source of information for farmers (Lubell et al. 2014; Garbach and Long 2017).

The importance of social influence in biodiversity management has implications for the Central Valley landscape and, ultimately, the species and services that benefit from these practices. First, because encouraging on-farm biodiversity can deliver public benefits, evidence that social factors matter for decisions about managing for biodiversity suggests a sort of alignment between action and impact. If sharing occurs between farmers who are spatially proximate, this pattern could aggregate across the landscape to increase connectivity and biodiversity outcomes. Some biodiversity management practices, such as prairie strips, produce benefits that increase nonlinearly as more farmers adopt them (Schulte et al. 2017). Moreover, the positive relationship between social influence and adoption of biodiversity management practices indicates that, for the sampled population, there are pro-biodiversity social norms. This is promising for increasing biodiversity and ecosystem services in this heavily cultivated region, since social norms are powerful behavior-change levers (Nyborg et al. 2016).

Perhaps unsurprisingly, participation in government programs and interest in wildlife are also positively associated with biodiversity management. The programs listed in the survey require an agreement or contract in which farmers promise to deliver some environmental action (Vaughan and Skinner 2008). If these actions are the adopted biodiversity management practices, then government programs may be delivering desired behaviors. The positive relationship between interest in wildlife and biodiversity management suggests that farmers in our sample are acting in accordance with their preferences.

The lack of a relationship between farm role and biodiversity management in our study is perhaps a function of our sample. For one, we do not have information on the specifics of tenure arrangements beyond respondent's farm role. If the renter and non-operating landowner respondents in our sample have long lease terms

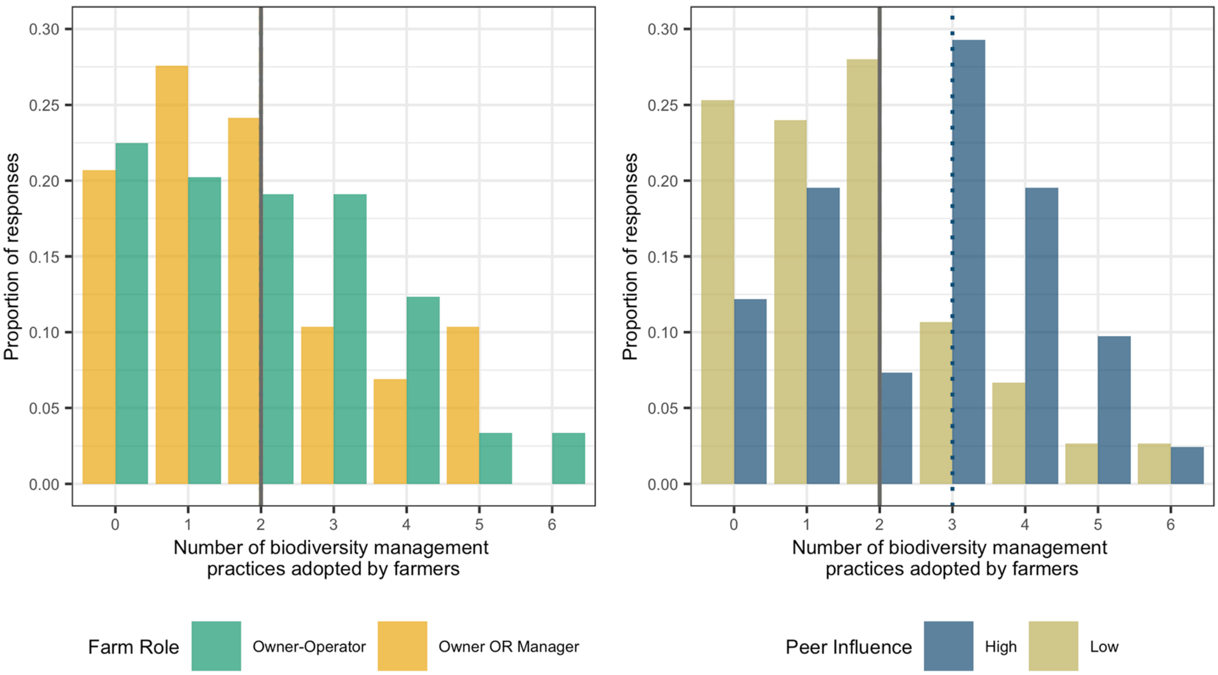

Fig. 1 Distribution of biodiversity management practices in California survey sample according to farm role (left) and peer influence (right). Biodiversity management practices include wildflowers, native grasses, cover crops, hedgerows, wetlands, and "other." The solid gray lines on each graph represent the median value for the sample (two practices). The dashed and dotted lines represent the median values for the groups matching that color in the plot legend. Note: both median values for farm role are equal to two, and the median value for Low peer influence is two

