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European farmers' incentives to promote natural pest control service in arable fields

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ABSTRACT

Integrated pest management (IPM) is widely encouraged among the European Union (EU) member states. The successful adoption of IPM techniques requires strong farmer motivation and participation. However, few studies have explored EU farmers' incentives to promote natural enemies of crop pests in the fields, and none have addressed how this could be influenced by farmers' recognition of natural pest control service. Based on interviews among arable farmers involved in an EU funded agri-environmental project across seven member states, natural pest control was perceived to be a less important contributor to crop production than soil fertility and pollination. Preferences toward managing semi-natural habitats for natural enemies were also relatively low, while insecticides were commonly used among participants. Ordinal logistic regression indicates that farmers' decision to promote natural pest control was positively associated with the perceived importance of this ecosystem service for crop production. However, they expressed a relatively low confidence in the pest control efficacies of natural enemies compared with insecticides, especially under high pest damage levels. Farmers with greater income have more financial flexibility to adopt either pest control method. The environment surrounding a farm may also influence its owner's willingness to promote natural pest control.

1. Introduction

Since Stern et al. (1959) introduced the concept of integrated pest management (IPM) as 'applied pest control which combines and integrates biological and chemical control', this method has gradually gained recognition worldwide as a key element in more sustainable agricultural systems (Barzman et al., 2015; Birch et al., 2011). Although its definition varies among studies and organizations (Bajwa and Kogan, 2002), the key message is that IPM is a systemic approach which encourages the integration of multiple methods to control pests in a 'safe, cost-effective, and environmentally friendly manner' (Parsa et al., 2014).

IPM is also highly encouraged under the 'EU Pesticide Package', a suite of European Union legislation (European Union, 2009a,b,c,d). Member states are required to develop National Action Plans to support their professional pesticide users in following the eight general principles of IPM (European Union, 2009b,c). The first principle (prevention and suppression) stresses the importance of protecting and enhancing natural pest control in the fields (European Union, 2009b).

Indeed, natural pest control is an important ecosystem service in the agricultural sector, which could help suppress pest damage and, by reducing the unnecessary insecticide inputs, reduce incidence of pest resistance (Power, 2010). Its value towards crop protection has been characterised through field experiments (Safarzoda et al., 2014; Thies

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et al., 2011), ecological modelling (Jonsson et al., 2014) and economic evaluation (Naranjo et al., 2015; Zhang et al., 2018). In this study, ‘pests’ referred to are animal pests, and natural enemies as the related species that target these pests.

Natural pest control is negatively influenced by the on-going agricultural intensification (Crowder and Jabbour, 2014), either through a subsequent increase in pesticides (especially insecticides) (Geiger et al., 2010), or the loss of (semi-) natural habitats from cropland expansion (Zhao et al., 2015). To enhance the contribution of this ecosystem service to crop protection, the EU Framework Directive 2009/128/EC has provided guidelines on using insecticides strategically: e.g., monitoring pest populations in the fields and using action thresholds to determine applications (Hallett et al., 2014). Also, as an important tool to conserve biodiversity, the agri-environment schemes (AES) have provided EU farmers options to establish/manage semi-natural habitats on their farmland (Batáry et al., 2015). This has shown positive effects on promoting natural pest control (Holland et al., 2016): e.g., hedgerows (Stutz and Entling, 2011), beetle banks (Collins et al., 2002), and cover crops (Aguilar-Fenollosa et al., 2011).

Nonetheless, the successful adoption of these techniques requires strong farmer participation, which is also an important element in the IPM regime (Junge et al., 2009; Lefebvre et al., 2015). However, knowledge gaps remain in understanding EU farmers’ incentives to apply related techniques to promote natural pest control in the fields (Lefebvre et al., 2015). Although numerous studies have shown natural pest control is valuable for sustainable agriculture (Letourneau et al., 2009), few have examined whether it is valuable from a farmer’s perspective (Segura et al., 2004). To our knowledge, no studies have analysed the influence of farmers’ perceptions of natural pest control on their decision-making in promoting this ecosystem service.

Based on an interview survey with arable farmers in seven EU countries, this study assesses the potential factors influencing farmers’ decisions on whether to promote natural pest control in their fields. In particular, it focuses on how farmers’ perceptions of natural pest control service influence their conservation actions. In parallel, the potential factors influencing farmers’ decisions on using insecticides are analysed.

2. Methods

2.1. Interview area and process

To gather relevant information on farmer perception and management, 85 farmers participating in the EU funded LIBERATION (Linking farmland biodiversity to ecosystem services for effective eco-functional intensification, www.fp7liberation.eu) project across Germany (11 participants), Hungary (18), Italy (13), Netherlands (20), Poland (10), Sweden (5), and the UK (8) were face-to-face interviewed. Farmers were recruited from the farmer networks associated with the research institutes involved in the LIBERATION project in each country. The interviewees represented the farm businesses who provided field sites to support experimental work within this project, which aims to quantify the contribution of multiple ecosystem services (e.g., natural pest control) towards crop production, and to analyse the effectiveness of environmental management practices (e.g., hedgerows) for promoting these ecosystem services. The participants were a combination of farm owners (82%), managers (27%) and tenants (18%). They were primarily arable farmers, and grew mostly wheat (99%), maize (45%), sugar beet (42%), and oilseed rape (35%; Appendix A). The interviews were conducted in the autumn and winter of 2014, after field sites were selected and initial experimental works undertaken.

