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Agri-environment schemes targeting farmland bird populations also provide food for pollinating insects

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Abstract

1 Farmland biodiversity has declined over the past few decades. European Common Agricultural Policy encourages farmers to set up agri-environment schemes (AES) that support biodiversity and associated ecosystem services such as pollination. Although few AES are specifically devoted to pollinating insects, many AES could provide resources for pollinators. In Belgium, AES designed to provide seed resources for wild birds (bird-strip AES) contain mixed-plant communities that may benefit insects, although their ability to support pollinators has not yet been evaluated.

2 The present study aimed to assess the ability of bird-strip AES to support pollinating insects. We identified and quantified floral resources, flower-visiting insects and insect–flower interaction networks over 2 years on four bird strips located in intensive agro-ecosystems in Belgium.

3 The bird strips contained plant species that were either purposely sown or established spontaneously. The spontaneous *Cirsium* species, with its high nectar production, offered floral resources that complemented those of the sown species *Raphanus sativus* and *Phacelia tanacetifolia*. Most of the flower-visiting insects considered as pollinators belonged to the orders Hymenoptera and Diptera.

4 In conclusion, bird-strip AES provided floral resources to pollinators, even in the absence of annual sowing.

Keywords Bees, *Cirsium*, field strips, flower resources, seed strips, syrphids.

Introduction

Pollinator abundance and diversity are decreasing worldwide (Kells *et al.*, 2001; Marshall & Moonen, 2002; Kluser & Peduzzi, 2007; Burkle *et al.*, 2013; Garibaldi *et al.*, 2013; Morandin & Kremen, 2013). This decline is widely linked to changes in agricultural management during the last century (Kluser & Peduzzi, 2007; Potts *et al.*, 2009; Kluser *et al.*, 2010; Ollerton *et al.*, 2014). Agricultural intensification, associated in particular with the widespread use of pesticides (Robinson & Sutherland, 2002; Goulson *et al.*, 2015), increased field size, and removal of field margins and hedgerows, has contributed to landscape simplification (MacDonald & Johnson, 2000). Simplified landscapes have fewer plant species (Kleijn & Raemakers, 2008; Scheper *et al.*, 2014) and fewer semi-natural areas to provide floral food resources and nesting habitats for insects (Kennedy *et al.*, 2013; Deguines *et al.*, 2014; Bretagnolle & Gaba, 2015; Goulson *et al.*, 2015).

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In the European Union, the second pillar of the Common Agricultural Policy subsidizes agri-environment schemes (AES) in an effort to combat landscape simplification and support farmland biodiversity (European Commission, 2017; Wood *et al.*, 2017). However, AES still need to be optimized to increase the resulting biodiversity gains (Merckx *et al.*, 2009). Most AES have focused on a single purpose (e.g. annual cornfield conservation, erosion limitation, beetle banks or skylark nesting plots in cereal fields); however, a single scheme could serve several purposes because improving habitat for one target species often improves the habitat for a wider group of nontarget species (Mckenzie *et al.*, 2013).

Flower-strips are common AES implemented in farmland areas (Marshall *et al.*, 2006; Haenke *et al.*, 2009; Haaland & Gyllin, 2010, 2011; Haaland *et al.*, 2011; Feltham *et al.*, 2015; Wood *et al.*, 2015; Campbell *et al.*, 2017; Sutter *et al.*, 2017). Such schemes aim to provide food and a refuge area for wild fauna, often birds or insects. In farmland areas, flower-strips are often implemented with the intention of supporting insects that then provide pollination or pest management services to the surrounding fields (Balzan *et al.*, 2014, 2016; Feltham *et al.*, 2015;

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Table 1 The four studied bird-strip agri-environment schemes (AES) located in Hesbaye, Belgium

Bird-strip AES	Locality	Location (Lat. Long.)	Length (m)	Width (m)	Number of sections
A	Opprebais	50°41′05″N 4°47′09″E	570	12	3
B	Opprebais	50°40′25″N 4°48′41″E	500	12	3
C	Gembloux	50°32′53″N 4°38′08″E	600	9	2
D	Goesnes	50°27′10″N 5°11′53″E	320	12	2

Tschumi *et al.*, 2016; Campbell *et al.*, 2017). When established in intensively managed farmland, flower-strips were found to be dominated by a limited number of common insect species that visited only a portion of the flowering plant species present (Pywell *et al.*, 2005; Carvell *et al.*, 2007). Therefore, the attractiveness and suitability of such flower-strips for insects are questionable (Kovács-Hostyánszki *et al.*, 2016).

In Wallonia (Belgium), pollinator flower-strip AES are specifically designed to support flower-visiting insects, in particular pollinators (Terzo & Rasmont, 2007; Service public de Wallonie, 2012). The most effective and recognized pollinating insects are Hymenoptera, including mainly bees (Kevan & Baker, 1983; Free, 1993; Willmer, 2011), Diptera, including mainly hoverflies (Ssymank *et al.*, 2008; Inouye *et al.*, 2015), and Lepidoptera (Crepet, 1984; Weiss, 1995; Willmer, 2011). Other categories of AES, such as Walloon AES that are designed to provide seed resources (food) and shelter to grain-eating farmland wild birds during the winter (bird strips, Natagriwal, 2016), could also be important for insects (Carvell *et al.*, 2007). Bird-strip AES may include entomophilous flowering plant species (e.g. *Helianthus annuus*, *Medicago sativa*, *Phacelia tanacetifolia*, *Raphanus sativus*, etc.) (Carreck *et al.*, 1999) sown in a 'feeding section' that can provide floral resources to insects. A further two components of bird strips include a tall grass 'refuge section', which is left uncut for several consecutive years, and an optional harrowed section. The presence of stubble and hollow-stem plants (Poaceae and Brassicaceae), as well as access to bare soil, provides potential nesting sites, especially for solitary bees (Westrich, 1996; Cane, 1997; Falk, 2015) and other small animals (Kells & Goulson, 2003; Cole *et al.*, 2015). However, the potential of such AES to provide appropriate food resources for pollinating insects has not yet been evaluated.

To effectively support insect propagation and diversity, an AES must provide uninterrupted dietary resources each year, in addition to nesting opportunities (Schellhorn *et al.*, 2015; Scheper, 2015; Holzschuh *et al.*, 2016; Moquet *et al.*, 2017). Regarding the plant species present in AES, the species that are deliberately sown are likely to be dominant, as observed in other annually sown schemes, although the final plant community will be a mix of both purposely sown and spontaneously established native plant species (Fiedler *et al.*, 2008). Therefore, it would be relevant to evaluate the relative contribution of insect floral resources by spontaneous and sown plant species in bird-strip AES.

In the present study, we investigated four bird-strip AES during 2015 and 2016 in southern Belgium to evaluate their ability to feed pollinating insects. We addressed five main questions: (i) what are the floral resources provided by bird-strip AES; (ii) what is the importance of sown versus spontaneous plant species regarding insect floral resources; (iii) what insect species are feeding on bird-strip flowers; (iv) which flowering plant species are visited by insects; and (v) are floral resources resilient to annual changes?

Materials and methods

To assess the diversity and quantity of available floral resources, we recorded floral diversity and density throughout the year and also estimated pollen and nectar quantity. To evaluate the attractiveness of bird-strip AES to pollinators, we recorded the diversity and number of visiting insects and the plant species that they visited.

Studied sites

From April to September in 2015 and 2016, we studied four bird strips in Hesbaye, southern Belgium (50°36′N, 4°34′E, 100–150 m a.s.l. (Table 1). This region is characterized by high soil fertility (Witte *et al.*, 2009). The agricultural landscapes are classical open fields dominated by cereals (44%), sugar beet (*Beta vulgaris*, 20%), potato (*Solanum tuberosum*, 5%) and maize (*Zea mays*, 5%), which are interspersed with meadows (13%) (Witte *et al.*, 2009). We chose bird-strip AES located in open field land, situated at least 2 km away from other landscape elements, such as apiaries, orchards, forests, hedges,or villages, to minimize interactions with honeybee hives or semi-natural habitats. All bird strips were 320–600 m long at least 3 km apart to avoid pseudo-replication.

