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Negative impact of roadside mowing on arthropod fauna and its reduction with 'arthropod-friendly' mowing technique

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Abstract

An underestimated factor that contributes to the decline of insects observed during the last year is probably the mortality, which is caused by mowing of grassland. We studied the negative impact of mowing on the arthropod fauna of roadside grassland, which might serve as potential habitat for insects to prevent their local extinction and as corridor for the dispersal in anthropogenic landscapes. In addition, we studied if losses due to mowing can be mitigated by the use of 'arthropod-friendly' mowing technique. In agreement with earlier studies, we found that mowing with a conventional mowing head (MK 1200 from MULAG) caused considerable losses in arthropods, ranging from 29% for Heteroptera over around 50% in Araneae, Cicadina, Hymenoptera and Diptera, up to 73% for holometabolous larvae, and 87% for Lepidoptera. These losses by mowing were fully offset for Araneae, Cicadina, Heteroptera, Lepidoptera and larvae of holometabolous insects when using the mowing head Eco 1200 from MULAG, which was designed to be 'arthropod-friendly'. For Hymenoptera and Diptera, the losses were reduced by 15% and 25% respectively. For Saltatoria and Coleoptera, we did not find any significant differences between all treatments. These data demonstrate that mowing of roadsides with conventional mowing technology has a highly detrimental effect on the grassland arthropod fauna. However, this effect can be offset or at least mitigated by the use of 'arthropod-friendly' mowing technique. Therefore, this technique has a high potential to reduce insect decline in roadside grassland, making these areas a habitat for insects.

KEYWORDS
'arthropod-friendly' mowing, biodiversity crisis, grassland mowing, insect decline

1 | INTRODUCTION

The world has been facing a drastic decline of insects during the past decades (Hallmann et al., 2017; Sánchez-Bayo & Wyckhuys, 2021; Seibold et al., 2019; Wagner et al., 2021). The industrialized agriculture is considered as the most important factor for this decline (Goulson, 2019). In agricultural fields, this is mostly due to the large monocultures causing the loss of habitats and structural diversity (Tscharntke et al., 2021), as well as the intensive use of pesticides (Wood & Goulson, 2017) and fertilizers (Kurze et al., 2018). In grassland, insect biodiversity and biomass is strongly affected by the overall decline of grassland areas in general but also by indirect negative effects based on fertilization and frequent mowing regimes. They both reduce the diversity of insect host plants (Gossner et al., 2016; Müller et al., 2016), the latter also causes thermally hostile environments for insects with excessively high temperatures (Gardiner & Hassall, 2009). An additional, so far underestimated direct reason for decline in grassland is probably insect mortality caused by highly efficient mowing machines (Gossner et al., 2016), which cut the grass and process the mowed material. This includes its pick-up and – in the case of silage production – its wrapping in foil, which directly kills grassland insects (Fluri et al., 2000). So far, there are only few studies on these direct effects of mowing, which report considerable mortality of up to 88% in insects (reviewed by Humbert et al., 2009). For instance, Fluri et al. (2000) calculated losses of up to 90,000 honeybees per ha in a field of *Phacelia tanacetifolia* on a sunny day, which is equivalent to the population size of two honeybee colonies in summer. Considering that grassland is mown up to five times per year and over many years (Niedrist et al., 2009), this might well result in an overfishing effect and lead to a drastic decline of grassland insects.

Currently, it is impossible to predict when or if at all a political framework will be established on national or international levels that will finally result in a more sustainable agriculture to stop insect decline. Therefore, it is paramount to identify and improve potential habitats for insects to prevent their local extinction. For grassland insects, road verges could provide these habitats. Although much more research is required to judge the detrimental effect of nearby roads on the fauna of roadsides, for example their role as barriers and mortality by traffic (Hoiß, 2020; Muñoz et al., 2015), the benefits of roadsides for biodiversity conservation are increasingly discussed (New et al., 2021; Phillips et al., 2020; Reck & Mueller, 2018). They comprise a considerable area of 6,767 km^2 in Germany (equivalent to 1.9% of the total area) (Reck & Mueller, 2018), and 270,000 km^2 worldwide (Phillips et al., 2020), are not used economically and hardly ever treated with insecticides or fertilizers. Therefore, they can provide habitats for plants and animals (Gardiner et al., 2018; Hopwood, 2008; Noordijk et al., 2009) and serve as corridor for the dispersal of organisms in anthropogenic landscapes (Lázaro-Lobo & Ervin, 2019) to promote genetic exchange between isolated populations. However, as with agricultural grassland, mowing has also a detrimental effect on insects along roadsides. Already in 1987, Hemmann et al. (1987) studied the loss of insects by roadside mowing on experimentally released insects and reported mortalities of up to 84% in true bugs and 30% in adult mealworm beetles.

