

# Phenology of microhymenoptera and their potential threat by insect decline

Maura Haas-Renninger<sup>1,2,3</sup>, Sonia Bigalk<sup>1</sup>, Tobias Frenzel<sup>1</sup>, Raffaele Gamba<sup>1</sup>,  
Sebastian Görn<sup>1</sup>, Michael Haas<sup>1</sup>, Andreas Haselböck<sup>4</sup>, Thomas Hörren<sup>5</sup>,  
Martin Sorg<sup>5</sup>, Ingo Wendt<sup>1</sup>, Petr Janšta<sup>6</sup>, Olaf Zimmermann<sup>7</sup>,  
Johannes L. M. Steidle<sup>2,3</sup>, Lars Krogmann<sup>1,2,3</sup>

**1** State Museum of Natural History Stuttgart, Department of Entomology, Rosenstein 1, 70191 Stuttgart, Germany **2** University of Hohenheim, Institute of Biology, Biological Systematics (190w), Garbenstraße 30, 70599 Stuttgart, Germany **3** Center of Excellence for Biodiversity and integrative Taxonomy (KomBioTä), Wolflgrasweg 23, 70599 Stuttgart, Germany **4** Entomological Society Stuttgart e.V., Wild Bee Cadastre, Rosenstein 1, D-70191 Stuttgart, Germany **5** Entomological Society Krefeld, Magdeburger Straße 30-40, 47800 Krefeld, Germany **6** Faculty of Science, Charles University, Prague, Czech Republic **7** Agricultural Research Centre Augustenberg (LTZ), Nesslerstraße 25, 76227 Karlsruhe, Germany

Corresponding author: Maura Haas-Renninger ([maura.haas-renninger@smns-bw.de](mailto:maura.haas-renninger@smns-bw.de))

Academic editor: Miles Zhang | Received 24 May 2024 | Accepted 30 July 2024 | Published 30 August 2024

<https://zoobank.org/4AB1A598-7346-459F-B9C5-793EA8495B19>

**Citation:** Haas-Renninger M, Bigalk S, Frenzel T, Gamba R, Görn S, Haas M, Haselböck A, Hörren T, Sorg M, Wendt I, Janšta P, Zimmermann O, Steidle JLM, Krogmann L (2024) Phenology of microhymenoptera and their potential threat by insect decline. *Journal of Hymenoptera Research* 97: 699–720. <https://doi.org/10.3897/jhr.97.128234>

## Abstract

Although microhymenoptera are highly abundant in all terrestrial ecosystems, they are overlooked in most of insect monitoring studies due to their small-size and demanding identification linked with lack of taxonomic experts. Until now, it is unclear to what extent microhymenoptera are affected by insect decline, as there is a huge knowledge gap on their abundance. To fill this knowledge gap, we used Malaise trap samples from three study sites of a complete vegetation period (March to November) of an ongoing insect monitoring study in south-western Germany (i) to study the relationship of insect total biomass, and abundance and diversity of microhymenoptera, and (ii) to assess the phenology of microhymenoptera families. Our results show that microhymenoptera abundance and diversity are positively correlated with total insect biomass, indicating that insect biomass is a valuable proxy for insect abundance trends even for small-sized insects. In total, we counted 90,452 specimens from 26 families belonging to 10 superfamilies of Hymenoptera. Microhymenoptera numbers peaked twice during the year, first between June and July and second between July and August. Interestingly, egg-parasitoids, such as Scelionidae, Mymaridae and

Trichogrammatidae had a slightly shifted second activity period in August and September. Our data provides a baseline for the occurrence of microhymenoptera in meadow ecosystems in south-western Germany and underlines the potential of mass samples to study microhymenoptera in the context of insect decline.

### Keywords

Activity pattern, biodiversity, biomass, fractionator, insect decline, malaise trap, seasonality

## Introduction

The global decline of insects (Hallmann et al. 2017; Sánchez-Bayo and Wyckhuys 2019; Seibold et al. 2019; Wagner et al. 2021) poses a major threat to humankind, as insects play an essential role for our ecosystems through providing functions such as pollination (Klein et al. 2007), natural balance of populations (DeBach and Rosen 1991), and nutrient cycling (Yang and Gratton 2014). Therefore, long-term assessments of insect population trends are necessary to implement and adapt conservation measures to preserve insects in the future. In recent years, several insect monitoring studies were conducted (e.g. Seibold et al. 2019; Karlsson et al. 2020; Lehmann et al. 2021; Staab et al. 2023), which are all facing various constraints. First, they are limited through funding sources (often granted only for a few years) and trained personnel for insect identification. Second, many long-term studies focus only on specific target groups, such as butterflies (Thomas 2005), wild bees (Turley et al. 2022), beetles, true bugs, grasshoppers and spiders (Seibold et al. 2019). Such groups are relatively well studied, easy to identify and historically used as indicators for diversity and landscape changes. In addition, calibrating estimates of abundance for long term studies can be difficult even for target groups as it highly depends on the trapping type used for the assessment (Battles et al. 2024).

An alternative to focusing on specific insect taxa is to use biomass as a proxy for abundance of insects. This has been done in the landmark study by Hallmann et al. (2017), in which biomass of flying insects was used to monitor insect population trends, showing a decline of 76% in insect biomass over 27 years on the study sites, but also in several other studies (Lister and Garcia 2018; Uhler et al. 2021; Welti et al. 2021; Müller et al. 2023). The benefits of using biomass is that the weighing setup is cheap, it can be done in a standardized way, and there is no need for time-consuming counting of specimens or taxonomic identification. However, the use of biomass as a proxy for diversity is also highly controversial (Hallmann et al. 2021b; Redlich et al. 2021). Intensive land use can lead to the mass occurrence of few insect species, compromising the relationship between biomass and diversity. In addition, the assessment of insect diversity using metabarcoding results still has methodological weaknesses that lead to bias in the data patterns (Zizka et al. 2022). Consequently, it depends on many factors to derive statements on species diversity from biomass information.

Malaise traps are used widely to assess biomass of flying insects in a standardized way. The two insect orders that are most abundant in such Malaise trap samples are Diptera and Hymenoptera (Geiger et al. 2016; Srivathsan et al. 2023). Although

numerous, especially small-sized parasitoid Hymenoptera (microhymenoptera) represent only a small fraction of the total biomass, where they are mostly considered 'by-catch' and remain unprocessed. This is problematic, because Hymenoptera are assumed to be the most diverse animal order in the world (Forbes et al. 2018), and play an important role in many terrestrial ecosystems. Ecologically, parasitoid Hymenoptera are important as top-down regulators of their specific hosts, often herbivorous insects (LaSalle 1993; Heraty 2017) and are essential for the resilience of ecosystems (LaSalle and Gauld 1991; Grissell 1999). In ecological studies, they can serve as indicators for the presence of their hosts (Anderson et al. 2011). Due to their high position in the food web, parasitoids are also particularly prone to extinction (Hassell 2000; Wagner et al. 2021; Klaus et al. 2023), although only few studies focused on their potential decline (but see Gatter et al. 2020; Janzen and Hallwachs 2021).

One reason for the neglect of parasitoid Hymenoptera in biodiversity studies is that they harbour many so-called 'dark taxa', which are extremely species-rich groups of small-sized insects that are hard to identify and that harbour mostly undescribed taxa (Shaw and Hochberg 2001; Hausmann et al. 2020a; Hartop et al. 2022). The taxonomic work that would be necessary to describe and identify dark taxa often lacks funding sources as taxonomy is poorly recognized in science and the public (but see Behm 2018). As a consequence, the scarcity of experts contributes to the taxonomic impediment (Engel et al. 2021). Altogether, this leads to a huge knowledge gap not only on the diversity of parasitoid Hymenoptera in terrestrial ecosystems, but also on their potential threat through agricultural activities (Sánchez-Bayo and Wyckhuys 2019), like mowing or pesticide application (Brühl et al. 2021; Schöfer et al. 2023).

To fill this gap, we studied microhymenoptera in Malaise trap samples of an ongoing insect monitoring program in south-western Germany. As Hallmann et al. (2017) highlighted the relevance of insect biomass for monitoring insect abundance trends, we studied the relationship of insect total biomass, and abundance and diversity of microhymenoptera to see, if a decrease in insect total biomass of Malaise trap samples, can be also indicative of a decrease of microhymenoptera. Moreover, we provide a phenology for different families of microhymenoptera of semi-arid grassland of south-western Germany. These data can be used for the timing of potentially harmful agricultural activities, e.g. mowing (Haas-Renninger et al. 2023b) or pesticide application, to avoid high activity periods of microhymenoptera.

