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Hoverfly diversity supported by vineyards and the importance of ground cover management

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Abstract

The association of hoverflies with vineyards and the response of the species to different types of ground cover management were investigated in two Swiss vineyards sampled using Malaise and emergence traps from March to July 2014. Eight of the 21 species collected in emergence traps, some of them with conservation interest, were identified as having a high association with vineyards. The most diverse fauna was found with ground cover of spontaneous, ruderal vegetation, which provided for, in particular, aphid-feeding species living in the grass-root zone. Plots in which there was no ground vegetation lacked these species. Sowing a grassy mixture of seeds, which resulted in a complete cover of ground vegetation, was not found to promote richness and abundance of hoverflies, and was interpreted as a "barrier" to development of syrphid biodiversity in vineyards. The various ground vegetation treatments studied were found to promote almost only polyvoltine aphidophagous species, except a few phytophagous species and univoltine species whose larvae live in the soil.

Thus, management of ground cover in vineyards can have a significant impact on abundance of hoverfly populations and spontaneous vegetation in the ground cover can maximise hoverfly diversity. Although hoverflies have no evident role in biological control in vineyards, vineyards can be regarded as potential reservoirs of beneficial insects to populate other crops.

Key words: Diptera Syrphidae, applied entomology, agrobiodiversity, viticulture, natural control, natural enemies.

Introduction

The Syrphidae comprise a well-studied family of Diptera with around 6,000 species described worldwide (Sommaggio, 1999). Hoverflies are increasingly used as environmental indicators in a variety of contexts (Castella and Speight, 1994; Gittings *et al*., 2006; Burgio and Sommaggio, 2007; Speight *et al*., 2007). In croplands hoverflies provide the important ecosystem service of biological control because many species (about one third of the family) feed on aphids (Speight *et al*., 2013). Furthermore, adults of the majority of species are effective pollinators (Sommaggio, 1999). Studies carried out on cereals (Chambers and Adams, 1986; Tenhumberg and Poehling, 1995; Hickman and Wratten, 1996), orchards (Vogt and Weigel, 1999; Gontijo *et al*., 2013) and vegetables (Francis *et al*., 2003) demonstrate the interest of hoverflies in the control of aphid populations. Few studies investigated vineyards. However, Daccordi *et al*. (1988) and Sommaggio and Burgio (2014) used various traps to identify hoverflies supported by vineyards. None of them used emergence traps or tried to investigate the associated ground vegetation and its influence on hoverflies. Ground vegetation is regarded as enhancing arthropod diversity within crops (Lu *et al*., 2014) and within vineyards (Sanguankeo and Leon, 2011; Pétremand *et al*., 2016), particularly with native grass cover (Danne *et al*., 2010), and thus promoting natural pest control (Altieri, 1999). It also increases predation upon weed seeds, hence promoting natural weed control (Sanguankeo and Leon, 2011). Some ground cover plants have revealed to attract more beneficial insects than grassy ground cover in Italian vineyards and specifically *Alyssum* and Buckwheat that are attractive for syrphids (Burgio *et al*., 2016). Although Raymond *et al*. (2014) showed that overwintering of several aphidophagous syrphid species in cultivated lands is possible, there is no information about species that can overwinter and/or develop in vineyards and other orchards, and their possible relation to the ground vegetation (or its absence) between the rows of vines or fruit trees.

For the promotion of Conservation Biological Control (CBC) (Ehler, 1998) of crop pests, increasing vegetation cover and provision of flower resources for natural enemies is thought to be one of the main requirements (Andow, 1991; Johnsson *et al*., 2002). Even so, there is still a lack of empirical studies on interactions between arthropods and vegetation (Bàrberi *et al*., 2010).

Considering hoverflies, it was proved that various herb layer plants, especially from the families Apiaceae, Asteraceae, Caryophyllaceae and Fabaceae, provide important floral resources and are intensively used by these insects (Frank, 1999; Colley and Luna, 2000; Hogg *et al*., 2011; Chapelin-Viscardi *et al*., 2015). We can therefore hypothesize that, as shown partly for apple orchards (Falta *et al*., 2010), the absence of ground vegetation or the dominance of Poaceae does not represent optimal conditions for a high diversity and abundance of hoverflies in vineyards.

In vineyards different seed mixes, composed mainly of Poaceae, can be used to provide ground cover. In Switzerland, Spring and Delabays (2006) conducted a study to compare different mixes in terms of compatibility with vines, weed reduction and fertiliser exchange. But the impact on entomological diversity of different ground cover managements in vineyards remains unknown.

We designed a comparative study of the hoverfly assemblages in Swiss vineyards differing in ground-cover management. The design incorporated both flying insects and those emerging from the ground and herb layer. The aims were: (i) to assess syrphid biodiversity supported by vineyards, (ii) to compare the influence of natural vegetation vs. bare ground between the rows, (iii) to compare syrphid assemblages in ground cover vegetation produced by two seed mixes and in natural vegetation and (iv) to characterize hoverflies overwintering and developing within vineyards.

The general biodiversity supported by vineyards could be regarded as poor but studies in Switzerland showed that they can support many rare and stenoecious species of birds (Sierro and Arlettaz, 2003), plants (Clavien and Delabays, 2006), ground beetles (Trivellone *et al.*, 2013b; Pétremand, 2015) or spiders (Trivellone *et al.*, 2013b) associated with dry habitats. Thus, it is possible to anticipate the occurrence of dry-grassland associated hoverfly species that are not common in Switzerland.

Materials and methods

Site characteristics

Sampling took place in two vineyards (Soral, SO and Bernex, BE) located 5 km apart and at the same altitude, in Geneva Canton (Switzerland), thus subject to the same climatic conditions (10.5 °C mean annual temperature, 1000 mm mean annual precipitation). Both vineyards rest on a calcareous soil that is more pebbly in SO.

The two plots are managed in “Integrated Production” (IP), a sustainable farming system that minimises inputs (fertilizers and pesticides). In Switzerland, fruits IP aims to (i) produce good quality fruits, (ii) protect environment and (iii) lead to an economically profitable crop (GTPI, 2015). It is not as strict as organic farming and thus can be considered intermediate between organic and conventional farming. The habitats occurring onsite were recorded in a 200 m radius around the plots (supplemental material, A).

