



Effects of management cessation on hoverflies (Diptera: Syrphidae) across Austrian and Swiss mountain meadows

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Abstract. Extensively managed grasslands, particularly in mountain regions, are considered to be one of the most diverse agroecosystems worldwide. Their decline due to land use abandonment affects the diversity of both plants and associated pollinators. Extensive grasslands constitute an important habitat type and food resource for hoverflies (syrphids); however, not much is known about the effects of abandonment on this important pollinator group. In the present study, we investigated how abandonment affects species richness and the composition of syrphids in mountainous meadows. We recorded the richness of vascular plants, vegetation cover, flower cover and the surrounding landscape to examine whether and how syrphids are affected by plant and landscape parameters. We investigated the species richness, abundance and species composition of syrphids by sweep netting and by using observation plots in 18 semidry meadows across two Austrian regions and one Swiss region. For each region, we selected three meadows abandoned for more than 20 years and three annually mown non-fertilized meadows. Abandonment or mowing had no significant effect on the total number of syrphid species or individuals or on the number of aphidophagous and non-aphidophagous species and individuals. However, the total number of species and the number of non-aphidophagous species significantly increased with the increasing number of plant species. The surrounding landscape and other plant parameters showed no association with the assessed syrphid parameters. Although syrphids were unaffected by abandonment, higher syrphid species numbers in response to a higher plant richness in annual mown meadows suggest that the management of mountain meadows is beneficial in preserving syrphid richness.

1 Introduction

Seminatural grasslands are considered one of the most valuable agroecosystems throughout Central European landscapes and are characterized by a high biodiversity (Chytrý et al., 2015; Habel et al., 2013; Maurer et al., 2006). In particular, extensive management by mowing or grazing is an important management scheme to maintain these habitats of high nature conservation value (Hansson and Fogelfors, 2000; Moog et al., 2002). Most of these grassland habitats have a long history and were maintained by local farm-

ers for hay making and animal husbandry over hundreds of years (Chemini and Rizzoli, 2003; Poschlod and WallisDeVries, 2002). Since their conservation relies strongly on human land use activities, they are considered seminatural habitats (Heijman et al., 2013). Due to a high economical pressure in recent decades, traditional management has become more and more unviable (Hinojosa et al., 2016; McGinlay et al., 2017). Thus, to increase the yield, new agricultural and cultivation techniques were developed which have led to an intensification of grasslands in favorable regions on the one hand and afforestation or abandonment in marginal

regions on the other hand (Graf et al., 2014; Tasser et al., 2007). Besides economical reasons, ecological factors like slope inclination and accessibility are important drivers for farmers' decisions to cease management especially in mountainous landscapes (Tasser et al., 2007; Rey Benayas et al., 2007; Strijker, 2005). Abandonment has led to an ongoing decline of traditionally managed seminatural meadows, confining them to small patches within the landscape (Graf et al., 2014). Successional processes alter habitat conditions and have been leading to an increase in dominant grass species and the establishment of trees and shrubs on formerly managed meadows (Cremene et al., 2005; Diemer et al., 2001; Galvánek and Lepš, 2008; Tasser and Tappeiner, 2002). Consequently, plant species which demand regular management decline during this succession process (Hülber et al., 2017; Pykälä et al., 2005). Thus, an important research question is how insect populations might respond to changing vegetation characteristics after abandonment.

Generally, the extent of how abandonment affects insects depends very much on the considered insect groups (Bonari et al., 2017; Burel, 1991; Walcher et al., 2017) and can even differ between species within the same taxon (Jovičić et al., 2017). While some insect taxa benefit from the altered structural and environmental conditions in abandoned meadows, e.g., ants (Azcarate and Peco, 2011; Wiezik et al., 2013) and grasshoppers (Baur et al., 2006; Schirmel et al., 2011), recent studies showed detrimental effects of abandonment on pollinators such as butterflies (Öckinger et al., 2006) and bumblebees (Walcher et al., 2017). Until now, the response of hoverflies (syrphids) to the abandonment of extensively managed meadows in mountainous regions has been little studied.