## Methods

### Site selection and environmental data

To obtain data on microhymenoptera families from sites that have a comparably high potential to harbour intact insect communities including rare or endangered species, three sites with high conservation values (CV) were selected out of twelve study sites sampled in 2019 within the project "Aerial Biomass" of the insect monitoring program

(see Sampling and specimen handling). We used the CV according to Görn and Fischer (2011), calculated from the number and threat level of wild bees as indicator species. Wild bees are considered useful indicators on the landscape level, as they are dependent on specific habitat requirements for reproduction and nesting (Schindler et al. 2013; Twerd et al. 2021). The data were obtained from the project “Aerial Biomass” (LUBW, unpublished). Threat levels are based on the German Red List (Westrich et al. 2011) and the Red List for bees in Baden-Wuerttemberg (Westrich et al. 2000). We use the term “trap location” for the exact location of the Malaise trap and the term “study site” for the trap location including a 500 m radius around the trap.

Statistical analyses were performed using the software ‘R’, version 4.0.4 (R Core Team 2021). To select three similar study sites from the twelve study sites that were sampled in 2019, we used available data on wild bee abundance. We calculated a hierarchical cluster analysis, method ‘binary’ data with complete linkage, to identify those study sites that cluster together. For climate data, we used daily station observations of mean temperature at 2 m above ground in °C and precipitation height in mm from the Climate Data Centre (DWD 2023; see above) from weather stations close to the study sites (< 17 km). We calculated the means over our two-week collecting periods. The proportion of land use around the trap location was calculated in QGIS (ver. 3.32.3-Lima, <http://www.qgis.org>). Therefore, different land uses were identified and mapped through georeferenced, digital orthophotos (resolution of 20 cm per pixel, imaged in 2018 by the Landesamt für Geoinformation und Landentwicklung Baden-Wuerttemberg) in a radius of 500 m around the trap location. The area for each land use type was then calculated within QGIS and converted in percentages.

## Sampling and specimen handling

We used Malaise trap samples from the project “Aerial Biomass” of the insect monitoring program in south-western Germany at the Stuttgart State Museum of Natural History (SMNS), which was launched in 2018 by the State Institute for Environment Baden-Wuerttemberg (LUBW, <https://www.lubw.baden-wuerttemberg.de/natur-und-landschaft/insektenmonitoring>). The aim of this program is to monitor long-term insect population trends using total insect biomass, and abundance and species richness of wild bees in protected and non-protected sites. The traps and methods are standardized and based on the recommendations by the Entomological Society Krefeld (Ssymank et al. 2018). The Malaise traps were set up in 2019 from the end of March until the beginning of November and emptied every two weeks, resulting in 16 samples per study site. Malaise traps according to the model by Henry Townes (Townes 1972) adapted after Schwan et al. (1993) were placed in the sites by members of the Entomological Society of Krefeld.

We used the samples from the three sites from the whole collecting period in 2019, resulting in 48 samples. We used the fractionator method based on Buffington and Gates (2008) with an adapted protocol (Haas-Renninger et al. 2023a) to more easily obtain our target taxa of microhymenoptera. This method is based on a sieve (2 mm mesh size) in a plastic tub into which a full fluid-conserved insect sample can be

poured in and carefully size fractioned on an orbital shaker. Both size fractions (macro and micro) were stored in a freezer at  $-20^{\circ}\text{C}$  at Stuttgart State Museum of Natural History (SMNS) until further processing. Only the micro fraction was used for further analyses. Therefore, larger-sized species of certain families remained in the macro fraction and thus might not be covered in the phenology of the Hymenoptera families.

Hymenoptera specimens from all micro fractions were sorted out, counted and identified at least to family level using Goulet and Huber (1993). Formicidae were not investigated. Wild bees had been sorted out before the fractioning process. The microhymenoptera were stored in 99.6% pure ethanol and remained in the freezer until further processing. As not all families that we obtained have a parasitoid lifestyle, we use the term ‘microhymenoptera’ instead of ‘parasitoid Hymenoptera’ for our data. We use the term ‘abundance’ for the total number of counted specimens of a specific taxon.

### **Insect biomass, microhymenoptera abundance and diversity**

Insect biomass data are unpublished and were obtained from the project “Aerial Biomass”. To test how total microhymenoptera abundance and diversity relate to insect biomass, we used statistical models. As our data were count data, we calculated a general linear model (family ‘poisson’) with total abundance of microhymenoptera as dependent variable, total insect biomass (in grams per sample) as explanatory variable, Julian Day number (JDN, end date of each two-week collecting interval), mean temperature and precipitation as covariates, and study site ( $n = 3$ ) as factor. To study the relationship of microhymenoptera diversity and insect biomass, we calculated a linear model. We used the R package ‘vegan’ version 2.6-4 (Oksanen et al. 2022) to calculate the Shannon diversity index ( $H'$ ) of every sample using microhymenoptera abundance on family level. Data were checked for normal distribution using Shapiro–Wilk normality test. Residual plots were optically checked for homogeneity of variances. We used family diversity as dependent variable, total insect biomass as explanatory variable, Julian Day number (JDN, end date of two week collecting interval), mean temperature and precipitation as covariates, and study site ( $n = 3$ ) as factor. For fitting the model, we used ANOVA to gradually subtract explanatory variables that had no significant effect. In addition, we created a model selection table based on small sample corrected AICc (package ‘AICcmodavg’, Suppl. material 1: table S3). Our final model included total insect biomass as explanatory variable and study site as factor.

## **Results**

### **Site selection**

From all twelve study sites from 2019, conservation values were highest for study site Apfelberg (CV = 237.5), Steiner Mittelberg (CV = 157.5), Weissach (CV = 132.5) and Köllbachtal (CV = 200) (Suppl. material 1: fig. S1). In a hierarchical cluster analysis

based on conservation values sites Apfelberg and Steiner Mittelberg clustered together and were closer to Weissach than to Köllbachtal (Suppl. material 1: fig. S2). Probably, this is because study site Köllbachtal differs markedly from the other three sites in terms of habitat characteristics (e.g., high moisture). Therefore, study sites Apfelberg, Steiner Mittelberg, and Weissach were chosen for our analysis. These sites are characterized by dry, low-intensity managed meadows and were mown or grazed only twice a year.

#### A) Apfelberg

The study site on the nature conservation area “Apfelberg” Schutzgebiets-Nr. 2.217 near Karlsruhe, Baden-Wuerttemberg (Table 1) is characterized by an extensively managed meadow with southern exposure (Fig. 1A). The study site was mown once between mid-July and end of July without removal of cut grass. Between end of September and beginning of October, sheep were grazing on the site. The trap location is surrounded by densely growing woody plants towards the north and west, including fruit trees and bushes (Fig. 2A). The study site is surrounded by vineyards and agricultural fields and towards the east, it is richly structured with woodlands and small patches of grassland. The site slopes southwards, where it is dominated by meadows and agricultural sites. Within a radius of 50 m surrounding the trap, the plant community is characterized by an oat grass meadow with elements of a semi-arid grassland.

#### B) Steiner Mittelberg

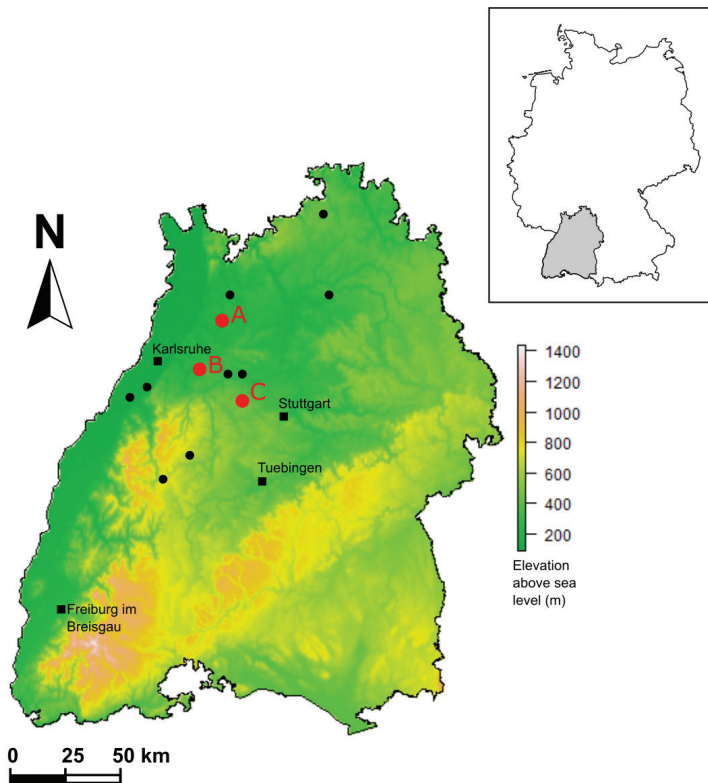
The study site on the nature conservation area “Beim Steiner Mittelberg” Schutzgebiets-Nr. 2.119, thereafter referred to as “Steiner Mittelberg” near Karlsruhe, Baden-Wuerttemberg (Table 1), is an extensively managed meadow. It is located in a dry valley surrounded by agricultural sites, that are managed organically (Fig. 1B). The site was mown between end of May and beginning of June and between mid- and end of August with the cut grass having been partly removed. Northwards, there are meadow orchards and gardens located close to a small forest (Fig. 2B). Westwards, there are managed meadows and an extensive forest. The site slopes towards the south, bordering on agricultural sites with wheat fields and smaller forest patches. The plant community is not fully developed and shows an interrupted stock of semi-arid grassland and oat grass meadow elements.