No insecticides were used in any of the vineyard plots, but mating disruption was applied against the European grapevine moth, *Lobesia botrana* (Denis et Schiffermuller), and the grape bud moth, *Eupoecilia ambiguella* (Hubner).

The SO vineyard is adjacent to a brook (La Laire) with a gallery forest and surrounded by *Quercus/Carpinus* forest and others annual arable crops, such as oilseed rape (*Brassica napus*) and corn (*Zea mays*) (supplemental material, B). The ground cover between the vine rows was managed in two different ways. Approximately half of the plot was treated with herbicides (twice a year: glyphosate) resulting in bare ground (BG). This management corresponds with conventional vineyard management. Natural (spontaneous) vegetation (NV) grows on the other part of the plot (IP management). It was mowed three times in 2014 and branches were pruned in March. In this part 49 plant species were found in June, as opposed to 16 in the BG part. Under the rows, herbicides (glyphosate) were also used twice in this part to remove weeds under grapevines. In both parts, fungicides were applied nine times against major diseases such as downy mildew (*Plasmopora viticola*), powdery mildew (*Erysiphe necator*) and grey mould (*Botrytis cinerea*). This plot had not been ploughed for 25 years.

The BE site is surrounded by other vineyards and contains two greenhouses 150 m apart and some isolated trees 300 m apart, surrounded by tall herbs (supplemental material, C). This site is a cantonal experimental station where six different seed mixes were sown between vine rows in August 2011, to compare their agronomic performance in relation to grapevines. Each seed mixture was repeated four times, with each replicate covering a 40 m^2 area. Four additional squares of the same size were left with spontaneous vegetation (C). In the latter 15 plant species were observed in June 2014, predominant among them *Trifolium repens*, *Convolvulus arvense*, *Cerastium fontanum*, *Picris hieracioides* and *Taraxacum offcinalis*, recognised as very frequent species in Swiss vineyards (Clavien and Delabays, 2006). In this study we chose plots sown in March with two seed mixtures that were significantly different (in terms of minimising weed cover):

- The "Schweizer Lenta grassy mixture" (L) where four species of Poaceae were sown and where *Festuca rubra*, *T. repens* and *Poa pratensis* predominated among 16 species identified in June. Percentage cover of Poaceae reached nearly 90%.
- The "Schweizer Neue biodiversity mixture" (N) where 24 plant species from various families (Lamiaceae, Campanulacae, Asteraceae, Fabaceae, etc.) were sown and where *T. repens*, *Lotus corniculatus*, *Medicago lupulina*, *Prunella vulgaris* and *Sanguisorba minor* predominated among 22 species identified in June.

Herbicides (glyphosate, glufosinate) were used twice in the year to remove weed growth under grapevines, where fungicides were also applied 13 times in 2014. The BE plot was mowed four times in the year and branches were pruned in March 2014.

Sampling design and syrphid identification

On both sites sampling was carried out from the 17th March to the 24th July 2014, using emergence and Malaise traps. It was stopped at the end of July because the main emergence period of anticipated species could then be regarded as covered, according to their biological characteristics (Speight *et al.*, 2013).

Emergence traps were used to collect adult hoverflies that developed as larvae in the soil, litter and herb layers between grapevine rows. These traps cover hermetically a soil area of 1.8 m^2 and are modified Malaise traps (B&S Entomological services, Co. Armagh, N. Ireland, UK). Four traps were installed in SO, two per treatment (BG, NV). In BE, two emergence traps were installed in each of three treatments: the spontaneous vegetation surface (C) and the two floral mixtures: the "Schweizer Lenta grassy mixture" (L) and the "Schweizer Neue biodiversity mixture" (N). All emergence traps were moved twice, in the middle of May and at the end of June, to collect the successive generations of polyvoltine species. Space and logistical constraints precluded use of larger numbers of emergence traps.

In addition, Malaise traps were used to collect adult hoverflies flying over the sites, to provide a picture of the local species pool. Three traps were set around the vineyards in SO, not far from the surrounding habitats (supplemental material, B). In BE, two traps were set on the northern and southern sides of the study site (supplemental material, C). Once installed, Malaise traps were not moved and were operated continuously during the study.

Collection bottles on all traps contained ethyl alcohol 70% and were replaced about every two weeks. The sampled material was manually sorted to extract hoverflies that were subsequently identified to species level using Verlinden (1991), Van Veen (2004), Bartsch *et al*. (2009), Speight (2014b), Speight and Sarthou (2014), Vujìc *et al*. (2013).

Site characteristics

The Syrph-the-Net database (StN) (Speight *et al*., 2013) was used to analyse the samples. StN compiles habitat preferences and other biological, ecological and distribution information for more than 900 European hoverfly species, in a digitised format. The hoverflies recorded were divided into two groups: species associated with the macrohabitats occurring in the surroundings of the Malaise traps and species not associated with those habitats.

StN was also used to extract information about two biological traits of the species and to calculate their percent representation in the samples:

- Food type of the larvae: aphidophagous, phytophagous or saprophagous/microphagous.
- Voltinism: univoltine, bivoltine or polyvoltine (more than 2 generations per annum).

In all analyses temporal variations were not taken into account - data were summed over the whole collection period. Specific richness (number of species), abundance (number of individuals), Shannon's diversity (Magurran, 1988), rarefied richness and its standard error (Heck *et al*., 1975) were calculated for every ground cover management at SO (BG, NV) and BE (C, L, N). Wilcoxon Signed Rank test (V) (Hollander and Wolfe, 1973) was applied to compare abundance of species between treatments.

The relative abundance of every species collected in emergence traps was calculated and species were each assigned to one of four larval trophic groups, based on Speight *et al*. (2013) and Sirfigest (Rojo *et al*., 2003): phytophagous (P), major aphidiphagous (MA) that are generalists and could feed on a large number of aphid species, minor aphidophagous (mA), specialists that feed on a few aphid species, minor commensal with root aphids and ants (mcA), that live in the grass-root layer of the soil and feed on aphids or ant larvae.

