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ORIGINAL CONTRIBUTION

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Predatory arthropod community composition in apple orchards: Orchard management, landscape structure and sampling method

Peter A. Hambäck[1] | **Mario Porcel**[2,3] | **Marco Tasin**[2,4] | **Ulrika Samnegård**[1,5,6]

[1]Department of Ecology, Environment and Plant Sciences, Stockholm University, Stockholm, 106 91, Sweden

[2]Department of Plant Protection Biology, Swedish University of Agricultural Sciences, Alnarp, Sweden

[3]Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), C.I. La Libertad, Vía Puerto López Km 17, Meta, Colombia

[4]Department of Chemical Sciences, University of Padova, Via Marzolo 1, Padova, 35121, Italy

[5]Department of Biology, Lund University, Lund, 223 62, Sweden

[6]NE School of Environmental & Rural Sciences, University of New England, Armidale, NSW 2351, Australia

Correspondence

Peter A. Hambäck, Department of Ecology, Environment and Plant Sciences, Stockholm University, 106 91 Stockholm, Sweden.
Email: peter.hamback@su.se

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Abstract

Studies on predatory arthropods in agricultural areas seldom include Diptera other than hoverflies, partly because common sampling methods are less effective for capturing species that easily fly off when disturbed. To study the effect from this bias when describing the predator community, we compared traditional beat sampling of branches and suction sampling for describing the community of predatory arthropods in Swedish apple orchards, both organic orchards and orchards using integrated pest management (IPM). Our results indicate that the proportion of both predatory dipterans and parasitic hymenopterans increase dramatically when using suction sampling (Diptera: 32% vs. 20%, Hymenoptera: 25% vs. 7%). In fact, predatory dipterans were the most abundant predatory group when using suction sampling, in contrast to beat sampling where spiders were the most abundant group. One group of predatory flies that was particularly rich in both species and individuals in the surveyed apple orchards was dance flies in the family Hybotidae. Even though the bias of sampling method was evident, it was encouraging that the method choice did not affect the conclusions concerning management on predatory arthropod communities. With both methods, dipteran and coleopteran predators were more abundant in organic apple orchards whereas opilionids were more abundant in orchards managed according to IPM. The inclusion of landscape variables further indicated effects of landscape diversity and of deciduous forest cover, but the response varied in sign between predatory groups. Whereas both Coleoptera and Heteroptera were more abundant in orchards surrounded by more complex landscapes (high landscape diversity and/or high deciduous forest cover), spiders, opilionids and dipterans were rather less abundant in these orchards. To conclude, our study points to the potential importance of predatory dipterans in apple orchards, and we highly recommend future studies of arthropod predators in apple and other crops to actively include predatory Diptera.

KEYWORDS

Diptera, Dolichopodidae, Hybotidae, integrated pest management, organic production

1 | INTRODUCTION

Predatory arthropods are important biocontrol agents in agricultural systems (Östman et al., 2001; Porcel et al., 2018; Schmidt et al., 2003; Thies et al., 2011; Thies & Tscharntke, 1999), and their abundance and community composition depend both on crop management and on the structure of the surrounding landscape (Caprio et al., 2015; Happe et al., 2019; Östman et al., 2001; Schmidt et al., 2005). Particularly organic production and complex landscapes tend to increase predator abundances, presumably because these areas either offer more resources for predatory arthropods or are less disrupted by the use of insecticides (Bianchi et al., 2006; Michalko & Košulič, 2020). However, some other taxa rather seem to have higher abundances in non-organic production (Happe et al., 2019).

In apple orchards, we have previously found differences in the abundance of predatory arthropod groups between organic production and integrated pest management (hereafter organic and IPM), and between major apple growing regions in Europe (Happe et al., 2019; Porcel et al., 2018). One unexpected finding in our previous study (Happe et al., 2019) was the comparatively high abundance of predatory dipterans (mainly Empididae, Hybotidae and Dolichopodidae) in Swedish apple orchards, and Sweden was also the only region where densities of predatory dipterans differed between organic and IPM. This finding was interesting because few previous studies on predatory arthropods in crop fields have reported predatory dipteran densities other than syrphids (e.g., Pfister et al., 2017; Stark & Wetzel, 1987; Weber et al., 1997). However, common methods used to estimate predatory arthropod densities, such as pitfall trapping and beat sampling, are less suitable for estimating flying insect densities, whereas other approaches, such as glue traps, may capture flying insects but generally do not allow for species identification. In our previous study, we got high number of predatory dipterans despite using beat sampling, suggesting that the found dipteran densities may have been an underestimation of the true dipteran densities.

