Received: 21 September 2017 | Accepted: 18 January 2018
DOI: 10.1111/1365-2664.13119

RESEARCH ARTICLE

Journal of Applied Ecology BRITISH ECOLOGICAL SOCIETY

Crop rotation and agri-environment schemes determine bumblebee communities via flower resources

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Funding information
European Union and Estonian government under the Technical Assistance measure of the 2007–2013 Rural Development Plan of Estonia; Estonian Ministry of Education, Grant/Award Number: IUT36-2; German Research Foundation, Grant/Award Number: DFG BA4438/2-1; Economic Development and Innovation Operational Programme of Hungary, Grant/Award Number: GINOP-2.3.2-15-2016-00019

Handling Editor: Lucas Garibaldi

Abstract

1. In many parts of the world, farmland pollinators decreased significantly during the last half of the 20th century mainly due to land-use changes and agricultural intensification.
2. We studied the effect of different typical crop rotations and agri-environment schemes (AES) on bumblebee diversity in Estonia. We compared species abundances between four crop rotation types (cereal rollover [no change from 1 year to the next], cereal to mass-flowering crops [hereafter MFC], MFC rollover and MFC to cereal fields) where all counts were conducted in the second year and in three farming types (conventional farming, organic farming and environmentally friendly management).
3. We surveyed bumblebees and flower cover along 401 field margins in five consecutive years and recorded 20 species and more than 6,000 individuals. Abundances of long-tongued and threatened bumblebee species were higher at the field margins of cereal rollover fields than for the other three crop rotation types. In addition, cereal rollover field margins had higher abundances of medium colony species, generalists and forest-scrub species than MFC rollover and MFC to cereal or cereal to MFC field margins. Bumblebee species richness was higher at the field margins of both AES types than those of conventional farming. However, in general, the strongest driver of bumblebee presence was flower cover.
4. Higher bumblebee abundances in cereal rollover field margins were probably owing to a concentration effect there and/or a dilution effect into MFC fields. Both AES schemes supported increasing flower cover in field margins and thereby diversity of bumblebees, indicating positive AES impacts upon wild pollinators.
5. *Synthesis and applications*. Crop rotation and agri-environment schemes determine bumblebee richness and abundance via the availability of flower resources, but crop rotation constrains bumblebees differently based on their traits. Therefore,

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future agri-environmental policy should account for these management options. Crop rotation could be a simple, but efficient solution to increase the biodiversity of agricultural landscapes.

KEYWORDS
biodiversity, concentration effect, dilution effect, functional traits, land use, mass-flowering crops, organic management, pollinator

1 | INTRODUCTION

Bumblebees, among other pollinating insects, contribute to wild plant and crop pollination, and, therefore, to plant biodiversity and food production (Kremen et al., 2007). Pollination by bumblebees is known to increase the yields of almost 40 crops (Goulson, 2010). Thirty-five per cent of global crop production depends, to a degree, on pollinators (Klein et al., 2007), and the global annual economic value of insect pollination is estimated to be between 215 and 529 billion dollars (IPBES, 2016). Therefore, conservation of farmland pollinators is one of the key challenges of global crop production (Potts et al., 2016).

Industrial agriculture has caused remarkable declines in the diversity and abundance of native flowers and semi-natural habitats, which in turn has caused decreases of wild pollinators, particularly long-tongued bumblebees (Goulson, Lye, & Darvill, 2008). Based on a recent IUCN report, 46% of bumblebee species populations in Europe have declined (Nieto et al., 2014). Drivers of the decline in pollinators include landscape homogenization, land-use changes (e.g. the loss of semi-natural habitats and the increase in the area of cereal crops) and the increasing use of synthetic pesticides and fertilizers (Bommarco, Lundin, Smith, & Rundlöf, 2012; Goulson, Nicholls, Botias, & Rotheray, 2015; Potts et al., 2010; Winfree, Aguilar, Vazquez, LeBuhn, & Aizen, 2009). A reduction in the number of small-scale farms has resulted in a decline in crop diversity and the loss of field margins (Sutcliffe et al., 2015). Agri-environment schemes (AES), such as set-aside semi-natural habitat, organic farming and wildflower strips for pollinators, have been developed and introduced in the European Union since the late 1980s as a tool to address the negative environmental impacts, including declines in biodiversity, of large-scale agricultural intensification (Batáry, Dicks, Kleijn, & Sutherland, 2015).

Across the EU, the effectiveness of AES in terms of species conservation has been questioned owing to goals remaining unachieved as a consequence of a lack of targeting (Hole et al., 2005; Kleijn, Rundlöf, Scheper, Smith, & Tscharntke, 2011). Nonetheless, there is evidence of a positive effect of many AES upon bumblebee abundances (recently, e.g., Carvell, Bourke, Osborne, & Heard, 2015; Wood, Holland, & Goulson, 2015; Wood, Holland, Hughes, & Goulson, 2015). However, AES availability and utilization might not be enough to halt and reverse declines in bumblebees and particularly threatened species. Therefore, agricultural intensity and landscape structure are also important factors with regard to conservation efforts (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005; Tscharntke et al., 2012).

Mass-flowering crops, such as clover species and oilseed rape, are significant food resources for bumblebees and at the same time benefit from being pollinated. For example, in Northern Europe, sweet and red clover, which have deep corolla, benefit from being pollinated by long-tongued bumblebee species (Westphal, Steffan-Dewenter, & Tscharntke, 2003; Wood, Holland, et al., 2015). In addition, resource continuity (Blüthgen & Klein, 2011) is important, because mass-flowering crops are not always available to bumblebees during their life cycles. Therefore, the availability of wild flowers, especially those with deep corolla, is an important driver of bumblebee diversity and population development (Williams & Osborne, 2009; Williams et al., 2015).

