


Mulching time of forest meadows influences insect diversity

Maria M. Georgi^{1,2}  | Stefanie M. Gärtner³ | Marc I. Förchler³ | Jörn Buse³ |
Felix Fornoff¹  | Axel Ssymank⁴ | Yvonne Oelmann⁵ | Alexandra-Maria Klein¹

¹University of Freiburg, Chair of Nature Conservation and Landscape Ecology, Freiburg, Germany

²Department of Forest Nature Conservation, Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg, Freiburg, Germany

³Department of Ecological Monitoring, Research and Species Conservation, Black Forest National Park, Freudenstadt, Germany

⁴Federal Agency for Nature Conservation (BfN), Bonn, Germany

⁵Geocology, University of Tübingen, Tübingen, Germany

Correspondence

Maria M. Georgi, Alpersbacherstraße 6, 79856 Hinterzarten, Germany.
Email: maria.georgi@posteo.de

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Abstract

1. The diversity in meadows is affected by numerous aspects, such as the amount and type of fertilisation and the timing and frequency of cutting. The effects of mowing on the diversity of plants and insects have been studied in detail. However, the effect of mulching (vegetation is cut, shredded, and left in place, instead of being removed) on insects in small forest meadows has received limited scrutiny to date.
2. In this study, we examined how different mulching times influenced insect diversity of forest meadows. We sampled insect larvae and observed flower-visiting insects at 24 sites in the Northern Black Forest in south-west Germany. We applied four treatments with six replicates each: (i) mulching in June, (ii) mulching in September, (iii) mulching in June and September, and (iv) no mulching as a control.
3. The overall larval community was dominated by Symphyta (45%, Hymenoptera) and Lepidoptera (44%). The flower-visiting insect community was dominated by Syrphidae (80%, Diptera).
4. The insect larvae were negatively influenced by all mulching treatments. The abundance and species richness of flower visitors was reduced by mulching in June only and by mulching in both June and September.
5. Summary: Given that meadow management is required for conserving grassland diversity our results indicate that for insect larvae other mulching methods, than those we tested, such as mulching with an arthropod-friendly mulching machine, strip-mulching, or delayed mulching may help this crucial stage of insect development. For insect flower visitors mulching in September is beneficial.

KEYWORDS

flower-visiting insects, forest meadows, grassland management, herbivorous larvae, insect conservation, species diversity

INTRODUCTION

The diversity in meadows is affected by numerous aspects, such as the amount and type of fertilisation and the timing and frequency of cutting (Schuch et al., 2012; Simons et al., 2015). Low-intensity grassland management leads to a higher biodiversity (Marriott et al., 2004;

Weiner et al., 2011). During recent decades, management intensity (e.g., increased fertilisation and cutting frequency) has increased and the area of low intensity managed grasslands has steadily declined throughout Europe (Bundesamt für Naturschutz (BfN), 2014; Dengler et al., 2014; Immoor et al., 2017; Schuch et al., 2012). However, species-rich grasslands are important for the conservation of plant

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(Pärtel et al., 1996) and insect diversity (Ebeling et al., 2018; Knops et al., 1999). Flower-visiting insects are in decline, among other reasons, due to intensified land use at the local and landscape scale (Biesmeijer et al., 2006; Hallmann et al., 2021; Potts et al., 2010). The severity of insect decline increases with management intensity and decreases with the proportion of semi-natural habitat in the surrounding landscape (Seibold et al., 2019).

Across ecosystems, surrounding landscape, is known to affect local insect communities (Gámez-Virués et al., 2015) and also meadow insects. For example, Orthoptera and butterfly diversity is increased when woody vegetation or unmown meadows are part of the surrounding landscape (Marini et al., 2009). Forest-dominated landscapes offer large natural or semi-natural habitats including meadows where the land-use intensity is low (Brand et al., 2018). A frequent type of forest meadows is small forest clearings maintained for game animal grazing, which are commonly referred to as game meadows. Forest meadows are managed with low intensity and occur frequently in the forests of Central Europe (Brand et al., 2018; Petrak, 2003; Tomić et al., 2010). In Germany, since the end of the 19th century (Völk, 1999) forest meadows are often established by foresters to reduce browsing pressure on tree seedlings and saplings in managed forests (Petrak, 2003; Tomić et al., 2010; Türcke, 1955).

The biodiversity of forest meadows has rarely been investigated, especially not their conservation value for insects and only a few studies about forest meadows have been published at all (Aboling, 2003; Buse et al., 2018; Petrak, 2003; Petrak et al., 2015; Tomić et al., 2010). Forest meadows may contain a distinct insect assemblage, made up of forest- and open land-dwelling species, as microclimate influences insects (Herrera, 1995) and insect groups are distributed differently over the landscape (Jauker et al., 2009). Due to the low management intensity and high habitat heterogeneity, high insect conservation value may be assigned to such forest meadows.