Results

Richness, abundances and predominant species

In total, 21 syrphid species were collected by the emergence traps (table 1). The Malaise traps collected a total of 89 species, listed in Pétremand and Speight (2015). At BE 134 individuals of 15 species were collected in the emergence traps (n = 6) and 1106 individuals of 42 species in the Malaise traps (n = 2). At SO there were 279 individuals of 16 species in the emergence traps (n = 4) and 2584 individuals of 83 species in the Malaise traps (n = 3). The most abundant species in the Malaise traps on the two sites were *Melanostoma mellinum* (L.) (35% at BE, 31% at SO) and *Sphaerophoria scripta* (L.) (3 % at BE, 19% at SO). In the emergence traps *Pipizella viduata* (L.) (22%), *Eupeodes corollae* (F.) (21%) and *Episyrphus balteatus* (DeGeer) (19%) were the most abundant at BE and *P. viduata* (41%) and *Paragus bicolor* (F.) (29%) at SO.

Delineation of vineyard-associated species

Since the species collected by the emergence traps were reared from vineyards, these 21 species can reasonably be regarded as vineyard-associated. The majority of these species are also recognised as occurring in the types of habitat observed in the surroundings of the study sites (supplemental material, A). But eight of them are not recognised as inhabitants of any of those habitats and so can be identified as potentially dependent upon vineyard management for their presence: *Cheilosia latifrons* (Zetterstedt), *Chrysotoxum vernale* Loew, *Paragus albifrons* (Fallen), *P. bicolor*, *Paragus haemorrhous* Meigen, *Paragus tibialis* (Fallen), *Sphaerophoria taeniata* (Meigen) and *Xanthogramma pedissequum* (Harris). This suggests two levels of association of the emergence-trapped species with vineyards: a high level (+++), exhibited by the eight species apparently dependent on vineyards for their presence in the local landscape and a lower level (+), exhibited by the other 13 emergence-trapped species which can inhabit both vineyards and other habitats present in the vicinity (table 1).

Extraction of the species recorded in the Malaise traps but not collected in the emergence traps and not known to be associated with the surrounding macrohabitats in each vineyard plot has provided a list of 13 species. One of these, *Helophilus pendulus* (L.), is highly migratory and has aquatic larvae. Its presence in the BE Malaise traps could be due to long-distance movement, so there is no basis for considering it as a vineyard species. This leaves the following 12 species unaccounted for, which might thus have a degree of association with vineyards, though this cannot be substantiated in an absence of emergence trap records: *Cheilosia albipila* Meigen, *Cheilosia proxima* (Zetterstedt), *Cheilosia urbana* (Meigen), *Eumerus elaverensis* Seguy, *Eumerus funeralis* Meigen, *Eupeodes flaviceps* (Rondani), *Merodon albifrons* Meigen, *Merodon nigritarsis* Rondani, *Platycheirus angustatus* (Zetterstedt), *Platycheirus europaeus* Goeldlin, Maibach et Speight, *Platycheirus fulviventris* (Macquart), *Rhingia campestris* Meigen.

Table 1. Relative abundance of the species collected in emergence traps at the two study sites for each ground cover management. In brackets: number of sampling period out of 9 where the species was present. Species are classified in four larval diet categories: P = phytophagous, mA = minor aphidophagous, MA = major aphidophagous, mcA = minor commensal with root aphids and ants. (n = 2 traps cumulated for each of the 5 treatments). High level of association with vineyards: +++; lower level of association with vineyards: +.

Species	SO		BE			Food	Vineyards
	BG	NV	C	L	N	diet	association
Cheilosia latifrons (Zetterstedt 1843)		0.5 (1)				P	+++
Chrysotoxum festivum (L. 1758)		0.5 (1)				mcA	+
Chrysotoxum vernale Loew 1841		2 (4)				mcA	+++
Episyrphus balteatus (DeGeer 1776)	3 (1)	1 (2)	20 (4)		21 (5)	MA	+
Eumerus strigatus (Fallen 1817)	3 (1)					P	+
Eupeodes corollae (F. 1794)	3 (1)	0.5 (1)	16 (3)	25 (3)	23 (6)	MA	+
Melanostoma mellinum (L. 1758)		2 (3)	10 (3)	50 (4)	7 (4)	P/MA	+
Melanostoma scalare (F. 1794)					1 (1)	P/mA	+
Paragus albifrons (Fallen 1817)		0.5 (1)			1 (1)	mA	+++
Paragus bicolor (F. 1794)	39 (5)	28 (8)	2 (1)			mA	+++
Paragus haemorrhous Meigen 1822	21 (2)	7 (3)	4 (1)			mA	+++
Paragus pecchiolii Rondani 1857		4 (3)	2 (1)			mA	+
Paragus quadrifasciatus Meigen 1822		0.5 (1)				mA	+
Paragus tibialis (Fallen 1817)	12 (2)	3 (2)				mA	+++
Pipizella viduata (L. 1758)		46 (8)	31 (6)		19 (3)	mcA	+
Platycheirus albimanus (F. 1781)	6 (2)		2 (1)		7 (4)	MA	+
Sphaerophoria interrupta (F. 1805)					3 (1)	mA	+
Sphaerophoria scripta (L. 1758)	12 (4)	5 (6)	6 (2)	17 (1)	12 (3)	MA	+
Sphaerophoria taeniata (Meigen 1822)					3 (1)	mA	+++
Syrphus ribesii (L. 1758)					1 (1)	MA	+
Xanthogramma pedissequum (Harris 1776)			6 (2)	8 (1)	1 (1)	mcA	+++

Table 2. Abundance and diversity in emergence traps for the different ground cover managements of the two vineyards plots (n = 2 traps cumulated for each of the 5 treatments). Rarefied richness was calculated on 30 individuals in SO and 10 in BE.

Plot	Ground cover management	Abundance	Richness	Shannon's Diversity	Rarefied richness (se)
SO	BG (Bare Ground)	33	8	1.7	7.72 (0.49)
	NV (Natural Vegetation)	246	14	1.6	6.97 (1.31)
BE	C (control)	49	10	2.18	5.46 (1.04)
	L (Schweizer Lenta)	12	4	1.85	3.82 (0.39)
	N (Schweizer Neue)	73	12	1.91	5.64 (1.05)

Differences between the syrphid fauna of plots subject to different ground cover management

At SO, the ground cover management regimes showed differences for both abundance and richness of syrphids (table 2). There were significantly more individuals in NV than in BG (V = 110.5, p = 0.004) and six more species. However, Shannon diversities were very close in the two treatments and the rarefied richness values were not significantly different.