Bird strips were organized into two or three longitudinal sections: (i) a 2–3 m wide unmown grass refuge section, sown in 2008 with a 20 kg/ha mix of *Dactylis glomerata* (50% seed weight), *Schedonorus arundinaceus* (49%) and *Trigonella* sp. (1%); (ii) a 3–9 m wide feeding section, sown in 2015 with a 40 kg/ha mix of the cereal *Triticum aestivum* (65% of seed weight) and the three entomophilous species *Fagopyrum esculentum* (25%), *Phacelia tanacetifolia* (3%) and *Raphanus sativus* (7%); and (iii) sn optional 2-m wide unsown and harrowed section, which was present in two bird strips (Table 1). In 2016, self-seeding was effective for the three entomophilous species sown in 2015 (*F. esculentum*, *P. tanacetifolia* and *R. sativus*) on bird strip B, for *P. tanacetifolia* and *R. sativus* in bird strip A, and for *R. sativus* only in bird strip C. None of these species were observed in bird strip D in 2016.

Climatic data

Climatic data were provided by the Belgian Royal Meteorological Institute (IRM). Data were collected hourly at the Ernage

Table 2 Climatic data from the Ernage station, Gembloux, Belgium

Period	Parameter	Value	2015	2016	Statisical values
From April to September	Sunshine (min/day)	Mean	435.8 ± 260.8	378.2 ± 242.2	$t_{364} = 2.1889$*
	Mean temp (°C)	Mean	12.30 ± 3.79	11.85 ± 4.26	$t_{350} = -1.2574$
	Minimum mean temp (°C)	Mean	6.45 ± 3.46	7.29 ± 4.56	$t_{350} = -0.64079$
	Maximum mean temp (°C)	Mean	17.28 ± 4.57	16.16 ± 4.72	$\chi^2 = 10.10$, d.f. = 1$P < 0.01$
		Median	17.0 (14.4–19.6)	16.5 (12.8–20.1)	
	Raining days		37	60	
During insect activity hours (09.00 h to 18.00 h) from April to June	Precipitation (mm/9 h)	Mean	0.51 ± 2.21	1.45 ± 2.52	$\chi^2 = 15.94$, d.f. = 1*$P < 0.01$
		Median	0.0 (0.0–1.6)	0.0 (0.0–0.0)	
	Mean temp (°C)	Mean	15.52 ± 4.42	14.36 ± 4.66	$t_{169} = 1.666$*
	Raining days		21	45	
	Heavy rains (> 5 mm/9 h)		2	10	

Values are the mean ± SD or median with interquartile ranges (25th to 75th percentiles). *Significant difference at $P < 0.05$. Data provided by the Belgian Royal Meteorological Institute (IRM).

station (Gembloux) from April to September 2015 and 2016. Total precipitation was recorded monthly and sunshine was recorded daily. Temperatures were recorded daily, from which monthly means were calculated (mean, minimum mean and maximum mean) (Table 2).

Experimental design

On each bird strip, a permanent transect (length 100 m, width 1 m) was established in the centre of each section; thus, two or three transects were analyzed per bird strip. Each transect was observed once a month from April to September in 2015 and 2016. All observations were conducted on sunny and warm days. As a result of bad weather, no field observations were conducted in June 2016. A total of 11 observations were performed per site: six in 2015 and five in 2016.

Floral resource quantities

For all entomophilous species, we recorded floral densities using 1-m^2 quadrats located every 5 m along each of the transects described above in accordance with Hicks *et al.* (2016). Plant species were identified according to APG III (Tison & de Foucault, 2014). For Asteraceae, a single floral unit corresponds to a capitulum, whereas, for all the other species, a floral unit corresponds to a single flower. The three species sown in 2015 (*F. esculentum*, *P. tanacetifolia* and *R. sativus*) constituted the 'sown' species group. We grouped all the other species into the 'spontaneous' species group, including not only unsown species, but also plants that had regrown from previously sown mixes (i.e. *H. annuus*, *Cyanus segetum* and *Trifolium incarnatum*).

For species with previously recorded nectar sugar and pollen production, we used data from Baude *et al.* (2016) and Hicks *et al.* (2016) (Table 3). For species with no data available but representing more than 2% of all the floral units, we evaluated floral resources in accordance with the methods described by Baude *et al.* (2016) and Hicks *et al.* (2016).

To estimate nectar production when insect visitors were excluded, we placed pollination bags (Delnet Pollination, Middletown, Deleware) on a minimum of 15 flowers for each plant species 24 h before sampling. Nectar was collected with 1-μL glass capillary tubes (Hirschmann Laborgerate, Germany). Nectar volumes were then estimated by measuring the length of the nectar column in the capillary tube. Sugar concentrations were measured with a low-volume hand refractometer (Eclipse Hand held Refractometer; Bellingham & Stanley Ltd, U.K.) and expressed as percentage sucrose (w/w) (Prys-Jones & Corbet, 2011).

To estimate pollen production, we sampled flowering plants. Open flowers were removed and branches were individually stored in water in the laboratory. The next morning, all the freshly dehiscent anthers were collected. Pollen was extracted in a 70% ethanol solution by three successive cycles of rinsing and ultra-sonication. Pollen solutions were centrifuged at 1304 *g* for 10 min. The pollen residue was dried overnight at room temperature and dissolved in a known volume of 70% ethanol. Pollen grains were counted in a known volume of solution using a 0.10-mm deep haemocytometer (assistant, Glaswarenfabrik Karl Hecht GmbH & Co KG, Germany) under a light microscope.

Insect observations

Each month, we recorded insect–flower interactions per section of each bird strip ($n = 10$) during two consecutive walks along each transect taken at least 10 min apart. All insects visiting an open flower were collected and recorded.

When possible, insects were identified in the field (e.g. *Apis mellifera*) and released. As a result of similar morphological characteristics, bumblebee individuals were identified up to the operational taxonomic unit (OTU) (Terzo & Rasmont, 2007). Because *Bombus* spp. were numerous in the field, we sampled at least one individual per OTU per bird strip and per transect walk for precise laboratory identification. All other taxa were individually collected for further laboratory identification.

Species were identified with reference to scientific literature. Specifically, we used Terzo & Rasmont (2010) for *Bombus* spp.; Skinner & Wilson (2009) and Tolman & Lewington (2009) for Lepidoptera; and Verlinden (1994), Stubbs & Falk (2002) and Speight & Sarthou (2016) for Syrphidae flies. The other Hymenoptera were identified by A. Pauly, a taxonomist at the Royal Institute of Natural Sciences of Brussels, Begium.