#### C) Weissach

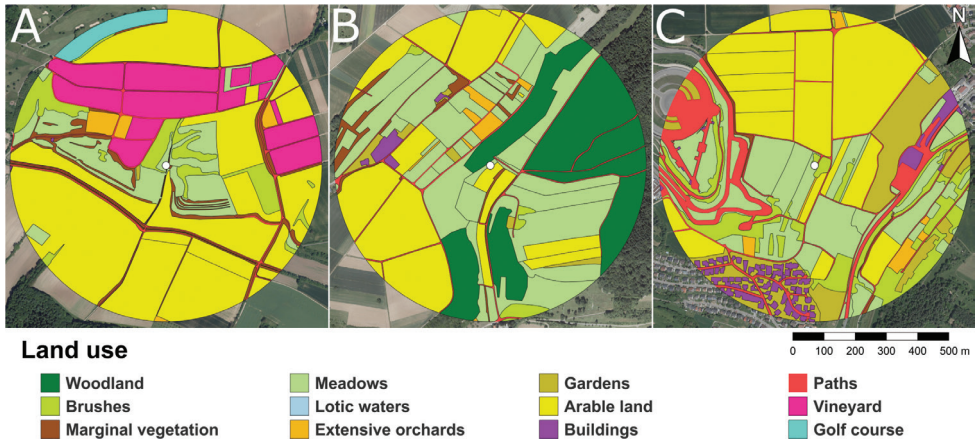
This study site is on a grassland area near Weissach, ÖFS 124 (Fig. 1C) located between Stuttgart and Karlsruhe, Baden-Wuerttemberg (Table 1). In contrast to the others, it does not belong to a nature conservation area and is a low-intensity managed meadow, near a test track for cars (Fig. 2C). This might influence the comparability with the other sites (Hausmann et al. 2020b). The site was mown between end of May and beginning of June, with removal of cut grass, and a second time in June, with the cut grass



removed around two weeks later. North of the site, there is a small wood patch, which is surrounded by intensively managed agricultural areas (Fig. 2C). Towards the East, a heap of stones separates the site from a small wood patch, which is surrounded by further agricultural sites and woodland. The area slopes towards southeast, where there is a row of fruit trees alongside the meadow, followed by small wood patches and meadow areas. Westwards, the meadow is bordered by the test track. The plant community can be described as an *Onobrychido-Brometum erecti*, a sainfoin-brome grass semi-arid grassland, which is strongly impoverished, and that develops into ruderal vegetation.



**Figure 1.** Malaise traps on semi-arid meadows in Baden-Wuerttemberg, south-western Germany, with two protected areas (**A** Apfelberg **B** Steiner Mittelberg) and one non-protected area (**C** Weissach). Black dots symbolize other study sites that were not further analysed in this study (for details, see Suppl. material 1: table S1).



**Figure 2.** Land use types in a radius of 500 m around the Malaise trap of the three study sites **A** Apfelberg **B** Steiner Mittelberg and **C** Weissach in Baden-Wuerttemberg, south-western Germany. The white dots in the centre of each circle symbolize the Malaise trap location. For land use proportions per study site in percent, see Suppl. material 1: table S2. Geobasisdaten © LGL, [www.lgl-bw.de](http://www.lgl-bw.de); RIPS, LUBW.

**Table 1.** Details on selected study sites. Start date: set up of Malaise trap; End date: dismantling of Malaise trap; DWD weather station: accessed using the Climate Data Centre (DWD 2023, [https://www.dwd.de/DE/Home/home\\_node.html](https://www.dwd.de/DE/Home/home_node.html)).

Study site	A) Apfelberg	B) Steiner Mittelberg	C) Weissach
<b>Trap location</b>	49.16754°N, 8.7903°E; 178 m AMSL	48.97039°N, 8.65899°E; 240 m AMSL	48.84296°N, 8.91448°E; 438 m AMSL
<b>Start date</b>	23.03.2019	23.03.2019	23.03.2019
<b>End date</b>	05.11.2019	06.11.2019	05.11.2019
<b>DWD weather station</b>	Temperature data “Waibstadt”; Germany, 49.2943°N, 8.9053°E; 237 AMSL; linear distance to trap: 16.38 km	“Pforzheim-Ispringen”; Germany, 48.9329°N, 8.6973°E; 332 m AMSL; linear distance to trap: 5.02 km	“Renningen-Ihinger Hof”; Germany, 48.7425°N, 8.9240°E; 478 m AMSL; linear distance to trap: 11.19 km
	Precipitation data See Temperature data	See Temperature data	“Weissach”; Germany, 48.8457°N, 8.9073°E; 455 m AMSL; linear distance to trap: 0.61 km

### Insect biomass, microhymenoptera abundance and diversity

In total, we counted 90,452 microhymenoptera specimens that we could assign to 26 families in 10 superfamilies. We found a significant relationship between insect biomass, study site, JDN, temperature, precipitation, and microhymenoptera abundance (Table 2). The linear model to study the relationship of insect biomass and diversity was also significant (Table 2). There was a significant relationship between diversity of microhymenoptera families, total insect biomass and study site (Table 2), while JDN and temperature were not significant.



**Table 2.** The results of linear models for abundance of microhymenoptera and diversity of microhymenoptera families.

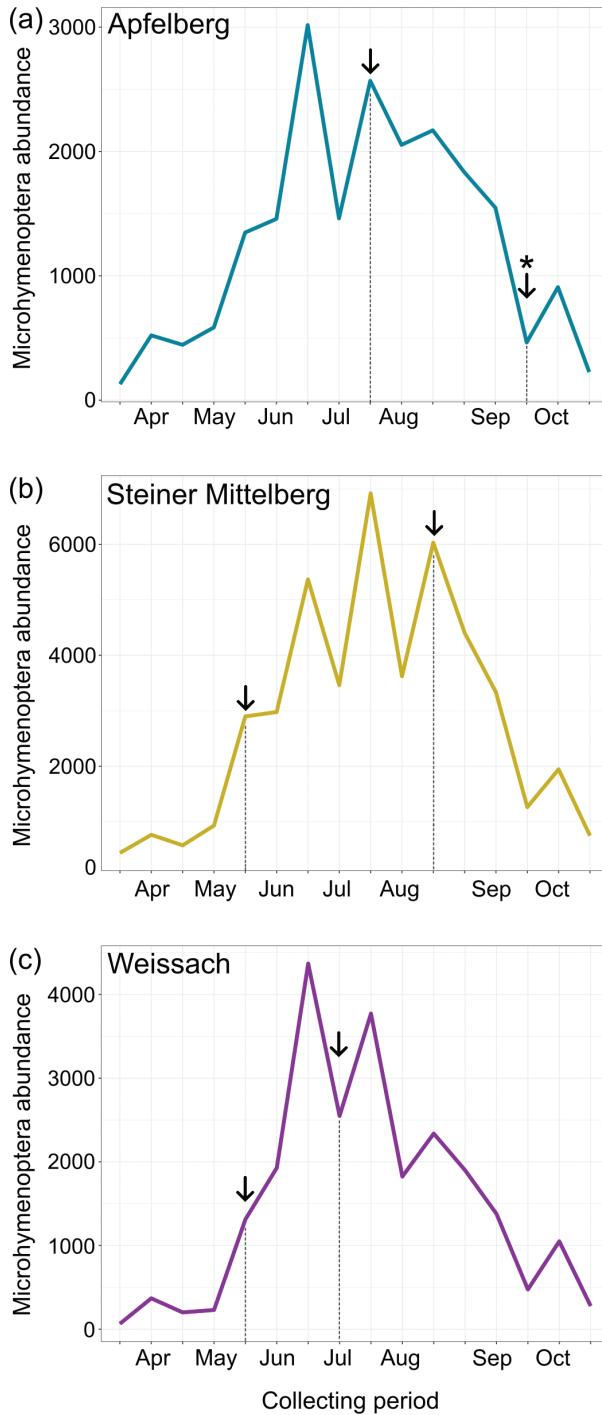
Abundance	Estimate	Std. Error	z value	<i>p</i>	
<b>(Intercept)</b>	-4414.00	205.70	-21.46		
Insect total biomass	0.00	0.00	-6.00	<0.001***	
Study site	0.93	0.01	92.22	<0.001***	
JDN	0.42	0.01	43.15	<0.001***	
Temperature	0.00	0.00	21.48	<0.001***	
Precipitation	0.18	0.00	100.00		
<b>Null deviance: 61345.1 on 47 degrees of freedom</b>					
<b>Residual deviance: 4668.6 on 41 degrees of freedom</b>					
Diversity	Df	Sum Sq	Mean Sq	F value	<i>p</i>
Insect total biomass	1	0.16	0.16	8.85	0.005**
Study site	2	0.16	0.08	4.48	0.017*
Residuals	44	0.77	0.02	-	-
Observations	48				
Multiple R <sup>2</sup>	0.29				
Adjusted R <sup>2</sup>	0.24				
<b><i>p</i></b>	<b>0.002</b>				

