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RESEARCH PAPER

Flower-rich road verges increase abundance of flower visitors in the surrounding landscape

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ABSTRACT

Flower-visiting insects and the plants that depend on them are declining due to habitat loss and deterioration. Road verges, which often provide abundant floral resources, are gaining attention for their potential conservation value, as they can support a high abundance and diversity of flower-visiting insects. Thereby, flower-abundant road verges may benefit pollination in surrounding landscapes. However, the potential negative effect of traffic on this benefit remains unexplored. We addressed the research gap using potted wild strawberry plants (*Fragaria vesca*, variety 'Rügen'), placed at 20 m and 80–100 m distance from road verges along roads with varying traffic intensity (around 100–5500 vehicles per day). We found that floral abundance in road verges enhanced the number of flower visitors to strawberry plants in nearby areas, regardless of the distance to the road verge. However, this positive effect was restricted by increasing traffic intensity and narrower road verge width. Despite similar numbers of flower visitors at both distances, the pollination success, measured as the number of developed achenes on each harvested strawberry, tended to be lower closer to the road verge than further away but was unrelated to flower density, traffic intensity and road verge width, which indicates potential differences in pollinator behaviour or in the pollen they carried. Our findings highlight the potential of flower-rich road verges to support the conservation of flower-visiting insects. However, we emphasise the need to consider road verge width and traffic intensity to ensure successful pollinator-friendly management.

Introduction

Semi-natural grasslands are among the most species-rich habitats in Europe and can be source habitats of flower-visiting insects (Ekroos et al., 2013; Öckinger & Smith, 2007; Wilson et al., 2012). However, agricultural intensification and abandonment have caused a severe reduction of the area of semi-natural grasslands and the biodiversity associated with them (Krauss et al., 2010; Strijker, 2005). Flower-visiting insects such as wild bees and butterflies suffer from the concomitant landscape homogenization and fragmentation and a lack of flower resources (Goulson et al., 2015; Potts et al., 2016; Sánchez-Bayo & Wyckhuys, 2019) and the abundance of insect-pollinated grassland plants have been shown to decline with increasing land-use intensity in the surrounding landscape (Clough et al., 2014).

To support flower-visiting insects with floral resources in homogeneous agricultural landscapes, conservation strategies such as the implementation of wildflower strips along or within arable fields are frequently used. Flower strips are habitats designed to provide nectar and pollen resources from a mix of sown plants often only throughout one growing season. Another potential conservation opportunity that is rapidly gaining attention as support for biodiversity are road verges, which have the benefit that they already exist in most landscapes (Meinzen et al., 2024). Flower strips typically have small effects on pollinator populations in adjacent fields (Albrecht et al., 2020; Zamorano et al., 2020), but it is unclear to what extent this also applies to road verges. The vegetation in road verges often resembles that in semi-natural grasslands due to the relatively low management intensity (Gardiner et al., 2018). They can host a wide variety of wild plants, including rare and endangered species, often exhibit high flower densities and thus support high abundance and richness of flower-visiting insects (Gardiner et al., 2018; Horstmann et al., 2024; Noordijk et al., 2009; Phillips et al., 2019). Like flower strips, road verges can provide

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pollen and nectar resources, but because they are permanent structures, they can also provide nesting and overwintering habitat, making them different from temporary flower strips (Halbritter et al., 2015; Noordijk et al., 2009; Valtonen et al., 2006). However, the benefit of these often suitable habitats can be limited by the nearness to traffic, resulting in pollution, turbulence and collision risk from and with vehicles (Meinzen et al., 2024; Phillips et al., 2021). Especially in narrow verges, increasing traffic intensities on the road reduces the abundance and species richness of wild bees as well as butterflies (Horstmann et al., 2024).

Patches of semi-natural grassland can act as source habitats for flower-visiting insects (Ekroos et al., 2013; Öckinger & Smith, 2007), and linear landscape elements such as flower strips, power line corridors, and verges of dirt roads with little traffic can have a similar role and increase flower-visiting insect abundance in the surrounding landscape (Berg et al., 2016; Jönsson et al., 2015; Monasterolo et al., 2022). Although road verges can support pollinator abundance and diversity locally (Dániel-Ferreira et al., 2023), it is unclear whether they also enhance flower-visiting insects and pollination in the surrounding landscape, and if this is mediated by traffic. Therefore, we expect that flower-rich road verges could also benefit pollination in the surrounding landscape. The effect of flower strips on monoculture crop pollination can be local and decrease severely even within just 20 m distance (Albrecht et al., 2020), but this may not translate to the pollination of wild plants. Furthermore, because increasing traffic intensity is known to limit the value of road verges for flower-visiting insects (Horstmann et al., 2024), it is likely that their importance for pollination may also be moderated by traffic. With these limitations in mind, there is a need to investigate to what extent flower-rich road verges benefit pollination in the surrounding landscape.