Along with wild bees, syrphids are important pollinators of both wildflowers and crops (Jauker and Wolters, 2008). They may also play a role as pollinators in habitats which are unsuitable, for example, for wild and honey bees (Jauker et al., 2009; Rader et al., 2016). Besides providing important pollination services, hoverfly species whose larvae are aphidophagous contribute strongly to the efficient control of aphid populations (Leroy et al., 2014). Furthermore, hoverflies represent important bioindicators, which makes them an important insect group to study the effects of land use changes (Burgio and Sommagio, 2007).

In a study investigating hoverfly communities in regularly mown and abandoned mountainous grasslands, extensively managed meadows contained a higher number of hoverfly individuals compared to abandoned meadows (Hussain et al., 2017). Furthermore, the study found a positive relationship between flower cover and plant richness with hoverfly abundance. However, it is unclear whether these relationships vary among different regions. Thus, it is important to collect and merge data from several mountainous regions to obtain more generally valid results. Therefore, in the present study, we analyzed the data of three regions including those reported by Hussain et al. (2017). Analogous to their study, we tested the effects of abandonment, vegetation

parameters and further surrounding landscape parameters on species richness and the abundance of syrphids in three regions across the Alps. In addition to the former study, here we further distinguished between species whose larvae have an aphidophagous or non-aphidophagous feeding mode. In the present study, we expected a clear response of hoverflies to abandonment due to altered vegetation characteristics, like decreasing plant and flower resources, which in turn are important determinants of hoverfly richness and abundance (Haenke et al., 2009). The surrounding landscape was included in the present study because it was reported to affect the number of hoverflies in grassland ecosystems (e.g., Gittings et al., 2006; Power et al., 2016).

We expected (i) different numbers of hoverfly species and individuals and a different hoverfly species composition between management types. Furthermore, we investigated (ii) whether and how hoverflies are affected by plant richness, flower cover, the cover of the vegetation and the surrounding landscape. Additionally, we investigated (iii) the effects of abandonment and plant and landscape parameters on both aphidophagous and non-aphidophagous hoverflies.

2 Material and methods

2.1 Study regions and sites

Investigations were carried out in June and August 2015. Altogether, 18 mountainous meadows in the Austrian and Swiss Alps were investigated. Two regions were located in Austria (central Ennstal and Großes Walsertal) and one region in Switzerland (Val Müstair) (Fig. 1). Investigations in the central Ennstal region were carried out in the municipalities of Sankt Gallen, Stainach and Pürgg, in Großes Walsertal in the municipality of Sonntag/Buchboden, and in the Val Müstair region in the municipalities of Valchava, St. Maria and Tschier. The central Ennstal region is located in the Austrian federal state of Styria ranging from the Gesäuse national park in the east to Grimming mountain in the west. The meadows were situated at altitudes between 690 and 770 m above sea level (a.s.l.). Großes Walsertal is a biosphere reserve located in the Austrian federal state of Vorarlberg. Meadows were situated at altitudes between 1170 and 1280 m a.s.l. Val Müstair in the canton of Graubünden is situated in the Eastern Alps of Switzerland near the border with South Tyrol (Italy). Meadows in this region were situated at altitudes between 1740 and 1800 m a.s.l. Detailed information on the investigated meadows is shown in Table S1 in the Supplement. Within each region, six south-facing meadows were selected ($n = 18$). Three of the six meadows were annually mown and non-fertilized. The farmers usually mow the meadows from the end of July to the beginning of August depending on the annual weather conditions. Due to restricted accessibility with mowing machines, the meadows are mown manually with sickle bar mowers. Three of the six meadows had been abandoned for at least 20 years (Val