There is a knowledge gap regarding how temporal land-use change affects bumblebees. To the best of our knowledge, this is the first multi-year study to evaluate the effect of crop rotation on bumblebee communities. We investigated the impact of four different common crop rotation types on bumblebee species richness and abundance, including comparisons between species with different functional traits (tongue length, threat status, colony size, habitat preference), during 2010–2014. In Estonia, crops are usually rotated every second year, for example, after being a cereal field for 1 or 2 years, there will be a rotation to mass-flowering crops or grasslands and vice versa. Hence, the overarching question is how does the type of crop rotation determine the following year's bumblebee community (species richness, total abundance and tongue length/threat status/colony size/habitat preference group abundances)? We hypothesized that bumblebee species richness and abundance are higher in the field margins of mass-flowering crops than in the field margins of cereal crops, regardless of the previous year's crop in those fields (illustrative photos are shown in Figure S1). In addition, we hypothesized a positive effect upon bumblebees of organic and environmentally friendly management compared with conventional farming. We collected data to test whether crop rotation and/or AES benefit bumblebees and to identify the possible drivers of bumblebee abundances (e.g. concentration or dilution effects depending on the crop rotation type).

2 | MATERIALS AND METHODS

2.1 | Monitoring areas

We sampled true bumblebees *Bombus* ssp. (hereafter bumblebees) as part of an ongoing evaluation of AES under the framework of the

TABLE 1 Cross-table of sample sizes by crop rotation and management types. Cereal (all rye, oat, barley, triticale and wheat fields), MFC = mass-flowering crops (pea, bean, clover, alfalfa, sweet clover species and oilseed rape)

Management type/crop rotation	Conventional farming	Environmentally friendly management	Organic farming	Crop rotation total
Cereal→cereal	86	22	9	117
Cereal→MFC	17	46	24	87
MFC→cereal	28	36	19	83
MFC→MFC	17	31	66	114
Management type total	148	135	118	401

Estonian Rural Development Plan 2007–2013 (Agricultural Research Centre, 2015). Two regions of Estonia were studied: Põlva, Võru and Valga counties (hereafter referred to as Southern Estonia; centre coordinates 57°52′N, 26°57′E) and Lääne-Viru, Järva and Jõgeva counties (hereafter Northern Estonia; centre coordinates 59°4′N, 26°12′E; a map of the study areas is available in Figure S2). These regions were selected based on differences in agricultural yields, AES uptake and landscape structure. Southern Estonia has a more diverse landscape and lower yields (average cereal yield over 2004–2013 was 2,792 kg/ha). Northern Estonia is characterized by larger fields, a more open landscape, and high yields by Estonian standards (average cereal yield for 2004–2013 was 3,011 kg/ha). Additional information about the regions, and selection of study farms, is available in Marja et al. (2014).

In each region 11 organic, 11 environmentally friendly managed (both had 5-year AES obligations with the possibility to prolong the obligation to 6 years, started in 2009) and 11 conventionally managed farms (non-AES) were surveyed, that is, 66 in total. One of the aims of environmentally friendly management scheme is to promote farmland biodiversity, with the major requirements of farmers being to allocate a minimum of 15% of arable land (including rotational grasslands) to legumes, use diversified crop rotation, take soil samples to determine optimal fertilizer requirements and create a fertilization plan, maintain/create permanent grassland field margins (2–5 m wide), not use black fallow (fallow land with bare soil, where the height of weeds does not exceed 5 cm), protect landscape elements, and limit glyphosate applications. Organic farmers followed the Organic Farming Act by not using any synthetic pesticides or GMOs, and restricting their use of most mineral fertilizers. Detailed information about AES requirements and conventional farming rules is provided in Table S1.

2.2 | Biodiversity survey and study design

Fieldwork for the evaluation of AES measures was carried out during the summers of 2010–2014. Every year, each transect was surveyed three times (once in June, July and August). The first visit was made during the 23–30 of June, the second visit from the 15 to 28 of July, and the third between the 12 and 23 of August. Bumblebees were surveyed by walking slowly along a 2-m wide and 500-m long transect, of which 400 m was permanent between years and located in field margins (usually permanent grassland strips between the field and a road/other field/ditch/forest, etc., or if the margin was narrow, occasionally also on the edge of a cropped field), with the remaining 100 m located in a field with an insect-pollinated crop (e.g. clover) if present in the crop rotation, or if not, also in a field margin. Data from these 100-m sections located in the field were not included in the analyses. Transects were divided into shorter sections differentiated by crop types. The sections were marked on a map (scale 1:5,000). During each fieldwork session, flower cover was estimated on a scale of 0–3 per whole 2-m wide transect section, where 0 = no flowers suitable for bumblebees; 1 = >0 to 1/3 of the area with flowers suitable for bumblebees; 2 = 1/3 to 2/3 with suitable flowers, 3 = >2/3 covered with suitable flowers (Marja et al., 2014). All flowering-plant species known to be used by bumblebees for foraging were classified as suitable (Table S2).

The bumblebee counts were conducted between 11.00 and 16.00 hr under good weather conditions (temperature always above 15°C, and no rain or strong wind). We mainly identified bumblebees on flowers to species in the field. If identification on flowers was impossible, individuals were caught, identified and released in the field, or on very rare occasions were retained to identify later in the laboratory. Each year, the number of each bumblebee species was summed per transect over the three counts.