## Seasonal changes in microhymenoptera

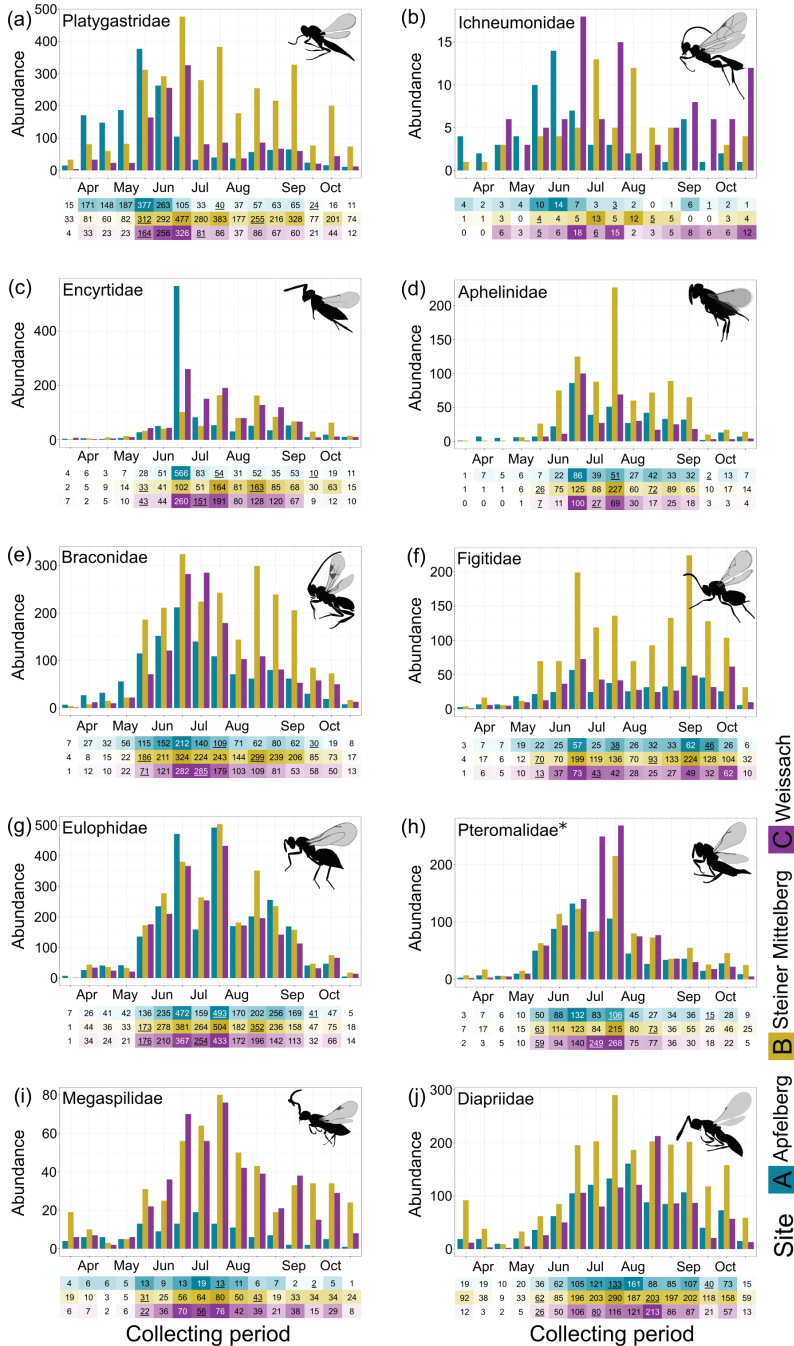
The study site Steiner Mittelberg had the highest abundance with 45,678 specimens, followed by Weissach with 24,037 specimens and Apfelberg with 20,737 specimens. The microhymenoptera family with the highest abundance was the family Mymaridae. It dominated throughout the year at Steiner Mittelberg and was outnumbered at Apfelberg only from April to June by Platygastridae, in July to August by Scelionidae and in September by Trichogrammatidae. At Weissach, Mymaridae was only outnumbered from July to August by Scelionidae and in September by Trichogrammatidae (Suppl. material 1: fig. S3).

The lowest abundance of microhymenoptera were observed at all three study sites between March and April in spring, and between Mid-September and October in autumn. The abundance reached a first peak between June and July, a second peak between July and August and a final small peak in October (Fig. 3). At Steiner Mittelberg, there was an additional fourth peak mid-August (Fig. 3b). Some families peaked early in the season (e.g. Platygastridae) and some showed high activity also in the late season (e.g. Figitidae, Trichogrammatidae). Some families had only one activity peak (e.g. Scelionidae, Mymaridae), whereas others had two (e.g. Figitidae, Eulophidae), or three (e.g. Trichogrammatidae). Also, timing and number of peaks of the families differed between the three sites. Families that were rarely found in the micro fractions, such as Proctotrupidae, Cynipidae, Ormyridae, Signiphoridae, Tetracampidae, Torymidae, Mymaromatidae and Crabronidae are shown in Suppl. material 1: fig. S4.

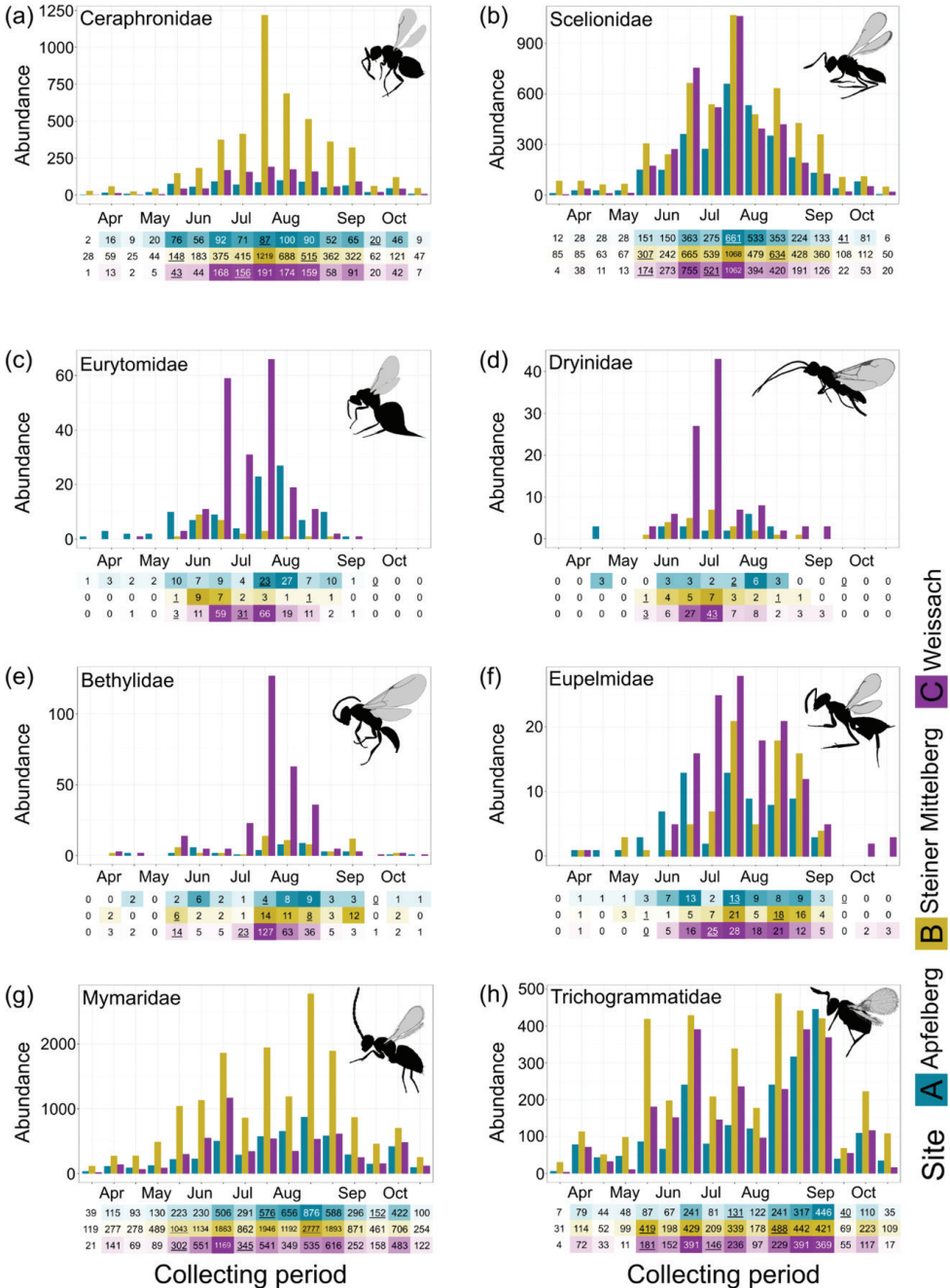
Interestingly, there was no consistent decline in microhymenoptera after mowing neither for total abundance (Fig. 3), nor for abundance of the different families (Figs 4, 5). For the total number of specimens, mowing was followed by a sharp de-



**Figure 3.** Seasonal abundance of microhymenoptera from Malaise traps at three study sites **a** Apfelberg **b** Steiner Mittelberg and **c** Weissach in Baden-Wuerttemberg, south-western Germany. The arrows mark mowing events and the asterisk marks grazing activities.