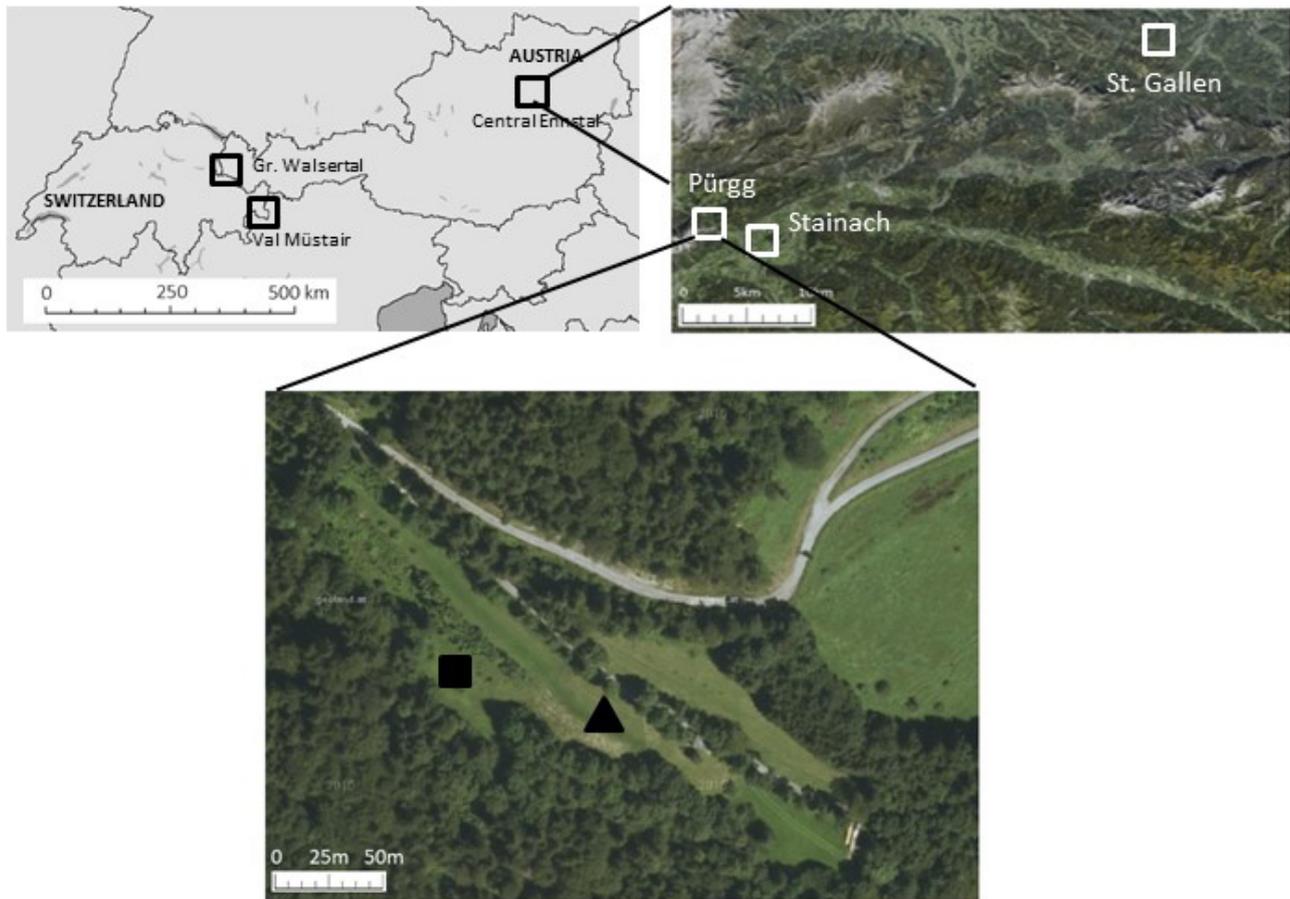


Figure 1. Location of the three study regions (central Ennstal, Großes Walsertal and Val Müstair). Detailed maps are shown for the central Ennstal region with the focus on two meadows in the municipality of Pürgg (the filled square outlines the location of one abandoned meadow, and the filled triangle outlines the location of one managed meadow). All panels are adapted from Basemap.at (2020), © data source: <http://www.basemap.at> (last access: April 2020), distributed under the Open Government Data Austrian license CC-BY 4.0.

Müstair 20 years, central Ennstal 20–40 years and Großes Walsertal 35–60 years since abandonment). Before the cessation of management, the abandoned meadows were annually mown and were never used as pastures. The annually mown meadows had an average area of 3049 m², and the abandoned meadows had an average area of 1366 m². The sizes of the abandoned and annually mown meadows were not significantly different within each region (*t* test: central Ennstal, $p = 0.295$; Großes Walsertal, $p = 0.131$; Müstair, $p = 0.323$).