The ecology of predatory dipterans is generally less well known than the ecology of other predatory arthropods, and these groups are rarely included in ecological studies (Delettre et al., 1998; Pfister et al., 2017; Pollet & Grootaert, 1996; Scherber et al., 2014), often because they are viewed as hard to identify. We therefore lack general knowledge about the distribution and importance of predatory dipterans in agricultural, and other, food webs, which is unfortunate because several dipteran predators may be important for control of pest species such as frit flies, planthoppers and thrips in agricultural areas and in greenhouses (Kühne & Schrameyer, 1994; Stark & Wetzel, 1987; Weber et al., 1997). In our previous study in apple orchards, the predatory dipterans with the highest abundances were dance flies (Empididae and Hybotidae) and stilt flies (Dolichopodidae), where both larvae and most adult flies are predatory. The diet of adult dance flies and stilt flies is poorly known for most species, but seems to include smaller flying insects (Chvála, 1983). The larvae of both groups develop in either humid soil environments or directly in the water (Chvála, 1983), and the adult abundance may therefore be connected to proximity of wetlands and moist forests (Pfister et al., 2017) as well as to seminatural grasslands (Holland et al., 2016; Rieux et al., 1999; Werling et al., 2011).

Because our previous study (Happe et al., 2019) used a sampling method (beat sampling) that probably underestimated the abundance of flying insects, and may have biased our conclusions (Silva et al., 2010), we decided to reanalyse our data after resampling the same orchards with suction sampling using an InsectaZooka (BioQuip Products). This sampling methodology has been successfully employed in orchards to capture lacewing adults and other flying natural enemies of common pest species (Porcel et al., 2018) and allowed us to sample apple branches directly, avoiding flying insects to escape capture. Through these two data collections, with different sampling techniques but at the same phenological state (early June when apple trees flower), we had the opportunity to compare the suitability of beat and suction sampling for estimating abundance of different predatory arthropod groups and more specifically the predatory dipterans. Moreover, this methodological comparison extends to the potential issue that the bias of different sampling methods may result in different ecological conclusions, in this case, how different predatory arthropod groups respond to management and landscape structure. Finally, because predatory dipterans have been shown to respond to proximity of wetlands and moist forests, we refined the landscape measures, compared to the previous study, to separate forest types (conifer vs. deciduous), to account for water availability and to include a measure on landscape diversity. Thus, in this study, we investigated (a) if beat and suction sampling provide different results on the broader predator community in apple orchards and (b) how the community of predatory dipterans varies depending on management, orchard and landscape structure.

2 | METHODS

The study was performed in the major Swedish apple growing region, Skåne, during 2015 and 2016 (see also Happe et al., 2019; Samnegård et al., 2019), as a part of the EcoFruit project. Sampling was performed in 28 apple orchards (14 organic and 14 IPM, Figure 1) that were selected along a land-use gradient, using forest cover as a proxy, and based on differences in the amount of agri-environmental structures (i.e. flower margins or other non-crop margins in the vicinity, see Samnegård et al., 2019). Pest management in orchards follow guidelines for IPM (Malavolta & Cross, 2009) or organic production (Council Regulation [EC] No 834/2007). We were unable to get information about specific chemicals and spraying regimes, but in general, organic orchards rely on products such as plant extracts, microorganisms and mating disruption whereas IPM orchards used chemical applications as main strategy, with varying number of sprays and active ingredients differing between orchards and years. In IPM orchards, applications consisted typically of one or two early (May–June) sprays for rosy apple aphid control (with for example flonicamid, acetamiprid or indoxacarb) and one or two additional application against tortricid moths (June–July). A minority of orchards