Forest meadows are often managed for the purpose of luring game animals, hence, they are sometimes sown with seed mixtures that are tailored to provide food for the specific game animals (Ueckermann & Scholz, 1970). To prevent forest succession and maintain the preferred vegetation for the game animals, meadow management is important (Ueckermann & Scholz, 1970). Suitable management options for maintaining diverse meadows include low-intensity mowing regimes (vegetation cut and removed), grazing by livestock, or prescribed burning (Schreiber et al., 2013). However, mowing, grazing by livestock or prescribed burning are sometimes difficult to implement in small and isolated forest meadows. Mulching (vegetation cut without removal of the cuttings) is a labour- and cost-effective management option for grasslands in general (Doležal et al., 2011; Gaisler et al., 2013; Schreiber et al., 2013). It is labour- and cost-effective, as only the mulching machine and no other equipment are needed. Since, the cuttings remain on the meadow, it does not have to be taken care of afterwards (Schreiber et al., 2013). Mulching can be done in different ways (Moog et al., 2002). The difference is, that either the cuttings are shredded during the process (Oelmann et al., 2017; Pavlů et al., 2016; Schreiber et al., 2013) or the meadows are only cut and the cuttings are left on site without

shredding (Bakker, 1989). The shredding promotes the quick decomposition of the cuttings and therefore is advantageous for the conservation of plant diversity (Schreiber et al., 2013).

Although mulching is a common practice in agriculture (Doležal et al., 2011), the scientific literature mainly focuses on the influences of mulching on vegetation (Bornholdt et al., 1997; Brauckmann, 2013; Doležal et al., 2011; Gaisler et al., 2013; Moog et al., 2002; Schreiber et al., 2013). However, the cutting, its timing and the mechanical shredding of the plant biomass also influence insects during and after mulching. It was shown that some arthropod species are directly killed in the cutting and shredding process (Humbert et al., 2010). Direct killing might strongly affect immobile larval arthropods associated with the aboveground grassland biomass (Humbert et al., 2010; van Klink et al., 2019), while migration is more likely for the more mobile adult arthropods (Achtziger et al., 1999; Thorbek & Bilde, 2004).

In this study, we evaluated the influence of mulching on herbivorous insect larvae and flower-visiting insects in forest meadows. Although all insects have a species specific phenology, the caterpillar density peaks at the start and end of the growing season (Holmes et al., 1979) while for mobile imago stages the peak of species richness, was shown to be between June and August (Evans & Murdoh, 1968; Földesi & Kovács-Hostyánszki, 2014). Therefore, the careful timing of mulching should lower the severity of negative influences on insect abundance and species richness. We expected larvae abundance and species richness to be highest at the beginning and the end of the growing period and flower visitor abundance and species richness to decrease after the peak of the growing period. Therefore, we also hypothesise that herbivorous insect larvae abundance and species richness will decrease in all tested mulching treatments, whereas the flower visitor abundance and species richness will decrease both by mulching in June or twice a year compared to the control (no mulching).

MATERIALS AND METHODS

Study area and meadow selection

The study area is located within the Black Forest National Park (Baden-Württemberg, Germany), which was established in 2014. The annual precipitation ranges between 1400 and 2200 mm making it one of the highest precipitation regions of Germany (DWD, 2019), the annual mean air temperature ranges between 5 and 7°C (Landesanstalt für Umwelt Baden-Württemberg (LUBW), 2006) and days with a maximum temperature of >25°C occur 5–15 times a year (Landesanstalt für Umwelt Baden-Württemberg (LUBW), 2006). The cool temperatures result in a short growing season.

The forest meadows in the park were used by hunters, for example, to improve grazing opportunities for game animals and for hunting red and roe deer (Tschöpe et al., 2017–2018). In the past the meadow management methods varied (from mowing to mulching and no fertilisation to low fertilisation) (Tschöpe et al., 2017–2018). Since the establishment of the national park the 24 examined forest meadows