2.2 Hoverfly sampling

We surveyed the number of hoverfly species and individuals once in mid-June and once in mid-August 2015 and finished one round of investigations within 2 d per month in each region. We started sampling at 10:00 and stopped at 17:00 (all times are in Central European time). In this time period, we found that optimal sampling conditions were a minimum temperature of 20 °C, dry vegetation and sunshine.

In order to increase sampling efficacy, we assessed the number of hoverfly species and individuals by sweep net sampling and an observation plot method (Hussain et al., 2018). Especially the observation plot method has been shown to increase the number of collected species and individuals (Hussain et al., 2018). Syrphid data from the central Ennstal region (Eisenwurzen) for June and August 2015 were provided by Hussain et al. (2017) who used the same sampling methods. Sweep net sampling was performed along three 15 m long and 2 m wide transects which were selected in the center of each meadow. Thus, we covered a sampling area of 90 m². The distances between the transects were 10 m. We used a sweep net consisting of a white cloth (40 cm opening diameter, 70 cm length). We conducted 30 sweeps per transect summing up to 90 sweeps per meadow. The contents of the sweep net were emptied after 30 sweeps and collected insects were killed with ethyl acetate and stored in previously prepared and labeled plastic vials. The sorting of hoverflies was carried out in the laboratory. Hoverflies were stored in glass vials filled with 70 % ethanol.

In addition to the sweep net method, we applied an observation plot method in which we observed four 2 m² plots each for 15 min within every meadow. The plots were distanced 3, 9 and 27 m from the first plot. The starting plot was selected approximately in the center of each meadow to avoid spillover effects from adjacent habitats. For the collection of single species, we used an insect net (20 cm opening diameter, 20 cm length) mounted on a handle 30 cm long. Syrphids entering an observation plot were caught and stored in plastic vials. In the laboratory, hoverfly individuals were preserved in glass vials in 70 % ethanol. For analysis, we pooled the individuals caught by sweep netting and those caught during the 15 min observations. Identification was performed using a binocular microscope and identification literature by Stubbs and Falk (1983) and van Veen (2010). For further analysis, we distinguished between hoverflies whose larvae are aphidophagous or non-aphidophagous. We did not consider hoverflies with saprophagous and phytophagous larvae separately due to the low number of species. Larvae of these species are all considered non-aphidophagous. The subdivision into feeding groups is an important aspect because the aphidophagous feeding group most likely contributes to an essential aphid control in nearby arable land. Thus, it is important to test whether the observed meadows can enhance aphidophagous syrphid populations.

2.3 Vegetation and landscape parameters

The assessment of plant parameters was carried out in June and August 2015 within 2 d in each month. We recorded plant parameters within four plots sized 1 m². As with the plots for syrphid sampling, these plots were situated in the center of the meadows. Within the plots, we identified all plants to the species level and assessed vegetation cover and flower cover. Besides living biomass, vegetation cover included necromass on the ground. For further analysis, we determined the amount of plant species with flowers having a flat corolla (hereafter designated as open nectar flowers, e.g., Ranunculaceae, Asteraceae and Apiaceae) because this flower type is an important food source for hoverflies. Additionally, we measured the surrounding landscape structure from orthophotos in ArcGIS (ArcGIS basemap). Therefore, we measured the percentage of open land (containing, for example, meadows and pastures in the surrounding) and forest (containing, for example, closed forest and hedges) within a 500 m circle drawn around the center of each meadow. We derived the vegetation and landscape data from the central Ennstal region (Eisenwurzen) for June and August 2015 from Hussain et al. (2017).