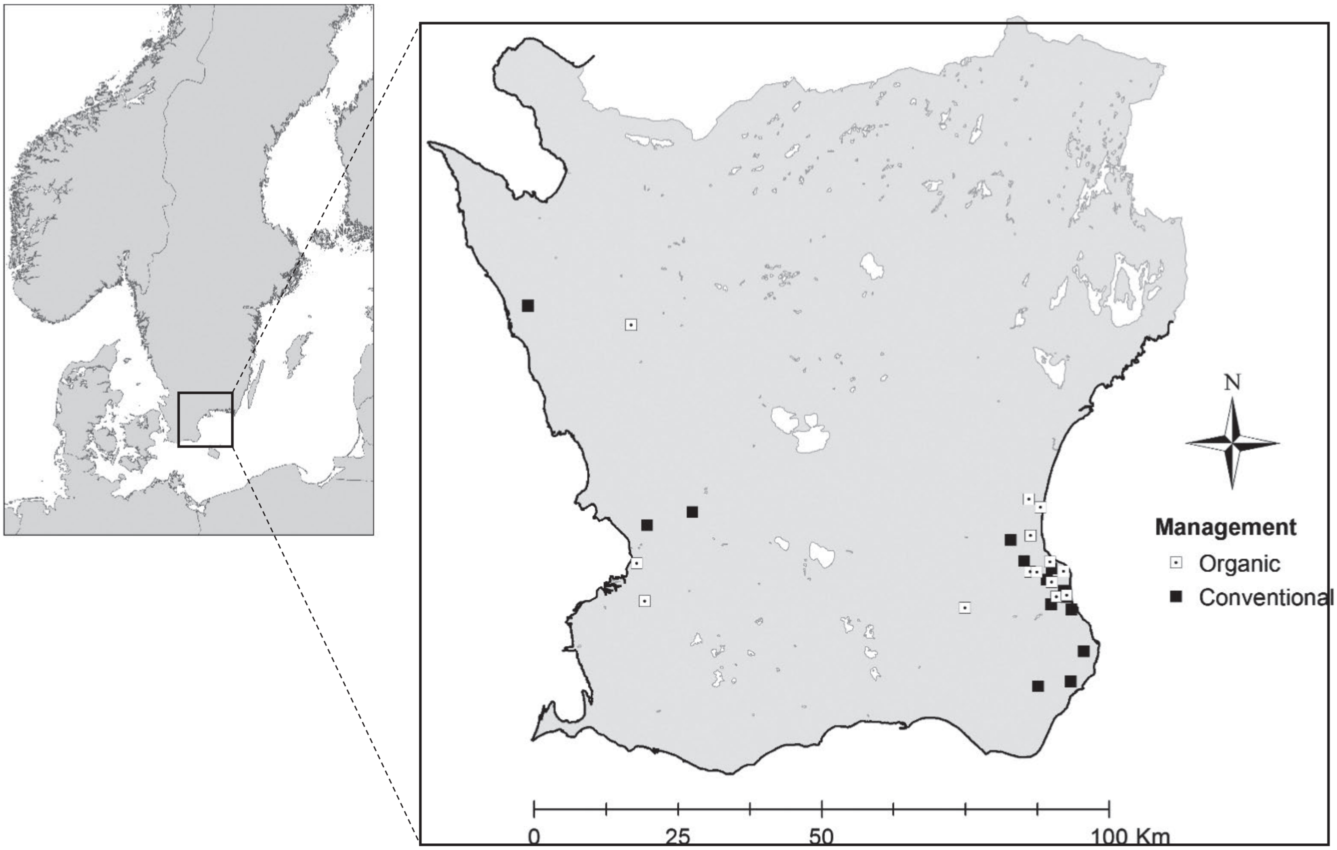

FIGURE 1 Map of the study region with all study sites included

included acaricides in their pest control program (the specific products allowed are given in Happe et al., 2019).

Sampling method differed between the 2015 and 2016. During 2015, arthropods were sampled using beat sampling at the end of the flowering period (early June) as described in Samnegård et al. (2019). Beat sampling was conducted on 24 trees per orchard and one branch per tree. The trees were located along a 40 m linear transect from field edge towards field interior. The size of sampled branches was selected to be similar to the beating tray. The tray consisted on a 65 × 50 cm wooden frame with a handle supporting a quadrangular funnel-shaped cloth (50 cm high) sloping down towards the centre to a cup containing 70% ethanol. Arthropods knocked off the apple canopy were collected inside the cup by shaking the tray after beating each branch. During 2016, we excluded two orchards that were totally unmanaged (non-commercial) and one orchard where owners declined our access. In the remaining 25 orchards, at the corresponding flowering stage as 2015, we collected arthropods using the InsectaZooka suction sampling device (Bioquip Products) for 10 × 2 min per orchard. During each 2 min sampling, we collected insects in a short stocking placed at the inlet (diameter 6 cm) of the suction sampling device and each sample contained arthropods from branches on 2–3 neighbouring apple trees depending on apple tree size. Thus, the total number of sampled trees was similar between beat and suction sampling. At the end of each 2 min sampling, the stocking was removed, sealed and placed in a cool box for transportation. In each orchard, five samples were collected close to the border of the orchard whereas the other five samples were collected 20 m away from the edge, similar to the design for beat samples (Happe et al., 2019). In the laboratory, stockings were placed in a −20°C freezer to kill arthropods, which were later sorted into predatory groups (spiders, beetles, dipterans, lacewings, hymenopteran parasitoids, opilionids and heteropterans). The focus in this study was on predatory Diptera, which were identified to species, whereas other groups were only counted at a higher taxonomical level (order or suborder). Among dipteran predatory groups, we captured Empididae, Hybotidae and Dolichopodidae in larger numbers whereas we captured few individuals of other predatory dipteran groups (Syrphidae, Scatophagidae and Tachinidae). We therefore decided to focus our analyses on the former three groups. After identification, we calculated species number per orchard for Diptera (pooled data from 2015 and 2016). A few specimens were damaged and could only be identified to genus and these were only included in the species count for the orchard if no species within that genus had been fully identified. Some Empididae (such as most *Empis* sp., *Hilara* sp. and *Rhamphomyia* sp., Chvála, 1983) have adults that largely feed on nectar and not regularly on insect prey. These species are included in the description of the dipteran community but not in the count of predatory species.