or legacy plans, they may have sufficient incentives to invest in biodiversity practices. Or, if owners have different discount rates than managers, then the aggregation of the two could offset their effects. There are not enough managers and owners in our sample to test these groups individually. We are also unable to discern from this survey whether farmers display consistent time preferences (i.e., some may want to adopt biodiversity management practices but keep delaying implementation).

Table 3 Model results from ordinal logistic regression. Dependent variable is number of biodiversity management practices adopted by farmers. Odds ratio indicates a change in the proportional odds of adopting biodiversity management practices for a one-unit change in that variable, holding all other variables in the model constant

Variable	Odds ratio	CI low	CI high	*p* value
Owner-operator	0.87	0.37	2.06	0.74
Peer influence	3.11	1.36	7.22	0.01
Program participation	2.29	1.07	4.95	0.03
Interest in wildlife	7.95	3.54	18.74	<0.01
Dependency on farm income	1.00	0.99	1.01	0.52
Age (60 or older)	1.21	0.57	2.59	0.62
Female	1.08	0.46	2.55	0.85
College education	0.70	0.23	2.14	0.53
Graduate education	1.20	0.57	2.52	0.63

Note: Odds ratio is the exponentiated coefficient from the ordinal logistic regression model

CI, 95% confidence interval

Compared to the study sample, the broader population of California farmers is similar in age (average 60 years old), but less male (63%), less likely to be an owner-operator (67%), and less likely to rely on their farm as the primary source of income (48%) (USDA NASS 2019). Data from the 2017 Census of Agriculture, 2016 Certified Organic Survey, and Farm Bureau (2019) indicate about 17% of California farmers have participated in the selected government programs. This proportion is considerably lower than that of survey respondents, of whom nearly half have participated in one program. This discrepancy suggests that the pro-conservation social norms that appear prevalent in the sample may be unique to this subset of the population who is more likely to participate in conservation programs than the broader farmer population.

Integrating behavioral science into biodiversity conservation in agricultural landscapes

Behavioral science shows how human behavior consistently defies traditional economic expectations, upon which many behavior-change interventions are based. Recognizing the importance of these factors offers new options that expand the toolbox for changing behavior. Indeed, we are beginning to see interest from environmental policymakers and researchers. The European Commission's report on the Common Agricultural Policy (2017) explicitly calls out the role of behavioral factors, including cognitive biases and social influence, as relevant to addressing environmental challenges in agriculture and rural areas. Scientists are considering the role of cognitive biases in adaptive natural resource management and conservation planning (Iftekhar and Pannell 2015; Catalano et al. 2018). Drawing from the previous two sections, we suggest areas where future research on farmer behavior and agri-environmental program design may improve biodiversity management.

Leverage social influence through peers and public recognition

Social influence is a promising lever to address farm management for biodiversity. Leveraging peer information and public recognition has increased contributions to public goods in other domains, such as resource use and charitable giving (Kraft-Todd et al. 2015). Information about neighbors' conservation behavior has shown to increase spatial coordination of land management in laboratory experiments (Banerjee et al. 2014). Farmers in our case study were more likely to adopt biodiversity management practices if they leaned on their peers for information. Future research should employ experimental methods that might identify the causal effects of such information on management. While behavioral science theory and evidence suggest public recognition motivates pro-social behavior, more evidence on land management decisions would be useful to programs that are already offering such incentives for participation.