2.4 Statistical analysis

We used generalized linear models (GLMs) for count data and Poisson error distributions to analyze the effects of management and plant and landscape parameters on hoverfly

species and individuals and aphidophagous species and individuals. We included the variable region as a fixed factor in the GLMs. Before testing plant and landscape parameters in a GLM, we ran correlation tests between them. Therefore, we first computed the *corr.test* function (R package *psych*; Revelle, 2019) to receive *p* values and correlation coefficients (*r*). We found certain correlations between plant and landscape parameters (Table 1). Furthermore, to assess for multicollinearity between predictor variables (management type and vegetation and landscape parameters), we computed the variance inflation factors (VIFs) using the R package *car* (Fox et al., 2020). Any variables with a VIF greater than 5 were removed from the models. Based on these results, we computed our GLMs. We found that the predictor variables of plant richness, flower cover, vegetation cover and open nectar flowers could have been included in one model (all predictor variables with a VIF less than 3) to evaluate their effects on hoverflies. To investigate the effects of open landscape and forest, we analyzed both factors in a separate model (VIF less than 5). Similarly, according to the VIF output, we also tested the variable management type separately. We accounted for over- and underdispersion of the data by computing the *dispersion.test* function in R (Kleiber and Zeileis, 2018). In cases of over- or underdispersion, we corrected the GLMs by using quasi-Poisson error distributions.

To avoid spatial autocorrelation, we performed the Moran's test by applying the *Moran.I* function (Paradis et al., 2017) for each region individually. Our analysis revealed no spatial autocorrelation between meadows within each region (central Ennstal, *p* = 0.678; Großes Walsertal, *p* = 0.339; Val Müstair, *p* = 0.563).

We performed a principal coordinate analysis based on a Bray–Curtis similarity matrix, to evaluate differences in hoverfly species composition between meadow types. As with the GLM, we included the variable region as a fixed factor. Possible significant differences in hoverfly species composition between meadow types were tested with a permutational ANOVA (analysis of variance; PERMANOVA). We calculated *p* values using 9999 permutations of residuals under a reduced model.

We used version 6.1.13 of the software PRIMER including PERMANOVA+ (PRIMER-e Ltd., Plymouth, UK) to conduct the principal coordinate analysis and PERMANOVA. We performed all other statistical analyses in R version 3.5.2 (R Core Team, 2018).

3 Results

We collected 175 syrphid individuals belonging to 30 species (Table S2). A total of 25 species with 84 individuals were detected in managed meadows and 18 species with 91 individuals in abandoned meadows. We distinguished between 15 aphidophagous and 12 non-aphidophagous species.

Table 1. Correlation between plant and landscape parameters. Significant and marginally significant *r* and *p* values are pointed out in bold.

	Plant species		Vegetation cover		Flower cover		Open flowers		Forest cover	
	<i>r</i>	<i>p</i> value	<i>r</i>	<i>p</i> value	<i>r</i>	<i>p</i> value	<i>r</i>	<i>p</i> value	<i>r</i>	<i>p</i> value
Vegetation cover	-0.22	0.375								
Flower cover	0.66	0.003	-0.51	<0.001						
Open flowers	0.77	<0.001	0.16	0.513	0.42	0.084				
Forest cover	-0.10	0.680	-0.54	0.020	0.40	0.103	-0.26	0.298		
Open landscape	-0.038	0.882	0.40	0.097	-0.45	0.060	-0.95	<0.001	0.044	0.862

Table 2. Generalized linear models (GLMs) showing the effects of plant and landscape parameters on hoverfly species and individuals and on aphidophagous and non-aphidophagous species and individuals. Significant *p* values are shown in bold, and “df” signifies degrees of freedom.