Table 3 Floral resources of the three sown plant species and 53 spontaneous species flowering in the four studied bird-strip agri-environment schemes (AES) in 2015 and 2016

	Origin	Families	Species	Mean floral density (floral units/m^2)	Nectar sugar (µg/floral units/24 h)	Pollen (µL/floral units/24 h)
Species with insert interaction record	Sown	Boraginaceae	*Phacelia tanacetifolia* Benth.	1.86 ± 8.86	328.46 ± 187.84	0.335 ± 0.160
		Brassicaceae	*Raphanus sativus* L.	4.79 ± 12.23	131.54 ± 79.44	0.444 ± 0.162
	Spontaneous	Apiaceae	*Daucus carota* L.	1.78 ± 10.58	27.18 ± 32.44*	0.019 ± 0.003*
		Asteraceae	*Centaurea jacea* L.	0.21 ± 0.91	1177.75 ± 1761.20	6.404 ± 2.030*
			Cirsium arvense Scop.	0.00 ± 0.02	2608.94 ± 239.08*	0.598 ± 0.210*
			Cirsium vulgare Ten.	0.73 ± 2.93	1534.23 ± 630.02	NA
			Crepis biennis L.	0.07 ± 0.33	NA	NA
			Cyanus segetum Hill.	0.00 ± 0.01	1479.49 ± 487.56	3.534 ± 0.500*
			Helianthus annuus L.	0.01 ± 0.02	NA	NA
			Matricaria chamomilla L.	0.56 ± 2.18	0.60 ± 1.29**	NA
			Matricaria discoidea DC.	1.46 ± 6.65	0.28 ± 0.89**	0.430 ± 0.072*
			Sonchus arvensis L.	0.16 ± 0.75	3.34 ± 4.11**	NA
			Sonchus asper Hill	0.02 ± 0.08	593.83 ± 16.8*	0.939 ± 0.230*
			Sonchus oleraceus L.	0.04 ± 0.25	568.84 ± 16.02*	1.326 ± 0.256*
			Taraxacum agg.	0.00 ± 0.00	2137.20 ± 286.43*	2.823 ± 0.661*
			Tripleurospermum inodorum L.	0.70 ± 2.78	1406.81 ± 81.86*	2.955 ± 0.226*
		Brassicaceae	*Sinapis alba* L.	1.84 ± 6.37	NA	0.822 ± 0.437
		Convolvulaceae	*Convolvulus arvensis* L.	0.18 ± 0.78	351.82 ± 188.29**	NA
			Convolvulus sepium L.	0.21 ± 1.06	1543.23 ± 630.02	NA
		Fabaceae	*Trifolium dubium* Sibth.	0.00 ± 0.00	0.00 ± 0.00**	NA
			Trifolium hybridum L.	0.49 ± 2.44	1.00′′	0.053′′
			Trifolium incarnatum L.	14.64 ± 69.29	31.15 ± 38.8	0.080 ± 0.010
			Trifolium pratense L.	0.02 ± 0.16	48.37 ± 34.28*	0.020 ± 0.002*
		Onagraceae	*Epilobium angustifolium* L.	0.01 ± 0.04	NA	NA
			Epilobium ciliatum Rafin	0.42 ± 1.57	144.71 ± 26.62*	0.010 ± 0.003*
Species without insert interaction record	Sown	Polygonaceae	*Fagopyrum esculentum* Moench	1.53 ± 3.76	90′	0.017 ± 0.006
	Spontaneous	Apiaceae	*Anthriscus sylvestris* Hoffman	0.01 ± 0.06	11.33 ± 14.26**	NA
		Asteraceae	*Achillea millefolium* L.	0.01 ± 0.09	28.48 ± 34.38*	1.128 ± 0.215*
			Cichorium intybus L.	0.00 ± 0.00	NA	NA
			Lapsana communis L.	0.00 ± 0.00	99.35 ± 7.88*	0.331 ± 0.033*
			Leucanthemum vulgare Lam.	0.03 ± 0.22	292.65 ± 459.43*	15.918 ± 3.900*
			Senecio vulgaris L.	0.05 ± 0.22	0.19 ± 0.83**	0.175 ± 0.019*
		Brassicaceae	*Arabidopsis thaliana* Heynh.	0.00 ± 0.02	NA	NA
			Brassica napus L.	0.15 ± 1.03	541.29 ± 580.43	NA
			Capsella bursa-pastoris Med.	0.03 ± 0.15	9.05 ± 1.6*	0.001 ± 0.000*
		Caryophyllaceae	*Cerastium fontanum* Baumg.	0.01 ± 0.03	11.56 ± 1.66**	0.035 ± 0.002*
			Silene x hampeana Meusel et K. Werner	0.01 ± 0.05	62.97 ± 63.01*	0.801 ± 0.015
			Stellaria media Vill.	0.02 ± 0.15	11.92 ± 2.90*	0.001 ± 0.000*

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Table 3 continued

Origin	Families	Species	Mean floral density (floral units/m^2)	Nectar sugar (µg/floral units/24 h)	Pollen (µL/floral units/24 h)
	Fabaceae	*Ervilia hirsuta* Opiz	0.24 ± 0.76	26.76 ± 7.26*	0.006 ± 0.004*
		Lathyrus nissolia L.	0.00 ± 0.01	NA	NA
		Lotus corniculatus L.	0.01 ± 0.06	67.98 ± 42.59	0.146 ± 0.012*
		Trifolium repens L.	0.02 ± 0.12	12.13 ± 8.12*	0.028 ± 0.002*
		Vicia cracca L.	0.00 ± 0.02	484.40 ± 411.27**	NA
	Lamiaceae	*Lamium purpureum* L.	0.01 ± 0.04	107.73 ± 23.60*	0.020 ± 0.004*
		Stachys arvensis L.	0.00 ± 0.03	NA	NA
	Onagraceae	*Epilobium montanum* L.	0.01 ± 0.08	36.57 ± 3.98*	0.053 ± 0.014*
	Papaveraceae	*Fumaria officinalis* L.	0.23 ± 1.24	21.90 ± 6.62*	0.010 ± 0.001*
		Papaver rhoeas L.	0.00 ± 0.01	0.57 ± 0.57*	13.343 ± 2.813*
	Plantaginaceae	*Veronica persica* Poiret	0.21 ± 0.51	4.69 ± 0.41*	0.031 ± 0.006*
	Polygonaceae	*Fallopia convolvulus* Á Löve	0.02 ± 0.12	65.08 ± 32.29**	NA
		Persicaria maculosa S.F.	0.18 ± 0.80	29.59 ± 5.82**	0.003 ± 0.000*
		Polygonum aviculare L.	3.34 ± 13.75	3.05 ± 4.97**	0.006 ± 0.001
	Primulaceae	*Lysimachia arvensis* U. Manns et Andreb.	0.02 ± 0.13	NA	NA
	Rubiaceae	*Galium album* Mill.	0.01 ± 0.06	7.06 ± 1.17*	0.005 ± 0.002*
		Galium aparine L.	0.01 ± 0.05	9.48 ± 3.52**	NA
	Violaceae	*Viola tricolor* L.	0.05 ± 0.38	NA	NA

Species nomenclature followed APG III nomenclature (Tison & de Foucault, 2014). We categorized plants species based on whether flower-visiting insects were observed (species with insect interaction recorded) or not (species without insect interaction recorded).

The reported data are from our results, as well as from Hicks *et al.* (2016) (*); from Baude *et al.* (2016) (**); from Cawoy *et al.* (2009) (′); and from Szabo & Najda (1985) (′′). Values are the mean ± SD. NA, not available.

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Pollen loads

Bumblebees are common insects able to fly several hundreds of metres to find floral resources across different landscapes (Le Féon, 2010). Therefore, we focused on this genus to determine which flowering plant species were visited for pollen collection, as well as to assess the proportion of pollen collected from outside the bird-strip AES. We sampled 26 pollen loads from *Bombus* spp. One corbicular pollen load was collected per individual, stored at −20 °C, then acetolyzed (Erdtman, 1954, 1960; Hesse & Waha, 1989; Moquet *et al.*, 2015). Using a light microscope, approximately 500 pollen grains were counted and identified per pollen load. We used the reference collection of our laboratory and reference to scientific literature (Reille, 1992, 1995) for pollen identification. Marginal species, meaning those that constituted < 2.0% of pollen-load content, were not included in the quantitative analysis (Free, 1970; Westrich & Schmidt, 1986).

Statistical analysis

All statistical analyses were conducted in R, version 3.2.4 GUI 1.67 (www.r-project.org). Bumblebees were grouped by OTU morphotypes. The non-Syrphidae Diptera were classified into a single group. For the other insects, a group corresponded to a single species.