2.2. Interview contents

The questionnaire (Appendix B) elicited information on farmers’ perspectives on three ecosystem services (natural pest control, pollination, and soil fertility) and disservices (pest, weed, and disease damage). For the scope of this paper, we focus on the following areas: (i) background information about the farms, (ii) preferences towards on-farm environmental management practices, (iii) perceptions of natural pest control service and pest damage.

The information about the farms included agricultural area (ha), average number of crops used in a rotation, average annual farm income (€, following a seven point scale from 1 = loss through to 7 = > €100,000, and included a ‘Prefer not to say’ option) for the last two financial years, years of farming, whether a farm is in a designated area of environmental interest (0 = ‘No’, 1 = ‘Yes’; the following questions with the same structure also used this code), and whether a farm is involved in an agri-environment scheme (AES).

The farmers were then asked to indicate their attitudes towards 17 environmental management practices (Appendix C), covering those being implemented across the study sites and additional environmental options not implemented. This followed a three point scale: 1 = ‘Dislike’ to 3 = ‘Like’ (and also included an ‘Unfamiliar’ option).

Finally, the perceived importance of natural enemies and pest damage for crop production were captured by a four point scale, from 1 = ‘Relatively unimportant’ to 4 = ‘Very important’. The number of perceived important natural enemy and pest species on-farm were also recorded. In terms of pest management, the number of methods used to promote natural pest control (Appendix E) and whether the farmers use chemicals to manage pests were recorded.

2.3. Statistical analyses

All analyses were done using R 3.2.5 (R Core Team, 2016), with significance levels set as 0.05. Mean values and standard deviations were used to summarize the data in the tables. If a data distribution is skewed, median values were also used to present the results to take into account outliers.

Information about farms and the perceptions of natural pest control service and pest damage were compared among seven countries using a Kruskal-Wallis one-way analysis of variance by ranks (R Core Team, 2016) and related post-hoc tests (Pohlert, 2014), to account for ordinal data characteristics and difference in data distribution.

For the environmental management practices provided in the survey, those that potentially provide semi-natural habitats with forage, shelter and reproductive opportunities for natural enemies were selected and grouped by the habitat management types reviewed from Holland et al. (2016) (Appendices C&D). For multiple management practices in the same group, the average preference score was calculated to represent a respondent's opinion for this habitat type. The perceived preference for each habitat management was compared among seven countries using the same method as for the information about farms and the farmers' perceptions outlined above.

To compare the perceived preferences among habitat management types, the Skillings–Mack (Srisuradetchai, 2015) and related post-hoc tests (Pohlert, 2014) were conducted. Following the same method, the perceived importance of natural pest control was compared with the other ecosystem services and disservices in this study.

Then, ordinal logistic regressions were used to analyse the potential factors that influenced the farmers' decision to promote natural pest control (Christensen, 2015a). The response variable was the number of methods mentioned by each participant to promote natural pest control, and the potential explanatory variables were the information about the farms (Table 1) and farmers' perceptions of natural pest control service and pest damage (Table 3). Farmers' preferences toward habitat management types (Table 2) were excluded in the model, because semi-natural habitats could potentially promote multiple ecosystem services, and it is unclear whether a respondent's opinion on a habitat type is primarily related to promoting natural pest control.

Based on the Kendall's Tau b association and related post-hoc tests (McLeod, 2011; R Core Team, 2016), the initial model included all variables from Tables 1 and 3 that have statistically significant associations with the response variable (i.e., importance of natural pest control, farm income, and whether a farm was located in a designated area of environmental interest; Appendix F). Because country differences were acknowledged for several variables (Tables 1&3), the variable 'Country' was firstly included as a random effect in the initial model, but was then taken out due to its non-significance by a likelihood ratio test (Christensen, 2015b).

Then, Wald statistics (the ratio of the coefficient to its standard error) were used to test whether the coefficient of each variable in the initial model was significantly different from zero, based on the normal distribution. If so, that variable was removed. Then, the rest of the variables from Tables 1 and 3 were added to the model one at a time. At each step, each variable that was not in the model was tested for inclusion in the model, and the most significant one was added to the model. This process continued until none of the remaining variables were significant when added to the model. Model convergence and fitness were assessed (Christensen, 2015c), and McFadden's Pseudo R-Square was then estimated (McFadden, 1973). Potential factors that influenced a farmer's decision to use insecticides for crop protection were modelled following the same procedure.

3. Results

3.1. Information about farms

Based on the 85 EU farmers involved in the LIBERATION project, there were significant differences between countries in terms of farm size, with the UK participants having the greatest agricultural area (average 446 ha) and Italian the smallest (average 17 ha) (Table 1). This was also reflected in the farm income, with UK reaching the highest annual income level (average > = € 100,000), and Poland and Italy the lowest (€1-20,000). Differences also existed in terms of the agri-environment scheme (AES) participation, with UK having the most participants involved (88%), while no participants in Poland were involved. Across all countries there were similarities in the number of crops within a rotation (average three) and the number of years in farming (average 25 years).

Table 1
Pairwise comparisons among countries of the general information about the farms: mean (# of respondents; standard deviations).