A standardised method to assess differences in environmental conditions on selected plant development measures such as growth, survival and pollination success are phytometers (Dietrich et al., 2013). Strawberry plants (*Fragaria* sp.) are suitable phytometers to assess pollination, because each pistil of the strawberry flower develops into an achene on the strawberry, with successfully pollinated pistils developing into large achenes (the true fruits of strawberries) separated by fruit flesh, and other pistils into small and aggregated achenes. Thus, pollination can be estimated by counting the number of developed achenes (Herbertsson et al., 2017; Klatt et al., 2014). While strawberries can develop from only wind- or self-pollinated flowers, insect pollination leads to a higher number of developed achenes (Lundgren et al., 2013; Wietzke et al., 2018) and heavier strawberries (Klatt et al., 2014). Wild strawberry (*Fragaria vesca*) flowers are visited by a variety of insects such as dipterans, solitary bees and hymenopterans (Blažytė-Čereškienė et al., 2012; Lundgren et al., 2013), and they are a relatively common plant species in road verges and other semi-natural habitats in our study region in southern Sweden.

In this study, we aim to contribute to filling knowledge gaps about the role of road verges along roads with a gradient in traffic intensity in supporting flower-visiting insects in the wider landscape and in contributing to wild plant pollination, using potted wild strawberries (*Fragaria vesca*) as phytometers. We expect a positive relationship between flower abundance in road verges and the number of strawberry flower visitors in the surrounding landscape, especially at shorter distance from the road verge. We expect the relationship between flower abundance and strawberry flower visitors to be stronger for roads with lower traffic intensities, since this can limit the potential of the road verge to support a larger community of flower-visiting insects (Horstmann et al., 2024). Furthermore, we expect that a higher number of flower visitors result in increased pollination success, i.e. higher numbers of developed achenes on the strawberry. Thus, we overall expect that strawberry plants are better pollinated if they are placed closer to flower-rich road verges than further away, and if the roads have lower traffic intensities and wider verges.

Materials and methods

Study sites

Our study was carried out in Skåne county, southernmost Sweden (Appendix A: Fig. 1). We selected 20 road verges along roads with a speed limit of 50–100 km/h and along a gradient of traffic intensities from 92 to 5558 vehicles per 24 h (Appendix A: Fig. 2; data from the national road database NVDB (Trafikverket, 2021)). All road verges were located in a similar landscape context with a maximum of 50% forest and minimum 30% arable land within a 2-km buffer around each road verge. We also made sure that there were no semi-natural grassland habitats within 350 m from the road (data from the National Land Cover Database (Naturvårdsverket, 2020) and the TUVA database of meadows and pastures of high nature value (Jordbruksverket, 2021). The road verges differed in mean width (2.7–13.9 m) but were selected so that width was unrelated to traffic intensity. Within each road verge, we chose a section that was 200 m long and had at least one linear landscape element diverging approximately orthogonal from the road verge, which was either a permanent field border between two fields, or a permanent border between a field and a small private road (Fig. 1A). Both types of linear landscape elements exhibited low and infrequent disturbance from farming practices or traffic during our study period (personal observation). We placed each one set of a garden variety of wild strawberry (*Fragaria vesca*, variety 'Ruegen'; hereafter strawberries) at two distances of 20 m and 80–100 m from the road verge, respectively (Fig. 1A). Each set consisted of three pots, each pot containing three strawberry plants. In summary, we had 20 study sites at linear landscape elements, each with two sets (one at each distance; total 40 sets), each with three pots (total 120 pots), and each pot with three plants (total 360 plants, 18 per linear landscape element). The pots in each set were placed close together and dug into the ground to limit dehydration (Fig. 1B). We used the same soil for every pot (peat-free soil, 'Weibulls') to standardize growth conditions among pots. Before we placed the plants in the field we removed open flowers, so that all harvested strawberries were the result of pollination when the plants were at their designated study site. We moved the plants to the study sites during the period 7–11 June 2021, and collected them after approximately five weeks, from 12 to 17 July 2021. One study site was later excluded because the plants were destroyed, resulting in 342 strawberry plants on 19 study sites.