So far, only few attempts have been made to avoid insect losses during mowing by developing alternative technologies. For agricultural grassland, tractor-operated beam mowers are causing less insect damage, while disc mowers, drum mowers and drum mowers with conditioners are increasingly detrimental for arthropods (Humbert et al., 2010; Poel & Zehm, 2014). However, because the latter are much more efficient, can be used at a greater speed, and require less maintenance, they are almost always preferred. We are aware of only one project in which a mechanical structure was mounted in front of a disc mower to scare away insects (Hotz, 2013), analogous to 'flushing bars' used to chase away wild fowl (Klonglan et al., 1959). For mowing of roadside grassland, recent developments of insect-friendly 'eco-mowers' and mowing techniques in Germany have been compiled in Gsell (2020) and Zeitner and Aschauer (2021). They make use of different types of flushing bars, blowing machines to chase insects away, increased mowing heights (>10 cm), modified disc mowing principles providing smaller attack surfaces and reduced suction effects and wheels with decreased contact surfaces. However, to the very best of our knowledge, there are no published studies demonstrating that these technical modifications are in fact reducing insect losses.

Here, we studied the effect of a roadside embankment mower ('Eco 1200 plus' from MULAG Fahrzeugwerk/Heinz Wössner GmbH u. Co. KG) that has been modified in a way that is expected to significantly reduce insect mortality. We compared it with a conventional flail mulching head with MS blades that is also mulching the cut grass and leaves the mowed material in place, thereby increasing the nutrient content of the site ('MK 1200' also from MULAG). Among others, the insect-friendly mowing head Eco 1200 features the following innovations (Mulag, 2021): (i) The mowing disc has a smaller contact surface with the grass, (ii) the mower has an increased mowing height of >10 cm, (iii) sucking up of insects into the mowing head is presumably prevented by the facts that the underside is largely closed and that no vertical airflow is generated from below, (iv) the contact area of the wheels is reduced which should prevent damage to insects on the soil surface and (v) the cut grass is not mulched but sucked up to remove nutrients from the site. In addition, the current version of the Eco 1200 is equipped with a flushing bar in front of the mower consisting of a skirt made of truck tarpaulin. Because we aimed to study the effect of the modified mowing head, the flushing bar was not used in our experiments.

2 | MATERIALS AND METHODS

2.1 | Field experiment

The experiments took place August 20–21 and 24–27 in 2020 on two meadows (A, B) in Löcherberg near Bad Peterstal-Griesbach (Baden-Württemberg, Germany) at sunny and dry weather conditions between 10 a.m. and 7 p.m. Both meadows were alternately wet to moist nutrient-rich valley meadows.

A conventional mulching mower (MK 1200 flail mulching head with MS blades) and a Eco 1200 plus green maintenance head without flushing bar were used. The Eco 1200 plus was mounted on the rear mowing arm of an UNIMOG vehicle equipped with a suction device which removed most of the cut grass. The conventional MK 1200 was mounted on the front mowing arm of the same vehicle and was used without suction device. Mowing speed was 2–4 km/h.

On the edge of both meadows, a strip of 6 m of width next to the road was divided into 7 m sections. In total, the strip was 126 m long on meadow A (18 sections), and 21 m long on meadow B (three sections). Each section consisted of three parallel tracks (2 m wide), which received different treatments (Figure 1): One of the tracks served as control and was not mown, one was mown with the MK 1200, and one was mown with the Eco 1200 plus. These three mowing treatments were assigned randomly to the tracks for each 7 m section. As mowing heads are 1.2 m wide, the distance between the mown tracks was about 0.8 m. Therefore, the different treatments did not influence each other.

On each track, the arthropods were collected on three 1 × 1 m plots with a distance of one metre between each other using biocoenometers with lids measuring 1 × 1 × 1 m (Mühlenberg, 1993). Before mowing of one seven metres section, three biocoenometers were placed on the plots of the control track. Then, the other two tracks were mown with the MK 1200 and the Eco 1200, respectively. Immediately after mowing, the biocoenometers were placed on the three plots of the two mown tracks (Figure 1). Then, all living arthropods within each of the biocoenometers were removed with an insect vacuum cleaner (ecoVac from EcoTech GmbH) and transferred to a plastic bottle, which was afterwards filled with 70% ethanol for preservation. Preliminary tests revealed that no specimens were left in biocoenometers after removal with the vacuum cleaner. Mowing and sampling of the three tracks of each section (see below) were done successionally on the same day within a few hours. Insects collected in one biocoenometer were treated as one sample. Thus, we collected 189 samples in total from the 21 sections, i.e. nine samples per section consisting of three tracks each.