	Germany	Hungary	Italy	Netherlands	Poland	Sweden	UK
Agriculture area (hectare)	94.9 (11; 70.5) ac	114.3 (18; 73.4) a	17.1 (13; 28.6) b	122.6 (20; 176.7) ac	43.7 (10; 52.8) bc	330.0 (5; 460.4) ad	446.3 (8; 178.8) d
# of Crops for a rotation	3.3 (11; 0.4) ab	2.9 (18; 0.8) b	3.3 (13; 0.9) ab	3.9 (20; 0.7) a	3.5 (9; 0.8) ab	3.4 (5; 0.6) ab	3.0 (8; 0.5) ab
Farm income	4.8 (8; 1.6) ac	4.3 (15; 2.2) ad	1.9 (13; 0.6) b	5.3 (12; 1.6) ac	2.4 (7; 0.5) bd	4.4 (5; 1.5) acd	6.6 (8; 1.1) c
Years of farming	25.3 (10; 15.5)	25.3 (18; 10.1)	29.3 (13; 9.2)	26.5 (20; 7.1)	21.8 (10; 7.8)	26.2 (5; 14.8)	26.5 (8; 18.1)
In a designated area of environmental interests?	0.09 (11; 0.3) ac	0.8 (18; 0.4) b	0.08 (13; 0.3) cd	0.0 (20; 0) ad	0.3 (9; 0.5) bcd	0.2 (5; 0.5) ac	0.5 (8; 0.5) bc
In an agri-environment scheme?	0.1 (7; 0.4) ab	0.6 (18; 0.5) ab	0.5 (10; 0.5) ab	0.5 (17; 0.5) ab	0 (7; 0) a	0.3 (4; 0.5) ab	0.9 (8; 0.4) b

Note: '#' denotes 'number'; farm income: the average annual farm income for the last two financial years, preceding the date of the survey (€, following a seven point scale: 1 = loss, 2 = 1–20,000, 3 = 20,001–40,000,…, 6 = 80,000-100,000, 7 = > 100,000); questions follow the codes of: 0 = 'No', 1 = 'Yes'; different letters within a row indicate significant differences at $p < 0.05$.

3.2. Preferences toward habitat management types

Overall, the EU farmer participants had similar preferences towards various habitat management types suggested by the AES (average opinion 'Indifferent') (Fig. 1). Preferences for the herbaceous ungrazed habitat, low-input cereal headlands, and undersowing/ cover crops were similar across countries ('Indifferent'). Italian and UK respondents expressed relatively high preferences for linear woody, grassy linear, and other AES habitats. Except for other AES habitats, Hungarian respondents expressed relatively low preference towards all options (Table 2).

3.3. Perceptions of natural pest control service and pest damage

The perceived importance of natural enemies for crop production was highest among Swedish and Italian farmer respondents (average 'Very important'), and lowest for Hungarian respondents ('Not as important') (Table 3). The average response from other countries was 'Important'. In terms of the most important natural enemies on farm, Dutch participants mentioned more species (average two) than German and UK (one). Insecticides were commonly used across all countries (average 80%). The incentives to use chemicals due to a lack of natural enemies were highest among the Dutch, Polish, Swedish and UK

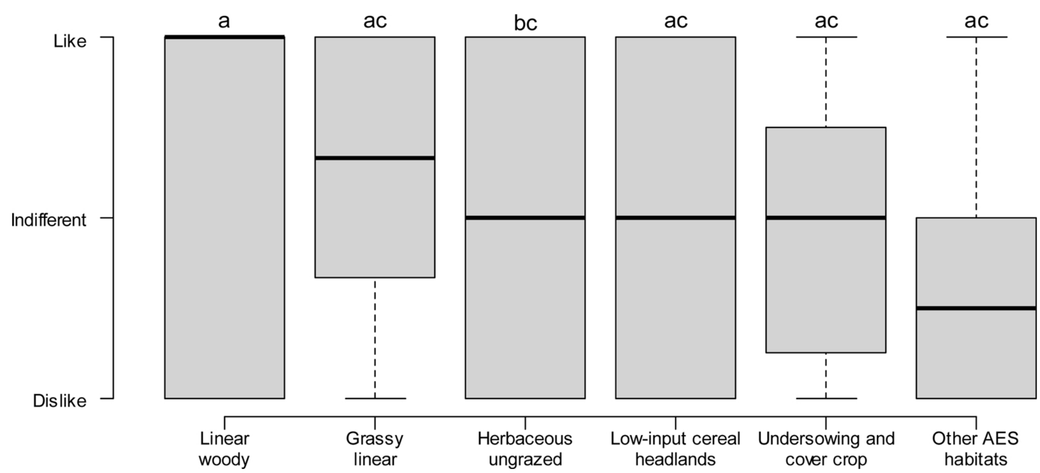

Fig. 1. Boxplot of EU farmers' preferences toward habitat management types (different letters denote significant difference between two group, with $p < 0.05$). The number of respondents is 84. The p value for the Skillings–Mack test is 0.04.

Table 2
Pairwise comparisons among countries of the preferences toward habitat management types: mean (# of respondents; # of 'Unfamiliar' option; standard deviations).