To test our hypotheses, we included only bumblebees, flower cover and crop rotation data of such transect sections, which were located in the two most common types of field margins, those alongside cereals and mass-flowering crops. Cereal fields included rye, oat, barley, triticale and wheat (hereafter cereals). The mass-flowering crop fields contained legumes (pea, bean, clover, alfalfa, sweet clover spp.) and oilseed rape (hereafter MFC). Crop harvest time depends on the crop and weather conditions and varies from June to September. Legumes are typically harvested in June (first cut) and August (second cut), but sometimes cut only once in July. Winter oilseed rape is harvested at the end of July or in August, spring oilseed rape in September, cereals typically in August or at the beginning of September (depending also if it is sown in autumn or in spring). The overall sample to test our hypotheses comprised 401 transect sections, whose lengths varied between 40 and 500 m (mean 226 ± *SEM* 6 m). Sample size for each year (number of transect sections) were as follows: 2010: 80; 2011: 78; 2012: 73, 2013: 84 and in 2014: 86 transect sections (401 in total). A cross table of sample size by crop rotation and management type is given in Table 1. All other crop rotation types such as potato, short-term grassland, permanent grassland and pasture were excluded from the analysis.

Part of the bumblebee dataset, the explanatory variables management type and flower cover (years 2010–2012), is already published in Marja et al. (2014). However, in this study, we used a more comprehensive bumblebee dataset (2010–2014) that also included crop rotation types. We added management type and flower cover into the analyses, as these are important drivers of bumblebee abundances (Marja et al., 2014). Moreover, the present study investigated different bumblebee variables: abundance of bumblebees subdivided by functional groups (tongue length, colony size and habitat preference) and threat status.

2.3 | Statistical analysis

We analysed flower cover and bumblebee variables using linear mixed-effects models in R (R Development Core Team, 2016). The "lme4" (Bates et al., 2016) package for R was used to conduct all analyses. Bumblebee response variables modelled were species richness, abundance of all bumblebee species, abundance of long-tongued species (three species: *Bombus distinguendus*, *Bombus hortorum* and *B. subterraneus*), abundance of short- and medium-tongued species (all other species, hereafter short-tongued species), abundance of threatened species and abundance of non-threatened species. We analysed long-tongued bumblebees separately due to their specific ecological niche, that is, only these species can pollinate flowers with deep corollas, such as red clover and field bean. Species classified as vulnerable (hereafter threatened) in Europe under the recent IUCN list (Nieto et al., 2014) were *Bombus confusus*, *B. distinguendus*, *Bombus hypnorum* and *Bombus muscorum*. We also modelled pooled bumblebee abundances based on species' colony size (large, medium and small) and main habitat (open-land specialists, forest-scrub specialists and generalists). We used these life-history traits, because a recent study indicated that bumblebees have trait-dependent vulnerability based on landscape heterogeneity (Persson, Rundlöf, Clough, & Smith, 2015). We provide a list of the bumblebee species with classification according to tongue length, colony size, preferred habitat and threat status in Table S3.

Owing to the bumblebees being over-dispersed, we used mixed-effects models with a negative binomial distribution. The explanatory variables of main interest were crop rotation type (four factors: cereal rollover fields [rollover = no change from 1 year to the next]; cereal to MFC fields; MFC rollover fields; MFC to cereal fields) (e.g. in cereal to MFC fields, surveying was done in MFC field margin), management type (three levels: conventional; environmentally friendly management; organic farming), and flower cover (average value over the three counts per transect). Note that bumblebee response variables were always taken during the second year of crop rotation. First, we tested flower cover as a dependent variable in relation to crop rotation and management. Second, we tested all bumblebee variables against crop rotation, management and flower cover. Since we had multiple years and the study regions had different landscape structures (Northern Estonia has a simpler landscape structure than Southern Estonia), we treated year and region as crossed random factors in the model (R command: (1|year)+(1|region). As the length of transect sections ranged from 40 to 500 m, they were treated as an offset function [R command: offset = log(transect length)]. We also calculated the variance inflation factor between explanatory variables (R package "car," Fox & Weisberg, 2011) and identified no values exceeding 1.4 for any of the models, which suggests that no collinearity occurred.

3 | RESULTS

We observed a total of 6,092 individuals of 20 bumblebee species during 2010–2014 (Table S3). We provide mean values and *SEs* of investigated flower cover and bumblebee variables per transect sections length according to crop rotation and management type in Tables S4 and S5.

Flower cover was higher in organic and environmentally friendly managed field margins, compared with the margins of conventional fields, but was not related with crop rotation types (Figure 1). As an explanatory variable, flower cover was positively associated with all bumblebee groups (Figures 2–4 and Figures S3 and S4).

Crop rotation type was not related to bumblebee species richness or abundance (Figure S3). Bumblebee species richness in the field margins of both AES management types were higher compared with the margins of conventional fields. Bumblebee abundance was significantly higher in environmentally friendly managed field margins compared with those of conventional fields; no significant difference in bumblebee abundance occurred between the field margins of organic and conventionally managed fields.

Abundances of non-threatened species did not differ between crop rotation types, but abundance of threatened species was highest in cereal rollover field margins, compared with the other three rotation types (Figure 2). Bumblebee abundance of non-threatened species was significantly higher in environmentally friendly managed field margins compared with those of conventional field margins. Abundances of threatened species were higher in both AES management types field margins, compared with the margins of conventional fields.