**Figure 4.** Seasonal abundance patterns of different microhymenoptera families from Malaise traps at three study sites in Baden-Wuerttemberg, south-western Germany. Families are sorted by the time of the first activity peak. Only families with  $n > 20$  during their activity peak are shown. Underlined values indicate mowing activity, except for one sheep grazing event at Apfelberg in September/October. \*: Family definition of ‘Pteromalidae’ is based on Goulet and Huber (1993) as specimen identification was done before Burks et al. (2022).



**Figure 5.** Seasonal abundance patterns of different microhymenoptera families from Malaise traps at three study sites in Baden-Wuerttemberg, south-western Germany. Families are sorted by the time of the first activity peak. Only families with  $n > 20$  during their activity peak are shown. Underlined values indicate mowing activity, except for one sheep grazing event at Apfelberg in September/October.

crease at Apfelberg in July and in Steiner Mittelberg in August, but an increase after grazing in Apfelberg in September, and after mowing in May in Steiner Mittelberg, and in Weissach in May and July.

## Discussion

To the very best of our knowledge, this is the first study on the diversity and the phenology of different families of microhymenoptera in meadow ecosystems using Malaise traps. Because it is currently not possible to study the abundance and the diversity of taxonomic groups in parallel at the same time using molecular methods, several thousands of microhymenoptera had to be sorted manually on family level, which took 18 person-months in the present study. Therefore, we restricted our analysis to data from one year and three sites. However, because all three sites are very similar, we consider it likely that these data are representative for insect communities in semi-arid grasslands of south-western Germany.

A current discussion revolves around the relationship between biomass of insects and biodiversity, and the potential of certain taxa to serve as indicators for biomass or species richness (Redlich et al. 2021; Uhler et al. 2021). This is important for the interpretation of recent data on insect decline and its ecological consequences, based on biomass data from malaise trap catches (Hallmann et al. 2017; Uhler et al. 2021). Recently, Hallmann et al. (2021a) found a significant relationship between hoverfly abundance and species richness with the total biomass of insects in malaise trap catches from six locations in North Rhine-Westphalia, Germany. These locations were also studied in the Krefeld study (Hallmann et al. 2017), at two time points, 1989 and 2014. From this, Hallmann et al. (2021a) concluded that the biomass decline reported by Hallmann et al. (2017) is in fact associated with a decline in abundance and diversity of hoverflies, and possibly other taxa as well. A positive correlation with hoverflies was confirmed by Redlich et al. (2021), and Uhler et al. (2021), using insect biomass data from malaise traps at 179 locations in South Germany from different habitats. Interestingly, the correlation of total insect biomass with species richness differed depending on temperature and habitat but was significantly positive in all habitats for Diptera, Lepidoptera and Orthoptera, but not for other groups on all studied habitats. From this, it was concluded that hoverflies might be indicators for large-bodied insect taxa such as Orthoptera and Lepidoptera, while taxa with small body size, but high diversity have less impact on biomass (Redlich et al. 2021). In contrast to this idea, our data on microhymenoptera from low-intensity managed meadows revealed not only a significant correlation between total insect biomass and diversity, but also with abundance. We assume that this is caused by the dependence of microhymenoptera on the abundance of their hosts, which at least partially belong to the Lepidoptera and Diptera. This finding indicates that the decline of insect biomass reported by Hallman et al. (2017) may also affect microhymenoptera.

There was a positive correlation between temperature, precipitation and abundance of microhymenoptera, which has been observed also in previous studies for insects (Pilotto et al. 2020; Uhler et al. 2021; Welti et al. 2021; Müller et al. 2023). This finding is reasonable considering the fact that insects are ectothermic organisms, which means that with increasing temperature, their metabolism increases, which can lead to higher flight activity (Klowden 2013). In his study on the influence of different climatic factors on parasitoid Hymenoptera, Ulrich (2000) identified precipitation as the most important climatic factor. In contrast, Juillet (1964) concluded that temperature and wind velocity are the main indicators of activity of Ichneumonoidea, and that precipitation is not an informative indicator, because of its occasional occurrence. Still, it remains unclear if microhymenoptera abundance and activity are affected by the weather directly or via their host densities.

At all sites, wasps were collected in larger numbers only after end of May in spring, and after September in autumn and had between one and four peaks in activity over the year, mostly between June and July, in July, and between July and August. It is unclear, if these peaks represent several generations of wasps throughout the year or are caused by different species within each family with non-matching peaks. As mowing showed to be harmful for microhymenoptera (Haas-Renninger et al. 2023b), our phenology data indicates two periods in the year which might be suitable for activities such as mowing, up to end of May in spring, and after September in autumn. However, our data do not provide evidence for a decline of microhymenoptera due to mowing. In fact, from the five mowing events and one grazing event observed during our study, only two were associated with a subsequent decline in abundance, while an increase was observed in four cases (Fig. 3). The large losses of up to 64% in individuals caused by mowing (Haas-Renninger et al. 2023b) may not affect the population sizes in the field. It can be suggested that mowing had no impact because microhymenoptera have a short lifespan and their population sizes strongly depend on newly emerged specimens. It might be possible that our study sites were quickly re-populated after mowing by wasps, which emerged from unmown habitats from surrounding areas (Fig. 2).

In our study, the most abundant microhymenopteran families were egg parasitoids of the families Mymaridae, Scelionidae and Trichogrammatidae, and Platygasteridae. Boness (1953), who used sweep netting, ground collectors and vegetation beating found that Chalcidoidea, the superfamily of Mymaridae and Trichogrammatidae, are the most abundant parasitoid wasps in meadows. This is consistent with Haas-Renninger et al. (2023b), which found that Chalcidoidea in general and especially Mymaridae dominated. However, Haas-Renninger et al. (2023b) found Ceraphronidae to be the family with the second largest abundance, which were found in much lower number in this study. This might be due to the different trapping methods, as Haas-Renninger et al. (2023b) used insect suction samplers. The egg-parasitoids in the families Scelionidae, Mymaridae and Trichogrammatidae show two main activities, the first between June and July and the second between August and September. This pattern was also observed by Ulrich (2005) for egg-parasitoid using emergence traps. Other endoparasitoids, such as some Braconidae, Encyrtidae and Ceraphronidae, that use various hosts,



show a high activity already in mid-May, and in the case of Platygastriidae even earlier in April. In the case of Braconidae, of which around one quarter of specimens are expected in the micro fraction (Haas-Renninger et al. 2023a), the observed phenology might be due to the activity of small-sized Aphidiinae, that are parasitoids of aphids. The high abundance of Encyrtidae between June and July at Apfelberg might be due to the mass-emergence of a few species. This is for example known from the genus *Copidosoma*, which are polyembryonic parasitoids of Lepidoptera and produce a high number of offspring (Smith et al. 2017). For the families that we found in the samples but did not discuss here, their biology comprises too many different host orders or life stages of hosts (Figitidae, Aphelinidae, Eulophidae, Eupelmidae, Eurytomidae, Pteromalidae), or they occurred in numbers that were too low to see a clear phenology (Cynipidae, Ormyridae, Signiphoridae, Tetracampidae, Mymarommatidae), partly due to the fractioning process (Ichneumonidae, Torymidae, Proctotrupidae, Aculeata) (Haas-Renninger et al. 2023a).

In our study, we used size-fractionated samples to separate small-sized specimens from larger ones and focused solely on the micro fraction, as we were interested in microhymenoptera. The efficiency of the fractionator to separate Hymenoptera families has already been tested (Haas-Renninger et al. 2023a) and has shown to be very useful in terms of specimen handling and expenditure of time considering the high number of sorted Malaise trap samples in this study. Our focus on the micro fraction explains the low numbers of Ichneumonoidea and Aculeata, which are generally very numerous in whole Malaise trap samples (Srivathsan et al. 2023). Another constraint of our study is the focus on the family level. Different genera and species within a family can have different phenologies depending on the host stages they are associated with (Gaasch et al. 1998). Nevertheless, we are confident that our results can show general activity patterns of microhymenopteran families, which might be interesting not only for hymenopterists focusing on a specific family, but also for conservation management. Therefore, this might be the first step towards assessing parasitoid Hymenoptera in a long-term monitoring approach and to consider them as useful indicators for biodiversity (LaSalle and Gauld 1993; Fraser et al. 2008; Anderson et al. 2011; Stevens et al. 2013). Species of higher trophic levels such as parasitoids are at particularly high risk of extinction due to habitat loss and landscape homogenisation (Hassell 2000; Wagner et al. 2021; Klaus et al. 2023). Another critical factor is climate change which was suggested by Janzen and Hallwachs (2021) as the main driver for a decline of parasitoid Hymenoptera species richness in a protected rain forest over 34 years.