As explanatory variables for abundance and diversity of predatory arthropods, we used both management (organic and IPM) and a range of landscape and orchard structure variables. At the orchard level, we estimated flowering plant cover as described in Samnegård et al. (2019). At the landscape level, we estimated areal cover within a 1 km radius from the centre of our sampling in the orchard of coniferous forests, deciduous forests, perennial crops (mainly apple orchards), annual crop fields (cereals, flowering crops such as oil seed rape and ley), wetlands (including ponds), seminatural grasslands and other vegetated areas (gardens, golf courses, parks etc), using land use extraction and rasterization from Swedish IACS databases. The choice of 1 km radius was based on common practice, but is probably relevant for most arthropod groups in this study. From the areal cover of the different habitat types, we calculated landscape diversity as the Shannon diversity of all recorded categories within a 1 km radius from the orchard.

The overall predatory community (abundance of all predatory arthropod groups) was first analysed with a permutational multivariate analysis of variance (PERMANOVA) using the adonis function in the vegan package in R (Oksanen et al., 2019) with site as stratifying variable. We used Bray–Curtis dissimilarity as distance metric and 999 permutations for probability tests. In this group-level analysis, we included explanatory variables (including sampling method) as well as the management-by-sampling method interaction, to examine eventual biases caused by sampling method. All continuous variables were standardized before the statistical analysis. Because landscape diversity was strongly correlated with some other variables (deciduous forest, seminatural grasslands and agricultural fields), we separated the analyses of landscape diversity and other environmental variables. The estimated landscape diversity describes a gradient from mainly agricultural fields (low values) to mainly deciduous forests and seminatural grasslands (high values). To further analyse effects on species composition of our focal group dipteran predators, we performed a similar PERMANOVA on this group at the species level.

To interpret patterns identified in the PERMANOVA models, we performed separate univariate models for each predator group using generalized mixed-effects models with a Poisson error distribution (glmer function in lme4, Bates et al., 2014) and site as random effect, again separately for landscape diversity and other environmental variables. In the univariate models, we only included variables that explained community variation in the PERMANOVA. Models were checked for overdispersion using the dispersion.glmer function in the blmeco package (Körner-Nievergelt et al., 2015), and in case of overdispersion we used a negative binomial error distribution (only for Diptera and Hybotidae). Univariate model validation was carried out by visually inspecting Pearson residuals versus fitted values and the histograms of residuals. All analyses were performed in R version 3.6.3 (R Core Team, 2020).

3 | RESULTS

In total, we captured 2,083 predatory arthropods of which 532 were captured in 2015 (beat sampling) and 1,551 in 2016 (suction sampling). This difference was mainly caused by higher captures of Hymenoptera (384 vs. 35) and Diptera (502 vs. 105) in 2016. Due to the different capture successes by the two methods, method (year) comparisons should be viewed mainly as relative differences between groups and less as absolute numbers within groups. When analysing the total predatory arthropod community (relative abundance of different predator groups), the PERMANOVA showed effects of sampling method (year) and management on predatory arthropod captures (Table 1) but no interaction between method (year) and management ($p > .4$). In addition, both landscape diversity and area of deciduous forests affected the predatory arthropod community when included in separate models (Table 1). In the PERMANOVA of dipteran species composition, we similarly observed effects of landscape diversity but not of deciduous forest cover or of management (Table 1). In addition, the dipteran species composition was affected by the flowering plant cover within orchards. The species number of predatory dipterans was not significantly explained by either management or any measured environmental variables, even though the best variable was management ($p < .12$).

TABLE 1 Output for community analysis based on PERMANOVA, for the species groups (Total community) and for dipteran species. Landscape diversity and deciduous forest cover were analysed in separate models. For other variables, results were similar for the two models and we only report results from the model with landscape diversity

	Total community	Dipteran community
Management	$F_{1,48} = 3.05$ ($p < .02$)	NS
Year (method)	$F_{1,48} = 19.7$ ($p < .002$)	NA
Deciduous forest	$F_{1,48} = 2.47$ ($p < .03$)	$F_{1,24} = 1.35$ ($p < .11$)
Landscape diversity	$F_{1,48} = 4.05$ ($p < .005$)	$F_{1,24} = 1.72$ ($p < .01$)
Flowering plant cover	NS	$F_{1,24} = 1.62$ ($p < .02$)

Note: NS: $p > .1$, NA: not applicable as the dipteran community was pooled for 2015 and 2016.