Flower visitor observations and strawberry assessment

Each study site was visited five times (about once per week). During each visit, we first observed flower visitors for 15 minutes per distance, second harvested any ripe strawberries (when more than 90% of the strawberry was red) and third watered the strawberry plants. We only assessed flower visitors between 10.00 and 17.00, when vegetation was dry, wind was moderate (max. Beaufort 5) and with air temperatures at least 13 °C if cloud cover was less than 50% or at least 17 °C with higher cloud cover. Between rounds, we alternated the time of day during which we visited the study sites so that all study sites were visited during different times of the day. We caught wild bees and butterflies and identified them to species level or collected them for later identification in the lab. Visitors of other taxa were noted but only identified to family level for hover flies, ants and mosquitos (Syrphidae, Formicidae, Culcidae) and order for non-syrphid flies, beetles and wasps (non-syrphid Diptera, Coleoptera, Hymenoptera). We also observed mites, spiders and dragonflies (superorder Acariformes, orders Araneae and Odonata, respectively) on strawberry flowers but did not include them as visitors as they are unlikely to be pollinators. After the last observation round, we collected all strawberry plants and moved them to an enclosed outdoor area with mesh protection against birds. We removed all open flowers and flower buds, and thus only left developing strawberries that were pollinated at the study sites. Between July 19–29, we collected all

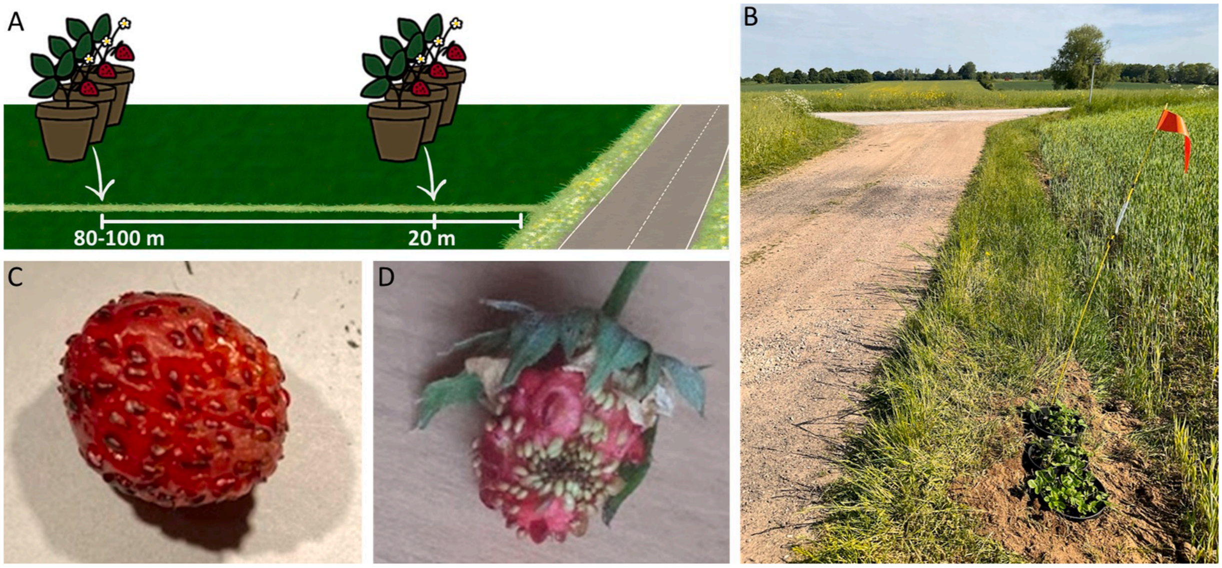

Fig. 1. (A) Graphical illustration of the study design: At a study site at a linear landscape element (a field border or a small road) diverging from a road verge, we placed sets of potted strawberry plants at two distances, at 20 m and 80–100 m. **(B)** Photo of one of our study sites, with one set (i.e. three pots) of strawberry plants dug into the ground at 20 m distance to the road verge in the background. Strawberries harvested from our experimental plants with **(C)** many developed achenes (large and separated), versus **(D)** many undeveloped achenes (small and close together). Photos and illustrations in A, B, D: Svenja Horstmann. Photo in C: Annika Swensson Källén.

ripe strawberries daily. For each harvested strawberry, we estimated the number of developed (i.e. large and separated; Fig. 1C) and undeveloped achenes (i.e. small and close together; Fig. 1D).