2.2 | Counting of arthropods

Due to time constraints, we were unable to count the arthropods in all 189 samples. Therefore, we randomly selected between 93 and 106 samples, i.e. 30–36 samples per treatment, depending on taxonomic group (Figure 2). From the total number of 106 samples, 88 samples were from meadow A and 18 from meadow B. Organisms were sorted under a stereomicroscope in dishes containing 70% ethanol and the number of individuals of the taxonomic groups Araneae, Saltatoria, Cicadina, Heteroptera, Coleoptera, Hymenoptera (incl. parasitoid wasps but excluding Formicidae), Diptera and Lepidoptera were counted for each sample. In addition, we also counted the number of larvae of holometabolous insects. Formicidae were excluded due to the heterogeneous spatial distribution of their nests. We included injured individuals in our counts, i.e. individuals missing single legs but excluded individual parts of insects such as legs.

2.3 | Statistical analysis

Statistical analysis was carried out with the software 'R' (R Core Team, 2016). Data were analysed for normal distribution using Shapiro-Wilk normality test and for homogeneity of variances using Levene's test. For Araneae and Coleoptera, data were sqrt-transformed and subsequently analysed using linear mixed models

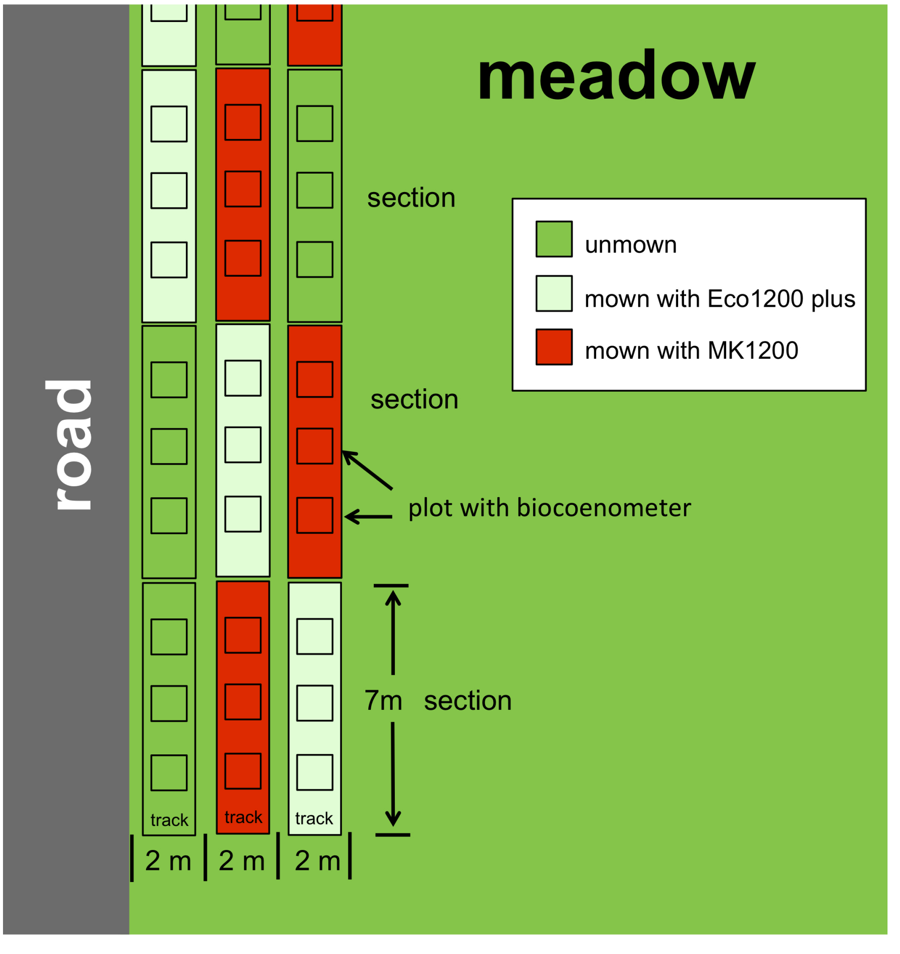

FIGURE 1 Experimental design showing the three tracks in each seven metre section and the plots with the biocoenometers within in each track [Colour figure can be viewed at wileyonlinelibrary.com]