We selected our study sites dependent on the conservation value which is based on the number and conservation status of indicator species, in our case wild bees, in a specific habitat (Görn and Fischer 2011). The microhymenoptera abundance at the protected area Apfelberg showed more similar patterns to the non-protected area Weis-sach than to the protected area Steiner Mittelberg, where abundance was nearly twice as high. This might be due to the location of the Malaise trap at Steiner Mittelberg, where the trap was placed in a low-intensity managed meadow, between an organically cultivated field and a forest edge (Fig. 1B). Therefore, many specimens might have

been trapped while migrating from meadow to forest and vice versa, or while migrating through the corridor between field and forest, especially as the Malaise trap was oriented orthogonally to this corridor. Edges of forests are known as insect flyways (Townes 1972) and trap locations directly at such border lines can massively influence the trap result (Hausmann et al. 2020b), which is especially the case for Weissach (Fig. 1C). By contrast, the Malaise traps at Apfelberg (Fig. 1A) was placed more centrally in the meadow. As we could not see strong differences in the phenology of the different microhymenoptera families as well as the family composition between the sites, we believe that our site selection based on conservation values of wild bees together with the hierarchical cluster analysis was reasonable for the purpose of our study.

Our data set forms the baseline for microhymenoptera occurrence in low-intensity managed meadows in south-western Germany. Our pre-sorted microhymenoptera specimens are a valuable resource for taxonomical approaches, such as Large-Scale Integrative Taxonomy (LIT) (Hartop et al. 2022), which aims to enable fast and reliable species delimitation based on preliminary species hypotheses acquired through inexpensive data, such as pictures and barcodes. Parts of the microhymenoptera specimens sampled in our study have already been taxonomically treated in the project GBOL III: Dark Taxa (<https://gbol.bolgermany.de/gbol3/de/gbol-dark-taxa/>) resulting in new microhymenopteran species descriptions (Moser et al. 2023). With our study, we want to raise awareness for the importance of standardized long-term monitoring projects to observe population trends of insects. Our study also highlights the value of the ‘black gold’ of mass samples, containing an unknown diversity of microhymenoptera waiting to be discovered.

## Acknowledgments

We want to thank Florian Theves for helpful comments on the first draft of this paper. We also thank the regional administrative authorities of Karlsruhe for granting sampling permissions. Funding for Maura Haas-Renninger was provided by the Ministry of Science and Art of Baden-Wuerttemberg through a graduate scholarship from the State Graduate Sponsorship Program. The Malaise trap samples were obtained from an ongoing biodiversity monitoring initiative coordinated by the LUBW (Landesanstalt für Umwelt Baden-Wuerttemberg) and funded by the state government of Baden-Wuerttemberg within the “Sonderprogramm zur Stärkung der biologischen Vielfalt”. We also thank three unknown reviewers for their helpful comments.

## References

- Anderson A, McCormack S, Helden A, Sheridan H, Kinsella A, Purvis G (2011) The potential of parasitoid Hymenoptera as bioindicators of arthropod diversity in agricultural grasslands. *Journal of Applied Ecology* 48: 382–390. <https://doi.org/10.1111/j.1365-2664.2010.01937.x>

- Battles I, Burkness E, Crossley MS, Edwards CB, Holmstrom K, Hutchison W, Ingerson-Mahar J, Owens D, Owens AC (2024) Moths are less attracted to light traps than they used to be. *Journal of Insect Conservation*, 12 pp. <https://doi.org/10.1007/s10841-024-00588-x>
- Behm J (2018) Das Sonderprogramm zur Stärkung der biologischen Vielfalt. Landesanstalt für Umwelt Baden-Württemberg 2.
- Boness M (1953) Die Fauna der Wiesen unter besonderer Berücksichtigung der Mahd. Ein Beitrag zur Agrarökologie. *Zeitschrift für Morphologie und Ökologie der Tiere* 42: 225–277. <https://doi.org/10.1007/BF00412995>
- Brühl CA, Bakanov N, Köthe S, Eichler L, Sorg M, Hörren T, Mühlethaler R, Meinel G, Lehmann GU (2021) Direct pesticide exposure of insects in nature conservation areas in Germany. *Scientific reports* 11: 24144. <https://doi.org/10.1038/s41598-021-03366-w>
- Buffington M, Gates M (2008) The Fractionator: a simple tool for mining ‘Black Gold’. *Ska-phion* 2: 1–4.
- Burks R, Mitroiu M-D, Fusu L, Heraty JM, Janšta P, Heydon S, Papilloud ND-S, Peters RS, Tselikh EV, Woolley JB, van Noort S, Baur H, Cruaud A, Darling C, Haas M, Hanson P, Krogmann L, Rasplus J-Y (2022) From hell’s heart I stab at thee! A determined approach towards a monophyletic Pteromalidae and reclassification of Chalcidoidea (Hymenoptera). *Journal of Hymenoptera Research* 94: 13–88. <https://doi.org/10.3897/jhr.94.94263>
- DeBach P, Rosen D (1991) *Biological control by natural enemies*, 2<sup>nd</sup> edn. Cambridge University Press, Cambridge England, New York.
- Engel MS, Ceríaco LM, Daniel GM, Dellapé PM, Löbl I, Marinov M, Reis RE, Young MT, Dubois A, Agarwal I, Lehmann A. P, Alvarado M, Alvarez N, Andreone F, Araujo-Vieira K, Ascher JS, Baêta D, Baldo D, Bandeira SA, Barden P, Barrasso DA, Bendifallah L, Bockmann FA, Böhme W, Borkent A, Brandão CR, Busack SD, Bybee SM, Channing A, Chatzimanolis S, Christenhusz MJ, Crisci JV, D’elía G, Da Costa LM, Davis SR, Lucena CA de, Deuve T, Fernandes Elizalde S, Faivovich J, Farooq H, Ferguson AW, Gippoliti S, Gonçalves FM, Gonzalez VH, Greenbaum E, Hinojosa-Díaz IA, Ineich I, Jiang J, Kahono S, Kury AB, Lucinda PH, Lynch JD, Malécot V, Marques MP, Marris JW, Mckellar RC, Mendes LF, Nihei SS, Nishikawa K, Ohler A, Orrico VG, Ota H, Paiva J, Parrinha D, Pauwels OS, Pereyra MO, Pestana LB, Pinheiro PD, Prendini L, Prokop J, Rasmussen C, Rödel M-O, Rodrigues MT, Rodríguez SM, Salatnaya H, Sampaio Í, Sánchez-García A, Shebl MA, Santos BS, Solórzano-Kraemer MM, Sousa AC, Stoev P, Teta P, Trape J-F, Dos Santos CV-D, Vasudevan K, Vink CJ, Vogel G, Wagner P, Wappler T, Ware JL, Wedmann S, Zacharie CK (2021) The taxonomic impediment: a shortage of taxonomists, not the lack of technical approaches. *Zoological Journal of the Linnean Society* 193: 381–387. <https://doi.org/10.1093/zoolinnean/zlab072>
- Forbes AA, Bagley RK, Beer MA, Hippee AC, Widmayer HA (2018) Quantifying the unquantifiable: why Hymenoptera, not Coleoptera, is the most speciose animal order. *BMC ecology* 18: 21. <https://doi.org/10.1186/s12898-018-0176-x>
- Fraser SE, Dytham C, Mayhew PJ (2008) The effectiveness and optimal use of Malaise traps for monitoring parasitoid wasps. *Insect Conservation and Diversity* 1: 22–31. <https://doi.org/10.1111/j.1752-4598.2007.00003.x>
- Gaasch CM, Pickering J, Moore CT (1998) Flight Phenology of Parasitic Wasps (Hymenoptera: Ichneumonidae) in Georgia’s Piedmont. *Environmental Entomology* 27: 606–614. <https://doi.org/10.1093/ee/27.3.606>