Abundance of flowers and flower-visiting insects in the road verges

While the strawberry plants were on the study sites, we quantified flower abundance (i.e. abundance of nectar-producing flowers), as well as abundance of wild bees and butterflies as part of a parallel study, once in each road verge (except for one where we did so two days after retrieving the strawberry plants; Horstmann et al., 2024). We used the abundance of wild bees and butterflies as an indicator of flower-visiting insect abundance in the road verge, not as potential strawberry pollinators per se. Within a 200 m long section of the road verge, covering its entire width, we quantified flower abundance of each species that was flowering at the time of the survey. We estimated their abundance in flower units on a scale from 1 to 6 (1: 1–10, 2: 11–50, 3: 51–150, 4: 151–500, 5: 501–1000, 6: > 1001), where one flower unit was counted as individual flower except for families with dense inflorescences of numerous small flowers (e.g. Apiaceae and Asteraceae), where one inflorescence was counted as one flower unit. We then summed up the minimum abundance of all species within each category (1 for category 1: 1–10 flower units, 11 for category 2: 11–50 flowers units, etc.) and of all transects per road verge to calculate the total flower abundance. Within the same transects and at the same day of the assessment of flower abundance, we conducted separate transect walks for wild bees and butterflies, with similar time and weather requirements as for the flower visitor observations. All transects were located directly alongside the road. For wild bees, the observer walked slowly for 10 min per transect, collecting all individuals within 1.5 m on each side and in front of the observer for later identification in the lab (except for bumblebees which were in most cases identified in the field). For butterflies, the observer walked slowly for 5 min per transect and caught and identified all individuals within 2.5 m to each side and in front. For road verges narrower than the transect width, we covered the whole road verge. We only counted individuals that either interacted with any part of a plant, searched for flowers or flew along the road verge, but not those that only flew across the road verge. We stopped the time for butterfly identifications in the field and collected solitary bees for later identification in the lab.

Statistical analyses

We only included undamaged strawberries in the analyses (damages included missing parts or squishy strawberries) and conducted the analyses in R, version 4.3.1 (R Core Team, 2021). We found no substantial correlation between predictor variables (i.e. no correlation > 0.7, see Dormann et al., 2013; Appendix A: Table 1), and assessed model fit using histograms, residual vs. fitted plots and Q-Q plots (base R and 'DHARMa' package: Hartig & Lohse, 2022).

First, we fitted two generalised mixed effects models to analyse how the number of strawberry flower visitors depend on the distance to the road verge and road verge characteristics (package 'glmmTMB': Brooks et al., 2017); one to assess general abundance of flower visitors and how this was affected by road verge characteristics, and another to relate the abundance of flower-visitors to their pollination service, by using the log-transformed number of strawberry flowers as an offset variable in the model. Predictor variables included in both models were the distance (20 or 80–100 m from road verge, categorical variable), the flower abundance in the road verge (estimated number of flower units), the combined abundance of wild bees and butterflies in the road verge (number of individuals), traffic intensity (vehicles per day) and road verge width (m). At first, we included the following two-way interactions: traffic intensity × road verge width, distance × traffic intensity, distance × road verge flower abundance and distance × combined abundance of wild bees and butterflies in the road verge. However, since none of the two-way interactions including distance were significant in any of the models, we excluded them in the final models to simplify model structure and only included traffic intensity × road verge width. We used the combined abundance of wild bees and butterflies as proxy for the overall abundance of flower-visiting insects in the road verge. Traffic intensity and flower abundance were log-transformed (assuming non-linear effects of these predictors, i.e. that a change from 200 to 500 vehicles per day has a larger effect than a change from 4200 to 4500). We did not differentiate between pots when observing flower visitors and hence only site identity was included as a random effect in the model. We used a negative binomial error distribution with quadratic parameterization ('nbinom2') and log-link to handle overdispersion.

Second, we fitted a linear mixed effect model with an identity link to model the number of developed achenes on the strawberries (package 'glmmTMB': Brooks et al., 2017). Although the number of developed achenes is count data, a linear model showed best model fit. Predictor variables included in the model were the number of strawberry flower visitor individuals, and, as in the previous model, the distance (20 or 80–100 m from road verge, categorical variable), the flower abundance in the road verge (estimated number of flower units), the combined abundance of wild bees and butterflies in the road verge (number of individuals), traffic intensity (vehicles per day) and road verge width (m). At first, we also included the following two-way interactions: traffic intensity × road verge width, distance × number of strawberry flower visitors, distance × combined abundance of wild bees and butterflies, distance × flower abundance in the road verge, distance × road verge width. However, since all two-way interactions were non-significant, we excluded all interactions to simplify model structure except traffic intensity × road verge width which we kept for consistency with the first two models (model results were qualitatively the same with or without the interaction). We included pot identity, nested within site, as random effects.