Total hoverfly species						Total hoverfly individuals					
Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value	Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value
Intercept		0.430	0.702	0.612	0.540	Intercept		2.064	1.148	1.797	0.095
Flower cover	17	-0.148	0.188	-0.786	0.432	Flower cover	17	-0.215	0.325	-0.663	0.518
Plant species	17	0.043	0.021	2.037	0.041	Plant species	17	0.017	0.035	0.476	0.642
Vegetation cover	17	0.003	0.008	0.425	0.670	Vegetation cover	17	-0.004	0.128	-0.358	0.726
Open flowers	17	-0.173	0.157	-1.109	0.267	Open flowers	17	0.020	0.264	0.076	0.940
Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value	Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value
Intercept		8.809	4.795	1.837	0.066	Intercept		8.922	7.780	1.147	0.269
Open landscape	17	-0.062	0.048	-1.277	0.201	Open landscape	17	-0.071	0.081	-0.889	0.388
Forest cover	17	-0.082	0.050	-1.654	0.098	Forest cover	17	-0.064	0.079	-0.804	0.434
Aphidophagous hoverfly species						Aphidophagous hoverfly individuals					
Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value	Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value
Intercept		0.641	0.629	1.019	0.326	Intercept		2.419	1.195	2.023	0.064
Flower cover	17	-0.164	0.176	-0.929	0.369	Flower cover	17	-0.290	0.358	-0.812	0.431
Plant species	17	0.037	0.019	1.918	0.077	Plant species	17	0.007	0.037	0.199	0.845
Vegetation cover	17	0.001	0.007	0.088	0.931	Vegetation cover	17	-0.009	0.013	-0.682	0.507
Open flowers	17	-0.202	1.142	-1.426	0.177	Open flowers	17	0.068	0.282	0.242	0.812
Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value	Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value
Intercept		3.587	4.684	0.766	0.456	Intercept		6.968	8.653	0.805	0.433
Open landscape	17	-0.013	0.047	-0.279	0.784	Open landscape	17	-0.056	0.089	-0.634	0.536
Forest cover	17	-0.033	0.048	-0.684	0.504	Forest cover	17	-0.044	0.088	-0.501	0.624
Non-aphidophagous hoverfly species						Non-aphidophagous hoverfly individuals					
Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value	Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value
Intercept		-1.850	1.424	-1.299	0.216	Intercept		-2.345	1.840	-1.274	0.225
Flower cover	17	-0.639	0.425	-1.504	0.157	Flower cover	17	-0.428	0.510	-0.839	0.417
Plant species	17	0.113	0.052	2.161	0.050	Plant species	17	0.131	0.067	1.951	0.073
Vegetation cover	17	0.001	0.014	0.113	0.912	Vegetation cover	17	0.010	0.018	0.565	0.582
Open flowers	17	-0.477	0.343	-1.389	0.188	Open flowers	17	-0.677	0.434	-1.559	0.143
Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value	Variables	df	Estimate	Std. Error	<i>z</i> value	<i>p</i> value
Intercept		3.587	4.684	0.766	0.459	Intercept		6.968	8.653	0.805	0.433
Open landscape	17	-0.013	0.047	-0.279	0.784	Open landscape	17	-0.056	0.089	-0.634	0.536
Forest cover	17	-0.033	0.048	-0.684	0.504	Forest cover	17	-0.044	0.088	-0.501	0.624

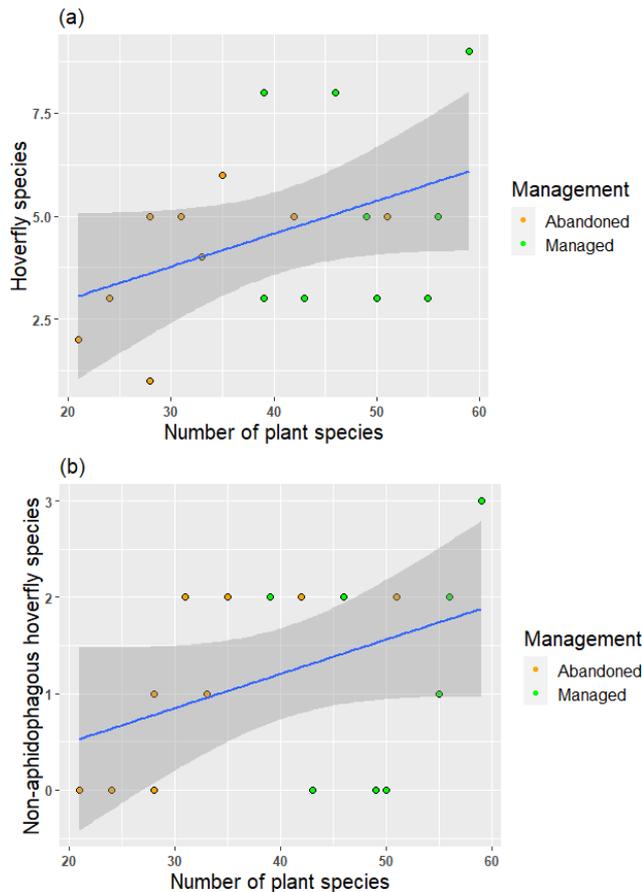


Figure 2. Regression showing (a) the significant relationship between the number of hoverfly species and the number of plant species and (b) the significant relationship between the number of non-aphidophagous species and the number of plant species in managed and abandoned meadows with a 95 % confidence interval.