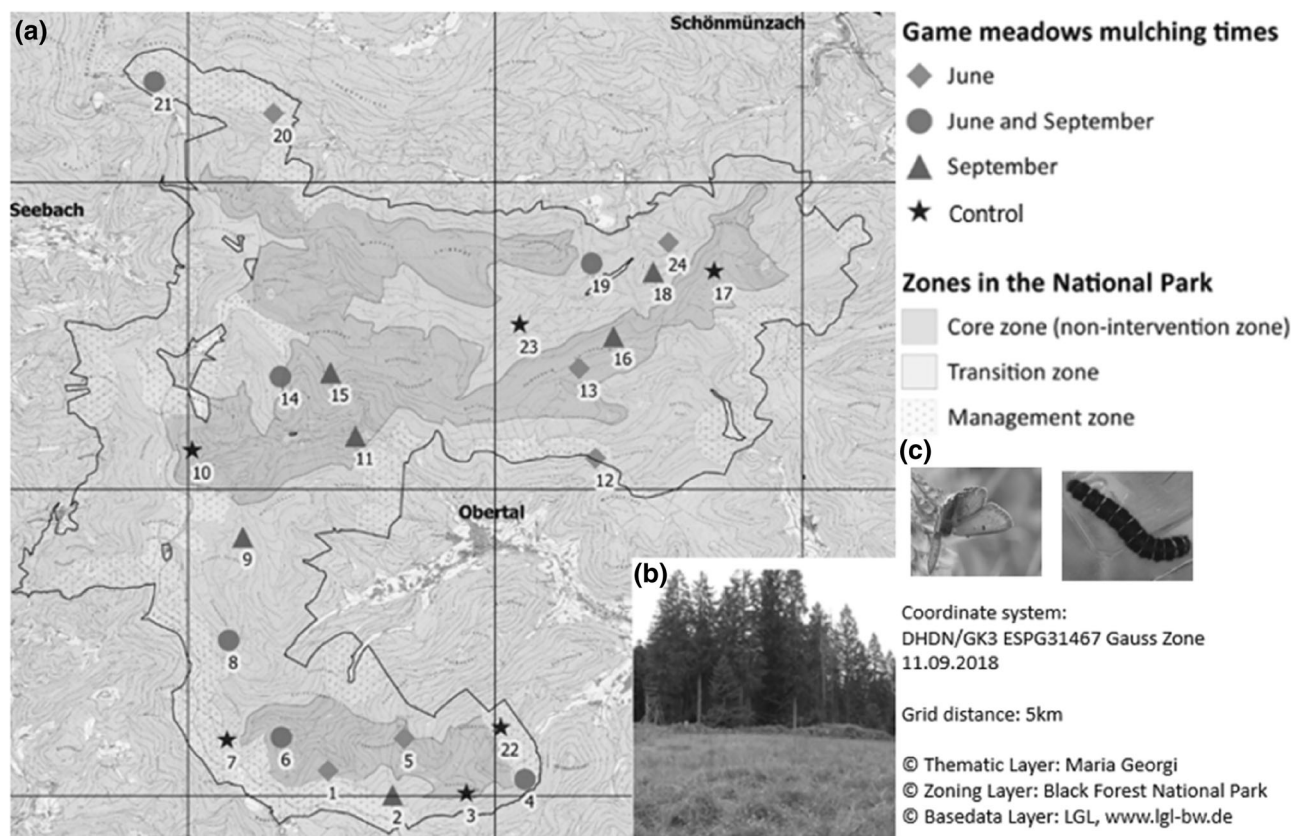


FIGURE 1 (a) The 24 examined forest meadows, spread over the Black Forest National Park. (b) A typical forest meadow in the study area. (c) The observed and collected insect groups (herbivorous insect larvae and flower visitors).

have been mulched once a year in June and no fertilisation has taken place (Tschöpe et al., 2017–2018).

The 24 selected meadows (Figure 1a), are each surrounded by coniferous forest (dominated by spruce, *Picea abies*), which was managed for timber production prior to 2014 (Figure 1b) (Förschler, 2015). The selection of the forest meadows was based on the following criteria: (1) The forest meadows must be evenly distributed over the area (because they are part of a long-term monitoring program within the Black Forest National Park), (2) that the distance between the selected meadows be as great as possible using q-GIS (the mean minimum distance is 1112 m (± 401 m)), (3) that the slope of the meadows be as flat as possible, and (4) that all meadows are nearly the same size and elevation and that each meadow is surrounded by forest.

To test the influence of mulching time and no mulching (control) on insects, we applied four different treatments. Out of 24 meadows (i) six meadows were mulched in June, (ii) six meadows were mulched in September, (iii) six meadows were mulched once in June and once in September and (iv) six meadows were not treated (control). The mulching was done within the first 5 days of each month during dry weather, between 10 am and 6 pm. A Fendt mulching machine (Marktoberdorf, Germany) was used, which cuts, shreds, and deposits the cut biomass on the meadow. In our study, mulching means to cut, shred and leave the grass on site (Schreiber et al., 2013).

Vegetation survey

To determine the plant species richness, of all plants in each meadow, (Supplement S1) three plots were laid out starting at the forest edge to the centre of the meadow. Each plot was sampled with a frequency frame (Kent & Coker, 1992) called the 'subplot-frequency method' (Goldsmith & Harrison, 1976). A frame (1 m by 1 m) subdivided into 100 internal fields was used to assess each species and its occurrence frequency within a plot. The transect started at the midpoint of the shortest meadow-forest border side and ran to the meadow centre. Plant data collection took place between: June and September 2016, June and September 2017 and June and August 2018. A schematic of the transect can be seen in Supplement S2A. The literature used for species identification and nomenclature is given in Supplement S3.

Herbivorous larvae survey

In all 24 meadows herbivorous insect larvae were collected within three sampling periods: (1) before the first mulching (May to June), (2) after the first mulching (July to August) and (3) after the second mulching (September to October). Sampling took place within 14 days after mulching treatments in 2017.