Investigate time horizons and make it easy to follow through

The temporal disconnects between the costs and benefits of land management that develop over long time scales will always work against nonmarket values of biodiversity. A better understanding of time horizons, whether through tenure arrangements, legacy planning, or other mechanisms that encourage long-run thinking, could help address this challenge. Results from our case study suggest no difference in biodiversity management between farmers who manage and own their land, compared to those who do either. Yet we were unable to measure more specific factors that could affect time horizons or determine whether some farmers intended to adopt biodiversity management practices but had failed to follow through, thus exhibiting present bias. Future research should explore whether and how much present bias might interfere with biodiversity management. For example, sending farmers simple reminder letters increased re-enrollment in the Conservation Reserve Program (Wallander et al. 2017). Reminders, commitments, and other efforts that make it easier to follow through with intentions may increase biodiversity management among interested farmers.

Consider behavioral responses to complexity, uncertainty, and risk

While biodiversity outcomes are inherently complex, recognizing and reducing the complexity of adopting beneficial management practices could encourage action. One strategy might be intentionally designing programs that recognize the way people evaluate options. The "choice architecture" of a decision, including default settings, reference points, message framing, and other features, influences the way options are perceived and evaluated (Sunstein 2015). When possible, test how changes to these features change behavior, such as automatically selecting all conservation practices and asking farmers to deselect those they will *not* adopt. Employing narratives to communicate science may also help convey the benefits of increasing on-farm biodiversity (Martinez-Conde and Macknik 2017). For example, translating statistical information on climate risk and uncertainty into concrete experiences could increase farmers' understanding (Marx et al. 2007). Future research could explore which types of narratives are most compelling and how to best leverage them to facilitate understanding of biodiversity benefits. Furthermore, framing these benefits as strategies for avoiding crop or profit losses, for example, by increasing resilience, may target a sensitivity to losses over gains. This may be an effective approach in cases where managing for biodiversity can be a strategy to reduce losses from climate change or invasive species (Fischer et al. 2006).

Looking ahead

A first step to tackling this agenda is conducting surveys and qualitative research that incorporate a behavioral science lens. These should ask questions that illuminate how behavioral factors influence decisions, such as barriers to biodiversity management and farmers' time horizons. Results can inform experimental research that tests changes to decision environments and identifies the causal effects of factors on management behaviors. If we consider changes in land management as the product of a series of decisions that ultimately produce a difference on the landscape, those decisions may provide "intervention points" to better understand and influence behavior (Valatin et al. 2016). The Center for Behavioral and Agri-Environmental Research (CBEAR)—a consortium of major land grant and research universities—is conducting and funding field experiments in partnership with the United States Department of Agriculture, and the European Commission issued a Science and Policy Report considering the role of economic experiments in the Common Agricultural Policy (Colen et al. 2015).

Of course, there are challenges and limitations. Many land management behaviors are unobservable to researchers and outcomes unfold over long time periods. It is also possible that decisions about land are so costly and connected to deeper processes that some behavioral insights are not relevant. They are not cheap, quick, or automatic "System 1" decisions that are often targeted by simple tweaks to the choice environment (known as "nudges") (Kahneman 2003). Yet policymakers are looking to leverage behavioral insights to address more intractable challenges (Sanders et al. 2018). And while depth of experience and high stakes of farmers' decisions may reduce susceptibility to biases, other profit-driven firms can be subject to the behavioral factors discussed (Armstrong and Huck 2010). Although behavioral nudges may be insufficient to change many land management practices, a better understanding of the factors that influence judgment and decision-making can improve program design and delivery to reduce unnecessary barriers.

Increasingly, conservationists are looking to working lands to encourage and steward biodiversity and ecosystem services (Fischer et al. 2006; Kremen and Merenlender 2018). Farmers, ranchers, and forest landowners make decisions about the management of their properties that aggregate to broader, often non-linear impacts on the landscape. The cognitive biases and social preferences that often influence human behavior may influence plot-level decisions to manage for biodiversity and inform more effective programs that deliver landscape-scale conservation.

The factors discussed herein are inherent to the challenge of increasing biodiversity and other public goods from private lands. Complexity, uncertainty, risk, temporal lags, and social interactions may always complicate efforts to change land manager behavior. Yet we are gaining a better understanding of how people manage these factors and how they shape behavior. Bringing behavioral science into conservation research, programs and policies may help make progress towards addressing biodiversity loss and maintaining the services private lands provide to society.

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