Third, we fitted a linear mixed effect model with identity link (package 'glmmTMB': Brooks et al., 2017) to explore if one or more groups of flower visitors are particularly important for strawberry pollination success, i.e. to predict the number of developed achenes. We used the mean number of developed achenes per distance (i.e. at 20 or 80–100 m, across the whole study period) as response variable, the total number of visitors of each family or order as separate predictor variables (ants, wild bees, beetles, non-syrphid flies, hoverflies and mosquitos), and study site as random effect. The identity of eight individuals was unknown, and for other groups we only had a few visitors (three butterflies, five wasps), so we did not include them in this model.

Results

In total we harvested 1537 strawberries from our 342 strawberry plants. Of these, 1337 were undamaged and included in our analyses. Strawberries had between 3 and 345 developed achenes (mean 145.22 ± 51.28 SD). Across the entire study period, during our 5 × 15 min observations, we observed between 5 and 82 strawberry flower visitors per set of strawberry plants, which had between 30 and 98 flowers (mean 61.8 ± 15.6 SD). Flower visitors were non-syrphid flies (non-syrphid Diptera, $n = 606$), followed by hoverflies (Syrphidae, $n = 382$), beetles (Coleoptera, $n = 269$), wild bees (non-Apis Apiformes, $n = 94$), ants (Formicidae, $n = 76$), mosquitos (Culicidae, $n = 31$), wasps (Hymenoptera, $n = 5$) and butterflies (Lepidoptera, $n = 3$) (Fig. 2).

The total number of strawberry flower visitors in linear landscape elements increased with increasing flower abundance in the adjacent road verge ($p = 0.04$, R^2_{cond}=0.24, Fig. 3A), independently of the distance to the road verge (Fig. 3C). On average, we observed 38.6 strawberry flower visitors per plant set across the whole study period. The number of strawberry flower visitors in the linear landscape elements decreased with traffic intensity on the nearby road, but only when the verge adjacent to the road was narrow (interaction: $p = 0.02$, R^2_{cond}=0.24, Fig. 3B). The combined abundance of wild bees and butterflies in the road verges did not predict the number of flower visitors of the strawberries in the linear landscape elements (see Appendix A: Table 2 for all model results).

The number of visitors per strawberry flower was not affected by any road verge characteristics (flower abundance or abundance of wild bees and butterflies in the road verge, traffic intensity regardless of verge width). Furthermore, the number of visitors per flower was similar between the two distances to the road verge and the model explained little variation in the data (R^2_{cond}=0.02).

We found a trend for a higher number of developed achenes at the larger distance to the road verge ($p = 0.06$; Fig. 4). The model estimated a slightly lower number of developed achenes 20 m from the road (95% CI: 131.9–145.8, $n = 660$) compared to 80–100 m from the road (95% CI: 139.8–153.8, $n = 677$). This corresponds to an average predicted increase of 5.8% developed achenes with increasing distance to the road verge (95% CI increase of −4.3–16.6 %). The number of developed achenes was not predicted by the number of strawberry flower visitors, the abundance of wild bees and butterflies or the flower abundance in the road verges, nor by the interaction between traffic intensity and road verge width (Fig. 4C). Overall, the model explained a relatively small amount of variation in the data (R^2_{cond}=0.13), and we found a high variance in the random effect, i.e. in the number of developed achenes per strawberry between pots within study sites (239.9 ± 15.5 SD).

There was no significant relationship between the number of developed achenes and any of the flower visitor groups and this model explained little variation in the data (R^2_{cond}=0.09).