Insect–flower interaction networks were visualized using the {bipartite} R-package. We used insect species as the higher trophic level and plant species as the lower trophic level. Grey-coloured heat maps were generated using the 'heatmap.2' function of the {gplot} R-package.

We conducted mean values comparisons (95% confidence) using several steps. Normality was tested with the Shapiro–Wilk normality test ('shapiro.test' function of the {stats} R-package). In the case of a non-normal distribution, we used the Kruskal–Wallis test ('kruskal.test' function of the {stats} R-package). When normality was accepted, we tested variance equality ('var.test' function of the {vegan} R-package) using the paired Student's *t*-test or Welsh test according to the equality (or inequality) of the variances ('t.test' function of the {stats} R-package). The *t*-values were compared with the *t* table values of the corresponding degree of freedom, with 95% confidence level ($P < 0.05$).

For normally distributed data, we report the mean ± SD. For non-normally distributed data, we report median values with interquartile ranges (25th to 75th percentiles).

Results

Climatic variation between years

There were varying climate conditions between 2015 and 2016; hours of sunshine were significantly lower and there were more frequent rainy days in 2016 compared with that in 2015 (60 versus 37 days) (Table 2). The climatic differences were strong in April, May and June with recorded monthly precipitations six, two and three times higher, respectively, in 2016 than those in 2015 ($\chi^2 = 15.96$, d.f. = 1, $P < 0.01$).

During periods of insect activity (09.00 to 18.00 h) from April to June, rainy days were more frequent in 2016 than in 2015 (45 versus 21 days). Precipitation was three-fold higher and heavy rain (> 5 mm in 9 h) was five-fold more frequent (10 versus 2 days) in 2016 compared with that in 2015.

Nevertheless, insect observations were only performed on sunny and warm days.

Floral diversity

We recorded a total of 56 flowering plant species (53 spontaneous and three sown) belonging to 17 families in the bird-strip AES (Table 3). Mean diversity was 17.5 ± 7.8 plant species per bird strip per year. Over the 2 years, nine Fabaceae species provided the highest number of floral units (35.3% of total floral units observed) followed by five species of Brassicaceae (21.8%) and four species of Polygonaceae (17.7%) (Fig. 1). Most of the observed flowering species (28.6–70.3% of species per bird strip) each provided less than 1.0% of the total floral units per bird strip.

Across all four bird strips during both 2015 and 2016, floral density was 34.9 ± 58.1 floral units/m^2. Most flowering species (84%) had very low floral density over the seasons regardless of the year (< 1 floral units/m^2) (Table 3). The highest floral densities were attained with *T. incarnatum*, with up to 215 and 109 floral units/m^2 in bird strip C in July and September, respectively, followed by *Polygonum aviculare* with up to 45 floral units/m^2 in August and *R. sativus* with up to 40 floral units/m^2 in July in bird strip B.

In total, the three sown entomophilous species, *F. esculentum*, *P. tanacetifolia* and *R. sativus*, represented 25.4% of the 81 539 floral units measured over the 2 years.

Spontaneous and sown plant species provided more floral units in 2015 than in 2016, specifically nine and two times more, respectively. Among the 56 total observed flowering species, 48 were observed in 2015 and 32 in 2016. We observed no significant differences in floral diversity per bird strip between the 2 years ($t_6 = 1.7273$). The three sown plant species provided 20.9% and 50.4% of all floral units in 2015 and 2016, respectively. These three plant species were all present in 2015, except in bird strip C where *P. tanacetifolia* did not germinate.

Global floral density significantly differed between the 2 years, with five-fold lower floral density recorded in 2016 [4.8 (1.5–22.9) floral units/m^2, $n = 20$] compared with that in 2015 [42.1 (0.0–89.0) floral units/m^2, $n = 24$; $\chi^2 = 0.85$, d.f. = 1, $P = 0.3569$].

Mean flowering period of recorded plant species (those constituting at least one floral unit in one bird strip) reached 1.6 ± 1.0 months in 2015 and 1.5 ± 0.7 months in 2016. The flowering periods were 4.0 ± 0.0 months in 2015 and 3.0 ± 1.7 months in 2016 for the sown species only. Four species were flowering during most of the 11-month observation period, specifically *R. sativus* and *Veronica persica*, which were flowering in eight observation sessions, and *P. aviculare* and *Tripleurospermum inodorum*, which were flowering in seven sessions. The flowering season started in June 2015 and May 2016 with 28.9 ± 29.0 and 2.9 ± 5.9 floral units/m^2, respectively. Peak flowering occurred from July to September, with 47.9%,

Figure 1 Mean floral densities (floral units/m^2) per plant species across the seasons for the four studied bird-strip agri-environment schemes (AES) in 2015 (left) and 2016 (right). Species are in alphabetical order; sown species are indicated in bold. *Species without any insect interaction recorded. Grey scale corresponds to floral unit density. No observation session was conducted in June 2016 as a result of unfavourable weather conditions.

18.3% and 23.1% of the total floral units recorded observed in July, August and September, respectively (Table 4).

Floral resources

Overall, most of the floral resources were provided by four plant families dominated by spontaneous plant species. Nectar sugar was mainly provided by flowers from the Asteraceae (75.8%), Brassicaceae (8.5%) and Boraginaceae (6.2%) families. Pollen was mainly provided by flowers from the Brassicaceae (44.7%), Asteraceae (37.0%), Fabaceae (10.7%) and Boraginaceae (6.3%) families. Regardless of the year, July was the month with the highest production of floral resources (Table 4).

Nectar

Over the 2 years, two spontaneous Asteraceae species, *Cirsium arvense* and *Cirsium vulgare*, produced most of the available nectar (> 63%) (Table 5). The three sown species, *F. esculentum*,

Table 4 Monthly floral densities (floral units/m^2) and floral resources (24-h pollen and nectar production/m^2) of sown and spontaneous plant species in the four studied bird-strip agri-environment schemes (AES) in 2015 and 2016

		Floral density (floral units/m^2)		Pollen μL/day/m^2		Nectar mg/day/m^2	
Year	Month	Sown species	Spontaneous species	Sown species	Spontaneous species	Sown species	Spontaneous species
2015	April	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	May	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	June	0.92 ± 0.95	14.45 ± 19.25	0.09 ± 0.06	11.81 ± 19.10	0.09 ± 0.09	0.06 ± 0.09
	July	43.98 ± 38.72	28 ± 17.98	13.3 ± 11.58	11.27 ± 17.26	9.24 ± 9.78	6.65 ± 9.07
	August	9.17 ± 6.41	73.46 ± 83.95	1.73 ± 1.76	17.29 ± 36.19	1.26 ± 0.90	9.45 ± 14.17
	September	5.00 ± 9.19	63.84 ± 126.81	2.17 ± 4.11	11.31 ± 25.13	0.66 ± 1.21	4.77 ± 9.15
2016	April	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	May	0.23 ± 0.46	2.71 ± 5.43	0.10 ± 0.21	0.00 ± 0.00	0.03 ± 0.06	0.97 ± 1.93
	June	NA	NA	NA	NA	NA	NA
	July	18.85 ± 34.52	12.03 ± 15.66	8.27 ± 15.15	2.35 ± 3.01	2.58 ± 4.71	2.83 ± 4.14
	August	5.30 ± 7.58	9.59 ± 4.06	2.28 ± 3.37	1.09 ± 0.77	0.69 ± 1.00	2.73 ± 2.30
	September	1.31 ± 1.52	3.53 ± 2.61	0.58 ± 0.67	1.15 ± 1.51	0.18 ± 0.21	1.15 ± 0.83

Nectar production corresponds to the mg of sugar produced per day per m^2. Values are the mean ± SD. NA, not available. No data were recorded in June 2016 as a result of bad weather.