	Germany	Hungary	Italy	Netherlands	Poland	Sweden	UK
Linear woody	2.6 (9; 0; 0.9) ab	1.5 (18; 0; 0.7) c	2.8 (13; 2; 0.4) a	NA	1.6 (8; 1; 1.0) bc	2.4 (5; 0; 0.9) ac	2.9 (8; 0; 0.4) a
Grassy linear	2.0 (8; 0; 0.6) ab	1.8 (18; 0; 0.7) a	2.6 (13; 1; 0.4) b	2.5 (10; 1; 0.8) b	1.7 (9; 2; 0.8) ab	2.8 (3; 0; 0.4) ab	2.4 (8; 0; 0.5) ab
Herbaceous ungrazed	2.3 (9; 0; 1.0)	1.8 (18; 0; 0.7)	1.4 (13; 1; 0.7)	1.9 (20; 3; 0.9)	1.4 (10; 3; 0.8)	NA	2.3 (8; 0; 1.0)
Low-input cereal headlands	2.3 (8; 0; 0.9)	1.7 (18; 1; 0.7)	2.6 (13; 4; 0.7)	NA	2.0 (9; 2; 1.0)	NA	2.0 (7; 0; 1.0)
Undersowing and cover crops	2.1 (8; 1; 0.4)	1.6 (18; 1; 0.6)	2.1 (13; 3; 0.8)	NA	1.6 (9; 0; 0.7)	2.2 (5; 0; 0.6)	2.0 (8; 2; 0.7)
Other AES habitats	1.9 (9; 1; 0.6) ab	1.9 (18; 1; 0.5) b	2.1 (13; 1; 0.9) b	1.2 (10; 1; 0.5) a	1.3 (9; 0; 0.6) a	1.4 (5; 1; 0.7) ab	2.3 (8; 0; 0.7) b

Note: these variables follow a three point scale: 1 = 'Dislike', 2 = 'Indifferent', 3 = 'Like'; different letters within a row indicate significant differences at $p < 0.05$. 'NA' is where no participants have provided answers. Linear woody habitat consists of hedgerows; grassy linear consists of buffer strips, grass field margins, and beetle banks; herbaceous ungrazed consists of wildflower strips; undersowing denotes undersown spring cereals; other AES habitats consist of land set aside and over winter stubbles. For detailed summaries see Appendices C&D.

Table 3
Pairwise comparisons among countries of the perceptions of natural pest control service and pest damage: mean (# of respondents; standard deviations).

	Germany	Hungary	Italy	Netherlands	Poland	Sweden	UK
Importance of natural pest control	3.2 (9; 0.8) ab	2.1 (18; 1.0) a	3.3 (12; 1.1) b	2.7 (20; 0.7) ab	2.8 (9; 0.8) ab	3.6 (5; 0.6) b	2.8 (8; 1.4) ab
# of important natural enemies mentioned	1.0 (4; 0) ac	2.1 (15; 1.0) ab	1.0 (2; 0) abc	2.1 (17; 0.7) b	1.0 (3; 0) abc	2.0 (4; 2.0) abc	0.9 (8; 0.6) c
Importance of pest damage	3.4 (9; 0.7)	3.3 (18; 0.5)	3.2 (12; 1.0)	3.0 (20; 0.7)	3.7 (9; 0.5)	3.8 (5; 0.5)	3.4 (8; 0.8)
# of important pests mentioned	1.3 (9; 0.9) a	3.2 (18; 1.0) b	1.4 (9; 1.0) a	3.6 (18; 1.2) b	2.3 (8; 0.9) ab	3.0 (5; 3.5) ab	2.1 (8; 1.1) ab
Do you use chemicals to manage pests?	0.9 (8; 0.4)	0.8 (18; 0.4)	0.5 (11; 0.5)	1.0 (20; 0.2)	0.8 (10; 0.4)	1.0 (5; 0)	0.8 (8; 0.5)
Do you use chemicals due to lack of natural enemies?	0.4 (7; 0.5) ab	0.2 (17; 0.4) a	0.5 (6; 0.5) ab	0.8 (19; 0.4) b	1.0 (9; 0) b	1.0 (5; 0) b	0.9 (8; 0.4) b
# of ways mentioned to promote natural pest control	1.4 (9; 0.5) a	0.4 (18; 0.6) b	0.8 (13; 0.4) ab	1.4 (20; 0.9) a	0.1 (9; 0.3) b	1.4 (5; 0.5) a	1.6 (8; 1.3) a

Note: '#' denotes 'number'; importance of natural pest control/ pest damage follows the codes of: 1 = 'Relatively unimportant', 2 = 'Not as important', 3 = 'Important', 4 = 'Very important'; questions follow the codes of: 0 = 'No', 1 = 'Yes'; different letters within a row indicate significant differences at $p < 0.05$.