Discussion

We found a positive relationship between flower abundance in road verges and the number of strawberry flower visitors, regardless of their distance to the road verge, suggesting that flower-rich road verges can benefit pollinator populations in the wider landscape. However, we did

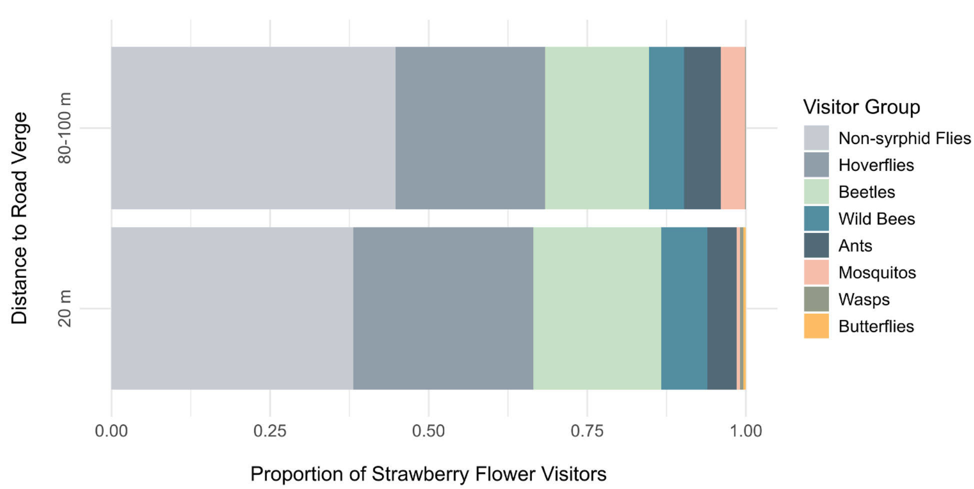

Fig. 2. The proportion of each group of strawberry flower visitors at strawberry phytometers placed at two distances to road verges. In total, we observed 758 flower visitors at 20 m distance and 708 at 80–100 m distance.