At BE, comparison between the three treatments (table 2) showed that L had lower values for all indices but its rarefied richness was not significantly different from both C and N. Abundances of species were significantly lower in L than in C (V = 52, p = 0.013) and than in N (V = 2.5, p = 0.007). Treatment L produced only four species.

In table 1, a difference between NV and BG is the predominance and constancy of *P. viduata* in NV and its absence in BG. Some common species, like *M. mellinum*, *Paragus pecchiolii* Rondani, and *S. scripta* and two species rare in Switzerland, *P. albifrons* and *P. quadrifasciatus*, were absent in BG. Two *Chrysotoxum* aphidophagous species that are, as larvae, ant commensals were also present in NV only (particularly *C. vernale* that was constant) as well as the phytophagous *C. latifrons.* Two common crop-associated syrphids were present in BG and not in NV: *Eumerus strigatus* (Fallen) and *Platycheirus albimanus* (F.).

In BE, the four species present in L were also recorded in C and N. The most frequent species in C and N were very similar and occurred in both types of ground cover. Another striking fact in table 1 is the absence from L of several common species like *E. balteatus*, *P. viduata* and *P. albimanus*, that were predominant in C and/or N and are major aphidophagous species, but also the absence of several rare species especially within the genus *Paragus*.

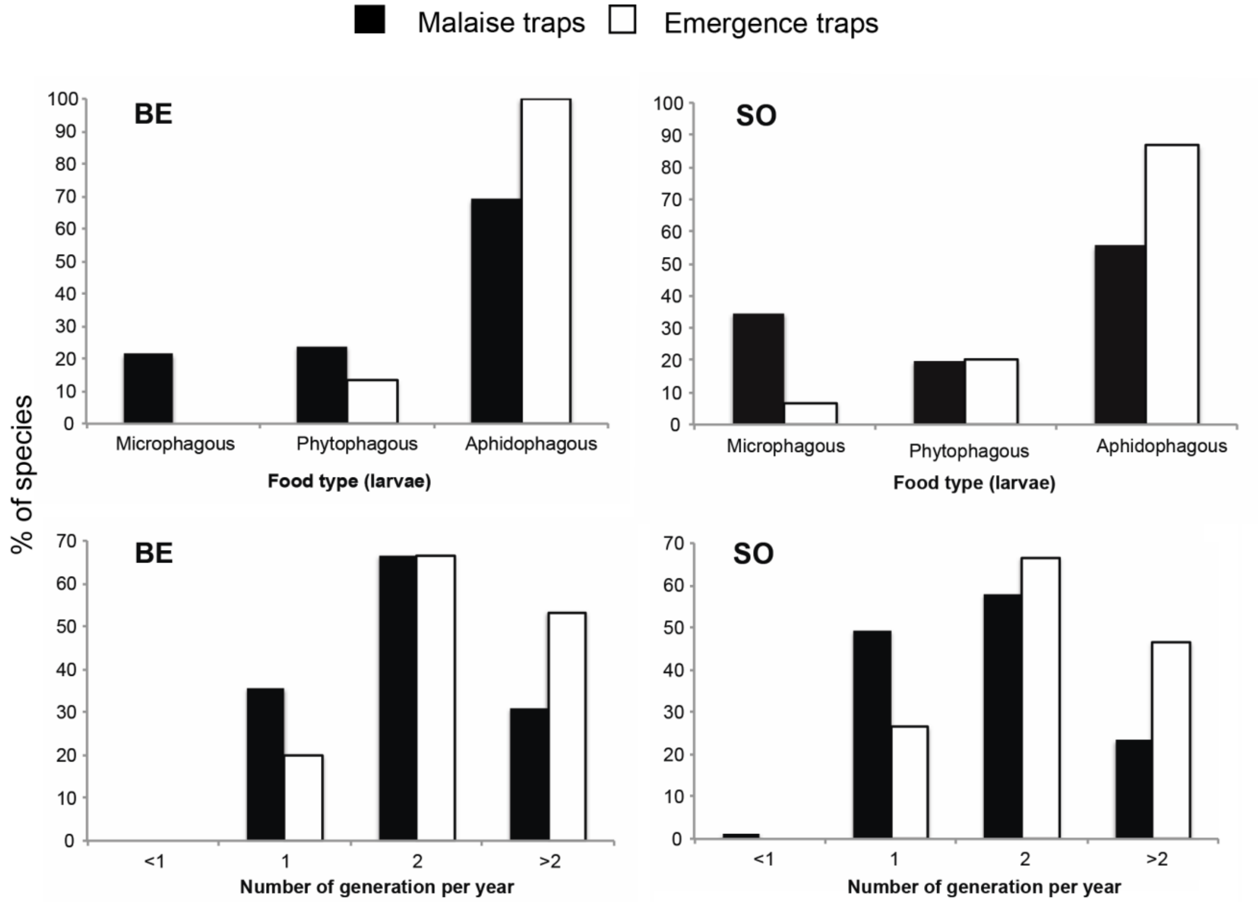

Figure 1. Proportion of species in BE and SO for each category of two biological traits: Food type (larvae) and Number of generations per year.

The most frequent species were generally constantly present except for instance in L where the low number of individuals collected leads all species to be predominant, only two were constantly present. *C. vernale* was not predominant in NV because of the high number of *P. viduata* and *P. bicolor* caught but was constant in this treatment. The most frequent species in BE were mostly major aphidophagous species that can play an important role in biological control of aphid populations. Phytophagous species were totally absent in BE and almost absent in SO.

Thus, additional species can be observed in plots with vegetated ground cover (NV). L treatment led to a low richness, and the absence of common species. The other treatments supported more species and more individuals.

Comparison of species in emergence and Malaise traps

There was a higher proportion of species with carnivorous larvae in emergence traps than in Malaise traps and more microphagous species in the Malaise traps. In emergence traps, species collected were proportionally more polyvoltine than in Malaise traps, where species were mostly univoltine and divoltine (figure 1). The proportion of univoltine species was low in emergence traps.

Emergence and Malaise trap results compared in the same site were always significantly different for each trait compared regarding to the chi square test (Number of generation: $p = 0.006$ at BE and $p = 0.001$ at SO; Food type: $p = 0.013$ at BE and $p = 3e\text{-}06$ at SO). On the other hand, proportions compared between same type of traps in the two sites were never statistically different (Number of generation: $p = 0.174$ for Malaise traps and $p = 0.497$ for emergence traps; Food type: $p = 0.075$ for Malaise traps and $p = 0.192$ for emergence traps).