P. tanacetifolia and *R. sativus*, provided 15.6% of the nectar. These same plant species provided 19.0% of the nectar in 2015 but only 10.0% in 2016. Daily nectar production per m^2 was significantly higher in 2016 [56.3 (5.7–293.4) mg/m^2, $n = 20$] than that in 2015 [38.1 (0–127.4) mg/m^2, $n = 24$; $\chi^2 = 0.56$, d.f. = 1, $P = 0.454$].

Pollen

The three sown plant species provided 32.3% of the available pollen (Table 5). The sown species provided 24.4% of the pollen in 2015; however, this pollen supply increased to 71.9% of all available pollen in 2016. Daily pollen production per m^2 was significantly higher in 2015 [109.4 (0.0–178.5) μL/m^2, $n = 24$] than that in 2016 [66.1 (1.3–78.6) μL/m^2, $n = 20$ $\chi^2 = 0.21$, d.f. = 1, $P = 0.6494$].

Insect visitors

During the present study, we recorded a total of 1523 insect–flower interactions. We identified 1389 insects in the field and caught 134 insect individuals for laboratory identification. We observed 60 different groups of flower-visiting insects: 43 in 2015 and 37 in 2016 (Figs 2 and 3). The non-Syrphidae flies comprised 17 morphotypes belonging to six families. More than a quarter (26.8%) of the observed insect species morphotypes were represented by a single individual (Fig. 2).

To compare insect–flower interactions between 2015 and 2016, we deleted data of June 2015 because no fieldwork was possible in June 2016. In total, more insect visits to flowers were observed in 2015 (67.3%). Bumblebee individuals represented 48.7% of the recorded flower-visiting insects in 2015 but only 11.0% in 2016. We identified three species among the captured *Bombus* morphotypes: *Bombus lapidarius*, *Bombus*

Table 5 Annual contributions of the 10 most dense, most visited, or main floral resource producing plant species

	% of floral units		% Pollen production		% Nectar sugar production		% of interactions ($N = 1523$)	
Plant species	2015 ($n = 346\,715$)	2016 ($n = 60\,930$)	2015	2016	2015	2016	2015 ($n = 1150$)	2016 ($n = 373$)
SOWN ($n = 3$ species)	**20.9**	**50.4**	**24.2**	**71.9**	**19.0**	**10.0**	**18.7**	**12.3**
SPONTANEOUS ($n = 53$ species)	79.1	49.6	75.8	81.1	81.0	90.0	81.3	87.7
Cirsium arvense	0.8	1.5	4.4	2.9	26.1	5.6	58.1	45.0
Cirsium vulgare	0.2	2.3	NA	NA	26.0	76.1	1.0	3.5
Daucus carota	5.0	0.0	0.4	0.0	0.7	0.0	0.6	0.0
Phacelia tanacetifolia	**5.7**	**1.1**	**7.3**	**1.2**	**9.8**	**0.6**	**10.3**	**0.0**
Polygonum aviculare	12.7	3.7	0.3	0.1	0.2	0.0	0.0	0.0
Raphanus sativus	**9.8**	**48.8**	**16.6**	**70.6**	**6.7**	**9.4**	**8.4**	**12.3**
Sinapis alba	6.3	5.5	19.7	14.7	NA	NA	1.9	3.2
Sonchus arvensis	0.0	3.0	NA	NA	0.0	0.0	2.8	18.0
Trifolium incarnatum	40.5	0.0	12.6	0.0	6.6	0.0	8.1	0.0
Tripleurospermum inodorum	1.9	0.4	21.3	4.0	13.9	0.9	1.0	2.4

All together, these 10 species represented 80% of the floral units and more than 90% of the floral resources and flower–insect interactions. Values are a percentage of the total annual observations over the four sites. Sown species are indicated in bold. NA, not available.

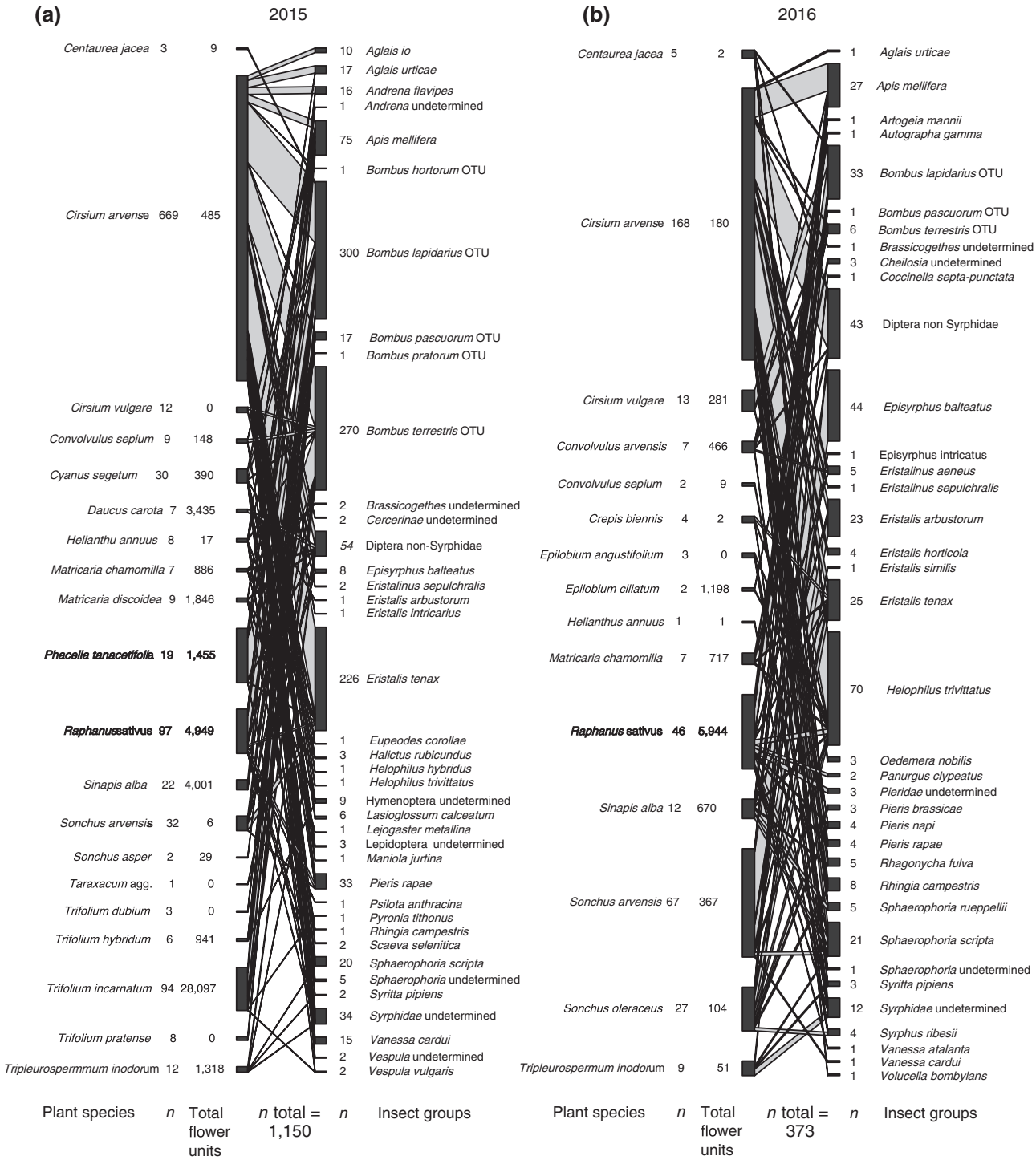

Figure 2 Global interaction networks among flowers and insects across the four studied bird-strip agri-environment schemes (AES) in 2015 (a) and 2016 (b). A total of 1523 interactions was recorded. The height of boxes is proportional to the number of insect visits (*n*). Total floral units refer to the total number of floral units observed. Zero indicates that the species was not sufficiently dense (< 5 floral units/100 m^2 per observation run) to be observed on sampled quadrats, even if present on the transect. Species are in alphabetical order; sown species are indicated in bold.