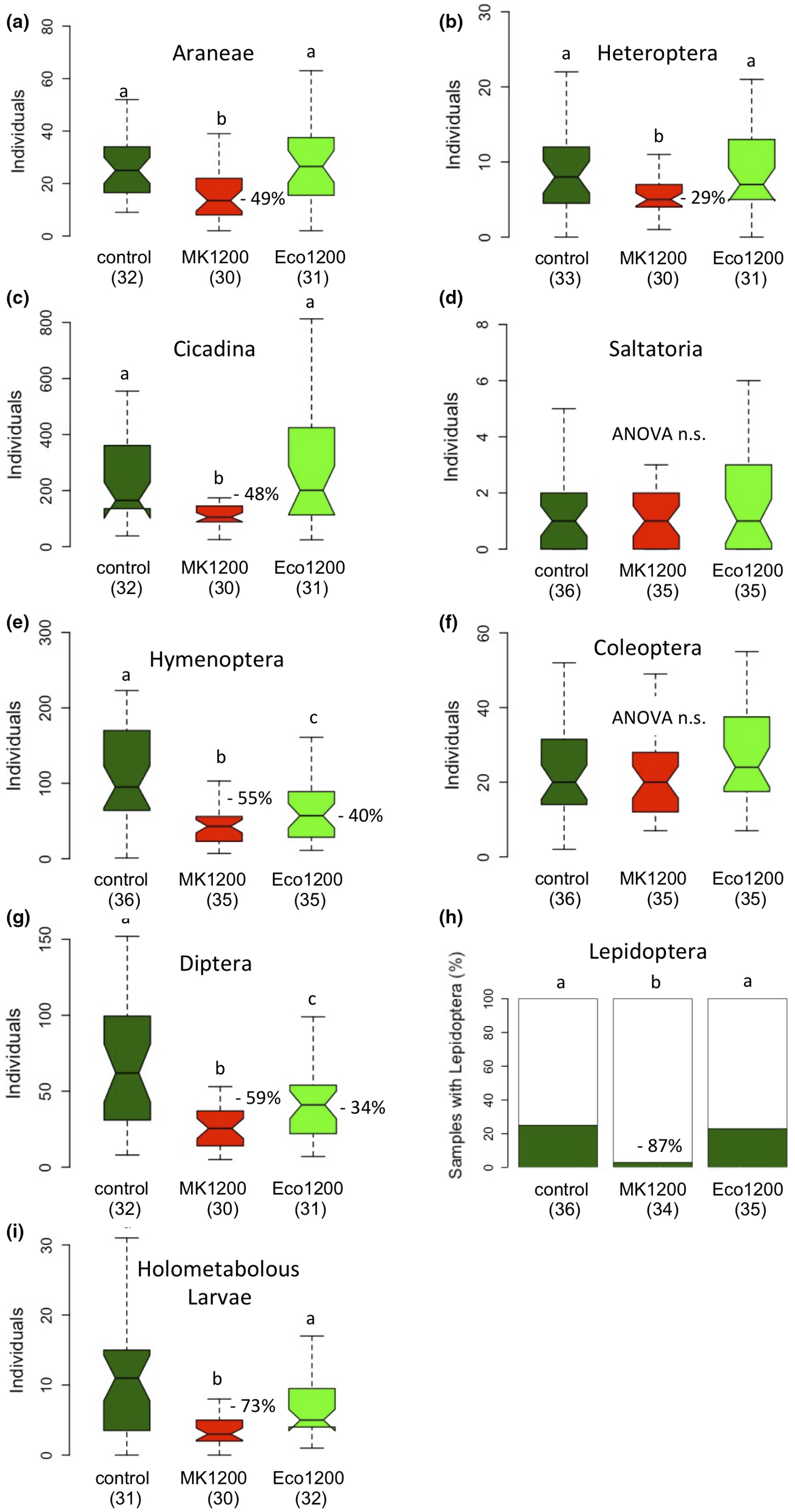

FIGURE 2 Effect of the conventional mower MK 1200 and the insect-friendly mower Eco 1200 on the number of individuals (box-and-whisker plots in a–g, i) for Araneae and different insect taxa, and the number of samples with Lepidoptera (barplot in h). Plots were unmown (control) or mown immediately before sampling with the conventional mower MK 1200 or the MULAG Eco 1200 plus. Percentage values are only provided when there are significant differences in the number of insects between control and MK 1200 or between control and Eco 1200. Different letters above the bars indicate significant differences between the treatments ($p < 0.05$). The data from A-H and I were analysed using linear or generalized mixed models (family negative binomial) with treatment as factor (unmown control, MK 1200, MULAG Eco 1200 plus) and study site as random factor followed by Tukey test. Data from H were analysed with the Fisher exact test for Count data. The number of samples per treatment analysed in the different taxonomic groups are given in brackets [Colour figure can be viewed at wileyonlinelibrary.com]

followed by ANOVA and Tukey test. Due to the absence of normal distribution and/or inhomogeneous variances of data from all the other taxa except of Lepidoptera, we used generalized mixed models, family negative binomial (Bates et al., 2014) followed by ANOVA and Tukey test (Hothorn et al., 2008). In all models, target variables were the number of individuals. Treatment (unmown, MK

1200, Eco 1200 plus) was used as factor, and the site (meadow A, meadow B) was included as random factor. Because Lepidoptera were rare, we analysed the number of samples in which Lepidoptera were found using Fisher's exact test for count data.