We visually inspected all aboveground plant parts for the presence of insect larvae within a 60 cm wide and 25 m long georeferenced transect for a period of 60 min. The larvae were collected for rearing and the respective food plant was identified to the species. To see a schematic of the transect see Supplement S2B. The transect positioning was the same as for the vegetation survey (see above).

The larvae were reared in plastic boxes on their respective host plants. For the diapause, larvae were stored at 3–4°C in a refrigerator from October to February. The imagines were identified to species level or grouped into morphospecies. Reference insects were stored in the collection of the Black Forest National Park. The literature used for species identification and nomenclature is given in Supplement S3.

Flower-visiting insect observations

For our flower visitor survey, we used the observation plot method (Hussain et al., 2018). To account for the potential variability within the meadows, we sampled insects at five 2 m² plots (geo-referenced) along a 25 m transect. Each plot was observed for 10 min in each sampling period, resulting in 150 min of observation time total (5 plots × 10 min × 3 sampling periods) for each of the 24 forest meadows. Insect sampling was conducted between 10 am and 6 pm on sunny days with no cloud cover, no wind and a temperature above 18°C in 2017. The location of the transect and the sampling periods were the same as for insect larvae (see above).

We recorded each insect-flower interaction. Insects were identified in the field or collected and identified after preparation. Some Diptera and Heteroptera could not be identified and were grouped into morphospecies. All flowering plant species were identified to the species level. Reference insects were stored in the collection of the Black Forest National Park. The literature used for species identification and nomenclature is given in Supplement S3. For a schematic of the transect see Supplement S2B.

Statistical analyses

We aggregated the larvae and flower visitor data of each meadow and calculated the abundance and species richness for each of the three sampling periods and each meadow separately (3 sampling periods × 24 meadows = 72 data points) (package ‘stats’ (R Core Team, 2002)). To account for the low insect species saturation of about 68% (Supplement S4), we used the ‘vegan’ rarefy function, which calculates the expected species richness in random subsamples from the community (expected species richness = rSR ; hereafter referred to as species richness) (Oksanen et al., 2018).

Generalised linear mixed models (GLMM) and linear mixed models (LMM) were used to test the influence of mulching time, sampling period and plant species richness on larvae and flower visitor abundance and species richness. An interaction between mulching time and sampling period was included in the model to account for the three sampling periods and the resulting before and after sampling

design. As random effect, sampling site (meadow number) was used, to account for environmental differences on the meadow level (Equation 1).

$$\text{model}_x \leq (\text{dependent variable} \sim \text{mulching time} \times \text{sampling period} + \text{plant species richness} + (1|\text{meadow}), \text{data}). \quad (1)$$

We applied GLMMs with Poisson distribution to the count data (=the abundance data) and LMMs to the rarefied species richness data. For GLMMs and LMMs we used the package ‘lme4’ (Bates et al., 2018). Before the models were built, we tested for correlations among the explanatory variables. We included only explanatory variables with $|r_{\text{spearman}}| < 0.7$ in our models (Dormann et al., 2013) or (for categorical variables) with a p value > 0.05 (Chi²-test) (package ‘stats’ (R Core Team, 2002)). Residual normality and dispersion were tested using the package ‘DHARMa’ (Hartig, 2017) and an observation level random effect (olre) was used, to account for overdispersion if needed. All statistical analyses were performed in R, version 3.6.2 (R Core Team, 2019).

RESULTS

Plant species richness

The meadow plant species richness was 38.7 ± 7.9 , which was comparable between our four tested treatments and had no influence on the abundance and species richness of insect larvae and flower visitors.