Six species contributed to more than 75 % of the total individuals. These were *Melanostoma mellinum* (26.3 %), *Sphaerophoria scripta* (14.3 %), *Lapposyrphus lapponicus* (12 %), *Melanostoma scalare* (11.43 %), *Episyrphus balteatus* (7.43 %) and *Syrirta pipiens* (4 %). Five species (*Orthonevra geniculata*, *Parasyrphus annulatus*, *Platycheirus albimanus*, *Rhingia borealis* and *Sphagina sibirica*) were only found in abandoned meadows; all other species were found in both meadow types. Three species which could only be identified to the genus level were not assigned to a feeding type. The total number of hoverfly species and individuals did not significantly differ between management types (GLM: $p = 0.158$ and $p = 0.823$, respectively), and this was also true for the number of aphidophagous and non-aphidophagous species and individuals (GLM: $p = 0.430$ and $p = 0.130$, respectively). The total number of species significantly increased with the increasing number of plant species (Fig. 2a; Table 2). Similarly, the number of non-aphidophagous species increased with the increasing num-

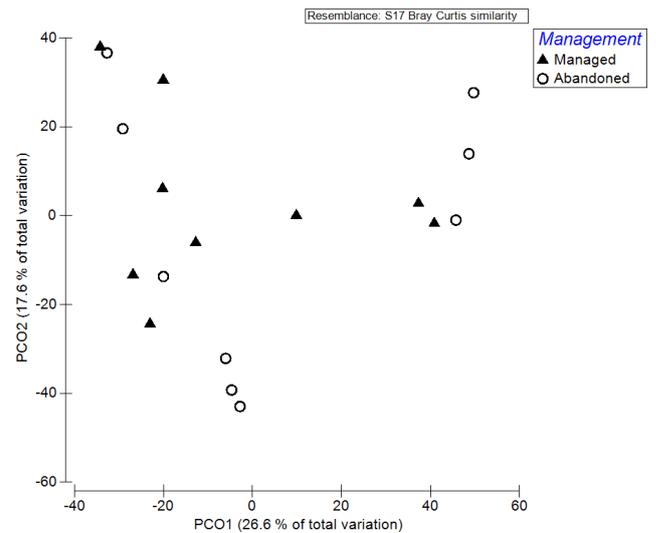


Figure 3. Principal coordinate analysis (PCO) showing hoverfly species composition in managed (▲) and abandoned (○) meadows.

ber of plant species (Fig. 2b; Table 2). All other recorded plant and landscape parameters did not significantly affect the number of species and individuals of syrphids, and they also had no influence on the number of aphidophagous and non-aphidophagous species and individuals (Table 2). Regarding species composition, there was no difference between both meadow types (PERMANOVA: $p = 0.549$), which is also graphically represented in the principal coordinate analysis (PCO) (Fig. 3). Regarding plant parameters, the number of vascular plant species was significantly higher in mown meadows (ANOVA: $F = 16.31$ and $p < 0.001$). Flower cover and vegetation cover were higher in mown compared to abandoned meadows (ANOVA: $F = 34.3$ and $p < 0.001$; $F = 6.52$ and $p = 0.020$, respectively). A species list of identified plant species in the three study regions is attached in the Supplement (Table S3).

4 Discussion

With 46 individuals, *Melanostoma mellinum* was by far the most abundant hoverfly species in the present study. Furthermore, a higher abundance was made up of the eurytopic species *Sphaerophoria scripta*, *Lapposyrphus lapponicus* and *Melanostoma scalare*. These species are highly migratory, which can lead to a higher abundance in favorable years (Röder, 1990; Speight, 2014).