3 | RESULTS

The statistical analysis revealed a significant influence of treatment on the number of individuals in the samples for Araneae, Heteroptera, Cicadina, Hymenoptera, Diptera and larvae of holometabolous insects (Table 1). No significant influence was found for Saltatoria and Coleoptera. For Lepidoptera, there were only few individuals in the samples. Therefore, we compared the number of samples with lepidopterans with the number of samples without lepidopterans in the three treatments using Fisher's exact test for count data. This also revealed a significant difference between treatments.

For those taxa, for which the overall comparison showed a significant effect, we performed single comparisons between treatments (Figure 2). There was a significant decrease between 29% and 73% in the number of insects between plots, which were mown using the MK 1200 standard mower as compared to the unmown control plots. For Lepidoptera, the reduction in the number of samples with individuals was 87% as compared to the control samples.

For Araneae, Cicadina, Heteroptera, Lepidoptera and holometabolous larvae, there were no differences between samples from Eco 1200 plots and the control plots, and significantly higher numbers in samples from the Eco 1200 plots as compared to the MK 1200 plots. For Hymenoptera and Diptera, the number of insects in samples of the plots mown with the Eco 1200 was significantly lower as compared to the control plots, but significantly higher than in sample from the MK 1200 plots. The difference was 15% and 25% respectively.

Taken together, mowing had no influence in the number of insects in the samples for Saltatoria and Coleoptera. For all the other taxa, there was a significant decrease by mowing with the conventional mower MK 1200. Using the mower Eco 1200, this loss was fully restored in Araneae, Heteroptera, Cicadina, Lepidoptera and holometabolous larvae and partially restored in Hymenoptera and Diptera.

4 | DISCUSSION

We studied the negative impact of roadside mowing on the grassland arthropod fauna and its potential mitigation with a newly developed slope mowing head (Eco 1200 plus), which was developed to reduce the losses of spiders and insects during the mowing process.

Our study revealed for most studied arthropod groups a considerable reduction in the number of specimens retrieved in plots mown with a conventional mowing head (MK 1200 from MULAG) as compared to unmown control plots. The losses ranged from 29% for Heteroptera over around 50% in Araneae, Cicadina, Hymenoptera and Diptera, up to 73% for holometabolous larvae. For Lepidoptera, the number of samples with adults was reduced by 87% in mown plots. This adds to the results of earlier studies, which report losses due to grassland mowing of 80%–97% for grasshoppers (Humbert et al., 2010), up to 60% in Coleoptera (Hemmann et al., 1987), up to 88% in Heteroptera (Hemmann et al., 1987), 55% for arthropods (Wasner, 1987, cited in Humbert et al., 2009) and 66% for invertebrates in general (Löbbert et al., 1994, cited in Humbert et al., 2009).

Surprisingly, we could not find a significant reduction in Saltatoria and Coleoptera, which is in contrast to these earlier studies. For Saltatoria, one reason could be their very low density of <2 specimens/m^2 on the study site, which prevented the collection of meaningful data for this group in our study. The beetles in the test and control blocks mostly were flea beetles (Alticinae), which might have escaped from destruction by the mowing machine due to their small size. In addition, Saltatoria and flea beetles have a highly developed jumping apparatus (e.g. Nadein & Betz, 2016), which might have enabled them to evade by jumping. Thus, more studies are required to assess the effect of conventional roadside mowing on grasshoppers and beetles in general.

TABLE 1 Test statistics for ANOVA based on linear or generalized mixed models with treatment as factor and study site as random factor, or Fisher's exact test for Count Data (Lepidoptera)

Taxon	Model or test	χ^2	*df*	*p*
Araneae	LMER with sqrt transformed data	20.72	2	3.16×10^{-3}***
Heteroptera	GLMER, family negative binomial	15.49	2	0.00043***
Auchenorrhyncha	GLMER, family negative binomial	32.23	2	1.01×10^{-7}***
Saltatoria	GLMER, family poisson	5.10	2	0.078 n.s.
Hymenoptera	GLMER, family negative binomial	40.42	2	1.68×10^{-9}***
Coleoptera	LMER with sqrt transformed data	4.52	2	0.10 n.s.
Diptera	GLMER, family negative binomial	43.12	2	4.34×10^{-10}***
Lepidoptera	Fisher's exact test for count data	–	–	0.018*
Holometabolous larvae	GLMER, family negative binomial	32.61	2	8.31×10^{-8}***

Note: *: $p < .05$; ***: $p < .01$; n.s.: $p < .05$.