In the following univariate analyses of predatory group separately, we found different patterns for different groups (Table 2, Figures 2–4) although the management-by-year interaction was not significant for any group. Coleopteran captures were four times higher in organic orchards, 80% higher in year 2 with suction sampling and captures were also higher in sites with higher landscape diversity and with a higher deciduous forest cover. Spider captures did not vary with management or year but were lower in sites with a higher landscape diversity. Although heteropteran captures did not vary with management or year, a higher relative abundance was scored in sites with a higher deciduous forest cover. Hymenopteran and neuropteran captures were, respectively, 12 and 7 times higher in year 2, with suction sampling, whereas they did not vary with management. Opilionid captures were twice as high in IPM orchards and eight times higher in year 2 with suction sampling. In addition, opilionid captures were lower in sites with higher landscape diversity. Finally, dipteran captures

TABLE 2 Output of generalized linear model for predatory arthropod groups (parameter estimate ± *SE*), and for two submodels on dipterans families. Landscape diversity and deciduous forest cover were analysed in separate models. For other variables, results were similar for the two models and we only report results from the model with landscape diversity. Only factors that were significant in community models (Table 1) were included in group-specific models. All models include site as random effect, and with either Poisson error or negative binomial error (for Diptera and Hybotidae, when models with Poisson error showed overdispersion). Earwigs did not relate to any environmental factor and are not presented

	Management	Year (method)	Landscape diversity	Deciduous forest cover	Flowering plant cover
Coleoptera	1.3 ± 0.3 ($p < .0001$)	0.7 ± 0.2 ($p < .0002$)	0.4 ± 0.2 ($p < .02$)	0.4 ± 0.1 ($p < .008$)	Not tested
Spiders	NS	NS	−0.2 ± 0.1 ($p < .05$)	NS	Not tested
Heteroptera	NS	NS	NS	0.6 ± 0.3 ($p < .02$)	Not tested
Hymenoptera	NS	2.5 ± 0.2 ($p < .0001$)	NS	NS	Not tested
Neuroptera	NS	2.0 ± 0.3 ($p < .0001$)	NS	NS	Not tested
Opiliones	−1.6 ± 0.6 ($p < .005$)	2.1 ± 0.3 ($p < .0001$)	−0.7 ± 0.3 ($p < .01$)	NS	Not tested
Diptera[a]	0.6 ± 0.3 ($p < .03$)	1.6 ± 0.2 ($p < .0001$)	−0.3 ± 0.1 ($p < .03$)	NS	NS
Hybotidae[a]	0.9 ± 0.3 ($p < .003$)	1.5 ± 0.3 ($p < .0001$)	−0.5 ± 0.2 ($p < .002$)	−0.6 ± 0.1 ($p < .0001$)	−0.3 ± 0.1 ($p < .03$)
Dolichopodidae	NS	2.9 ± 0.4 ($p < .0001$)	NS	NS	0.8 ± 0.2 ($p < .0006$)

[a] Negative binomial error.