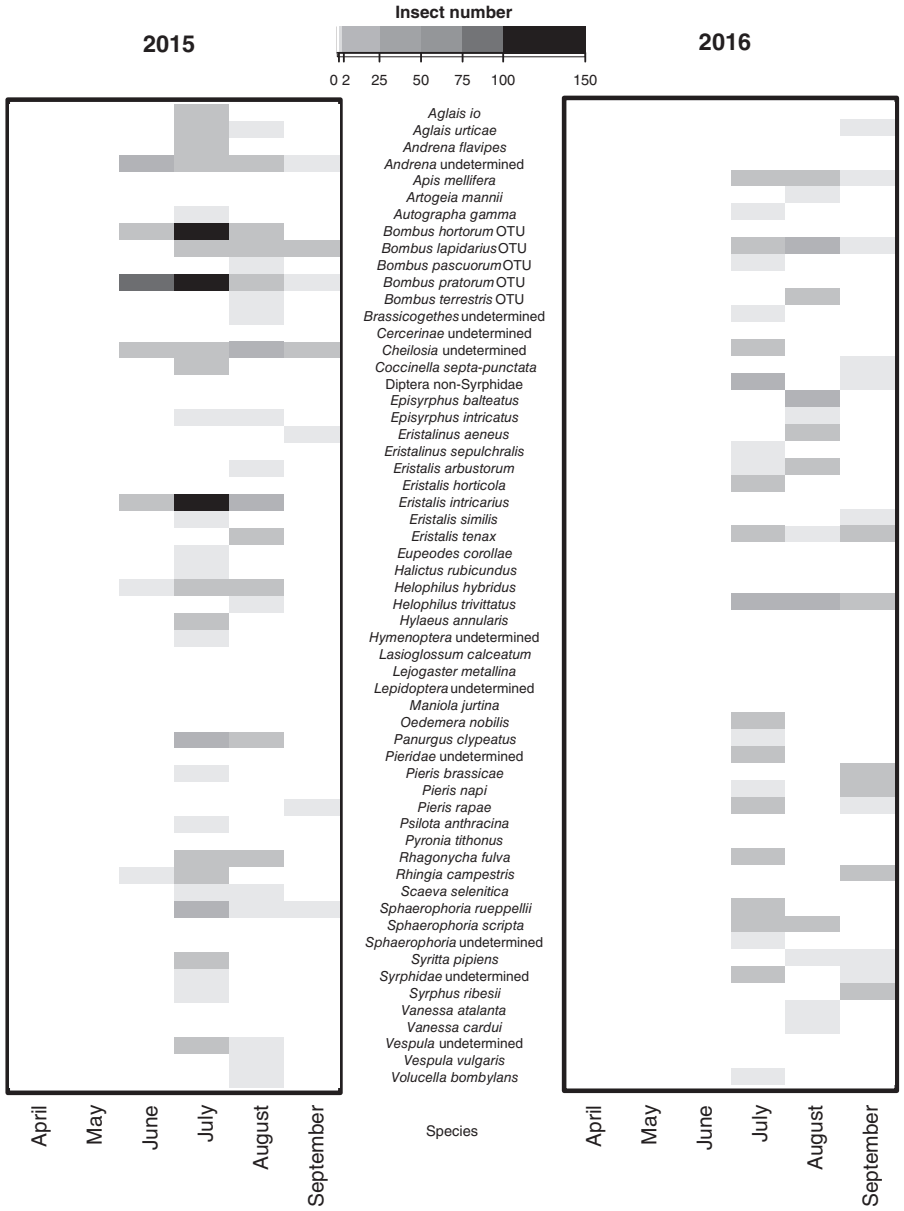

Figure 3 Number and diversity of insects visiting flowers across seasons in the four bird-strip agri-environment schemes (AES) in 2015 (left) and 2016 (right): total number of insects observed on flowers ($n = 1523$). Species are in alphabetical order. Grey scale corresponds to the number of insects observed. No observation session was conducted in June 2016 as a result of unfavourable weather conditions.

pascuorum and *Bombus terrestris*. Five solitary bee species (0.8% of total insects recorded) were observed in 2015 (*Andrena flavipes*, *Andrena* sp., *Halictus rubicundus*, *Hylaeus annularis* and *Lasioglossum calceatum*), although none were observed in 2016. We observed almost as many *A. mellifera* in 2015 (26, 2.2% of the visitors) as in 2016 (27, 7.2% of the visitors).

The density of Diptera (both Syrphidae and non-Syrphidae) flower visitors was similar between 2015 (307 Syrphidae and 54 non-Syrphidae flies) and 2016 (233 Syrphidae and 45 non-Syrphidae flies). Consequently, the relative proportion of Diptera flower visitors was twice as high in 2016 (74.5%) than that in 2015 (35.5%). The diversity of Syrphidae flower visitors was also higher in 2016 (19 species) than that in 2015 (13 species) and only 10 species were present both years. *Eristalis tenax* represented the most abundant Syrphidae flower visitor observed in 2015 (54.6%), whereas *Helophilus trivittatus* was the most observed visitor in 2016 (24.9%).

We recorded only four Lepidoptera species visiting the bird-strip flowers.

Flowers visited

Insect visits were observed on 25 of the 56 recorded plant species (Table 3). Twenty out of 46 plant species were visited

in 2015 and 15 out of 31 were visited in 2016 (Fig. 2). In both years, *C. arvense* floral units received most of the insect visits (54.9% of all insect-flower interactions) despite its low density (Table 5). The second and third most visited plant species were *P. tanacetifolia* and *R. sativus* in 2015, and *Sonchus arvensis* and *R. sativus* in 2016, respectively. The three sown plant species received 17.2% of the insect visits; however, of these three species, no insect visits were observed on *F. esculentum*.

Five Asteraceae species exhibited a global floral unit visit rate (total visits/total floral units) higher than 0.10: *Centaurea jacea* (0.13 in 2015, 0.50 in 2016), *C. arvense* (0.28 in 2015, 0.19 in 2016), *Crepis biennis* (0.40 in 2016), *H. annuus* (0.20 in 2016) and *S. arvensis* (1.07 in 2015).

Insect–flower interactions

Flower visits were mainly observed in summer, with 54.1% occurring in July and 28.4% in August. The first visits were observed in June, representing 11.2% of all the recorded visits (Fig. 3). The mean flower-visit frequencies were zero in both April and May, 0.4 visits/100 m^2/25 min in June, 5.2 visits/100 m^2/25 min in July, 3.9 visits/100 m^2/25 min in August and 0.9 visits/100 m^2/25 min in September.

Annual insect–flower interactions can be summarized by global bipartite networks (Fig. 2). Of the 61 insect groups observed, 23 visited sown plant species and 53 visited spontaneous plant species. A third of the observed insect groups (19) visited both sown and spontaneous species. Only six groups of insects exclusively visited the sown species and 36 visited only the spontaneous species. In 2015, the sown species received visits from only 33% of the insect species, whereas they hosted 43% and 38% of the insect species in 2016 and over the 2 years combined, respectively. Most of the insect diversity was represented in those insects visiting spontaneous plant species (Fig. 2).

The number of flower-visiting insects was three-fold lower in 2016 than that in 2015 and, although insects did not visit the same plant species, insect–flower interaction networks maintained a similar complexity between the 2 years. In 2015 and 2016, networks had 1.8 links per species. Nevertheless, the connectance varied from 0.14 in 2015 to 0.17 in 2016 and web asymmetry varied from 0.3 to 0.4. *Cirsium arvense* attracted the largest diversity of insects, with 79.5% and 59.5% of the insect diversity observed visiting this plant species in 2015 and 2016, respectively. In 2015, two other plant species attracted more than 20% of the insect diversity, namely *R. sativus* (29.5%) and *C. segetum* (20.5%). In 2016, four other plant species attracted more than 20.0% of the insect diversity, namely *R. sativus* (43.2%), *Sonchus oleraceus* (27.0%), *S. arvensis* (24.0%) and *Sinapis alba* (21.6%) (Fig. 2).