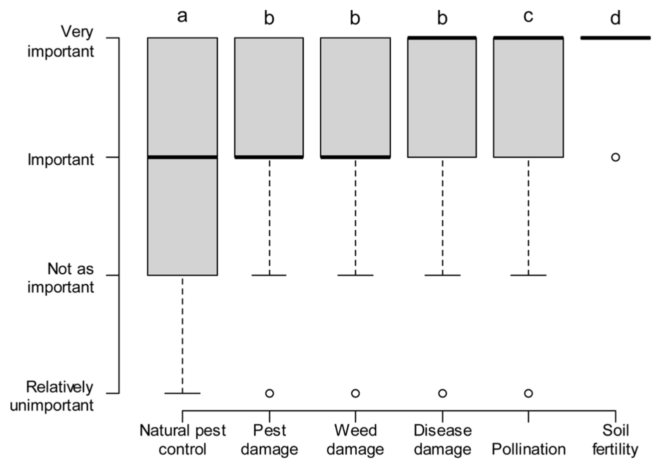

Fig. 2. Boxplots of EU farmers' perceived importance of ecosystem services and disservices on the success/failure of crop production (different letters above the boxplots denote significant differences among groups, with $p < 0.05$). The number of respondents is 83. The p value for the Skillings–Mack test is < 0.00001.

participants (average 88%) and were lowest among Hungarian (24%). The number of ways used by respondents to promote natural pest control was lowest in Hungary and Poland (median zero).

When comparing the perceived importance of different ecosystem services and disservices towards the success/failure of crop production among the member states (Fig. 2), participants perceived natural pest control as the least important (average 'Important'), followed by three types of ecosystem disservices. Soil fertility and pollination (including self and cross pollination types) received the most importance ('Very important'). The perceived importance of natural pest control also had the largest variation (from 'Not as important' to 'Very important'), whereas the others, except for soil ('Very important'), varied from 'Important' to 'Very important'.

3.4. What influences EU farmers' decision to promote natural pest control?

The coefficients (β) of the ordinal logistic regression models are log-transformed (base = e) odds ratios (Tables 4 and 5). Odds ratios (e^{β}) are achieved by comparing the odds/likelihood that an outcome will occur given an exposure, with the odds/likelihood of outcome occurring without that exposure (Szumilas, 2010). For example, the predictor 'Importance of natural pest control' (Table 4) indicates that, the likelihood for an EU farmer to promote natural pest control when he/her view on the importance of natural pest control is 'Not as important' is 13 times higher than when the view is 'relatively not important'.

Table 5
Ordinal logistic regression results of EU farmers' decisions to use chemical control (McFadden's Pseudo R-Square is 0.4).

Coefficients	β (standard error)	z value	*p*	Odds ratios (e^{β})
Importance of pest damage*				
Important	1.5 (1.2)	1.2	0.2	4.4
Very important	2.4 (1.3)	1.9	0.06	11.5
Farm income	0.6 (0.3)	2.6	0.009	1.9

Note: * Baseline category is 'Not as important'; 'Relatively unimportant' is not included because only one respondent selected this category; importance of pest damage follows the codes of: 1= 'Relatively unimportant', 2='Not as important', 3='Important', 4='Very important'; farm income: the average annual farm income for the last two financial years, preceding the date of the survey (€, following a seven point scale: 1 = loss, 2 = 1–20,000, 3 = 20,001–40,000,…, 6 = 80,000–100,000, 7 = > 100,000).

Thus, based on the 85 participants, EU farmers' decision to encourage natural pest control was positively associated with farm income and the perceived importance of natural pest control on crop production, but negatively associated with the number of perceived important pests listed, and whether a farm was located in a designated area of environmental interest (Table 4). The decision to use insecticide was positively associated with both income and a farmer's perception of the importance of pest damage on crop production (Table 5). Country effect was not significant for either model.

The predicted probabilities of the response variables were plotted against each predictor, while keeping other predictors constant at their average values (perceived importance of natural pest control = 'Important', number of important pests mentioned = 3, farm income = € 40–60,000, whether a farm is in a designated area of environmental interests = 'No').

Based on the farmer interviews, an increase in farm income (Fig. 3) decreases the probability that an EU farmer does not use any methods to promote natural pest control (zero method - denoted by the black line, from 64 to 4%), whereas the probability of taking actions increase (denoted by the green line, from 4 to 53%). Similar effects could be found for the perceived importance of natural enemies. By contrast, with an increase in the number of perceived important pests mentioned, the probability that a farmer takes actions to conserve would decrease, whereas the probability for no conservation effort increase (8 to 70%). It is also clear that (Fig. 4), with an increase in farm income and the perceived importance of pest damage to crop production, the probability of using insecticides increases.

4. Discussion

Based on interviews with 85 farmers across seven EU member states, we found that their decisions on pest control practices were

Table 4
Ordinal logistic regression results of EU farmers' decision to promote natural pest control (McFadden's Pseudo R-Square is 0.5).

Coefficients	β (standard error)	z value	*p*	Odds ratios (e^{β})
Importance of natural pest control*				
Not as important	2.6 (1.1)	2.3	0.02	13.0
Important	2.9 (1.1)	2.7	0.007	17.7
Very important	3.5 (1.1)	3.2	0.002	32.7
# of important pests mentioned	−0.4 (0.2)	−2.0	0.05	0.7
Farm income	0.6 (0.2)	3.5	0.0005	1.9
In a designated area of environmental interest?	−1.5 (0.6)	−2.4	0.02	0.2

Note: * Baseline category is 'Relatively unimportant'; '#' denotes 'number'; importance of natural pest control follows the codes of: 1= 'Relatively unimportant', 2='Not as important', 3='Important', 4='Very important'; farm income: the average annual farm income for the last two financial years, preceding the date of the survey (€, following a seven point scale: 1 = loss, 2 = 1–20,000, 3 = 20,001-40,000,…, 6 = 80,000-100,000, 7 = > 100,000); questions follow the codes of: 0 = 'No', 1 = 'Yes'.