Crop rotation type was associated with abundances of bumblebees of medium colony sizes (Figure 3). Abundance of medium colony sized species was higher in cereal rollover field margins, compared with MFC rollover filed margins. Both AES management types had higher abundances of small-sized colony species.

Abundance of open-land bumblebee species did not differ between crop rotation types. Abundance of generalist species was higher in cereal rollover field margins, compared with cereal to MFC and MFC rollover field margins (Figure 4). Abundance of forest-scrub species was higher in cereal rollover field margins compared with MFC to cereal and MFC rollover field margins. Abundances of open-land species and generalists did not differ between field margins

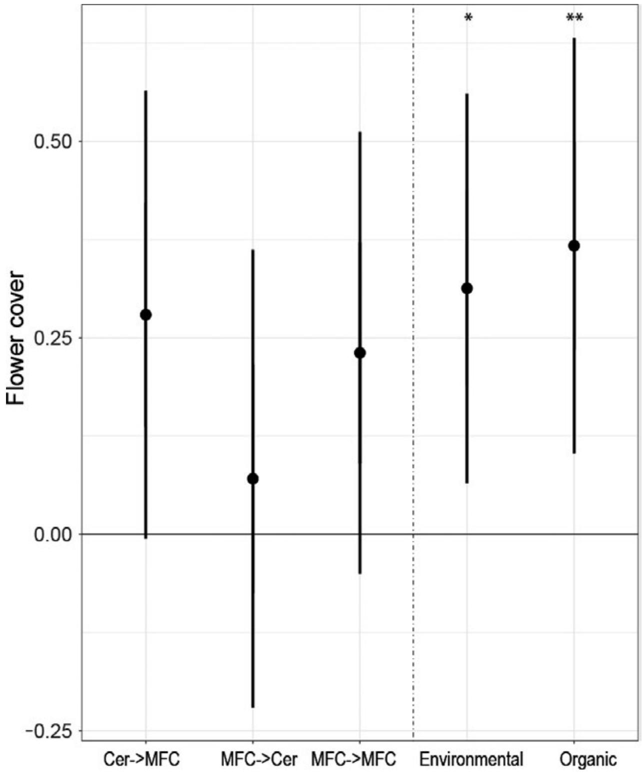

FIGURE 1 Comparison of flower cover in field margins between different crop rotation and management types. The figure shows results from linear mixed-effects models (*p*-value, lower and upper boundary of 95% CI). Indicated are effect sizes (*y*-axis) compared to the crop rotation type control group (cereal rollover field margins) and management type control group (conventional farming). The effect size is significantly different if the CIs do not overlap with zero. Asterisk symbols represent statistically significant *p*-values below .05 and .01 (* and **, respectively). Cer = cereals (all rye, oat, barley, triticale and wheat fields), MFC = mass-flowering crops (pea, bean, clover, alfalfa, sweet clover species and oilseed rape), Environmental = environmentally friendly management, Organic = organic farming

under AES and conventional farming. Organic field margins hosted a higher abundance of forest-scrub species compared with the margins of conventional fields.

Abundances of short-tongued species were similar in all investigated crop rotation types (Figure S4). Abundance of long-tongued species was higher in cereal rollover field margins compared with the other three crop rotation types. Bumblebee abundance of short-tongued species was significantly higher in environmentally friendly managed field margins compared with those of conventional field margins. Abundances of long-tongued bumblebee species did not differ between management types.

4 | DISCUSSION

Our study shows that crop rotation has an important role in determining bumblebee community. We found that some bumblebee abundances (e.g. of long-tongued and threatened species) are higher at cereal rollover field margins than at the field margins of the other three crop rotation types. Furthermore, we found higher abundances of medium-sized colony species, forest-scrub species and habitat generalists in cereal rollover field margins than in MFC rollover and MFC to cereal or cereal to MFC field margins.

4.1 | Concentration and dilution effects of bumblebees at field margins

Our study suggests that crop rotation type is an important management driver of bumblebee communities in field margins. Abundances of several bumblebee groups (e.g. long-tongued, threatened and forest-scrub species) were higher at the field margins of cereal rollover compared with MFC rollover. This may not indicate that the *status quo* of fields remaining as cereals from 1 year to the next has a positive effect on bumblebee abundance, or that cereal margins are more important to bumblebees than MFC margins.

Our results can be interpreted in two ways. First, this might have been caused by a concentration effect in cereal field margins, similar to that found in Environmental Stewardship AES in England (Carvell, Meek, Pywell, Goulson, & Nowakowski, 2007). More flower resources are available in the margins of cereal fields than inside the fields, owing to herbicide use controlling arable weeds within crops, thus reducing nectar sources (Brittain, Vighi, Bommarco, Settele, & Potts, 2010). Second, a dilution effect in MFC fields (Holzschuh, Dormann, Tscharntke, & Steffan-Dewenter, 2011) is likely as bumblebees may disperse into MFC fields, as they have more nectar resources than cereal fields. June and July, when 2/3 of our data were collected, is the main blooming time of legumes and oilseed rape in Estonia. Therefore, dilution of bumblebee individuals from certain trait based groups onto MFC fields was probably the main reason for the differences in bumblebee abundances between cereal and MFC rollover field margins. One limitation of our investigation was that it only accounted for bumblebees at field margins, not within fields. An important potential confounding factor that needs to be mentioned *vis-à-vie* the concentration–dilution hypothesis of bumblebees (and other pollinators) in cereal/MFC/other field margins is the type of crop(s) being grown in adjacent fields. For example, is there a stronger concentration effect if cereal fields are on both sides of the field margin, than if the margin is between a cereal and MFC field? We suggest that future studies test the concentration–dilution hypothesis by (1) also running flower/pollinator transects from the edge to the centre of fields and (2) taking into account adjacent fields.