Discussion

Considerations about abundance, richness and surrounding habitats

We collected a high number of specimens with emergence traps compared to Raymond *et al*. (2014), who collected 179 individuals in two years of sampling from 54 traps in various crops and field margins, so we can consider that the field sampling worked well and that Syrphidae are relatively abundant in ground cover within vineyards. The high number of species in the Malaise trap catches from the SO site could be explained by the more complex landscape and the higher diversity of the surrounding habitats. Species most abundant in Malaise traps in the two sites were *M. mellinum* and *S. scripta*. Daccordi *et al*. (1988) found different species to be predominant in trap catches from

Italian vineyards: *Eristalis tenax* (L.) and *E. corollae* in one vineyard and *E. tenax* and *E. balteatus* in another. There is no larval microhabitat for *Eristalis* species in vineyards (they have aquatic larvae), demonstrating that predominant species in trap catches from vineyards are not necessarily linked with vineyards, but can depend on the surrounding landscape and maybe on the bioclimatic conditions. This is also indicated by our findings that the species most frequent in emergence traps catches were not the same as those in the Malaise traps. Thus, the most frequent species in Malaise traps can be strongly influenced by the surroundings of the plot. All of the species predominating in these traps catches (except *E. tenax*) are major aphidophagous predators and are very common in crop systems in general.

Malaise trapping in the two Geneva vineyards has revealed a very diverse species pool associated with macrohabitats present in the surrounding landscape. This confirms conclusions of others studies using Malaise traps (e.g. Burgio and Sommaggio, 2006; Gittings *et al*., 2007), which noted that Malaise traps sample the hoverfly fauna at the landscape scale (within about 200 m radius) and not only in the immediate proximity of the trap.

Hoverfly fauna developing in vineyards

The use of the StN database allows us to target the species in the Geneva canton species pool that could potentially live in vineyards. Emergence traps can confirm this preliminary choice, by collecting species that actually develop within the vineyards. Among the eight species identified as having a high level of association with vineyards, six are generally associated with relatively dry grassland habitats: *C. vernale*, *P. albifrons*, *P. bicolor*, *P. haemorrhous*, *P. tibialis* and *X. pedissequum*. Two of them, *P. albifrons* and *P. bicolor*, are rarely recorded in Switzerland (Maibach *et al*., 1992) and in some other European countries (Speight *et al*., 2013). Sommaggio and Burgio (2014) predicted two of them (*P. bicolor* and *P. haemorrhous*) to be potentially associated with vineyards in Emilia Romagna (Italy), from their Malaise trap results. They did not employ emergence traps to confirm their prediction. They also predicted *C. latifrons* to be associated with vineyards, another species collected by vineyard emergence traps during the present study.

As larvae, these eight species are, with one exception, aphid-feeding in ground-layer vegetation or the grass-root zone (Speight *et al*., 2013). The exception, *C. latifrons*, has phytophagous larvae known to feed in the tap-root of *Leontodon hispidus* (Stuke and Carstensen, 2002). Except for *E. strigatus*, all of the collected species held in common by vineyards and other habitats are aphidophagous as larvae. They include *E. balteatus*, *E. corollae* and *S. scripta*, all of which are recognised as playing a role in control of aphid infestations in croplands, identifying vineyards as potential population reservoirs of biocontrol by beneficial insects. *E. strigatus* has saprophagous/microphagous larvae in the bulbs of various geophytes (Speight, 2014a).

Of the 12 Malaise trap syrphids not associated with vineyards or the surrounding habitats, seven have larvae that inhabit stem-bases or underground parts of herbaceous plants in unimproved grassland of various types and, with one exception, the rest have aphid-feeding larvae in various types of grassland. The exception is *R. campestris*, whose larvae inhabit cow dung. Very few individuals were collected, of most of these species, but a high number were collected of *M. nigritarsis*, *P. europaeus* and *R. campestris*. *M. nigritarsis* has only rarely been found in Switzerland (Maibach *et al*., 1992). It was only found in the Malaise traps on the BE site. A probable larval host-plant, *Muscari racemosum*, is present along the tracks there, providing potential explanation for this otherwise enigmatic syrphid record. There is no apparent explanation for the presence of *R. campestris* in the Malaise traps, on either site. Flushes observed along the base of the slope above the La Laire stream could explain the presence of *P. europaeus* on the SO site, since this syrphid is associated with flushes within unimproved grassland. But its presence at BE is less explicable. This site does have an extensive network of tracks within the vineyards, bordered by wide, grassy, semi-permanent "field margins". These track margins have the character of unimproved grassland. It is possible they support populations of *P. europaeus*. Such wide track margins are not necessarily a feature of vineyards, but where present, they would be expected to support a fauna and require to be taken into consideration. Unfortunately, they were not subject to emergence trapping in the present study.

Our study showed that vineyards support a diversity of Syrphidae not directly associated with the vines themselves, including some species rarely encountered in Switzerland, probably because of the relatively dry soil and the presence of some bulbiferous plant species typical of vineyards, e.g. *Muscari racemosum* and *Allium vineale*.

The importance of ground cover vegetation and its composition

According to Sanguankeo and Leon (2011) and Pétremand *et al*. (2016), natural vegetation (NV) in vineyards provides a higher richness and abundance of various arthropods than bare ground (BG) weeded by herbicides, an observation repeated here for hoverflies. Some of the hoverflies not collected by the BG traps have larvae which feed on root aphids that live in commensalism with ants in the grassroots zone of the soil. Their presence in the NV traps demonstrates that the fauna responds not only to the above-ground part of the ground vegetation, but also to its presence in the root zone. *P. viduata* and *C. vernale* are good examples. But the NV vineyard plots also host some common and rarer species that could not live without the presence of some above-ground vegetation.