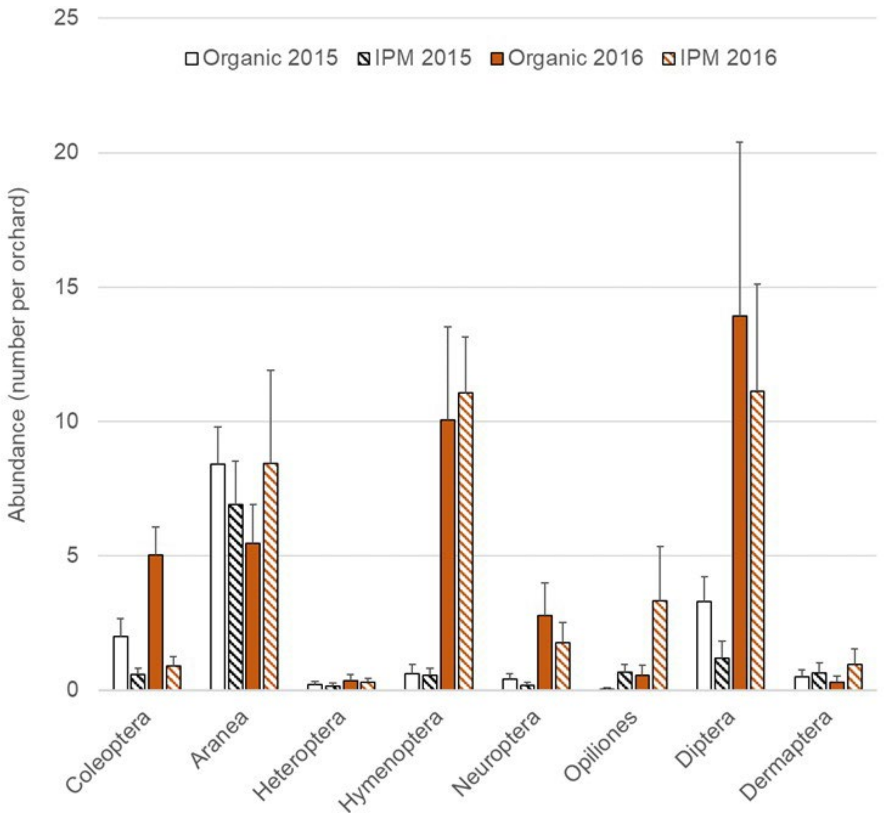

FIGURE 2 Captures of predatory arthropods (mean ± *SE*) in organic and IPM orchards for 2015, when arthropods were captured using beat sampling, and for 2016, when arthropods were captured using suction sampling (see Table 1 for statistics) [Colour figure can be viewed at wileyonlinelibrary.com]

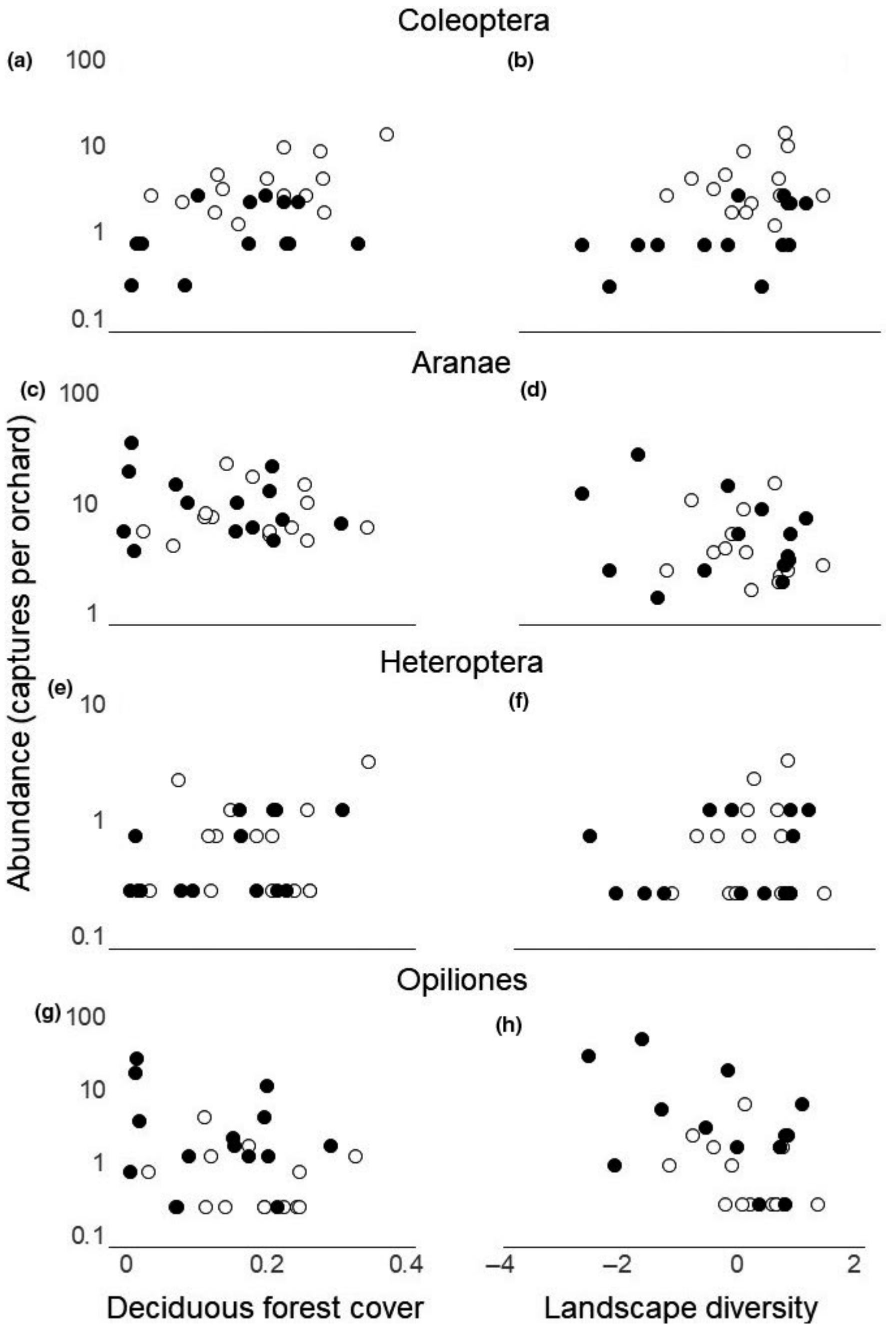

FIGURE 3 Abundance of Coleoptera, Aranae, Heteroptera and Opiliones in relation to the proportion of deciduous forests and landscape diversity within 1 km radius. Empty circles indicate organic orchards and filled circles indicate orchards managed according to IPM. For statistics, see Table 2

were about 40% higher in organic orchards, six times higher in year 2 with suction sampling and lower in landscapes with high diversity.