Herbivorous larvae

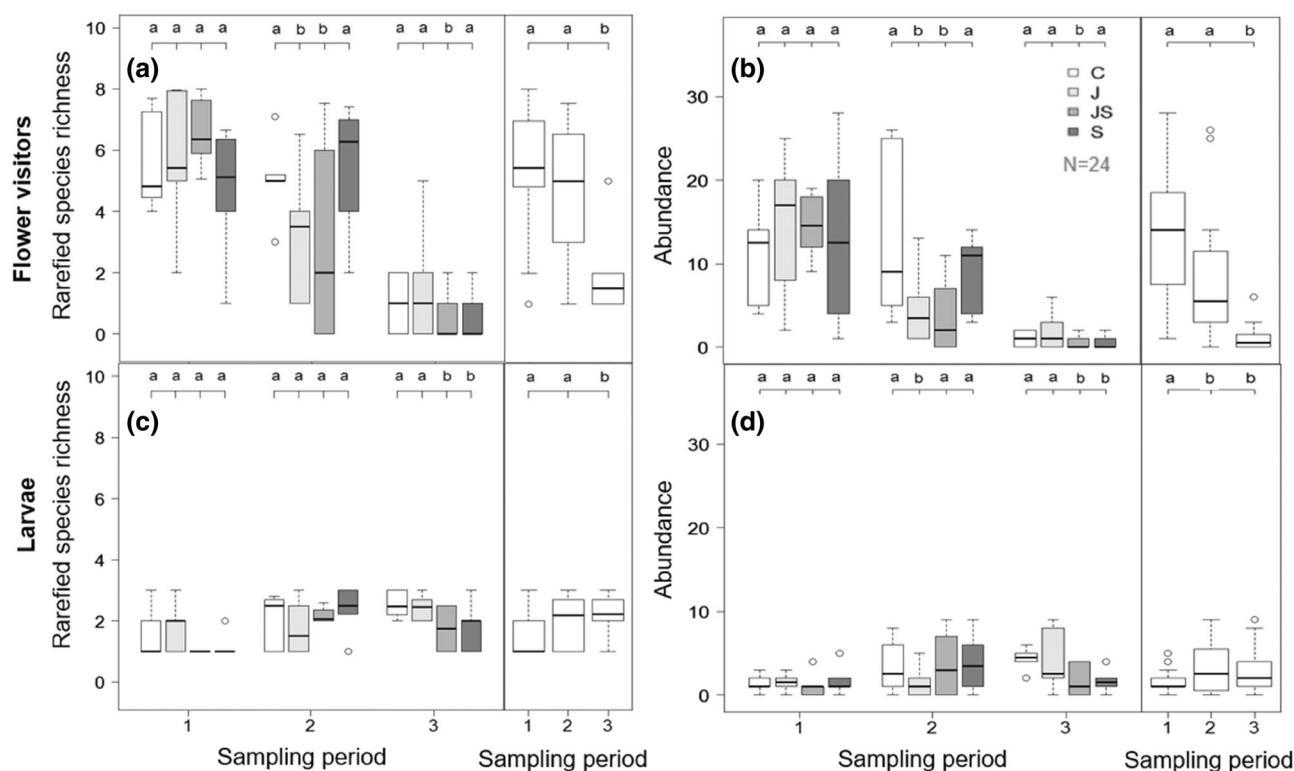
We observed 174 larvae of Symphyta (45.4%), Lepidoptera (44.3%) and Coleoptera (7.5%). Out of the 174 larvae, we determined 44 larvae individuals to species level, all others to morphospecies. The most abundant larvae were *Dolerus* spec. (Symphyta) with 28.6% and *Protodeltote pygarga* (Lepidoptera) with 16.1%. We identified 69.5% of all host plants to species level (Supplement S5). Thirty-four out of the 174 larvae hatched and 18 of them were parasitised. The parasitoids were from the insect groups Ichneumonidae (7 individuals), Diptera (7 individuals), Braconidae (3 individuals), and Chalcididae (1 individual). For the interactions between larvae and plants and for the larvae species, see Supplements S5 and S6. None of the insect larvae and food plants were red-listed species according to the Red Lists of Germany (Liston et al., 2011; Metzger et al., 2018; Reinhardt & Bolz, 2011).

Flower-visiting insects

In total, we observed 527 flower visitor interactions in which Syrphidae (81.1%) and Hymenoptera (9.6% of flower visits) were most

TABLE 1 Model information about the abundance and species richness of larvae and flower visitors during the growing period.

| Model | Estimate | SE | t value (LMM) Z value (GLMM) | p value |
|--|----------|------|------------------------------|---------|
| Larvae | | | | |
| GLMM, abundance, second sampling period | 0.90 | 0.25 | 3.64 | <0.01 |
| GLMM, abundance, third sampling period | 1.19 | 0.24 | 4.97 | <0.01 |
| LMM, species richness, third sampling period | 1.19 | 0.24 | 4.95 | <0.01 |
| Flower visitors | | | | |
| LMM, species richness | −4.50 | 0.48 | −9.42 | <0.01 |
| GLMM, abundance | −2.48 | 0.28 | −8.75 | <0.01 |

**FIGURE 2** (a, left side) Flower visitor species richness vs. the sampling period compared to the control. (a, right side) Flower visitor species richness over the growing period summarised over all 24 meadows. Sampling period 2 and 3 are compared to sampling period 1. (b) same as (a) but for the flower visitor abundance. (c, d) same as (a, b) but for the insect larvae. The error bars represent a distance of 1.5 times the interquartile range (=default of the boxplot () function in R). C, Control; J, mulching in June; JS, mulching in June and September, S, mulching in September.

abundant. Other insect groups contributed less than 5%: Coleoptera (3.7%), Diptera other than Syrphidae (3.4%), Lepidoptera (1.9%), and Heteroptera (0.4% of flower visits). We determined 78% of all flower visitors to the species level and the remaining to morphospecies. We found 44 species of Syrphidae, 22 species of Apiformes, 14 species of Coleoptera and five Lepidoptera species, two species and three morphospecies of Diptera and two morphospecies of Heteroptera. The most abundant flower-visiting insect species were *Platycheirus albimanus* (15%), *Apis mellifera* (12.5%), *Episyrphus balteatus* (4.6%) and *Lapposyrphus lapponicus* (4.6%). We found five flower visitor species with the German Red List status vulnerable (status 3) and three flower visitors with the Red List status near threatened. The insects interacted

with 62 flowering plant species (Supplement S6 and S7). Seven of them are near threatened and one is vulnerable according to the Red List for plants in Germany (Metzing et al., 2018).