As shown for carabids (Coleptera Carabidae) by Pétremand *et al*. (2016), the L mix shows lower values of richness, abundance and diversity of hoverflies. The additional species observed in the other grass mixture plots C and N are common, mostly major aphidophagous species, or rare and strongly associated with vineyards, like the *Paragus* species. So there is a high interest for biological control and for biodiversity conservation not to sow grassy mixtures in vineyards, as was also shown under very different conditions in Australia (Danne *et al*., 2010). These findings join those of Burgio *et al*. (2016) in vineyards showing the attractive impact on beneficial insects (including syrphids) of specific plants sown as ground cover in comparison with traditional grassing and those of Falta *et al*. (2010) in apple orchards, which showed that syrphids (and other insects) are more diverse and abundant in orchards with flowering strips, rather than traditional grassing. Such results might be expected to be paralleled in any type of orchard, where syrphids like *E. balteatus* can feed on aphids on low-growing plants and also on aphids on trees (Speight *et al*., 2013), so playing a role in controlling aphid populations that are pests of fruit trees.

Aphidophagous and plurivoltine species developing inside vineyards

Because of their shorter generation times, polyvoltine syrphids can complete their development in vineyards despite perturbation of the ground layer vegetation by mowing and mulching. By contrast, univoltine species living in the vegetation are disadvantaged. But species whose larvae inhabit the upper layer of the soil are not, as evidenced by the collection of univoltine *Chrysotoxum* species by the emergence traps, along with the polyvoltine *P. viduata* (BE, SO) and bivoltine *X. pedissequum* (BE). Therefore, it appears in this study that ground vegetation management probably prevents univoltine species from successfully completing generations in the ground vegetation and the fact that in SO winemakers stopped ploughing about twenty-five years previously allowed univoltine ground layer/grass-root zone species to find a suitable habitat.

In the emergence traps, 86% of the syrphid species collected at SO and 100% of the species at BE are aphidophagous as larvae. These are higher proportions of aphidophagous species than were collected by Malaise trap. This means that the ground cover vegetation and soil are providing almost only aphids as a food resource for hoverfly larvae. Two phytophagous species were found (*C. latifrons* and *E. strigatus*) in emergence traps, but with just one individual each at SO. Thus, although our data do not show that plant species present in vineyards represent a good syrphid larval food resource in themselves (excepted in the case of *Eumerus amoenus* Loew and *M. nigritarsis* as discussed above) they can attract aphidophagous syrphids to consume aphid populations in the soil and in the low vegetation layer.

Our results show that vineyards can support populations of common Syrphidae that are recognized as playing an important role in biological control of aphid populations in various crops. But the abundance and the richness of these predators depend on the way the ground cover is managed. It is *a priori* better to let the natural vegetation develop, or to sow some biodiversity mix of seeds. But to stop weeding all the surface of plots with herbicides should enable more species to colonize them, as would avoidance of sowing grassy mixes which impoverish the ground cover and disadvantage rare species and species that are useful in biological control. These results are concordant with those found for carabids in the same vineyards (Pétremand *et al*., 2016). Given that the naturally-vegetated plots, and the plots sown with ground vegetation seed mixes, had only received these treatments for at maximum five years, it is not clear what longer term impact these treatments would have on syrphid biodiversity. These results have contributed to elaborate a new seed mix adapted for the Lake Geneva region with little impact on vine growth, to ensure a good recovery and sustainability of the ground cover and to enhance biodiversity inside vineyards (Delabays *et al*., 2016).

In line with the findings of Raymond *et al*. (2014), species (and their abundance) collected in emergence traps confirm that cultivated lands are potential habitats for overwintering of hoverfly larvae of mainly aphidophagous but also some phytophagous species. Our results highlight the importance of informed ground cover vegetation management in vineyards and in other types of orchards, to enhance overwintering habitats for as many species of hoverfly as possible.

We note that hoverflies do not provide for predation of pest aphid species on grapevine because no aphids are important pests in vineyards, so in this context there is no economic value for vine growers to promote hoverflies. Additionally, syrphids do not provide pollination service to vine due to its self-pollination, although two species (*E. balteatus* and *P. albimanus*) were found visiting vine flowers during this study, meaning that they use vine nectar and/or pollen resource for their development. However, larvae of the hoverfly *Xanthandrus comtus* (Harris) are recognised as a predator of the grape berry moth larva (*L. botrana*) (Belcari and Raspi, 1989), one of the main grapevine pests. Only one specimen of *X. comtus* was found at SO, suggesting that although it is not abundant in the vineyards it is available in the vicinity, to potentially colonize vineyards if *L. botrana* were present. Trivellone *et al*. (2013a) showed that one of the vine pests, the plant bug *Scaphoideus titanus* Ball (Hemiptera Cicadellidae) can potentially be present and can survive in ground vegetation of vineyards. This leafhopper is a vector of the grapevine "flavescence dorée", a quarantine disease in Europe, so its capability to maintain populations in ground vegetation in vineyards is potentially a negative feature of promoting a ground vegetation cover. A molecular study, like that carried out by Gomez-Polo *et al*. (2015), would be useful to establish whether hoverfly larvae predate the nymphs of *S. titanus*, and thus have a potential impact in biological control in vineyards.

Despite the low potential of hoverflies in biological control of grapevine pests, from a CBC point of view, after pesticide (fungicides and herbicides) applications or ploughing in the surrounding landscape, vineyards can be regarded as a reservoir of hoverfly auxiliaries for recolonization of crops grown in the surrounding.

Conclusion

This study is the first demonstrating syrphid species completing their development in the ground cover of vineyards. It shows that vineyards can be an important habitat for overwintering and development of aphidophagous and polyvoltine hoverflies. The way the ground cover between the rows is managed influences hoverfly populations: development of natural vegetation cover promotes establishment of a reservoir of auxiliaries which would be absent if only bare ground were present. These beneficial insects are then available for others crops. The vineyard syrphid fauna can also include some species of conservation interest. Given the small number of vineyards studied, their restriction to one canton in Switzerland and the short duration (one season) of our study, a longer term investigation, involving a wider geographical spread of vineyards, would be worthwhile to establish the extent to which our conclusions apply to vineyards in general.

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References

ANDOW D. A., 1991.- Vegetational diversity and arthropod population response.- *Annual Review of Entomology*, 36 (1): 561-586.

BÀRBERI P., BURGIO G., DINELLI G., MOONEN A. C., OTTO S., VAZZANA C., ZANIN G., 2010.- Functional biodiversity in the agricultural landscape: relationships between weeds and arthropod fauna.- *Weed Research*, 50 (5): 388-401.