When subdivided into predatory dipteran families (Table 2, Figure 4), we found that captures of hybotid flies were on average 120% higher in organic orchards and increased by more than five times in year 2 with suction sampling. Hybotid fly captures were also higher in landscapes with a lower diversity, in landscapes with a low deciduous forest cover and in orchards with a higher flowering plant cover. Finally, captures of dolichopid flies did not vary with management, but were more than 15 times higher in year 2 with suction sampling and were also higher in orchards with a higher flowering plant cover.

4 | DISCUSSION

It is evident that sampling method matters when describing arthropod communities because different methods are differently biased. Whereas beat sampling is a commonly accepted method for sampling arboreal arthropods, it favours non-flying arthropods while underestimating densities of more robust fliers that easily fly off due to the disturbance (Silva et al., 2010). In this study, we investigated this potential bias in order to understand if the relative abundance of particularly predatory dipterans were even larger than our previous studies caused us to believe. Our results confirmed our expectations and showed large methodological differences in capture rates for species groups that more actively fly and no differences for species

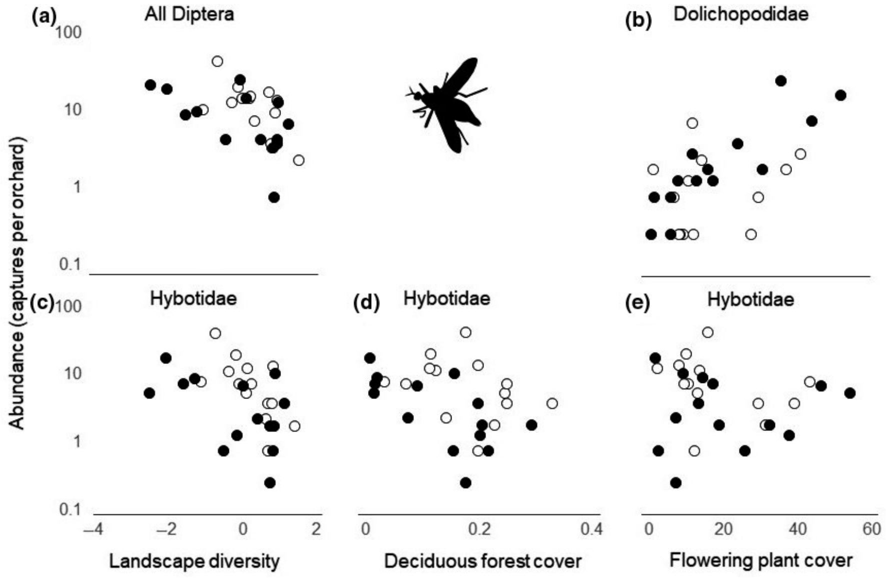

FIGURE 4 Abundance of Diptera in relation to proportion of deciduous forest and landscape diversity within 1 km radius and flowering plant cover within orchards. Empty circles indicate organic orchards and filled circles indicate orchards managed according to IPM. For statistics, see Table 2. Empid silhouette obtained from Phylopic.org

groups that less commonly fly. Most notably, the three major groups of insects that commonly fly away when disturbed, Hymenoptera, Diptera and Neuroptera, were captured in much higher numbers by suction sampling compared with beat samples. Moreover, the fact that capture rates of spiders and heteropterans, that are either unable to fly or that less commonly fly away when disturbed, did not vary between sampling methods suggest that the sampling effort was comparable between years and methods. Therefore, we can assume that the observed yearly differences for other groups are mainly due to differences in sampling method.