Our results suggest a negative temporal effect of cereal fields upon the food resources of bumblebees. Abundances of threatened, long-tongued and forest-scrub species were lower in the field margins of MFC to cereal than cereal rollover fields. We offer the following explanation: if cereals are grown for two consecutive years, this may already negatively influence the flowering-plant community of the field, reducing food resources for bumblebees within fields, thus making margins more attractive to bumblebees. In addition, as cereal rollover fields were mainly on conventional farms (Table 1), such

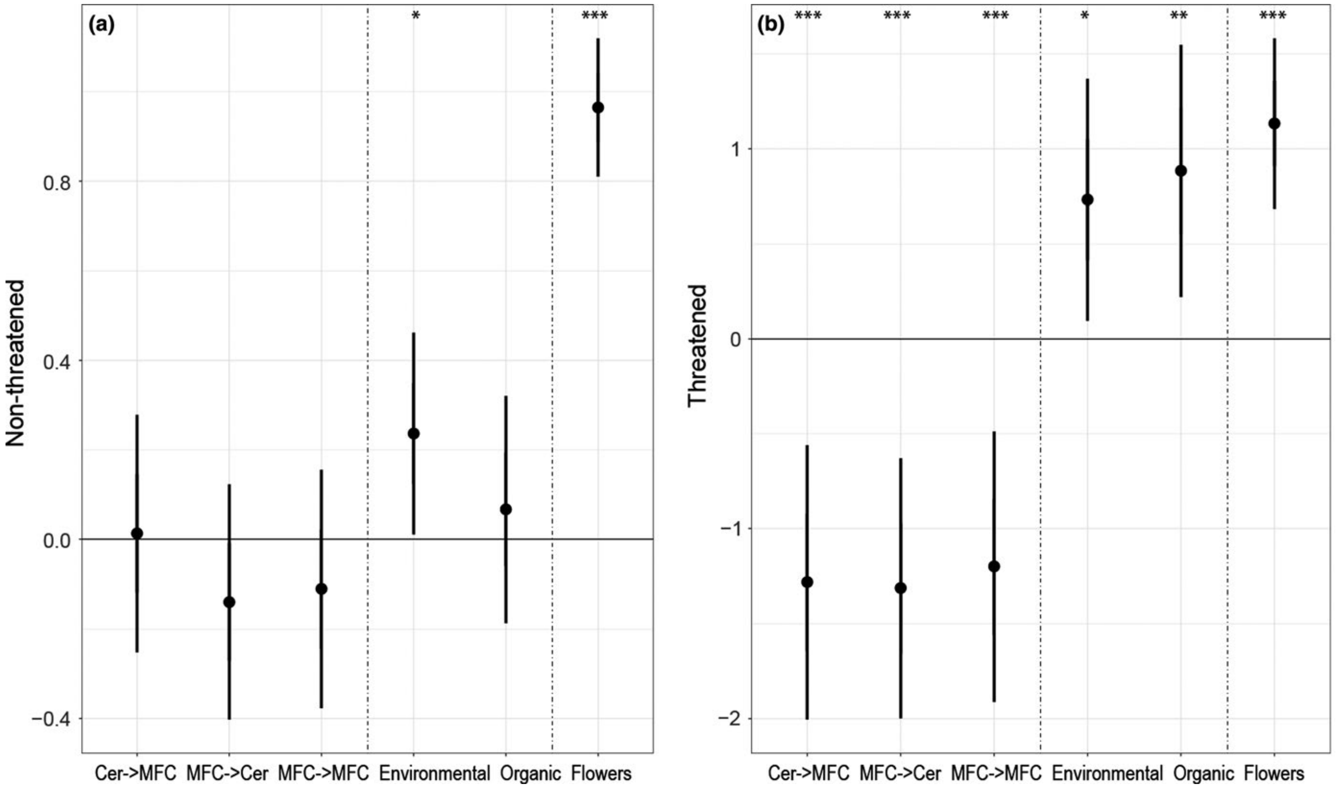

FIGURE 2 Comparison of bumblebee abundances in field margins between different crop rotation types, management types and effect of flower cover for (a) non-threatened and (b) threatened bumblebee species. The figure shows results from linear mixed-effects models (*p*-value, lower and upper boundary of 95% CI). Indicated are effect sizes (*y*-axis) compared with the crop rotation type control group (cereal rollover field margins) and management type control group (conventional farming). The effect size is significantly different if the CIs do not overlap with zero. Asterisk symbols represent statistically significant *p*-values below .05, .01 and .001 (*, ** and ***, respectively). Cer = cereals (all rye, oat, barley, triticale and wheat fields), MFC = mass-flowering crops (pea, bean, clover, alfalfa, sweet clover species and oilseed rape), Environmental = environmentally friendly management, Organic = organic farming, Flowers = flower cover

field margins are less likely to: (1) have MFC dispersal into the margin from the previous year; (2) be managed (including the sowing of seed mixes) for wildflowers. From a recent study (Magrach, González-Varo, Boiffier, Vilà, & Bartomeus, 2017), it is known that honeybees spillover from mass-flowering orange groves to flower-rich woodlands after orange bloom leading to a change in wild bee community composition and lower seed set of the most common plant species. Nevertheless, for the honeybee itself, this might be a benefit. In a similar way, it is possible that for at least some bumblebee species, MFC can provide a benefit the following year, as suggested by our results (MFC>cereal compared with cereal rollover).