Abundance and species richness of larvae and flower visitors during the growing period

The flower-visiting insects at all 24 meadows dominated the first sampling period (91.5%) and the second sampling period (71.1%) compared to the insect larvae. In the third sampling period, only 24.7% of the observed insects were flower visitors and the insect larvae were

TABLE 2 Model information about the influence of mulching on the abundance and species richness of insect larvae and flower visitors.

| Model | Estimate | SE | t value (LMM) Z value (GLMM) | p value |
|---|----------|------|------------------------------|---------|
| Larvae | | | | |
| GLMM, mulching in June, abundance, second sampling period | −0.90 | 0.37 | −2.43 | 0.02 |
| GLMM, mulching twice, abundance, third sampling period | −0.85 | 0.38 | −2.25 | 0.02 |
| GLMM, mulching in September, abundance, third sampling period | −1.19 | 0.36 | −3.36 | <0.01 |
| LMM, mulching twice, species richness, third sampling period | −0.69 | 0.34 | −2.03 | 0.04 |
| LMM, mulching in September, species richness, third sampling period | −0.69 | 0.34 | −2.03 | 0.04 |
| Flower visitors | | | | |
| GLMM, mulching in June, abundance, second sampling period | −1.27 | 0.26 | −4.86 | <0.01 |
| GLMM, mulching twice, abundance, second sampling period | −1.60 | 0.27 | −6.00 | <0.01 |
| GLMM, mulching twice, abundance, third sampling period | −0.96 | 0.46 | −2.09 | 0.04 |
| LMM, mulching in June, species richness, second sampling period | −1.92 | 0.68 | −2.83 | 0.01 |
| LMM, mulching twice, species richness, second sampling period | −3.17 | 0.68 | −4.69 | 0.01 |
| LMM, mulching twice, species richness, third sampling period | −1.54 | 0.68 | −2.28 | 0.02 |

dominant compared to the flower visitors. The models showed that at all 24 meadows the larvae abundance was significantly higher in the second and third sampling period compared to the first sampling period and the species richness of the larvae was significantly higher in the third sampling period compared to the first one. In contrast, the flower visitor abundance and species richness were reduced in the third sampling period compared to the first (Table 1).

Influence of the mulching on larvae and flower visitor abundance and species richness

For insect larvae the abundance was reduced in the second sampling period if mulching took place in June and in the third sampling period if mulching took place twice a year or in September compared to the control. Mulching twice or mulching in September reduced the species richness in the third sampling period compared to the control. (Figure 2, Table 2).

Mulching in June reduced the abundance and species richness of the flower visitors in the second sampling period compared to the control. In the second and third sampling period, mulching two times reduced the abundance and species richness of flower visitors compared to the control. For flower visitors, no influence of mulching in September was found compared to the control (Table 2).

DISCUSSION

Our results showed that the insect larvae were negatively influenced by all mulching treatments we tested compared to the control. They also showed a detrimental influence of mulching in June (alone or in combination with mulching in September) on flower visitors. Besides these management effects, phenology and seasonality also played a role, as in the third sampling period (September/October) the

abundance and species richness of larvae were higher and the abundance and species richness of flower visitors were lower compared to the first sampling period (May/June). While increased larvae abundance and richness at the third sampling period indicates that eggs are being deposited after the vegetation has regrown, a decline in flower visitors points to the end of the flowering period. Our results also show that forest meadows are important for flower visitors and herbivorous larvae as feeding resources. In terms of management recommendations, for herbivorous insect larvae, we reference the literature. That using arthropod-friendly machines (Steidle et al., 2022), strip-mulching (Humbert et al., 2009) and varying the mulching time to something other than we tested (e.g., July) (van Klink et al., 2019), may protect herbivore insect larvae. For conserving flower visitors, we can recommend mulching in September.

Plant species richness

While mulching had an influence on insect larvae attached to vegetation and to flower visitors, plant species richness did not. This can be explained by the high plant species richness in the examined forest meadows (38.7 ± 7.9 plant species) and that the species richness on our 24 meadows was comparable between our treatments and thereby there was no numerical gradient which could have had an influence on the abundance and species richness of insect larvae and flower visitors.