Despite these differences in sampling efficacy, it is apparent that the method choice did not change our previous conclusions on the effect of management, organic versus IPM, on predatory arthropod abundance. We found in no case that the management effect on abundance of the different predatory arthropod groups varied between years (methods), suggesting that beat sampling captures a proportional subset of dipterans and hymenopterans captured by suction sampling. This finding is good news, as effect sizes from studies using the different methods considered in this study can then be included in comparative meta-analyses. As previously reported (Happe et al., 2019), coleopteran and dipteran predators were more common in organic than in IPM orchards whereas opilionids were more common in IPM than in organic orchards. In addition, our results showed that Hybotidae, and particularly *Platypalpus* spp, is the dipteran group that mainly explained the difference caused by management. The hybotid fauna was surprisingly rich in these apple orchards, and we found one new species for Sweden (*P. leucocephalus*) and 17 of 86 *Platypalpus* species recorded in Sweden. The reason why hybotids are common in apple orchards is not clear, even though our study shows the importance of flowering plant cover within orchards (see also Cahenzli et al., 2019; Herz et al., 2019), but it may be that the access of potential prey and the relatively open habitat in the orchards are important. Hybotids are a group of dipterans that are strictly predatory, running on the leaves or making short flying expeditions to catch small insects, such as other dipterans, thrips and psyllids (Chvála, 1975). Other studies, from wheat fields, similarly suggest that *Platypalpus* may be abundant in agricultural areas, and then prey on frit flies and midges (Stark & Wetzel, 1987). Studies from greenhouses (Kühne & Schrameyer, 1994) indicate the predatory potential of *Platypalpus* and estimates that a single fly may capture 2–3 prey per day. However, these studies also showed that at least the investigated *Platypalpus* species avoided preying on aphids, one important pest insect in apple orchards. Clearly, we need more studies to understand the predatory potential of these, and other, predatory flies in field situations.

Beside the effect of management, it was apparent that landscape structure, particularly deciduous forest cover and landscape diversity, affected abundance of several predatory arthropod groups, including Diptera. These two factors were strongly correlated and we could therefore not fully separate their effect. For instance, both the overall predatory community and the species composition of the dipteran community were equally well explained by deciduous forest cover and landscape diversity. In other cases, either landscape diversity (Opiliones, Diptera, Aranae) or deciduous forest cover (Heteroptera) was evidently a stronger predictor. These differences may be due to cover of other habitat structures, where particularly seminatural grasslands had higher cover and agricultural fields had lower cover in landscapes with a high habitat diversity, besides the positive correlation between landscape diversity of deciduous forest cover. When examining predatory groups separately, we unexpectedly found that an increased landscape diversity did not always result in a higher abundance. Whereas both beetle (Coccinellidae and Cantharidae) and heteropteran (mainly Anthocoridae) predators were more abundant in orchards situated in landscapes with a high habitat diversity and/or a high deciduous forest cover, other groups such as spiders, opilionids and dipteran predators were instead less abundant in these orchards. Moreover, we also found that availability of wetlands in the surrounding landscape did not affect the dipteran community, which in combination with the result that forest cover was negatively correlated with abundance of Diptera contrast with previous studies (Pfister et al., 2017). At this stage, we can only speculate about these results but one possibility is that the species composition of Diptera differs between our study and that of Pfister et al. (2017) or that forest and wetland habitat have a different structure between our respective study areas. In either case, this variability is a further motivation for the need of additional studies on the response of predatory dipterans to different habitats in the agricultural landscape.

The focus here has been on those flies common in apple orchards, but there are many common predatory dipterans, such as robber flies (Asilidae), hunter flies (Muscidae: Coenosia) and dung flies (Scathophagidae), that may be potentially important predators in various ecosystems (e.g. Couri et al., 2018; Joern & Rudd, 1982; Kühne, 2000; Pohl et al., 2012). To understand the complete food web in these areas, it is important that future studies investigating the abundance, diversity and function of predatory arthropods do not overlook predatory Diptera. Even though some dipterans groups are challenging to identify, other groups are fairly easy to group into families or genera. We also need to learn more about the diet of these predators. Most commonly, predatory dipterans feed on small and fragile arthropods such as thrips, psyllids and midges, where some may be potentially important pest species. However, some Diptera, particularly robber flies, may capture even quite large prey, such as bees. In our study orchards, it was evident that predatory dipterans were perhaps the most abundant group of predatory arthropods. Whether that observation is due elsewhere is a question worthy of exploration, but to answer that question it is important to use a sampling method that is effective for capturing also flying insects.

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CONFLICT OF INTEREST

No conflict of interest exists.

AUTHOR CONTRIBUTIONS

PAH conceived of the study. MT, MP and US collected the data. PAH and US performed statistical analyses. PAH drafted the first version of the manuscript and all coauthors contributed to the final text.

DATA AVAILABILITY STATEMENT

All data underlying the analyses in this study are available on Dryad (https://doi.org/10.5061/dryad.p8cz8w9n2, Hambäck et al., 2020).

ORCID

Peter A. Hambäck https://orcid.org/0000-0001-6362-6199
Mario Porcel https://orcid.org/0000-0002-8445-5621
Marco Tasin https://orcid.org/0000-0001-7379-4954
Ulrika Samnegård https://orcid.org/0000-0002-3791-4688

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