BARTSCH H., BINKIEWICZ E., KLINTBJER A., RÅDEN A., NASIBOV E., 2009.- *Nationalnyckeln till Sveriges flora och fauna. Tvåvingar: Blomflugor. Diptera: Syrphidae: Eristalinae & Microdontinae*.- ArtDatabanken, SLU, Uppsala, Sweden.

BELCARI A., RASPI A., 1989.- A new predator of *Lobesia botrana* (Denn. & Schiff.) (Lepidoptera Tortricidae): *Xanthandrus comtus* (Harr.)(Diptera Syrphidae).- *Bollettino di Zoologia Agraria e di Bachicoltura*, 21: 185-192.

BURGIO G., SOMMAGGIO D., 2007.- Syrphids as landscape bioindicators in Italian agroecosystems.- *Agriculture, Ecosystems and Environment*, 120: 416-422.

BURGIO G., MARCHESINI E., REGGIANI N., MONTEPAONE G., SCHIATTI P., SOMMAGGIO D., 2016.- Habitat management of organic vineyard in Northern Italy: the role of cover plants management on arthropod functional biodiversity.- *Bulletin of Entomological Research*, 106: 759-768.

CHAMBERS R. J., ADAMS T. H. L., 1986.- Quantification of the impact of hoverflies (Diptera: Syrphidae) on cereal aphids in winter wheat: an analysis of field populations.- *Journal of Applied Ecology*, 23: 895-904.

CHAPELIN-VISCARDI J.-D., TOSSER V., MAILLET-MEZERAY J., SARTHOU V., 2015.- Contribution à la connaissance de la consommation de pollen par six espèces de Syrphes auxiliaires en milieux agricoles (Diptera Syrphidae).- *L'Entomologiste*, 71 (3): 169-178.

CLAVIEN Y., DELABAYS N., 2006.- Inventaire floristique des vignes de Suisse romande: connaître la flore pour mieux la gérer.- *Revue suisse de Viticulture, Arboriculture et Horticulture*, 38 (6): 335-341.

COLLEY M. R., LUNA J. M., 2000.- Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverflies (Diptera: Syrphidae).- *Environmental Entomology*, 29 (5): 1054-1059.

DACCORDI M., MASON F., PLUCHINO P., 1988.- Ditteri sirfidi raccolti in due vigneti della provincia di Verona: applicazioni di alcuni algoritmi per l'analisi di comunità (Diptera: Syrphidae).- *Atti e Memorie dell'Accademia d'Agricoltura, Scienze e Lettere di Verona*, 27: 33-43.

DANNE A., THOMSON L. J., SHARLEY D. J., PENFOLD C. M., HOFFMANN A. A., 2010.- Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards.- *Environmental Entomology*, 39 (3): 970-978.

DELABAYS N., PÉTREMAND G., FLEURY D., 2016.- Comparaison de six mélanges pour l'enherbement viticole dans l'arc lémanique.- *Revue Suisse de Viticulture, Arboriculture et Horticulture*, 48 (5): 322-329.

EHLER L. E., 1998.- Conservation biological control: past, present, and future, pp. 1-8. In: *Conservation biological control* (BARBOSA P. A., Ed.).- Academic Press, New York, USA.

FALTA V., HOLY K., VAVRA R., 2010.- Enhancing abundance of natural enemies in apple orchard using flowering strips, pp. 395-398. In: *Ecofruit*, 14th international conference on organic fruit-growing. Proceedings for the conference, 22-24 February, Hohenheim, Germany.

FRANCIS F., COLIGNON P., HAUBRUGE E., 2003.- Evaluation de la présence des Syrphidae (Diptera) en cultures maraîchères et relation avec les populations aphidiennes.- *Parasitica*, 59 (3-4): 129-139.

GITTINGS T., O'HALLORAN J., KELLY T., GILLER P. S., 2006.- The contribution of open spaces to the maintenance of hoverfly (Diptera, Syrphidae) biodiversity in Irish plantation forests.- *Forest Ecology & Management*, 237: 290-300.

GOMEZ-POLO P., ALOMAR O., CASTAÑÉ C., LUNDGREN J. G. PIÑOL J., AGUSTÍ N., 2015.- Molecular assessment of predation by hoverflies (Diptera: Syrphidae) in Mediterranean lettuce crops.- *Pest management science*, 71 (9): 1219-1227.

GONTIJO L. M., BEERS E. H., SNYDER W. E., 2013.- Flowers promote aphid suppression in apple orchards.- *Biological Control*, 66 (1): 8-15.

GTPI, 2015.- *Directives pour les PER et la production fruitière intégrée en Suisse*.- Secrétariat du GTPI (Groupe de Travail pour la Production fruitière Intégrée), Zoug, Switzerland.

HECK K. L., VAN BELLE G., SIMBERLOFF D., 1975.- Explicit calculation of the rarefaction diversity measurement and the determination of sufficient sample size.- *Ecology*, 56: 1459-1461.

HICKMAN J. M., WRATTEN S. D., 1996.- Use of *Phacelia tanacetifolia* strips to enhance biological control of aphids by overfly larvae in cereal fields.- *Journal of Economic Entomology*, 89 (4): 832-840.

HOGG B. N., BUGG R. L., DAANE K. M., 2011.- Attractiveness of common insectary and harvestable floral resources to beneficial insects.- *Biological Control*, 56 (1): 76-84.

HOLLANDER M., WOLFE D. A., 1973.- *Nonparametric statistical methods*.- John Wiley & Sons, New York, USA.

JONSSON M., WRATTEN S. D., LANDIS D. A., GURR G. M., 2008.- Recent advances in conservation biological control of arthropods by arthropods.- *Biological control*, 45 (2): 172-175.

LU Z. X., ZHU P. Y., GURR G. M., ZHENG X. S., READ D. M., HEONG K. L., XU H. X., 2014.- Mechanisms for flowering plants to benefit arthropod natural enemies of insect pests: Prospects for enhanced use in agriculture.- *Insect Science*, 21 (1): 1-12.

MAGURRAN A. E., 1988.- *Ecological diversity and its measurement*.- Princeton University Press, Princeton, UK.

MAIBACH A., GOELDLIN DE TIEFENAU P., DIRICKX H. G., 1992.- Liste faunistique des Syrphidae de Suisse (Diptera).- *Miscellanea Faunistica Helvetiae*, 1: 1-51.