Insect larvae

The most abundant larvae were *Dolerus* spec. (Symphyta) with 28.6% and *Protodeltote pygarga* (Lepidoptera) with 16.1%. This is a moth common to open forests or open shrubby landscapes (Steiner, 2014). In general, the larval species composition included a broad assemblage

of insect species involving species typical of forests, light forests, forest edges and open grasslands (Steiner, 2014). None of the insect larvae nor their food plants were red-listed species according to the Red Lists of Germany (Liston et al., 2011; Metzger et al., 2018; Reinhardt & Bolz, 2011). However, this could be because we were not able to identify all insect larvae to the species level. That the insect larvae attached to the meadow plants were influenced by all mulching treatments does not come as a surprise given that they are more immobile than imagines (Achtziger et al., 1999) and thus, have a higher risk of being killed by grassland management (Humbert et al., 2010; van Klink et al., 2019). Although we only collected herbivorous insect larvae, remarkably 18 of our insect larvae were parasitised by four different groups of parasitoids. Research about land use intensity (fertilisation and mowing vs. grazing) and its influence at multi-trophic levels shows that all trophic levels are influenced by different management intensities (Herbst et al., 2013). This suggests that protecting the herbivorous insect larvae also indirectly protects species that parasitise them. Some insect larvae seem to be able to escape the mulching treatment by dropping to the ground, as suggested previously (Myers & Campbell, 1976) but that seems not to prevent a decrease of abundance and species richness by mulching. Nevertheless, the relatively low abundance and species richness of insect larvae from mid-May to the beginning of June compared to our second and third sampling period indicates that most of the insect larvae had already emerged as imagines before mulching in June. Therefore, one could argue that mulching in June would be better for insect larvae than mulching in September. Yet, an improved conservation strategy having no negative effect on insect larvae should be a goal. Mulching with an arthropod-friendly machine and strip-mulching may help to further protect grassland insect larvae. An arthropod-friendly mowing machine already exists (Steidle et al., 2022). The arthropod-friendly mowing machine uses a special mowing head which flushes the insects sitting in the grass ahead of it, allowing them to escape. It functions by picking up the cuttings using a special air flow from above and has a cutting height above 10 cm. For Araneae, Cicadina, Heteroptera, Lepidoptera and larvae of holometabolous insects, the use of the arthropod-friendly mowing head prevented the losses that would be incurred using a conventional mowing head. For Hymenoptera, the losses declined by 15% and for Diptera the losses were reduced by 25% compared to a conventional mowing head (Steidle et al., 2022). As mowing small, isolated forest meadows can be difficult, it may be possible to develop this kind of cutter head for use with a mulching machine in the future. Mulching in strips (leaving parts unmown), according to other studies is another way to conserve insect diversity in grasslands (Hoste-Danyłow et al., 2010; Humbert et al., 2009). However, the plant perspective would need further investigation, as Schreiber et al. (2013) showed that mulching only every second year can reduce plant species diversity and change the species assemblage towards grasses. A third option to protect herbivorous insect larvae from harm by mulching might be by scheduling mulching somewhere in between our two tested mulching times, as van Klink et al. (2019) showed that mowing in July had a favourable effect on the following year's abundance of sawfly larvae. Whether

these results are transferrable to mulching could be a goal of future research projects.

Interestingly, the larvae collected on the meadows were mainly other species than the flower visitors observed. Only *Maniola jurtina* was found as larvae and as flower-visiting imago. Apparently, the flower visitor insect larvae already emerged as imagines before mid-May and were of species that either overwintered as imagines or else had their larval stages within the forest. Such a strategy is typical for hoverflies (van Veen, 2010). However, our flower visitor sampling did not include the trapping of night active moths, and our larvae sampling did not include the trapping of ground-nesting bees or ground-dwelling beetles. Additionally, we may have overlooked the difficult to spot hoverfly larvae dwelling in plant stems (Kormann, 2002). Nevertheless, we expected at least the flower-visiting sawflies, and butterflies to be similar in the larvae and adult stage. An explanation could be due to the different phenologies of the flower visitor and herbivorous insect larvae community we observed. Perhaps the flower visitor community on forest meadows consists of early hatching insects and the larvae community we observed of late hatching insects. To shed light into this, the observation and sampling period should start earlier than mid-May in future studies. In order to preserve insect groups with different phenologies, mulching times should be adjusted to insect larvae phenology.