For the plots mown with the putative arthropod-friendly mowing head Eco 1200, there was no significant difference for Araneae, Cicadina, Heteroptera, Saltatoria, Coleoptera, Lepidoptera and larvae of holometabolous insects in the number of specimens found as compared to the unmown control plots. Thus, the Eco 1200 does not cause detectable losses in these groups. For Hymenoptera and Diptera, the number of specimens after mowing with the Eco 1200 was reduced, but was still 15% and 25% respectively, higher than on plots mown with the conventional mowing head. It is unclear if the reductions in the MK 1200 and the Eco 1200 plots in Hymenoptera and Diptera are due to mortality caused by the mowing heads, or because the representatives of these groups were not killed but have escaped from the approaching mowing head by flying away. In any case, except for Saltatoria and Coleoptera (see above) our data demonstrate, that the Eco 1200 is in fact arthropod 'friendly', i.e. it either totally or partially reduces insect losses caused by mowing.

It remains to be studied which of the specific features (smaller contact surface with the grass, increased mowing height, largely closed underside, no vertical airflow from below, reduced contact area of the wheels) is responsible for this mitigating effect of the Eco 1200. We believe it is mostly caused by the closed underside and the avoidance of a vertical airflow from below. This is because in our experiments the mowing head of the Eco 1200 was attached to a suction device that removed the mowed material but also all the arthropods present in the mowing head. Therefore, all specimens found in our samples must have escaped from being sucked up into the mowing head, most likely because they were protected on the ground from the closed underside of the mowing head and the absence of the vertical airflow from below. Based on an earlier unpublished study (R. Oppermann, S. Johnen, R. Bleil, 2021, unpublished) an additional mitigating effect is to be expected from the flushing bar that scares away insects in front of the Eco 1200 mower. This device was not used in our experiments. It remains to be studied if its additional use will result in the total offset of the losses by mowing in the Hymenoptera and Diptera, which are highly mobile flying insects and therefore should be especially responsive to these bars.

We believe that adopting this insect-friendly mowing technology by building yards, road maintenance departments, communal institutions and water management companies, would be an important contribution to the protection of biodiversity and the preservation of ecosystem functions in grassland. This is especially true in the extensively maintained sections of the road bank that are mowed only once or twice per year. Because mowing machines have to be replaced every 10–15 years due to wear out, this change might take about a decade, provided that users can afford the additional costs, e.g. about 40% for the Eco 1200 as compared to the MK 1200 (Schwarz, 2021). However, in addition to insect-friendly mowing technique, it is also important to adopt sustainable mowing regimes. For instance, Krogmann et al. (2018) voted for the implementation of a '10–10 rule', i.e. to (i) leave 10% of a grassland area unmown (also over the winter) to preserve parts of the grassland population as a source for resettlement in the upcoming year and (ii) keep a mowing height of at least 10 cm to save insects sitting at the lower heights of the plants and to keep the microclimatic conditions for the remaining insects humid. Alternatively, Unterweger et al. (2018) suggested the combination of different mowing regimes to support metapopulation dynamics and the recolonization of mown areas. Generally, however, insect-friendly mowing technology should be included in the package of measures that has been suggested to counteract insect decline (Harvey et al., 2020; Kawahara et al., 2021; Krogmann et al., 2018).

5 | CONCLUSION

In conclusion, our study demonstrates that mowing of roadsides with conventional mowing technology has a highly detrimental effect on the grassland arthropod fauna of these areas. This compromises the potential beneficial effect of these sites for biodiversity and most likely contributes to the decline of insects observed during the last decades (Hallmann et al., 2017; Seibold et al., 2019). However, this effect can be mitigated or even offset by appropriate mowing technique, which prevents the loss of arthropods during the mowing process. Therefore, more studies are required to further develop the tested Eco 1200 as well as other putative insect-friendly mowing machines.

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CONFLICT OF INTERESTS

The study was financed by MULAG Company but did not cause any conflict of interests between the authors and the company.

AUTHOR CONTRIBUTION

JLMS and OB conceived the research. TK and MC conducted the experiments. JLMS analysed data and conducted the statistical analyses. JLMS and OB wrote the manuscript. JLMS and OB secured funding. All authors read and approved the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in dryad: https://doi.org/10.5061/dryad.rxwdbrv98.

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REFERENCES

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48.

Fluri, P., Frick, R., & Jaun, A. (2000). Bienenverluste beim Mähen mit Rotationsmähwerken. *Schweizerisches Zentrum Für Bienenforschung, Mitteilung*, *39*, 1–21.