Regarding the total number of species and individuals, we found no differences between both meadow types. Considering the habitat requirements, most of the observed hoverfly species were eurytopic habitat generalists which use a variety of different habitats (Röder, 1990; Speight, 2014), and it can be assumed that both meadow types fulfilled hoverfly needs by providing similar resources and facilitating suit-

able microhabitats for their development. The most important factors which a habitat should provide for hoverflies are the availability of suitable floral resources (Hennig and Ghazoul, 2012; Moquet et al., 2018) and the presence of diverse larval habitats (Jauker et al., 2009; Weiner et al., 2014). Similar to the total number of species and abundance, the number of hoverfly species and individuals belonging to the aphidophagous and non-aphidophagous feeding guilds did not differ between meadow types. Especially the abundance of aphidophagous hoverflies is mainly determined by the presence of suitable aphid hosts (Almohamad et al., 2009). There is a very important contribution by Kök et al. (2020) which focused on the tritrophic relationships between plants, aphids and hoverflies. They found that plant species host different aphid species which in turn are a suitable prey for the larvae of aphidophagous hoverfly species like *Sphaerophoria scripta* and *Episyrphus balteatus*. This suggests that the choice of the habitats is mainly driven by these relationships.

Consistent with the lack of differences of species richness and abundance, we found a similar species composition in both meadow types. Only five species were confined to abandoned meadows and all other species were found in both meadow types. In contrast to, for example, bumblebees who have to provide pollen for their offspring, adult hoverflies are highly mobile, free in their dispersal (Meyer et al., 2009; Sutherland et al., 2001) and able to track suitable flower resources among a wide range of habitats (Jauker et al., 2009; Meyer et al., 2017).

The diversity of vascular plants turned out to be an important factor for hoverflies. Both the number of total hoverfly species and the number of non-aphidophagous species increased with an increasing plant richness. This indicates that a high variety of plant resources is most beneficial in maintaining hoverfly diversity in these grasslands (e.g., Meyer et al., 2009). The status of a high plant richness can only be preserved through regular extensive management. Grassland abandonment results in a decrease in plant richness (Pykälä et al., 2005) and consequently would have negative effects on hoverfly richness.

Surprisingly, we found no relationship between hoverflies and flower cover, contradicting the results of other studies (Meyer et al., 2009; Frank, 1999; Fründ et al., 2010; Power et al., 2016). However, our results are in line with those of Hussain et al. (2017) who reported that flower cover had no effect on syrphid richness and abundance. They mainly attributed this result to the presence of more flowers which have a deep, non-accessible corolla (e.g., *Salvia pratensis* and *Rhinanthus minor*), which is presumably also a good explanation for the findings in our study. For example, only a few syrphid species from the genus *Rhingia* developed specialized mouth parts to access the hidden nectar (Speight, 2014). However, with the exception of *Rhingia borealis*, these species were absent in our meadows. Another explanation for the missing relationship between flowers and hoverflies could be that hoverflies

also feed on the honeydew from aphids that can be unrelated to the abundance of suitable flowers (van Rijn et al., 2013).

5 Conclusion

Although there was no overall effect of abandonment on syrphid richness, abundance and composition in the present study, plant richness turned out to be an important determinant for syrphid diversity in the investigated meadows, confirming also the results of other studies (e.g., Meyer et al., 2009; Hussain et al., 2017). In turn, this high plant richness can only be maintained by a regular extensive management. However, abandoned meadows also have the potential to contribute to a high hoverfly diversity in mountainous grasslands since some species were only found in abandoned meadows. Our results suggest that the maintenance of a heterogeneous landscape containing both regularly mown and abandoned meadows is most beneficial for the conservation of hoverfly diversity in mountainous grasslands.

Data availability. The data used in this study are provided in the Supplement.

Supplement. The supplement related to this article is available online at: <https://doi.org/10.5194/we-20-143-2020-supplement>.

Author contributions. RW conducted field work, analyzed the data and wrote the paper. RIH and DB sampled and identified collected syrphids. RIH contributed hoverfly data from central Ennstal, and JK and AB recorded plant parameters. AA, JGZ and TF were the project leaders who designed and developed the “Healthy Alps” project. All authors reviewed the paper.

Competing interests. The authors declare that they have no conflict of interest.

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