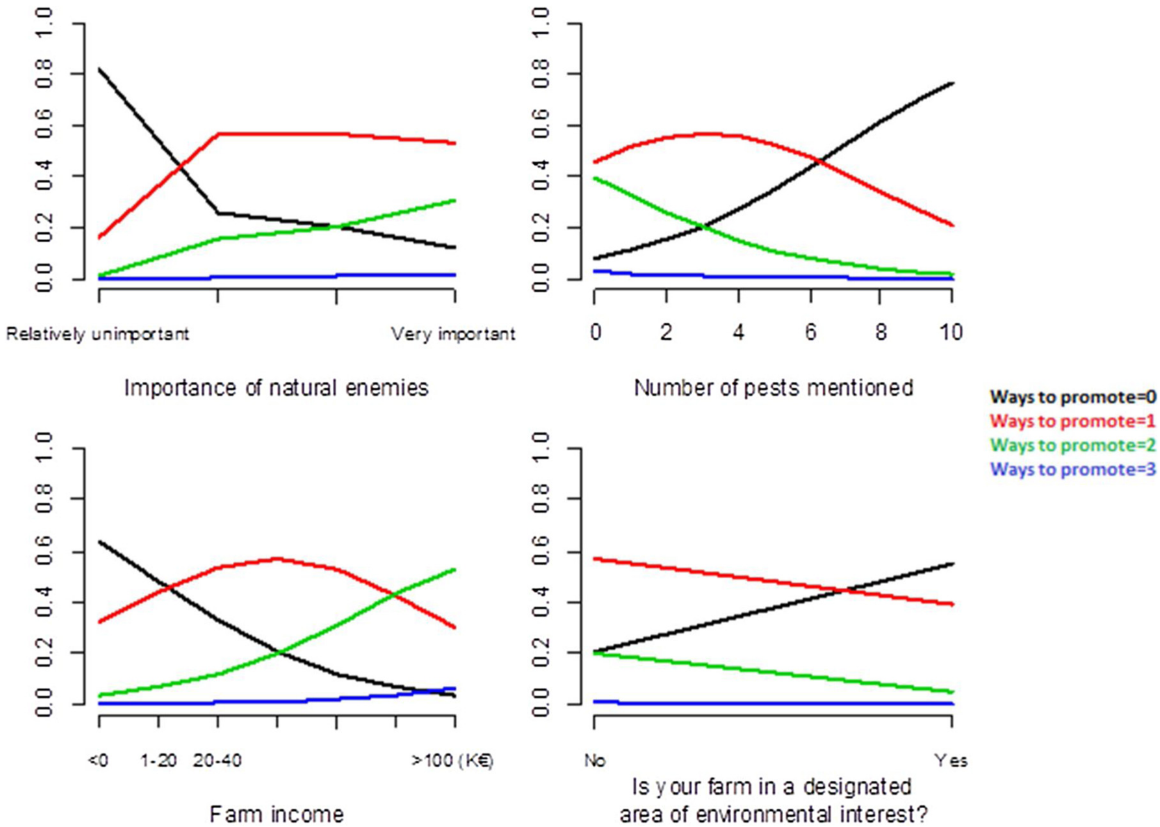

Fig. 3. The predicted probabilities of EU farmers' decision to promote natural pest control in relation to each predictor, while keeping other predictors constant at their average values. For the predicted 95% confidence intervals see Appendix G.

associated with psychological, financial, and environmental factors. For the first time, we quantified the influence of farmers' perceptions of natural pest control service and pest damage disservice on their behaviour in pest management. This is also one of the first studies that analysed how attitudes toward an ecosystem service would influence decision-making at an individual level (Lamarque et al., 2014; Poppenborg and Koellner, 2013).

The positive association between the perceived value of an ecosystem service (in this study, natural pest control) and decision-making in related conservation action (promoting natural pest control in the cropland) has also been illustrated in Poppenborg and Koellner (2013). From the questionnaire design (Appendix B), a participant's evaluation of the importance of natural pest control service was based on its perceived contribution to crop production, and Fig. 2 highlights a limited