Gardiner, M. M., Riley, C. B., Bommarco, R., & Öckinger, E. (2018). Rights-of-way: A potential conservation resource. *Frontiers in Ecology and the Environment*, *16*, 149–158. https://doi.org/10.1002/fee.1778

Gardiner, T., & Hassall, M. (2009). Does microclimate affect grasshopper populations after cutting of hay in improved grassland? *Journal of Insect Conservation*, *13*, 97–102. https://doi.org/10.1007/s10841-007-9129-y

Gossner, M. M., Lewinsohn, T. M., Kahl, T., Grassein, F., Boch, S., Prati, D., Birkhofer, K., Renner, S. C., Sikorski, J., Wubet, T., Arndt, H., Baumgartner, V., Blaser, S., Blüthgen, N., Börschig, C., Buscot, F., Diekötter, T., Jorge, L. R., Jung, K., … Allan, E. (2016). Land-use intensification causes multitrophic homogenization of grassland communities. *Nature*, *540*, 266–269. https://doi.org/10.1038/nature20575

Goulson, D. (2019). The insect apocalypse, and why it matters. *Current Biology*, *29*, R967–R971. https://doi.org/10.1016/j.cub.2019.06.069

Gsell, J. (2020). Schonend für Tier und Pflanze: Was leisten die neuen Öko-Mäher und -Mulcher. *Bauhof-Online.de*, *5*, 14–17.

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS One*, *12*, e0185809. https://doi.org/10.1371/journal.pone.0185809

Harvey, J. A., Heinen, R., Armbrecht, I., Basset, Y., Baxter-Gilbert, J. H., Bezemer, T. M., Böhm, M., Bommarco, R., Borges, P. A., & Cardoso, P. (2020). International scientists formulate a roadmap for insect conservation and recovery. *Nature Ecology & Evolution*, *4*, 174–176.

Hemmann, K., Hopp, I., & Paulus, H. F. (1987). Zum Einfluß der Mahd durch Messerbalken, Mulcher und Saugmäher auf Insekten am Straßenrand". *Natur Und Landschaft*, *62*, 103–106.

Hoiß, B. (2020). Roadkill Von Insekten. *Anliegen Natur*, *42*, 1–4.

Hopwood, J. L. (2008). The contribution of roadside grassland restorations to native bee conservation. *Biological Conservation*, *141*, 2632–2640. https://doi.org/10.1016/j.biocon.2008.07.026

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*, 346–363. https://doi.org/10.1002/bimj.200810425

Hotz, S. (2013). Beim Mähen Leben retten–amphibien-und insektenfreundliches Mähwerk. *Naturschutzinfo*, *1*, 21.

Humbert, J.-Y., Ghazoul, J., Richner, N., & Walter, T. (2010). Hay harvesting causes high orthopteran mortality. *Agriculture, Ecosystems & Environment*, *139*, 522–527. https://doi.org/10.1016/j.agee.2010.09.012

Humbert, J.-Y., Ghazoul, J., & Walter, T. (2009). Meadow harvesting techniques and their impacts on field fauna. *Agriculture, Ecosystems & Environment*, *130*, 1–8. https://doi.org/10.1016/j.agee.2008.11.014

Humbert, J.-Y., Richner, N., Sauter, J., Walter, T., & Ghazoul, J. (2010). Wiesen-Ernteprozesse und ihre Wirkung auf die Fauna. *ART-Bericht*, *724*, 1–12.

Kawahara, A. Y., Reeves, L. E., Barber, J. R., & Black, S. H. (2021). Opinion: Eight simple actions that individuals can take to save insects from global declines. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(2), e2002547117.

Klonglan, E. D., Robbins, R. L., & Ridley, B. L. (1959). *Evaluation of effectiveness of pheasant flushing bars in Iowa Hayfields*. Presented at the Proceedings of the Iowa Academy of Science, 534–552.

Krogmann, L., Betz, O., Geldmann, J., Goulson, D., Menzel, R., RIecken, U., Ruther, J., Schwenninger, H., Sorg, M., & Steidle, J. (2018). Neun-Punkte-Plan gegen das Insektensterben. Die Perspektive Der Wissenschaft. *Entomologische Zeitschrift*, *128*, 247–249.

Kurze, S., Heinken, T., & Fartmann, T. (2018). Nitrogen enrichment in host plants increases the mortality of common *Lepidoptera* species. *Oecologia*, *188*, 1227–1237. https://doi.org/10.1007/s00442-018-4266-4

Lázaro-Lobo, A., & Ervin, G. N. (2019). A global examination on the differential impacts of roadsides on native vs. exotic and weedy plant species. *Global Ecology and Conservation*, *17*, e00555. https://doi.org/10.1016/j.gecco.2019.e00555

Löbbert, M., Kromer, K., & Wieland, C. (1994). Einfluss von Mäh-und Mulchgeräten auf die bodennahe Fauna. Forschungsberichte" Integrative Extensivierungs-und Naturschutzstrategien. *Heft*, *15*, 7–26.