- Gatter W, Ebenhöf H, Kima R, Gatter W, Scherer F (2020) 50-jährige Untersuchungen an migrierenden Schwebfliegen, Waffenschwebfliegen und Schlupfwespen belegen extreme Rückgänge (Diptera: Syrphidae, Stratiomyidae; Hymenoptera: Ichneumonidae). *Entomologische Zeitschrift* 130: 131–142.
- Geiger MF, Moriniere J, Hausmann A, Haszprunar G, Wägele W, Hebert PD, Rulik B (2016) Testing the Global Malaise Trap Program - How well does the current barcode reference library identify flying insects in Germany? *Biodiversity data journal* 4: e10671. <https://doi.org/10.3897/BDJ.4.e10671>
- Görn S, Fischer K (2011) Niedermoore Nordostdeutschlands bewerten. Vorschlag für ein faunistisches Bewertungsverfahren. *Naturschutz und Landschaftsplanung* 43: 211–217.
- Goulet H, Huber JT (1993) *Hymenoptera of the world: an identification guide to families*. Agriculture Canada.
- Grissell EE (1999) Hymenopteran Biodiversity: Some Alien Notions. *American Entomologist* 45: 235–244.
- Haas-Renninger M, Schwabe N, Moser M, Krogmann L (2023a) Black gold rush - Evaluating the efficiency of the Fractionator in separating Hymenoptera families in a meadow ecosystem over a two week period. *Biodiversity data journal* 11: e107051. <https://doi.org/10.3897/BDJ.11.e107051>
- Haas-Renninger M, Weber J, Felske I, Kimmich T, Csader M, Betz O, Krogmann L, Steidle JL (2023b) Microhymenoptera in roadside verges and the potential of arthropod-friendly mowing for their preservation. *Journal of Applied Entomology* 147(10): 1035–1044. <https://doi.org/10.1111/jen.13199>
- Hallmann CA, Sorg M, Jongejans E, Siepel H, Hoffland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörrén T, Goulson D, Kroon H de (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE* 12(10): e0185809. <https://doi.org/10.1371/journal.pone.0185809>
- Hallmann CA, Ssymank A, Sorg M, Kroon H de, Jongejans E (2021a) Insect biomass decline scaled to species diversity: General patterns derived from a hoverfly community. *Proceedings of the National Academy of Sciences of the United States of America* 118(2): e2002554117. <https://doi.org/10.1073/pnas.2002554117>
- Hallmann CA, Ssymank A, Sorg M, Kroon H de, Jongejans E (2021b) Reply to Redlich et al.: Insect biomass and diversity do correlate, over time. *Proceedings of the National Academy of Sciences of the United States of America* 118(49): e2114567118. <https://doi.org/10.1073/pnas.2114567118>
- Hartop E, Srivathsan A, Ronquist F, Meier R (2022) Towards Large-scale Integrative Taxonomy (LIT): resolving the data conundrum for dark taxa. *Systematic biology* 71: 1404–1422. <https://doi.org/10.1093/sysbio/syac033>
- Hassell MP (2000) Host–parasitoid population dynamics. *Journal of Animal Ecology* 69: 543–566. <https://doi.org/10.1046/j.1365-2656.2000.00445.x>
- Hausmann A, Krogmann L, Peters R, Rduch V, Schmidt S (2020a) GBOL III: Dark Taxa - iBOL Barcode Bulletin. 2020. GBOL III: dark taxa. <https://doi.org/10.21083/ibol.v10i1.6242>
- Hausmann A, Segerer AH, Greifenstein T, Knubben J, Moriniere J, Bozicevic V, Doczkal D, Günter A, Ulrich W, Habel JC (2020b) Toward a standardized quantitative and quali-

- tative insect monitoring scheme. *Ecology and Evolution* 10: 4009–4020. <https://doi.org/10.1002/ece3.6166>
- Heraty J (2017) Parasitoid Biodiversity and Insect Pest Management. In: Foottit RG (Ed.) *Insect Biodiversity*. Wiley, 603–625. <https://doi.org/10.1002/9781118945568.ch19>
- Janzen DH, Hallwachs W (2021) To us insectometers, it is clear that insect decline in our Costa Rican tropics is real, so let's be kind to the survivors. *Proceedings of the National Academy of Sciences of the United States of America* 118(2): e2002546117. <https://doi.org/10.1073/pnas.2002546117>
- Juillet JA (1964) Influence of weather on flight activity of parasitic Hymenoptera. *Canadian Journal of Zoology* 42: 1133–1141. <https://doi.org/10.1139/z64-110>
- Karlsson D, Hartop E, Forshage M, Jaschhof M, Ronquist F (2020) The Swedish Malaise trap project: a 15 year retrospective on a countrywide insect inventory. *Biodiversity data journal* 8: e47255. <https://doi.org/10.3897/BDJ.8.e47255>
- Klaus F, Tschardt T, Grass I (2023) Trophic level and specialization moderate effects of habitat loss and landscape diversity on cavity-nesting bees, wasps and their parasitoids. *Insect Conservation and Diversity* 17(1): 65–76. <https://doi.org/10.1111/icad.12688>
- Klein A-M, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tschardt T (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences* 274: 303–313. <https://doi.org/10.1098/rspb.2006.3721>
- Klowden MJ (2013) *Physiological systems in insects*. Academic press. <https://doi.org/10.1016/C2011-0-04120-0>
- LaSalle J (1993) Parasitic Hymenoptera, biological control and biodiversity. In: LaSalle J, Gauld ID (Eds) *Hymenoptera and biodiversity*. C.A.B. International, Wallingford, Oxon, 197–215.
- LaSalle J, Gauld ID [Eds] (1993) *Hymenoptera and biodiversity*. C.A.B. International, Wallingford, Oxon.
- LaSalle J, Gauld ID (1991) Parasitic Hymenoptera and the biodiversity crisis. *Redia* 74: 315–334.
- Lehmann GU, Bakanov N, Behnisch M, Bourlat SJ, Brühl CA, Eichler L, Fickel T, Geiger MF, Gemeinholzer B, Hörren T, Köthe S, Lux A, Meinel G, Mühlethaler R, Poglitsch H, Schäffler L, Schlechtriemen U, Schneider FD, Schulte R, Sorg M, Sprenger M, Swenson SJ, Terlau W, Turck A, Zizka VM (2021) Diversity of Insects in Nature protected Areas (DINA): an interdisciplinary German research project. *Biodiversity and Conservation* 30: 2605–2614. <https://doi.org/10.1007/s10531-021-02209-4>
- Lister BC, Garcia A (2018) Climate-driven declines in arthropod abundance restructure a rain-forest food web. *Proceedings of the National Academy of Sciences of the United States of America* 115: E10397–E10406. <https://doi.org/10.1073/pnas.1722477115>
- Moser M, Ulmer JM, van de Kamp T, Vasilița C, Renninger M, Mikó I, Krogmann L (2023) Surprising morphological diversity in ceraphronid wasps revealed by a distinctive new species of *Aphanogmus* (Hymenoptera: Ceraphronoidea). *European Journal of Taxonomy* 864: 146–166. <https://doi.org/10.5852/ejt.2023.864.2095>
- Müller J, Hothorn T, Yuan Y, Seibold S, Mitesser O, Rothacher J, Freund J, Wild C, Wolz M, Menzel A (2023) Weather explains the decline and rise of insect biomass over 34 years. *Nature*. <https://doi.org/10.1038/s41586-023-06402-z>

- Oksanen J, Simpson GL, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Solyomos P, Stevens MH, Szoecs E, Wagner H, Barbour M, Bolker M, Bolker B, Borcard D, Carvalho G, Chirico M, Caceres M de, Durand S, Evangelista HB, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill MO, Lahti L, McGlenn D, Ouellette M-H, Cunha ER, Smith T, Stier A, Braak JC ter, Weedon J (2022) *vegan*: Community Ecology Package. R package version 2.6-4. <https://CRAN.R-project.org/package=vegan>
- Pilotto F, Kühn I, Adrian R, Alber R, Alignier A, Andrews C, Bäck J, Barbaro L, Beaumont D, Beenaerts N, Benham S, Boukal DS, Bretagnolle V, Camatti E, Canullo R, Cardoso PG, Ens BJ, Everaert G, Evtimova V, Feuchtmayr H, García-González R, Gómez García D, Grandin U, Gutowski JM, Hadar L, Halada L, Halassy M, Hummel H, Huttunen K-L, Jaroszewicz B, Jensen TC, Kalivoda H, Schmidt IK, Kröncke I, Leinonen R, Martinho F, Meesenburg H, Meyer J, Minerbi S, Monteith D, Nikolov BP, Oro D, Ozoliņš D, Padedda BM, Pallett D, Pansera M, Pardal MÂ, Petriccione B, Pipan T, Pöyry J, Schäfer SM, Schaub M, Schneider SC, Skuja A, Soetaert K, Sprünge G, Stanchev R, Stockan JA, Stoll S, Sundqvist L, Thimonier A, van Hoey G, van Ryckegem G, Visser ME, Vorhauer S, Haase P (2020) Meta-analysis of multidecadal biodiversity trends in Europe. *Nature communications* 11: 3486. <https://doi.org/10.1038/s41467-020-17171-y>
- R Core Team (2021) R: A language and environment for statistical computing. <https://www.R-project.org/>
- Redlich S, Steffan-Dewenter I, Uhler J, Müller J (2021) Hover flies: An incomplete indicator of biodiversity. *Proceedings of the National Academy of Sciences of the United States of America* 118(49): e2112619118. <https://doi.org/10.1073/pnas.2112619118>
- Sánchez-Bayo F, Wyckhuys KA (2019) Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation* 232: 8–27. <https://doi.org/10.1016/j.biocon.2019.01.020>
- Schindler M, Diestelhorst O, Haertel S, Saure C, Scharnowski A, Schwenninger HR (2013) Monitoring agricultural ecosystems by using wild bees as environmental indicators. *Biorisk* 8: 53–71. <https://doi.org/10.3897/biorisk.8.3600>
- Schöfer N, Ackermann J, Hoheneder J, Hofferberth J, Ruther J (2023) Sublethal Effects of Four Insecticides Targeting Cholinergic Neurons on Partner and Host Finding in the Parasitic Wasp *Nasonia vitripennis*. *Environmental toxicology and chemistry* 42: 2400–2411. <https://doi.org/10.1002/etc.5721>
- Schwan H, Sorg M, Stenmans W (1993) Naturkundliche Untersuchungen zum Naturschutzgebiet Die Spey (Stadt Krefeld, Kreis Neuss). I. Untersuchungsstandorte und Methoden. *Natur am Niederrhein (NF)* 8: 1–13.
- Seibold S, Gossner MM, Simons NK, Blüthgen N, Müller J, Ambarlı D, Ammer C, Bauhus J, Fischer M, Habel JC, Linsenmair KE, Nauss T, Penone C, Prati D, Schall P, Schulze E-D, Vogt J, Wöllauer S, Weisser WW (2019) Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature* 574: 671–674. <https://doi.org/10.1038/s41586-019-1684-3>
- Shaw MR, Hochberg ME (2001) The Neglect of Parasitic Hymenoptera in Insect Conservation Strategies: The British Fauna as a Prime Example. *Journal of Insect Conservation* 5: 253–263. <https://doi.org/10.1023/A:1013393229923>
- Smith MS, Shirley A, Strand MR (2017) *Copidosoma floridanum* (Hymenoptera: Encyrtidae) Rapidly Alters Production of Soldier Embryos in Response to Competition. *Annals of the Entomological Society of America* 110: 501–505. <https://doi.org/10.1093/aesa/sax056>