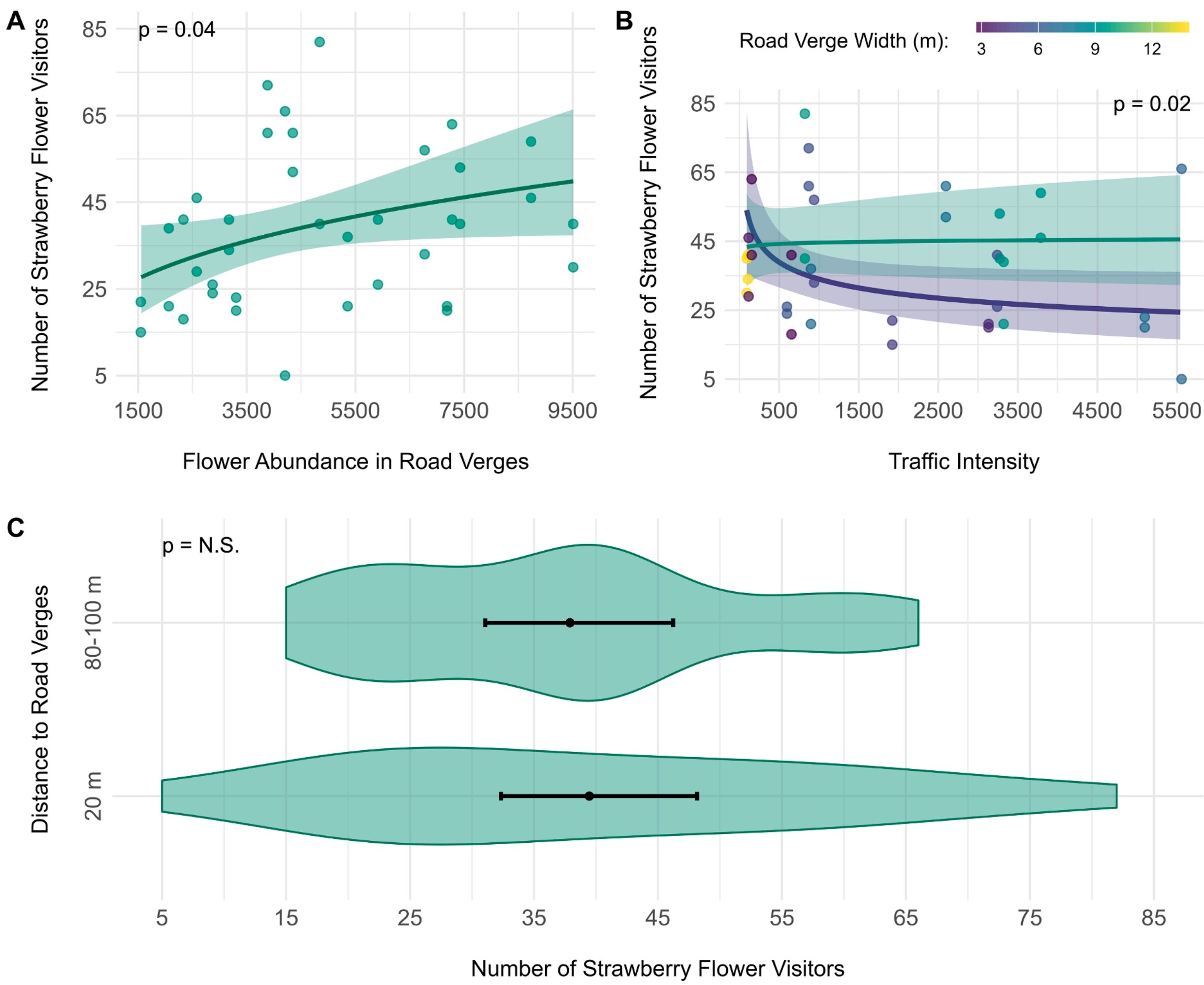

Fig. 3. **(A)** We found a positive relationship between flower abundance in the road verges and the number of strawberry flower visitors. Flower abundance was log-transformed for the analyses. Dots indicate raw data, lines and error bands indicate the predicted mean and 95% confidence intervals. **(B)** The relationship between the number of strawberry flower visitors and traffic intensity in the nearby road changes depended on the width of the road verge (gradient in road verge width is indicated by the colour variance). Traffic intensity was log-transformed for the analyses. Dots indicate raw data, lines and error bands indicate the predicted mean and 95% confidence intervals. The colour gradient illustrates the width of the road verge for samples (represented as circles), model predictions (lines) for 4.7 and 9.3 m width respectively, and confidence intervals (shaded areas). **(C)** The number of strawberry flower visitors was similar between the two distances to the road verge. Axes were flipped for better visualisation. Violin shapes represent spread of raw data, with wider parts indicating more data points. Black dots with error bars indicate predicted means and 95% confidence intervals.

not find the same patterns regarding potential pollination services, estimated as the number of visitors per flower and number of developed achenes per strawberry. In fact, we found that the pollination success was lower closer to the road than further away. High traffic intensities on the road reduced the total number of flower visitors, highlighting that traffic can constitute a risk towards pollinating insects and limit the benefits of the road verge for pollinator populations even in the surrounding landscape.

More flower visitors near flower-rich road verges

We found a positive relationship between the flower abundance in the road verges and the total number of flower visitors on potted strawberry plants, regardless of the distance from the road verge. Our result aligns with the findings of Monasterolo et al. (2022), who also found a positive effect of flower abundance in road verges on the number of flower-visiting insects on phytometers located in arable fields at a 30 m distance from rural dirt roads with low traffic. Here, we show that flower-rich road verges increase the number of flower-visiting insects in their surroundings even up to a distance of 100 m. However, we did not find the same effect on pollination services, estimated as the number of visitors per flower and developed achenes per strawberry. Instead, we found that the pollination success was marginally lower closer to the road than further away. Hence, we further conclude that the effect of flower-rich road verges may be too weak to enhance pollination services. Furthermore, one major drawback of road verges may be the proximity of the road verge habitat to the road and thus to traffic (Horstmann et al., 2024; Phillips et al., 2019). We show that this is indeed a problem, also when it comes to pollination in the surrounding landscape.

Traffic limits the number of flower-visiting insects

The positive effects of flower abundance in road verges on the abundance of flower visitors in the surrounding landscape were counteracted by traffic intensity. Higher traffic intensities reduced the number of strawberry flower visitors when the respective road verges were narrow compared to wide, suggesting that increasing width of the road verge mitigates negative effects of the traffic. In a previous study including the same study sites, we found lower numbers of bees and butterflies in narrow road verges than in wide road verges if the traffic intensity was high (Horstmann et al., 2024). We found no relationship