Few insect species visited the majority of flowers present in the bird strips. *Bombus lapidarius* OTU was observed on 60.0% of the visited plant species, whereas *B. terrestris* OTU and *E. tenax* were each observed on 48.0% of visited species, and *A. mellifera* and *H. trivitatus* were each observed on 44.0% of visited species (Fig. 2). As many as 93.1% of the non-*Bombus* spp. wild bee visits were recorded on spontaneous plant species, with *C. arvense* being responsible for 89.7% of these visits. The sown species *R. sativus* received 6.9% of the insect visits (Fig. 2).

Insect fidelity

We identified a total of 10 plant species in *Bombus* spp. pollen loads. The most frequently collected pollens were from the two sown species, *P. tanacetifolia* and *R. sativus*, which represented 43.1% and 45.0% of the collected pollen grains, respectively (Table 6). Fidelity of *Bombus* spp. individuals was high. In each pollen load, the dominant species represented 94.0 ± 8.2% of the content. Pollen from plant species outside of the bird strips was marginal (2.3% of the collected pollen) (Table 6).

Discussion

Effects of annual climatic variation

Climatic variations. Periods of sunshine were 1.5-fold shorter and precipitation was 2.8-fold higher in 2016 than in 2015. Farmers were unable to sow their bird strips in 2016. We were unable to perform observations in June 2016 as result of bad climatic conditions. In 2016, we observed fewer interactions (by three-fold) among flowers and insects than that in 2015, despite the fact we only performed observations during sunny and warm days. These wet weather conditions, especially during spring, negatively affected plant germination and growth, as well as insect numbers (Williams, 1940, 1961; Willmer & Stone, 2004; Baldock *et al.*, 2015).

Plant community: spontaneous species are more affected than sown species. In 2016, plant diversity was reduced from 46 to 31 species and thus was decreased by approximately one-third compared with that in 2015. The absence of soil disturbance was deleterious to annual species (e.g. *C. segetum*, *F. esculentum* and *P. tanacetifolia*) that need annual tillage to germinate (Dyer, 1995). Conversely, the absence of soil disturbance favoured perennial species such as *Cirsium* and *Convolvulus* spp. (Free *et al.*, 1975; Carvell *et al.*, 2006). Moreover, *R. sativus* flowered similarly between the 2 years; this species is known for its self-seeding capacity (Warwick & Francis, 2005).

Surprisingly, sown species provided only 24% of the pollen available in the year of sowing (2015), whereas, in 2016, when only spontaneous sowing occurred, species from the sown species group provided 72% of the available pollen. The maintenance of pollen production was excellent, with a lower reduction observed for pollen production than that for floral unit numbers.

Insect communities were more affected than plant communities. In 2016, we recorded almost 15-fold fewer bumblebee individuals than in 2015. We observed reduced visitation rates in 2016. Hymenoptera populations remain low in the face of floral resource availability shortages (Kim, 1999; Scheper *et al.*, 2015; Thomson, 2016). In particular, a shortage of floral resources in spring, during which time insect colonies are founded, affects insect populations for the entire season (Williams, 1940; Williams *et al.*, 2012). The foundation of bumblebee colonies might therefore have decreased in 2016 from 2015, explaining the reduced numbers of observed bumblebees in the bird strips. Solitary bees might be even more affected by adverse weather

Table 6 Pollen load composition (% of collected pollen grains) and importance of each plant species (all pollen loads grouped together) in the diets of the three main *Bombus* operational taxonomic units (OTU) caught in the four studied bird-strip agri-environment schemes (AES) in 2015 and 2016

Plant family	Plant species OTU	Boraginaceae	Brassicaceae		Fabaceae			Poaceae	Rhinantheae	Solanaceae
		Phacelia tanacetifolia	*Brassica nigra*	***Raphanus sativus***	*Lotus corniculatus*	*Medicago sativa*	*Trifolium incarnatum*	*Trifolium repens*	*Poaceae* sp.	*Pedicularis* sp.	*Solanum tuberosum*
Mean % in pollen load (number of pollen loads)	*Bombus lapidarius* $n = 12$	**9.9 ± 7.6(4)**	99.5 (1)	**96.2 ± 6.9(10)**			71.1 (1)				
	Bombus pascuorum $n = 1$	**8.4(1)**		**89.2(1)**		2.2 (1)					
	Bombus terrestris $n = 13$	**95.7 ± 2.2(11)**		**99.4(1)**	4.1 ± 2.7 (6)			3.4 (1)	14.5 (1)	13.6 (1)	71.1 (1)
% in *Bombus* OTU diet	*Bombus lapidarius* $n = 12$	**3.7**	**3.7**	**81.4**			6.0				
	Bombus pascuorum $n = 1$	**8.4**		**89.2**		2.2					
	Bombus terrestris $n = 13$	**81.1**		**7.88**	2.4			0.4	1.1	1.1	5.5

Values are the mean ± SD for the pollen load composition and percentage. Only species representing more than 2% of pollen load composition were considered. *Species from outside of the bird-strips; sown species are indicated in bold ($n = 26$).

conditions in the spring because we did not observe any solitary bees in 2016.

Syrphidae numbers are usually constant from year to year and always represented by the same dominant species (Owen & Gilbert, 1989). However, we observed a change in the dominant Syrphidae species (*E. tenax* versus *H. trivitatus*), although total numbers of Syrphidae remained unchanged over the 2 years. The reduction in floral unit abundance was compensated by a diversification of the plant species visited by Syrphidae (10 in 2015 versus 16 in 2016). The sown species were marginally used by Syrphidae (4.4% of the visits). As a consequence, the more numerous spontaneous plant species present in 2016 were visited by Syrphidae.

Bird-strip quality

Diverse floral resources for insects. Across the four studied bird strips, spontaneous plant species were dominant, providing most of the floral units (75%). These spontaneous plant species attracted most of the observed insect diversity (88%) and volume (82%). Nevertheless, the sown plant species were the species most visited by *Bombus* spp. for pollen collection. Pollen quality is a predominant factor influencing bumblebee flower choice and explains their floral fidelity (Leonhardt & Blüthgen, 2012; Ruedenauer *et al.*, 2016). The high fidelity of *Bombus* spp. to sown species that we observed based on their pollen diet likely reflects the poor pollen quality of the other plant species. Therefore, for *Bombus* spp., the sown species were critical for providing pollen and the spontaneous plant species provided nectar.

In 2016, the failure of the sown plant species to establish was mitigated by the growth of spontaneous plant species. In our bird strips, the diversity of sown entomophilous plants was low, represented by only three species, whereas the diversity of spontaneous entomophilous plants, represented by 52 species, was among the highest of that in studied bird strips in Europe. Usually, numbers of spontaneous plant species ranges from 10 to 60 (Engels *et al.*, 1994; Bokenstrand *et al.*, 2004; Carvell *et al.*, 2006; Haaland *et al.*, 2011; Hicks *et al.*, 2016; Campbell *et al.*, 2017). Insect visitors were observed on 25 plant species, although most visits were to Asteraceae species (69%).

Despite the attractiveness of the nectar resources of Asteraceae species to insects (Hicks *et al.*, 2016), the pollen quality is poor as a result of a lack of several essential amino acids (Goulson *et al.*, 2005; Hanley *et al.*, 2008; Forcone *et al.*, 2011; Nicolson & Human, 2013; Somme *et al.*, 2015; Spear *et al.*, 2016; Vanderplanck *et al.*, 2018).

All of the observed *Bombus* spp. emerged in spring (March to April, Benton, 2006; Falk, 2015) and required floral resources early in the season. The poor floral resources in spring in the bird-strip AES (first floral units observed in May) reduced their attractiveness to insects during this season (Dicks *et al.*, 2015).