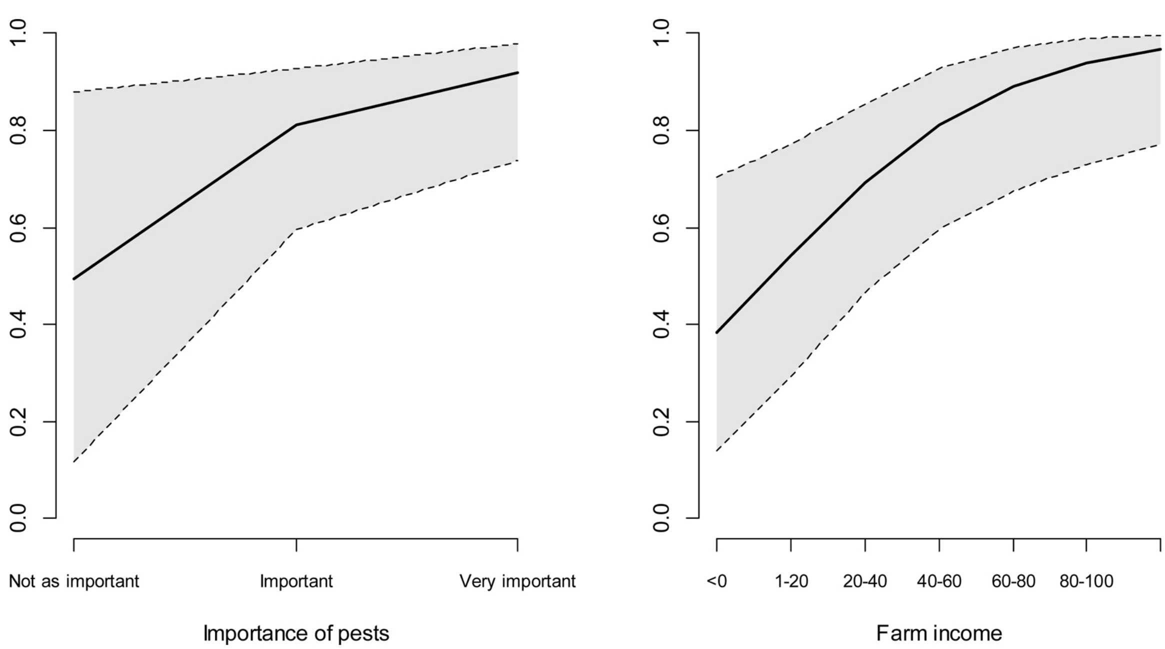

Fig. 4. The predicted probabilities of EU farmers' decision to use insecticides in relation to each predictor, while keeping other predictors constant at their average values. Grey areas denote 95% confidence intervals.

recognition for this ecosystem service compared with others (e.g., soil fertility). This issue has also been revealed in other studies (e.g. Heong and Escalada, 1999; Wyckhuys and O'Neil, 2007). One possible reason is that, despite some related reviews demonstrating the contribution of crop protection by natural enemies (Letourneau et al., 2009; Symondson et al., 2002; Thies et al., 2011), there are relatively large variations among individual studies. These variations are the product of a number of factors: e.g., climate (Abbott et al., 2014), landscape structure (Chaplin-Kramer et al., 2011; Martin et al., 2013), and farm management (Zhao et al., 2015). It is thus difficult to devise an experiment that would provide sufficient, observable evidence that natural pest control would contribute to a crop production system in a certain location that matches any individual farmer's situation. This potentially decreases EU farmers' confidence towards this ecosystem service.

However, the perceived value of natural pest control could potentially be increased if other contributions by this ecosystem service were taken into account: e.g., reduction in insecticide resistance, improvement in workers' health, and protection of the wider environment (Lefebvre et al., 2015; Naranjo et al., 2015). Consequently, EU farmers' willingness to promote natural pest control would be increased.

This study revealed a negative association between the number of perceived important pest species mentioned by a farmer participant with his/her decision to promote natural pest control in the fields. The association test also showed a negative link between the perceived importance of pest damage to crop production and decisions on the conservation actions (Appendix F; Kendall's tau b test = −0.16). This may further justify farmers' relatively low confidence in sufficient crop protection by natural enemies, especially when pest damage is at a high level. Indeed, limits of natural pest control under high pest damage levels have been demonstrated by field experimental studies (Collins et al., 2002). By comparison, a positive association between the perceived importance of pest damage and decision to use chemical control was revealed (Fig. 4). Since their introduction, insecticides have proved their effectiveness in controlling pests and improving crop production worldwide (Cooper and Dobson, 2007). They are also commonly used during the post-harvest storage phase (Waterfield and Zilberman, 2012). However, it should be noted that using chemicals does not guarantee success: failures have occurred partly due to the development of insecticide resistance in pests (Sparks and Nauen, 2015). Insecticide efficacy could also be negatively influenced by weather conditions and the timing and method of application. Nonetheless, it is economically reasonable for farmers to apply insecticides, especially when they perceive pest damage to be high (Popp et al., 2013). They would also apply insecticides for insurance purposes to reduce potential risk of crop loss by pests (Cooper and Dobson, 2007).

The negative association between the number of perceived important pest species with the decision-making on conservation, however, may also indicate that farmers have relatively low confidence that the related environmental management options could enhance natural pest control in croplands. This could be reflected by the relatively low preference levels ('Indifferent') with large variations among the semi-natural habitat management types (Fig. 1). Indeed, although mounting evidence suggests that semi-natural habitats could support natural enemies by providing food resources and shelters (Bianchi et al., 2013; Holland et al., 2016), limited studies have been conducted to show that they could enhance natural enemy densities in the adjacent crop fields and/or increase natural pest control efficacies (Dicks et al., 2016; Holland et al., 2016; Pywell et al., 2015; Straub et al., 2008).