The importance of field margins is related to nectar and/or pollen continuity in agricultural landscapes (Schellhorn, Gagic, & Bommarco, 2015). Owing to the seasonality and duration of nectar sources, legumes and oilseed rape fields are not fully available to bees throughout spring and summer in Northern Europe, thus bumblebees likely also use semi-natural habitats, such as field margins (Bäckman & Tiainen, 2002; Batáry et al., 2015). Therefore, flowering field margins are of high importance during periods when legumes or oilseed rape resources are not available, thus creating a resource bottleneck (Persson et al., 2015; Schellhorn et al., 2015). In our study areas, a resource bottleneck might occur if MFC are not grown in certain years, do not flower until a certain date, or are harvested from a certain date onwards. Thus, it is highly likely that a combination of all three presented reasons affects the availability of food resources for bumblebees.

4.2 | AES has a role in determining the bumblebee communities of field margins

We found that both organic farming and environmentally friendly management promoted bumblebee species richness in field margins. It might be possible that farming practice had a confounding effect on the results, for example, conventional farms had a higher percentage of cereal rollover fields compared with organic and environmentally friendly management farms, but owing to the lack of collinearity, a significant bias seems to be unlikely. Nonetheless, future studies should aim to collect more balanced datasets. However, Marja et al. (2014) also demonstrated that Estonian AES promoted bumblebees, both within the fields and at their margins. Environmentally friendly management involves requirements to conserve or sow field margins with a flower mix of at least three species (including graminaceous); organic farming does not have such a requirement, but abundances of bumblebee threatened species, small-sized colony species and