- Srivathsan A, Ang Y, Heraty JM, Hwang WS, Jusoh WF, Kutty SN, Puniamorthy J, Yeo D, Roslin T, Meier R (2023) Convergence of dominance and neglect in flying insect diversity. *Nature Ecology & Evolution* 7: 1012–1021. <https://doi.org/10.1038/s41559-023-02066-0>
- Szymank A, Sorg M, Doczkal D, Rulik B, Merkel-Wallner G, Vischer-Leopold M (2018) Praktische Hinweise und Empfehlungen zur Anwendung von Malaisefallen für Insekten in der Biodiversitätserfassung und im Monitoring. Series Naturalis 1. [http://www.entomologica.org/sn/naturalis2018\\_1.pdf](http://www.entomologica.org/sn/naturalis2018_1.pdf)
- Staab M, Gossner MM, Simons NK, Achury R, Ambarlı D, Bae S, Schall P, Weisser WW, Blüthgen N (2023) Insect decline in forests depends on species' traits and may be mitigated by management. *Communications biology* 6: 338. <https://doi.org/10.1038/s42003-023-04690-9>
- Stevens NB, Rodman SM, O'Keeffe TC, Jasper DA (2013) The use of the biodiverse parasitoid Hymenoptera (Insecta) to assess arthropod diversity associated with topsoil stockpiled for future rehabilitation purposes on Barrow Island, Western Australia. *Records of the Western Australian Museum, Supplement* 83: 355. <https://doi.org/10.18195/issn.0313-122x.83.2013.355-374>
- Thomas JA (2005) Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society B: Biological Sciences* 360: 339–357. <https://doi.org/10.1098/rstb.2004.1585>
- Townes H (1972) A light-weight Malaise trap. *Entomological news* 83: 239–247.
- Turley NE, Biddinger DJ, Joshi NK, López-Uribe MM (2022) Six years of wild bee monitoring shows changes in biodiversity within and across years and declines in abundance. *Ecology and Evolution* 12:e9190. <https://doi.org/10.1002/ece3.9190>
- Twerd L, Banaszak-Cibicka W, Sobieraj-Betlińska A, Waldon-Rudziolek B, Hoffmann R (2021) Contributions of phenological groups of wild bees as an indicator of food availability in urban wastelands. *Ecological Indicators* 126: 107616. <https://doi.org/10.1016/j.ecolind.2021.107616>
- Uhler J, Redlich S, Zhang J, Hothorn T, Tobisch C, Ewald J, Thorn S, Seibold S, Mitesser O, Morinière J, Bozicevic V, Benjamin CS, Englmeier J, Fricke U, Ganuza C, Haensel M, Riebl R, Rojas-Botero S, Rummeler T, Uphus L, Schmidt S, Steffan-Dewenter I, Müller J (2021) Relationship of insect biomass and richness with land use along a climate gradient. *Nature communications* 12: 5946. <https://doi.org/10.1038/s41467-021-26181-3>
- Ulrich W (2000) Influence of weather conditions on populations of parasitic Hymenoptera in a beech forest on limestone. *Polish Journal of Entomology* 69: 47–64.
- Ulrich W (2005) Die Hymenopteren einer Wiese auf Kalkgestein: Ökologische Muster einer lokalen Tiergemeinschaft. *Schriftenreihe Forschungszentrum Waldökosysteme A 195*, Göttingen.
- Wagner DL, Grames EM, Forister ML, Berenbaum MR, Stopak D (2021) Insect decline in the Anthropocene: Death by a thousand cuts. *Proceedings of the National Academy of Sciences of the United States of America* 118(2): e2023989118. <https://doi.org/10.1073/pnas.2023989118>
- Welti EA, Zajicek P, Frenzel M, Ayasse M, Bornholdt T, Buse J, Classen A, Dziock F, Engelmann RA, Englmeier J, Fellendorf M, Förchler MI, Fricke U, Ganuza C, Hippke M, Hoenselaar G, Kaus-Thiel A, Kerner J, Kilian D, Mandery K, Marten A, Monaghan MT, Morkel C, Müller J, Puffpaff S, Redlich S, Richter R, Rojas-Botero S, Scharnweber T, Scheiffarth G, Yáñez PS, Schumann R, Seibold S, Steffan-Dewenter I, Stoll S, Tobisch C,

- Twietmeyer S, Uhler J, Vogt J, Weis D, Weisser WW, Wilmking M, Haase P (2021) Temperature drives variation in flying insect biomass across a German malaise trap network. *Insect Conservation and Diversity* 15(2): 168–180. <https://doi.org/10.1111/icad.12555>
- Westrich P, Schwenninger HR, Herrmann M, Klatt M, Klemm M, Prosi R, Schanowski A (2000) Rote Liste der Bienen Baden-Württembergs. *Naturschutz-Praxis, Artenschutz* 4.
- Westrich P, Frommer U, Mandery K, Riemann H, Ruhnke H, Saure C, Voith J (2011) Rote Liste und Gesamtartenliste der Bienen (Hymenoptera, Apidae) Deutschlands. 5. Fassung. *Naturschutz und Biologische Vielfalt* 70(3): 373–416.
- Yang LH, Gratton C (2014) Insects as drivers of ecosystem processes. *Current Opinion in Insect Science* 2: 26–32. <https://doi.org/10.1016/j.cois.2014.06.004>
- Zizka VM, Geiger MF, Hörren T, Kirse A, Noll NW, Schäffler L, Scherges AM, Sorg M (2022) Repeated subsamples during DNA extraction reveal increased diversity estimates in DNA metabarcoding of Malaise traps. *Ecology and Evolution* 12: e9502. <https://doi.org/10.1002/ece3.9502>

## Supplementary material I

### Supplementary information

Authors: Maura Haas-Renninger, Sonia Bigalk, Tobias Frenzel, Raffaele Gamba, Sebastian Görn, Michael Haas, Andreas Haselböck, Thomas Hörren, Martin Sorg, Ingo Wendt, Petr Janšta, Olaf Zimmermann, Johannes L. M. Steidle, Lars Krogmann  
Data type: docx

Explanation note: **figure S1**. Conservation value for study sites based on wild bee species occurrence. **figure S2**. Cluster dendrogram for wild bee species presence at twelve different study sites. **figure S3**. Composition of microhymenoptera families in the micro fractions of Malaise trap samples from three study sites in Baden-Wuerttemberg, south-western Germany. **figure S4**. Seasonal abundance of different microhymenoptera families from Malaise traps at three study sites in Baden-Wuerttemberg, south-western Germany. **table S1**. Study sites in Baden-Wuerttemberg, Germany, that were sampled in 2019 within the insect monitoring project “Aerial Biomass”. **table S2**. Area proportions of land use of the three study sites in a 500 m radius around the Malaise trap. **table S3**. Model selection table of linear models for diversity of microhymenoptera families.

Copyright notice: This dataset is made available under the Open Database License (<http://opendatacommons.org/licenses/odbl/1.0/>). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: <https://doi.org/10.3897/jhr.97.128234.suppl1>