Studies have found that farmers' perception of risk could influence their behaviour in pest control (Milne et al., 2016), and that farmers with more income are on average less risk adverse (Bar-Shira et al., 1997). This could partly explain the positive association between farm income and farmers' decision to adopt related environmental managements to promote natural pest control service (Allahyari et al., 2016; Chandran, 2014). Indeed, higher income gives farmers a greater ability to bear the risk of potential financial loss from a less effective management option. It also allows farmers to have more flexibility to invest in related technologies in the first place (e.g., by purchasing related equipment and hiring expertise) (Cullen and Warner, 2008; Lefebvre et al., 2015; Waterfield and Zilberman, 2012). More financial flexibility may also play a positive role in farmers' decision to use insecticides (Fig. 4; Anang and Amikuzuno, 2015). On the other hand, effective insecticides could help maintain or increase crop yields, thus deliver more income to the users (Cooper and Dobson, 2007; Popp et al., 2013).

Environmental factors may also influence a farmer's decision-making processes (Singh and Dhillon, 2004; Wyckhuys and O'Neil, 2010). It is not clear why an EU farmer's decision to encourage natural pest control was negatively associated with whether his/her farm was located in a designated area of environmental interest (e.g., nature reserve). One possible reason is that a farm located in such protected locations is potentially adjacent to already well-structured (semi-) natural habitats, thus reducing the willingness/needs of its owners to take conservation actions. Another reason could be that farm owners in these locations have specific restrictions on managing the land (JNCC, 2016).

In addition to the factors assessed in this study, many other factors may also influence farmers' behaviour in pest control. One of the most important is the individual knowledge level. Studies show that by gaining more awareness of the existence and role of natural enemies in the fields, farmers become more capable to adopt alternative pest control techniques (Segura et al., 2004; Wyckhuys and O'Neil, 2007). Other potential influences include: farmers' environmental awareness, accessibility to information, and market interventions (Lefebvre et al., 2015). Because the farmer participants in this study were involved in an agri-environmental project, they might be more aware of the natural pest control service and/or environmental protection than the general EU arable farmer population. Thus the average EU arable farmers' recognition of this ecosystem service and related conservation options might be even lower.

Compared among the seven EU countries, Hungarian participants expressed relatively low recognition of natural pest control service and low willingness to promote this ecosystem service (Table 3). This might be partly due to the less developed IPM policy compared with other countries (e.g., according to the Hungarian National Action Plan, regional/national pest forecasting systems have not been put in place; European Commission, 2017a; Ministry of Rural Development, 2013). Hungarian participants also showed relatively low preference for habitat management types suggested by AES (Table 2). One reason could be that as a relatively new EU member state, Hungarian farmers have less experience and/or less support historically from the government to adopt various management options. This may be reflected by the relatively low AES expenditure in Hungary among the seven countries (sixth place; Fig. 1 in Batáry et al., 2015).

Although all Polish farmers interviewed agreed that the reason to use insecticides is because of a perceived lack of natural pest control in the fields, only one farmer mentioned one method to promote this ecosystem service (Table 3). This may partly result from the less developed AES policy (similar to Hungary), which constrained farmers' conservation options. In comparison, the Italian government has made extensive use of the Rural Development funds to develop AES (third place; Batáry et al., 2015; Defrancesco et al., 2008). Farmers also receive additional payments to keep detailed records of crop production (European Commission, 2017b). This is reflected in the participants' relatively high preferences toward various habitat management types (Table 2) and high recognition of natural pest control (Table 3).

Sweden, UK, Germany and the Netherlands have relatively long histories of implementing IPM (since 1980s, 1990s, 2004, and 1990s respectively; European Commission, 2017b) and AES (1986, 1987, 1985, and 1981 respectively; Batáry et al., 2015), which may partly explain participants' relatively high willingness to use alternative pest control methods. In particular, Dutch participants showed a relatively good knowledge about natural pest control (indicator: number of species; Table 3). One contributing factor might be that Dutch farmers are required to record IPM measures used in their fields (European Commission, 2017b). The Netherlands has also developed a good extension program, where farmers and other stakeholders jointly decide on matters regarding sustainable crop protection (Barzman and Dachbrodt-Saaydeh, 2011).

Also, because of the variations in the agricultural systems and social-economic factors among EU member states, the drivers influencing a farmer's decision in pest management could differ by countries. These differences could potentially be identified with a larger sample size. Indeed, to better implement IPM and related conservation policies in the EU, more research should be conducted to compare farmers' attitudes to these aspects among the member states (Babai et al., 2015; Lefebvre et al., 2015).

5. Conclusion

Based on the interviews among EU arable farmers who participated in an agri-environmental project, this study analysed farmers' incentives to promote natural pest control in the fields. Although strongly encouraged under the EU IPM legislation, farmer participants expressed a relatively low recognition for this ecosystem service, and low preference towards the related AES habitat management types. On the other hand, using insecticides was a consensus among the member states. EU farmers' decision to promote natural pest control was positively associated with their attitudes toward the perceived importance of this ecosystem service on crop production. However, they expressed a relatively low confidence in the effectiveness of pest suppression by this mechanism, especially under high pest damage levels. Farmers with greater income would have more financial flexibility to adopt related conservation actions. The environment surrounding a farm may also influence its owner's willingness to promote natural pest control. More field studies should be conducted to analyse the efficacy of natural pest control and the effectiveness of related conservation management options for the major crop production systems that are relevant for the EU arable farmers. Future work should also explore the drivers of potential differences in farmers' uptake of these conservation actions within and between the member states.

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Appendices.

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