PÉTREMAND G., 2015.- Trois espèces de carabes (Coleoptera: Carabidae) sur la liste rouge capturés dans le vignoble du canton de Genève.- *Entomo Helvetica*, 8: 157-160.

PÉTREMAND G., SPEIGHT M. C. D., 2015.- Additions à la liste des Syrphidae (Diptera) du canton de Genève, incluant des espèces rares en Suisse.- *Entomo Helvetica*, 8: 47-58.

PÉTREMAND G., FLEURY D., CASTELLA E., DELABAYS N., 2016.- Influence de l'enherbement viticole sur les Carabidae (Coleoptera) et intérêt potentiel pour le contrôle de certains ravageurs de la vigne.- *Biotechnologie, Agronomie, Société et Environnement*, 20 (3): 375-385.

RAYMOND L., SARTHOU J. P., PLANTEGENEST M., GAUFFRE B., LADET S., VIALATTE A., 2014.- Immature hoverflies overwinter in cultivated fields and may significantly control aphid populations in autumn.- *Agriculture, Ecosystems & Environment*, 185: 99-105.

ROJO S., GILBERT F., MARCOS-GARCIA M. A., NIETO J. M., MIER P. M., 2003.- *A world review of predatory hoverflies (Diptera, Syrphidae: Syrphinae) and their prey*.- CIBIO Ediciones, Alicante, Spain.

SANGUANKEO P. P., LEON R. G., 2011.- Weed management practices determine plant and arthropod diversity and seed predation in vineyards.- *Weed Research*, 51 (4): 404-412.

SIERRO A., ARLETTAZ R., 2003.- L'avifaune du vignoble en Valais central: évaluation de la diversité à l'aide de transects.- *Nos Oiseaux*, 50: 89-100.

SOMMAGGIO D., 1999.- Syrphidae: can they be used as environmental bioindicators?- *Agriculture, Ecosystems & Environment*, 74 (1): 343-356.

SOMMAGGIO D., BURGIO G., 2014.- The use of Syrphidae as functional bioindicator to compare vineyards with different managements.- *Bulletin of Insectology*, 67 (1): 147-156.

SPEIGHT M. C. D., 2014a.- *Species accounts of European Syrphidae (Diptera), 2014*. Syrph the Net, the database of European Syrphidae 78.- Syrph the Net publications, Dublin, Ireland.

SPEIGHT M. C. D., 2014b.- *StN key for the identification of the genera of European Syrphidae (Diptera) 2014*. Syrph the Net, the database of European Syrphidae 79.- Syrph the Net publications, Dublin, Ireland.

SPEIGHT M.C.D., SARTHOU J. P., 2014.- *StN keys for the identification of the European species of various genera of Syrphidae (Diptera) 2014/Clés StN pour la détermination des espèces Européennes de plusieurs genres des Syrphidae (Diptères) 2014*. Syrph the Net, the database of European Syrphidae 80.- Syrph the Net publications, Dublin, Ireland.

SPEIGHT M. C. D., CASTELLA E., OBRDLIK P., 2000.- *Use of the Syrph the Net database 2000*. Syrph the Net, the database of European Syrphidae 25.- Syrph the Net publications, Dublin, Ireland.

SPEIGHT M. C. D., GOOD J. A., CASTELLA E., 2002.- Predicting the changes in farm syrphid faunas that could be caused by changes in farm management regimes (Diptera, Syrphidae).- *Volucella*, 6: 125-137.

SPEIGHT M. C. D., SARTHOU V., SARTHOU J. P., CASTELLA E., 2007.- *Le Syrphe, l'ordinateur et la gestion de la biodiversité*.- Rapport du Conservatoire Départemental des Espaces Naturels de Haute-Savoie (Asters), France.

SPEIGHT M. C. D., MONTEIL C., CASTELLA E., SARTHOU J. P., 2013.- *StN 2013*.- Syrph the Net publications, Dublin, Ireland.

SPRING J. L., DELABAYS N., 2006.- Essai d'enherbement de la vigne avec des espèces peu concurrentielles: aspects agronomiques.- *Revue suisse de Viticulture, Arboriculture et Horticulture*, 38 (6): 355-359.

STUKE J. H., CARSTENSEN L. B., 2002.- Die Biologie und Morphologie der dritten Larvenstadien von vier Mitteleuropäischen *Cheilosia* Arten (Diptera: Syrphidae).- *Beiträge für Entomologie*, 52: 283-307.

TENHUMBERG B., POEHLING H. M., 1995.- Syrphids as natural enemies of cereal aphids in Germany: aspects of their biology and efficacy in different years and regions.- *Agriculture, Ecosystems and Environment*, 52: 39-43.

THOMSON L. J., HOFFMANN A. A., 2009.- Vegetation increases the abundance of natural enemies in vineyards.- *Biological Control*, 49 (3): 259-269.

TRIVELLONE V., JERMINI M., LINDER C., CARA C., DELABAYS N., BAUMGÄRTNER J., 2013a.- Rôle de la flore du vignoble sur la distribution de *Scaphoideus titanus*.- *Revue suisse de Viticulture, Arboriculture et Horticulture*, 45 (4): 222-228.

TRIVELLONE V., PEDRETTI A., CAPRANI M., POLLINI L., JERMINI M., MORETTI M., 2013b.- Ragni e carabidi dei vigneti del Cantone Ticino (Svizzera).- *Bollettino della Società Ticinese di Scienze Naturali*, 101: 63-72.

VAN VEEN M. P., 2004.- *Hoverflies of Northwest Europe: identification keys to the Syrphidae*.- KNNV Publishing, Utrecht, Holland.

VERLINDEN L., 1991.- *Zweefvliegen (Syrphidae)*.- Fauna van Belgie, Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussel, Belgium.

VOGT H., WEIGEL A., 1999.- Is it possible to enhance biological control of aphids in an apple orchard with flowering strips?- *IOBC/wprs Bulletin*, 22 (7): 39-46.

VUJIĆ A., RADENKOVIĆ S., LIKOV L., TRIFUNOV S., NIKOLIĆ T., 2013.- Three new species of the *Merodon nigritarsis* group (Diptera: Syrphidae) from the Middle East.- *Zootaxa*, 3640: 442-464.

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