Importance of C. arvense. Observation of insect–flower interactions revealed that only a few plant species attracted the majority of insects (Carvell *et al.*, 2006; Haaland & Gyllin, 2010). Despite its low floral density (0.6 floral units/m^2), *C. arvense* hosted 55% of the observed insect interactions. The attractiveness of this

species, regardless of year, can be explained by a combination of high nectar production (up to 2.6 mg of sugar/day/floral unit) and plant morphology (i.e. tall stems with highly visible purple capitula) (Kirk & Howes, 2012). *Cirsium arvense* has been previously reported as being very attractive for numerous insects, primarily for generalist inset species such as those we observed (Knuth, 1908; Kirk & Howes, 2012; Vray *et al.*, 2017) and thus could represent a valuable floral resource, especially in farmlands where other floral resources are rare (Haaland & Gyllin, 2010). Nevertheless, *C. arvense* is an aggressive, hard-to-control weed with a strong potential for field colonization and is reputed as a problematic species in agronomy; indeed, *C. arvense* is regulated by state law. In several countries, including Belgium, France and the U.S.A., the eradication of *C. arvense* is compulsory during flowering (Welton *et al.*, 1929; Hill, 1983; Vray *et al.*, 2017). Despite its capacity to provide floral resources to numerous insects, integrating such species in AES is not realistic. *Centaurea jacea*, another Asteraceae species that was evenly scattered in the bird strips, had higher rates of insect visits than *C. arvense*. These two perennial Asteraceae species share similar morphology and floral resources. In pollinator-strip AES, *C. jacea* constitutes a major floral resource (Ouvrard *et al.*, 2018) and thus may provide a good alternative to *C. arvense* in bird-strip AES.

Brassicaceae and Fabaceae resources. For insect nutrition, quality pollen consists of high polypeptide and sterol contents and the presence of all the essential amino acids (Somme *et al.*, 2015). For example, Boraginaceae, Brassicaceae and Fabaceae are recognized plant families that produce high-quality pollen for insects (Williams & Christian, 1991; Cook *et al.*, 2003; Hanley *et al.*, 2008; Huang, 2012; Liolios *et al.*, 2016). Nevertheless, polylectic generalist insect species can mix different pollen sources to obtain a balanced diet (Di Pasquale *et al.*, 2013; Eckhardt *et al.*, 2014). Moreover, eusocial bees, such as bumblebees, need pollen throughout the season to sustain their colonies, and require different pollen sources according to the extent of the different flowering periods. Dietary requirements vary even among closely-related bee species (Sedivy *et al.*, 2011; Leonhardt & Blüthgen, 2012; Vaudo *et al.*, 2016). If the goal of insect-targeted AES is to support a diverse array of pollinators, it is therefore necessary to provide various high-quality pollen sources with both spatial and temporal complementarity. However, if the goal of these AES is to preserve rare oligolectic specialist insect species, defining the particular insect taxa to which the floral composition is adapted constitutes a crucial first step.

Bird-strip AES attracted mainly polylectic flower-visiting insects. The flower-visiting insect volume that we observed (2.6 visits/100 m^2/25 min from June to September) was lower than that in areas favourable for pollinators in summer. In Belgium, Blaauw and Isaacs (2014) recorded 32.6 visits/100 m^2/25 min in sown wild-flower plots (even if they recorded only bees and Syrphidae), Forup and Memmott (2005) observed 28.6 visits/100 m^2/25 min in meadows, and Ouvrard *et al.* (2018) recorded 116.8 visits/100 m^2/25 min in pollinating insect flower-strip AES that made use of flowering hay meadows. The observed insect numbers in our bird strips were even lower than those in U.K. areas without specific pollinator-friendly management plans, specifically 6.7, 11.1 and 13.0 visits/100 m^2/25 min, respectively, in urban areas, farmlands and nature reserves (Baldock *et al.*, 2015).

We observed only a small subsample of common insect species present in Wallonia. We recorded three *Bombus* spp. among 30% (Pauly & Rasmont, 2010), five non-*Bombus* wild bee species among 300 (Rasmont *et al.*, 2005), 24 Syrphidae species among 310 (Speight *et al.*, 2015) and four Lepidoptera species among 115 (Dopagne, 2015). However, the observed flower-visiting insect diversity (74 morphotypes) was the same as that in Belgian AES devoted to pollinators (Ouvrard *et al.*, 2018) and within the range of other observations on European farmland floral areas dedicated to insects (25–131) (Fründ *et al.*, 2010; Ebeling *et al.*, 2011; Campbell *et al.*, 2017). The observed insect diversity was higher than the flower-visiting insect diversity reported in a recent U.K. study across urban, farmland or nature reserve landscapes (32, 48 and 46 insect species, respectively) that were lacking specific pollinator-friendly management (Baldock *et al.*, 2015). The solitary bee diversity (five species) was similar to another flower-strip AES nearby (Ouvrard *et al.*, 2018) and higher than that found in several countries (0.8–3.1 average bee species diversity per set of sites, Baldock *et al.*, 2015; Scheper *et al.*, 2015).

The pool of insects observed was mainly represented by the four common polylectic species *A. mellifera*, *E. tenax*, *B. lapidaries* and *B. terrestris* OTUs that represented 63% of flower-visiting insects. The dominance of these common Hymenoptera and Syrphidae species is typical in field flower-strip AES (Rader *et al.*, 2012; Kleijn *et al.*, 2015; Wood *et al.*, 2017). Many pollinator-focused AES can be criticized for predominantly supporting a few common species; however, the studied bird-strip AES did not perform better. Nevertheless, the observed polylectic insects are known as pollinating insects (Free, 1993; McGregor, 2009; Willmer, 2011) and their presence in high numbers may support effective landscape-level pollination services (Kleijn *et al.*, 2015; Wood *et al.*, 2017). Moreover, one-third of the 24 observed Syrphidae species have a carnivorous larval stage (Speight, 2016) that can provide additional pest management services (Ssymank *et al.*, 2008).

Recommendations. Unless the seeds that *F. esculentum* produced are important for birds, this plant species could be removed from the sowing mix because it provided only 0.2% and 1.6% of final pollen and nectar resources, respectively, and its flowers were not visited by insects. The addition of early flowering species, such as *Erysimum* spp. or *Vicia faba*, to the feeding section, or *Lamium* species, which are particularly attractive for bumblebees (Sikora & Kelm, 2012), to the refuge section, could help fill the spring gaps regarding insect food resources. Moreover, we highly recommend adding *C. jacea* to the seed mix in the refuge section to increase nectar resources and replace *C. arvense*, which must legally be destroyed in Belgium. Implementing such simple recommendations could increase the provision of floral resources and render bird-strip AES more beneficial to insects.

Conclusions

Management of bird-strip AES allows spontaneously established, self-seeding plant species to grow and flower. We found that the spontaneously established plants are overwhelmingly important for insect diversity and number, as well as insect–flower interactions. These plant species provided floral resources to most of the insect visitors during the summer, although the sown plant species were particularly important for providing pollen to insects. One sown plant species, *R. sativus*, is particularly valuable as a result of the quantity and quality of its pollen and its resilience to varying climatic conditions. Nevertheless, spontaneous plant species increased nectar quantity in the bird strips.

Although designed for birds, bird-strip AES offers opportunities for wild plants to establish, which in turn can provide food resources for insects. Actual management of bird strips may provide little benefit for insects. Spontaneous colonization of bird strips will depend on the plant species pool available and potentially local management, which might differ markedly outside of the small sample of bird strips investigated in the present study. Nevertheless, the addition of early annual flowering Fabaceae species in the feeding section and Asteraceae species in the perennial refuge section could make significant improvements to the benefits for insects offered by bird-strip AES.

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