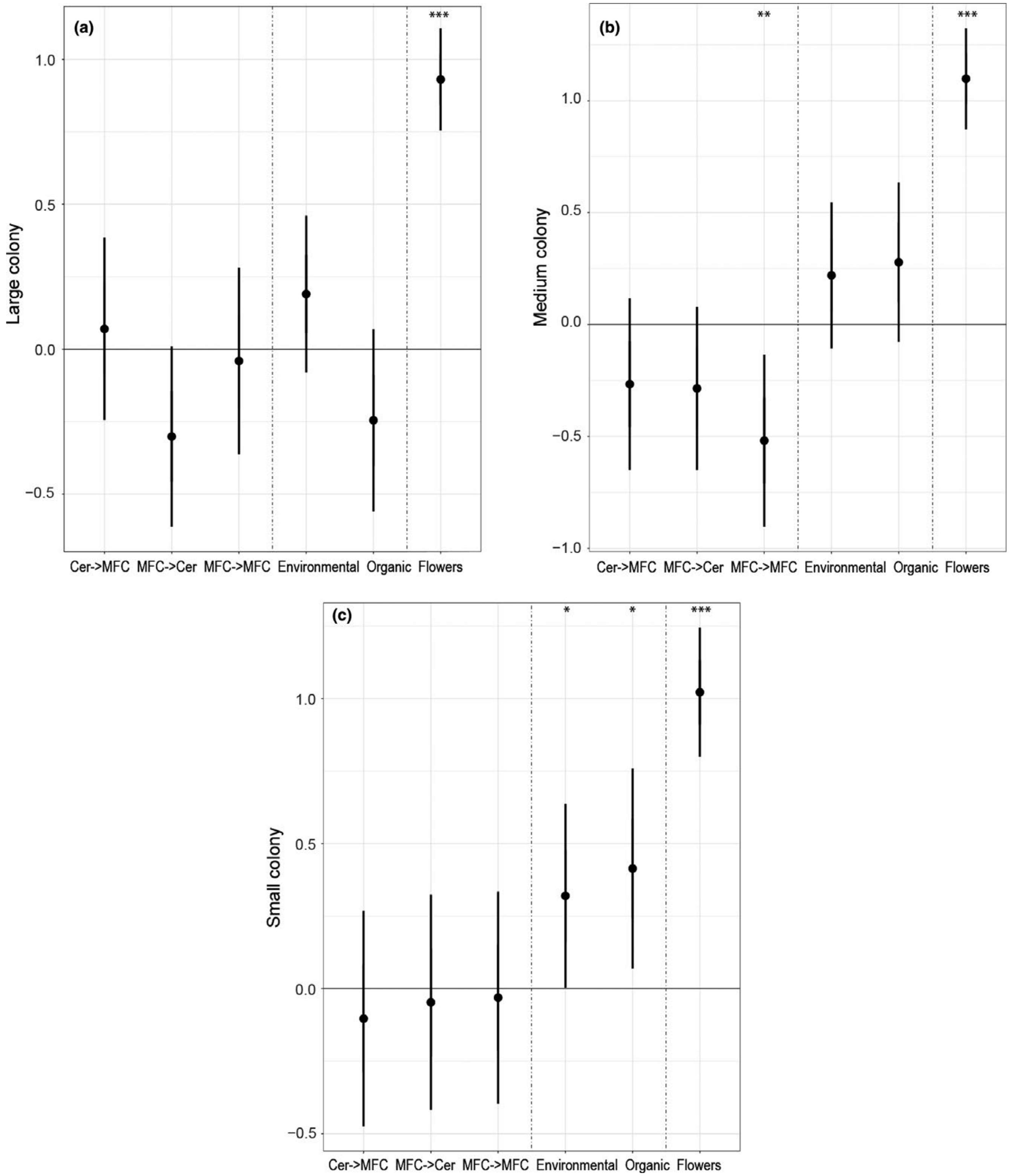

FIGURE 3 Comparison of bumblebee abundances in field margins between different crop rotation types, management types and effect of flower cover for species based on their colony size, that is, (a) large, (b) medium and (c) small colonies. The figure shows results from linear mixed-effects models (*p*-value, lower and upper boundary of 95% CI). Indicated are effect sizes (*y*-axis) compared with the crop rotation type control group (cereal rollover field margins) and management type control group (conventional farming). The effect size is significantly different if the CIs do not overlap with zero. Asterisk symbols represent statistically significant *p*-values below .05, .01 and .001 (*, ** and ***, respectively). Cer = cereals (all rye, oat, barley, triticale and wheat fields), MFC = mass-flowering crops (pea, bean, clover, alfalfa, sweet clover species and oilseed rape), Environmental = environmentally friendly management, Organic = organic farming, Flowers = flower cover

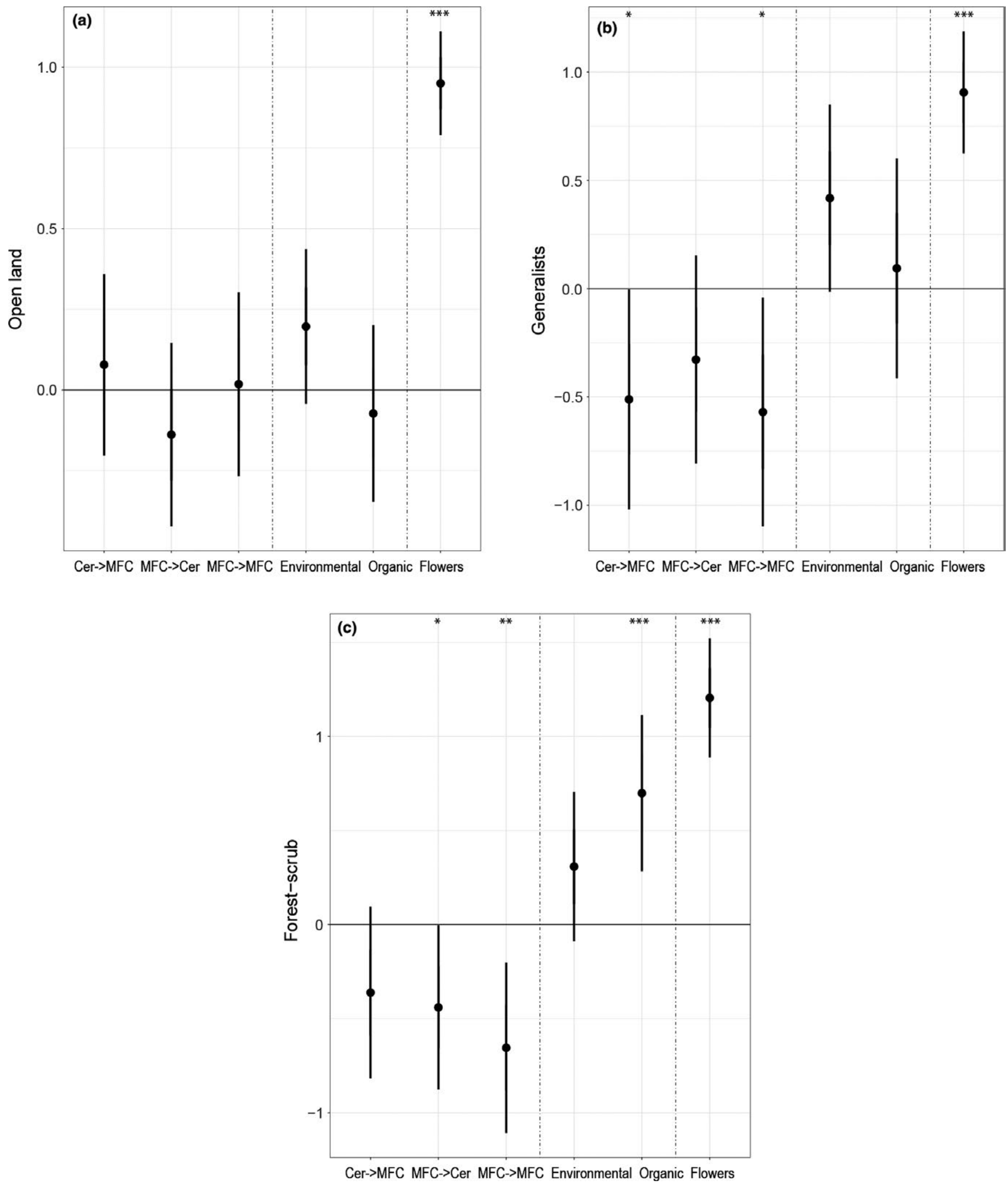

FIGURE 4 Comparison of bumblebee abundances in field margins between different crop rotation types, management types and effect of flower cover for species based on their habitat preference, that is, (a) open land, (b) generalists and (c) forest-scrub. The figure shows results from linear mixed-effects models (*p*-value, lower and upper boundary of 95% CI). Indicated are effect sizes (*y*-axis) compared with the crop rotation type control group (cereal rollover field margins) and management type control group (conventional farming). The effect size is significantly different if the CIs do not overlap with zero. Asterisk symbols represent statistically significant *p*-values below .05, .01 and .001 (*, ** and ***, respectively). Cer = cereals (all rye, oat, barley, triticale and wheat fields), MFC = mass-flowering crops (pea, bean, clover, alfalfa, sweet clover species and oilseed rape), Environmental = environmentally friendly management, Organic = organic farming, Flowers = flower cover

forest-scrub species were still higher than per conventional farming. This was probably related to the strict management requirements (synthetic pesticides and most mineral fertilizers are forbidden) of organic farming. Our results indicate that threatened species are remarkably sensitive to agricultural management, and prefer more AES farms; non-threatened species seemed to be less sensitive to management.