Mühlenberg, M. (1993). *Freilandökologie*. Quelle Meyer.

Mulag (2021). *Eco 1200 plus [WWW Document]*. https://www.mulag.de/de/strassenunterhaltung/produkte/arbeitsgeraete/maehen-und-aufnehmen/eco-1200-plus/

Müller, I. B., Buhk, C., Lange, D., Entling, M. H., & Schirmel, J. (2016). Contrasting effects of irrigation and fertilization on plant diversity in hay meadows. *Basic and Applied Ecology*, *17*, 576–585. https://doi.org/10.1016/j.baae.2016.04.008

Muñoz, P. T., Torres, F. P., & Megías, A. G. (2015). Effects of roads on insects: A review. *Biodiversity and Conservation*, *24*, 659–682. https://doi.org/10.1007/s10531-014-0831-2

Nadein, K., & Betz, O. (2016). Jumping mechanisms and performance in beetles. I. Flea beetles (Coleoptera: Chrysomelidae: Alticini). *Journal of Experimental Biology*, *219*, 2015–2027. https://doi.org/10.1242/jeb.140533

New, T. R., Sands, D. P., & Taylor, G. S. (2021). Roles of roadside vegetation in insect conservation in Australia. *Austral Entomology*, *60*, 128–137. https://doi.org/10.1111/aen.12511

Niedrist, G., Tasser, E., Lüth, C., Dalla Via, J., & Tappeiner, U. (2009). Plant diversity declines with recent land use changes in European Alps. *Plant Ecology*, *202*, 195. https://doi.org/10.1007/s11258-008-9487-x

Noordijk, J., Delille, K., Schaffers, A. P., & Sýkora, K. V. (2009). Optimizing grassland management for flower-visiting insects in roadside verges. *Biological Conservation*, *142*, 2097–2103. https://doi.org/10.1016/j.biocon.2009.04.009

Phillips, B. B., Bullock, J. M., Osborne, J. L., & Gaston, K. J. (2020). Ecosystem service provision by road verges. *Journal of Applied Ecology*, *57*, 488–501. https://doi.org/10.1111/1365-2664.13556

R Core Team (2016). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Reck, H., & Mueller, K. (2018). *Strassenbegleitgruen und biologische Vielfalt: Potenziale und Realitaet*. Strassenverkehrstechnik 62.

Sánchez-Bayo, F., & Wyckhuys, K. A. (2021). Further evidence for a global decline of the entomofauna. *Austral Entomology*, *60*, 9–26. https://doi.org/10.1111/aen.12509

Schwarz, C. (2021). *Freut Euch, Ihr Krabbler! Insektenschonenes Mähgerät in Bad Saulgau vorgestellt*. Südfinder, 1–2.

Seibold, S., Gossner, M. M., Simons, N. K., Blüthgen, N., Müller, J., Ambarlı, D., Ammer, C., Bauhus, J., Fischer, M., Habel, J. C., Linsenmair, K. E., Nauss, T., Penone, C., Prati, D., Schall, P., Schulze, E.-D., Vogt, J., Wöllauer, S., & Weisser, W. W. (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

Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C., & Batáry, P. (2021). Beyond organic farming-harnessing biodiversity-friendly landscapes. *Trends in Ecology & Evolution*, *36*, 919–930. https://doi.org/10.1016/j.tree.2021.06.010

Unterweger, P. A., Klammer, J., Unger, M., & Betz, O. (2018). Insect hibernation on urban green land: A winter-adapted mowing regime as a management tool for insect conservation. *Biodiversity and Ecosystem Risk Assessment*, *13*, 1–29. https://doi.org/10.3897/biorisk.13.22316

van de Poel, D., & Zehm, A. (2014). Die Wirkung des Mähens auf die Fauna der Wiesen – Eine Literaturauswertung für den Naturschutz. *Anliegen Natur*, *36*, 36–51.

Wagner, D. L., Grames, E. M., Forister, M. L., Berenbaum, M. R., & 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.

Wasner, U. (1987). Wirkung der Saugmahd auf den Insektenbestand am Straßenrand. *Mitteilungen Der Landesanstalt Für Ökologie, Landschaftsentwicklung Und Forstplanung*, *12*, 34–39.

Wood, T. J., & Goulson, D. (2017). The environmental risks of neonicotinoid pesticides: A review of the evidence post 2013. *Environmental Science and Pollution Research*, *24*, 17285–17325. https://doi.org/10.1007/s11356-017-9240-x

Zeitner, J., & Aschauer, S. (2021). Artenfreundliche Mähtechnik - Lebensraum statt Abstandsgrün. *Flächenmanager*, *1*, 20–29.

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