Flower visiting insects

The flower-visiting insect community in forest meadows in the Black Forest was dominated by hoverflies (Syrphidae). Several studies showed that forest-dominated landscapes (Kanstrup & Olesen, 2000; Ssymank, 1991) or habitats at higher elevations show higher Syrphid abundance (Kanstrup & Olesen, 2000; Keil & Konvicka, 2005). This finding is different from that found in open landscapes where the pollinator community is often dominated by bees (Jauker et al., 2009; Woodcock et al., 2014). Furthermore, our results show that forest meadows contain a specific flower visitor species assemblage including species typical of forests, forest edges, light forests, open grasslands and red-listed species (Kormann, 2002; Steiner, 2014; van Veen, 2010; Westrich, 1996; Westrich et al., 2011). As one of the three most abundant flower visitors in our samples, *Platycheirus albi-manus*, is a common Syrphid which depends on grass and herbaceous vegetation with aphidophagous larvae (van Veen, 2010). *Episyrphus balteatus* is also a common Syrphid and the larvae of this species feed on aphids or Symphyta larvae (Kormann, 2002). *E. balteatus* lives in a broad range of habitats (van Veen, 2010). *Lapposyrphus lapponicus* is a species of open landscapes (Kormann, 2002). *Chrysogaster cernitorum*, a hoverfly with the Red List status vulnerable (3) lives close to forest edges (Kormann, 2002). Besides hoverflies, bumblebees are adapted to a colder climate (Heinrich, 1975) and are commonly observed at higher elevations (Benadi et al., 2014; Pradervand et al., 2014). The underrepresentation of bumblebees in our study may indicate a shortage of flower resources to support bumblebee colonies (Carvell et al., 2012). Nevertheless, we found *Bombus humilis*,

a bumblebee species with the Red List status vulnerable (3) (Westrich et al., 2011). This species can be found in habitats ranging from forest edges to open landscapes (Westrich, 1996).

The flower visitor abundance and species richness were reduced after either mulching in June or two times a year and over the growing period, the abundance and species richness of flower visitors was reduced in September compared to May and June. This means that due to their phenology, the flower visitors on forest meadows were more vulnerable early in the growing period. A loss of resources (Cizek et al., 2012) during that vulnerable time, induced by cutting, might lead to the migration or death (Thorbek & Bilde, 2004) of flower visitors. Therefore, for flower visitors, mulching in September is more favourable.

For plants, long-term mulching studies focusing on maximising plant diversity, have shown that mulching once early in summer or mulching twice, once at the end of June/beginning of July and the second time at the end of August/beginning of September, is favourable for preserving species rich plant communities (Doležal et al., 2011; Gaisler et al., 2013; Schreiber et al., 2013). Our results show that this management regime negatively influences flower visitors, if the early mulching date is chosen. However, mulching late, for example, September, which would be good for flower visitors, can lead to biomass accumulation resulting in negative effects on the vegetation community composition (Moog et al., 2002). As flower visitors rely on diverse flower species (Blaauw & Isaacs, 2014; Fründ et al., 2010) and flowering plants on a diverse and abundant flower visitor community (Albrecht et al., 2012) both management recommendations need to be considered for the long term conservation of meadow plant and insect species.

Outlook

Management is necessary to maintain forest meadows and regardless of the timing schedule, the cutting of plants will always influence the associated insects. As suggested in the introduction, the forest meadows contain a specific insect species assemblage including forest, forest edge, light forest, open grassland, and red-listed species. Therefore, they can contribute to insect conservation and it can be beneficial to keep forest meadows open. The best management strategy targeting biodiversity conservation, should balance vegetation diversity and insect losses. This should always include larvae and imagines insect stages. In conclusion, we suggest mulching in September to preserve flower visitors. However, further studies are required to resolve the trade-offs between management methods for the benefit of plants and insects, especially for insect larvae. For this purpose, the opportunities presented by arthropod-friendly mulching machines, strip-mulching, and mulching at different times (e.g., July) might be promising future research goals.

AUTHOR CONTRIBUTIONS

Maria Georgi: Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead);

methodology (equal); project administration (lead); resources (equal); validation (equal); visualization (lead); writing – original draft (lead); writing – review and editing (equal). **Stefanie Gärtner:** Conceptualization (supporting); funding acquisition (supporting); methodology (supporting); resources (supporting); supervision (supporting); validation (supporting); writing – review and editing (supporting). **Marc Förschler:** Project administration (supporting); resources (supporting); supervision (supporting); validation (supporting); writing – review and editing (supporting). **Jörn Buse:** Resources (supporting); validation (supporting); writing – review and editing (supporting). **Felix Fornoff:** Conceptualization (supporting); formal analysis (supporting); methodology (supporting); validation (supporting); visualization (supporting); writing – review and editing (supporting). **Axel Ssymank:** Investigation (supporting); resources (supporting); validation (supporting); writing – review and editing (supporting). **Yvonne Oelmann:** Conceptualization (supporting); funding acquisition (supporting); methodology (supporting); project administration (supporting); resources (supporting); supervision (supporting); validation (supporting); writing – review and editing (supporting). **Alexandra Klein:** Conceptualization (equal); funding acquisition (supporting); methodology (supporting); project administration (supporting); resources (equal); supervision (lead); validation (supporting); visualization (supporting); writing – review and editing (supporting).

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CONFLICT OF INTEREST STATEMENT

None of the authors declare any conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Maria M. Georgi  <https://orcid.org/0000-0002-1314-2716>

Felix Fornoff  <https://orcid.org/0000-0003-0446-7153>

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1. Supporting Information

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