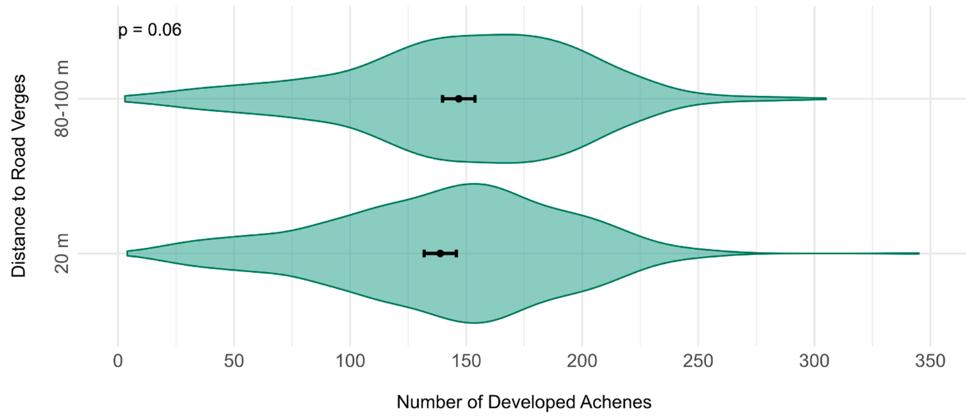

Fig. 4. Trend in the difference in the number of developed achenes depending on the distance to the road verge. Axes were flipped for better visualisation. Violin shapes represent spread of raw data, with wider parts indicating more data points. Black dots with error bars indicate predicted means and 95% confidence intervals.

between the abundance of wild bees and butterflies in a road verge with the number of strawberry flower visitors, but most flower visitors were also from other groups (mostly non-syrphid flies and hoverflies). Two reviews conclude that high traffic and concomitant pollution and disturbances may influence pollinator behaviour and effectiveness and lead to higher mortality rates through collision with vehicles (Meinzen et al., 2024; Phillips et al., 2021). Hence, high traffic may limit the potential of road verges to support flower-visiting insects from various groups in the road verge, especially in narrow road verges. In turn, this can result in fewer flower-visiting insects moving into the wider landscape.

Pollination success affected by distance to road verges

We found a trend for on average 5.8 % more developed achenes on strawberries that were placed at 80–100 m distance from the road verge than at 20 m distance. The variation in the number of developed achenes on individual strawberries was high both within and between study sites, which can be due to naturally high variations in the strawberry flowers or indicate differences due to environmental variation unexplained by our model, but captured through the crossed random effect of study site and distance. The fact that there was marginally different pollination outcomes despite a similar number of visitors per strawberry flower between the two distances could indicate that our observation time was insufficient to capture more nuanced differences, but it can also suggest that the pollinator efficiency varied. There are a few potential visitor-centred explanations: a difference in the identity of the visitors, in their behaviour, or in the quality of the pollen they carried. Regarding identity, we found no significant effect of any of the pollinator groups on the number of developed achenes. However, within the coarse groups we used some species might be better pollinators than others (Chagnon et al., 1993), which we did not capture. The importance of a specific insect can also depend on its behaviour as well as the pollen it carries (Chagnon et al., 1993; Herbertsson et al., 2017). We did not measure the number of flower visits per insect, but only the number of visitors. It is thus possible that each insect visited fewer flowers nearby the road verge than further away from it, thereby contributing less to pollination than further away from the road verge. The lower number of developed achenes closer to the road verge despite a similar number of flower visitors might also be caused by a higher proportion of heterospecific pollen on the flower-visitor's body, reducing their efficiency as pollinators (Villa-Galaviz et al., 2023).

Conclusions and implications

In this study, we contribute to filling the knowledge gap about the role of road verges in supporting flower-visiting insects in the wider landscape and in contributing to wild plant pollination, under consideration of traffic intensity. Our findings highlight the potential of flower-rich road verges to benefit populations of flower-visiting insects in the surrounding landscape. However, this positive effect of high-quality road verges may be too weak to also enhance pollination services, since we found no increase in the number of visitors per flower. Although we focused on a single plant species, we conclude that by increasing the availability of pollinators for wild plants in general, road verges could nevertheless play a role in sustaining natural processes and biodiversity, which are fundamental for ecosystem resilience. But alarmingly, we found that high traffic intensity can limit the benefit of the road verge in the wider landscape regardless of the distance to the road verge, likely due to a smaller community of flower-visiting insects persisting in the road verge itself.

Preserving and enhancing floral diversity in road verges may be an important strategy to support pollinator communities also in the surrounding landscape. Since not all road verges are flower-rich, we suggest that measures to enhance flower-richness, for example by applying adequate mowing regimes or sowing regionally occurring wildflower species, should be focused on roads with low traffic intensity or wide verges. We emphasise that compared to flower strips, road verges may be an underrated tool to support flower-visiting insects in agricultural landscapes, especially those with low traffic intensity.

CRediT authorship contribution statement

Svenja Horstmann: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lina Herbertsson:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Björn K. Klatt:** Writing – review & editing, Methodology, Formal analysis. **Alistair G. Auffret:** Writing – original draft, Methodology, Formal analysis. **Erik Öckinger:** Writing – review & editing, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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