We found that the abundances of species with small colonies were related to AES management types, whereas abundances of species with medium and large colonies did not differ between management types. These results can be related to the mobility potential. Species with small colonies have more limited dispersal distances (Westphal, Steffan-Dewenter, & Tscharntke, 2006). This adaptation makes them more sensitive to local environmental and agricultural conditions. It is also probable that there were more suitable habitat conditions in organic and environmentally friendly management field margins for bumblebee species with small colonies. Species with medium and large colonies are more mobile and search for resources at larger scales and are, therefore, less influenced by local conditions.

4.3 | Conservation of bumblebees

Both naturally occurring plants and the sowing of seed mixes to provide nectar-rich plants (e.g. clover) at field margins can benefit bumblebees and other pollinators in Estonia as well as in Northern Europe in general (Scheper et al., 2013). It is important when sowing nectar-rich plants mixes, to use only local flora to avoid introducing alien species. The conservation of non-cropped landscape elements, such as field margins and other flower resources, is essential to support the diversity of wild pollinators and their food plants. For instance, the latest results from Estonia showed that field margins need to be at least 3 m wide to support "high nature value" plant species intolerant of modern farming practices (Aavik & Liira, 2010). For bumblebees, these plant species are potentially of higher value and provide more temporally stable food resources than agro-tolerant plant species. Thus, non-cropped field margins at least 3–5 m wide could be a key and simple solution to improve bumblebee diversity in cereal-dominated agricultural landscapes. Furthermore, permanent field margins are important for bumblebees in terms of the continuity of resources other than food, such as nesting and wintering habitat (Bäckman & Tiainen, 2002; Batáry et al., 2015).

A recent study showed that almost 80% of crop pollination is performed by a limited number of bee species, and threatened bee species contribute little (Kleijn et al., 2015). However, protecting the main, common pollinator species only is not a sustainable solution to the conservation of pollinator biodiversity. Senapathi et al. (2015) highlighted that maintaining whole pollinator species diversity, including widespread and rare species, is essential to provide ecosystem resilience and functioning in the future. Therefore, the conservation of different habitats and the whole pollinator species spectrum is crucial, because different pollinator species visit different parts of crops, or crops at different times of the day or year and respond differently to environmental disturbances (Goulson et al., 2015).

5 | CONCLUSIONS

Our results indicate that cereal field margins can act as refugia to forest-scrub, long-tongued and threatened bumblebee species, such as *B. hypnorum*, *B. distinguendus* and *B. muscorum*, which are vulnerable in Europe (Nieto et al., 2014). Semi-natural field margins, especially in intensively managed cropland, may be a viable option to support these species in Europe, because they represent permanent valuable landscape elements, offering places to nest and overwinter, as well as providing food resources. It is possible that the field margin requirement of Estonian AES is one of the reasons why Estonian bumblebee abundances were stable over a recent 5-year period (Agriculture Research Centre, 2015). Our study indicated a concentration–dilution effect of field margins upon bumblebee abundances, dependant on the type of crop being grown in the field (cereal = concentration at the margin; MFC = dilution into the field). To test the concentration–dilution hypothesis of field margins upon pollinators, future studies should account for within-field pollinator/flower abundances, and the influence of adjacent fields (or even landscape composition). Nonetheless, our results show that management of flower-rich field margins, especially in cereal rollover fields, where few alternative nectar sources exist, is important and should form part of all AES targeting pollinators.

ACKNOWLEDGEMENTS

The census work was coordinated by the Agricultural Research Centre as part of the ongoing evaluation of AES within the framework of the Estonian Rural Development Plan 2007–2013, financed by the European Union and Estonian government under the Technical Assistance measure of the 2007–2013 Rural Development Plan of Estonia. M.M. research was partly supported by Institutional Research Funding (IUT36-2) of the Estonian Ministry of Education. P.B. was supported by the German Research Foundation (DFG BA4438/2-1) and by the Economic Development and Innovation Operational Programme of Hungary (GINOP-2.3.2-15-2016-00019). The authors are thankful to Katrin Jõgar, Martin Jürgenson, Reet Karise, Irja Kivimägi, Eha Kruus, Reelika Päädam, Eve Veromann, Kai-Riin Veromann, Linda-Liisa Veromann-Jürgenson and Peeter Veromann for their help in conducting the fieldwork. We also thank associated editor and anonymous reviewers for their helpful comments.

AUTHORS' CONTRIBUTIONS

R.M. and P.B. conceived the study and designed the methodology; E.V. and M.M. coordinated data collection; R.M. analysed the data; R.M. led the writing of the manuscript. All authors (R.M., E.V., M.M., J.P., A.M.K. and P.B.) contributed critically to the manuscript and approved the submission.

DATA ACCESSIBILITY

Data available via Zenodo https://doi.org/10.5281/zenodo.1161430 (Marja et al., 2018).

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How to cite this article: Marja R, Viik E, Mänd M, Phillips J, Klein A-M, Batáry P. Crop rotation and agri-environment schemes determine bumblebee communities via flower resources. *J Appl Ecol*. 2018;55:1714–1724. https://doi.org/10.1111/1365-2664.13119