



Road-associated variation in insect abundance differs between three common orders

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Abstract

The ecological impacts of roads are well-researched for many vertebrates, but studies are relatively lacking with regards to invertebrates. Here, changes in the abundance of ground-dwelling species of the three most common insect orders, Hymenoptera (specifically ants), Hemiptera (true bugs) and Coleoptera (beetles), with distance from a gravel road in a grassland system in South Africa, are documented. Insects were collected by means of pitfall traps ($n = 164$) installed at 2, 5, 10 and 20 m perpendicular to a gravel road, and abundances of these three orders were compared statistically between the four distances. Whereas no significant differences in the numbers of Hymenoptera and Coleoptera were observed with distance from road, the abundance of Hemiptera was greater closer to the road. Our results show that quieter, low-traffic roads can affect the distribution of insect species at finer spatial scales.

Keywords Coleoptera · Hemiptera · Hymenoptera · Invertebrate · Dispersal barrier · Roadside ecology

Introduction

Roads form an integral part in connecting modern societies, but they have ecological consequences for many taxa, including invertebrates, such as insects (Muñoz et al. 2015). Road effects on insects mainly happen via four non-exclusive mechanisms, namely (1) by roads acting as sources of pollution, (2) forming dispersal barriers, (3) causing road-kills and (4) via the construction process itself. Roads can act as sources of pollution. For example, a host of studies from the 1970s and 80s—when unleaded gasoline was still commonly used—document increased lead levels in invertebrates, including insects, from areas of high traffic intensity (Robel et al. 1981). Dust emissions, on the other hand, are pollutants typically associated with unpaved roads (Spiess et al. 2020).

Roads can also alter insect behaviour, for example by posing substantial barriers to movement and dispersal in bees

(Fitch and Vaidya 2021), bumblebees (Bhattacharya et al. 2003), butterflies (Dennis 1986) and ground beetles (Keller and Largiadèr 2003). Road-kill plays a role in insect mortality, especially along roads with high traffic volumes (Melis et al. 2009) and speed limits (McKenna et al. 2001). Road-kills can, however, also happen along quieter dirt roads, when mud puddles attract butterflies, leading to invertebrate road-kill by slower-moving farm vehicles (Campioni et al. 2022). Lastly, road construction in itself not only leads to habitat destruction and alteration (Trombulak and Frissell 2000), but is also associated with disturbances, such as excavation, ground clearing and grading, which can alter the width of edge effects in invertebrate species (Lin 2015).

Here, we studied the effects of a gravel road in a South African grassland system on the abundance of ground-dwelling species within three common insect taxa: ants (Hymenoptera), true bugs (Hemiptera) and beetles (Coleoptera). We focus on ground-dwelling species as the distributions of flying species are less likely to be affected by relatively quiet gravel roads. In addition to being some of the largest insect orders, these three insect orders are also of ecological and economic importance. For example, both Hymenoptera and Coleoptera, specifically ants and dung beetles, play an important role in seed dispersal and nutrient cycling. Similarly, predatory species of both Coleoptera and Hemiptera are of economic value, as they function as

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biocontrol agents against pests. However, some species (within all three orders) are also commonly viewed as agricultural and horticultural pests themselves, damaging crops and plantations. Road effects have been documented on all three of these orders and can therefore potentially impact on their ecological roles. For example, beetles are typically negatively affected by roads (Keller and Largiadèr 2003; Noordijk et al. 2006; Yamada et al. 2010), which could have negative knock-on effects on seed distribution and nutrient cycling next to roads. Similarly, increasing aphid (Hemiptera) numbers have been associated with roadsides (Martinez and Wool 2006). Where pest aphid species are concerned, such findings have implications for where and how management efforts should be directed. Studying these three orders is therefore of interest to both fundamental and applied entomology.

Materials and methods

Study site

Field sampling was conducted at Telperion Nature Reserve (25.686°S, 29.012°E), South Africa (Fig. 1), in the summer season. Telperion is situated at the border of the Gauteng and Mpumalanga provinces and experiences warm, wet summers, with a mean December maximum of approximately 26 °C; and cool, dry winters, with a mean June maximum of approximately 17 °C. The reserve falls under South Africa's grassland biome (Mucina and Rutherford 2006), but also contains patches of open shrublands. The Wilge River, which connects the Tugela and Vaal River basins, flows through the reserve.

Sampling design

Forty-two transects, separated by 100 m, were established perpendicular to the road, along two sections of the main gravel road in the reserve (Fig. 1). The road along these sections is approximately 4 m wide. All transects were on the southern side of the road. Natural grassland vegetation occurs on either side of the road at both sections, with no obvious artificial relationship (e.g., because of clearing) between vegetation characteristics and distance from road at either section.

Each transect contained four sampling sites, at 2, 5, 10 and 20 m from the centre of the road. At each sampling site we placed a 1 L-bucket pitfall trap (13 × 12 cm) with a 50/50 mixture of propylene glycol and water to preserve and prevent the escape of individuals. After four days, pitfall trap contents were collected for identification. Upon collection, four pitfall traps had been upturned, one at each

distance, presumably by wild animals. These were not used in the analyses. Because one pitfall trap was coincidentally upturned at each of the four distances, this did not lead to unequal sample sizes. Therefore, excluding these pitfall traps did not introduce sampling bias. Lastly, as vegetation cover typically affects insect numbers (González et al. 2017), the percentage tree-, shrub-, grass- and bare soil cover was visually estimated at each sampling site, using a 4 m² quadrat.

Statistical analyses

Statistical analyses were performed for the three most abundant orders: Hymenoptera, Hemiptera and Coleoptera, which together comprised more than 90% of collected individuals. All statistical analyses were performed in R (version 4.2.2, R Core team 2022). The relationship between abundance and distance from the road was analysed using Generalised Linear Models (GLMs), using a Poisson distribution (appropriate for count data, Dunn and Smyth 2018) and the natural log as link function (implemented through the *lme4* package, Bates et al. 2015) for the three orders individually. Residual plots were used to assess model fits, and values for Hymenoptera and Coleoptera were log transformed to improve model fits. In addition to distance from road, the combined cover of shrubs and grasses (hereafter 'vegetation ground cover') was included as a covariate. Hypothesis tests (Wald Chi-square test) were carried out on GLMs to determine statistical significance (implemented through the *car* package, Fox and Weisberg 2019). Statistical significance was set at $p < 0.05$.

Results

In total 28 602 invertebrate individuals were collected in the 164 pitfall traps, of which more than 26 000 were of the three most common orders (Fig. 2). Hymenoptera (specifically ants) was the most abundant order by far (76% of all individuals), followed by Hemiptera (true bugs, 8.5%) and Coleoptera (beetles, 7.2%).

Ant and beetle abundance did not differ between distance categories (Table 1), but true bugs showed a significant negative relationship with distance from road, declining by approximately 30% across the distance transect (Fig. 2). None of the orders showed any relationships with vegetation ground cover (Table 1).

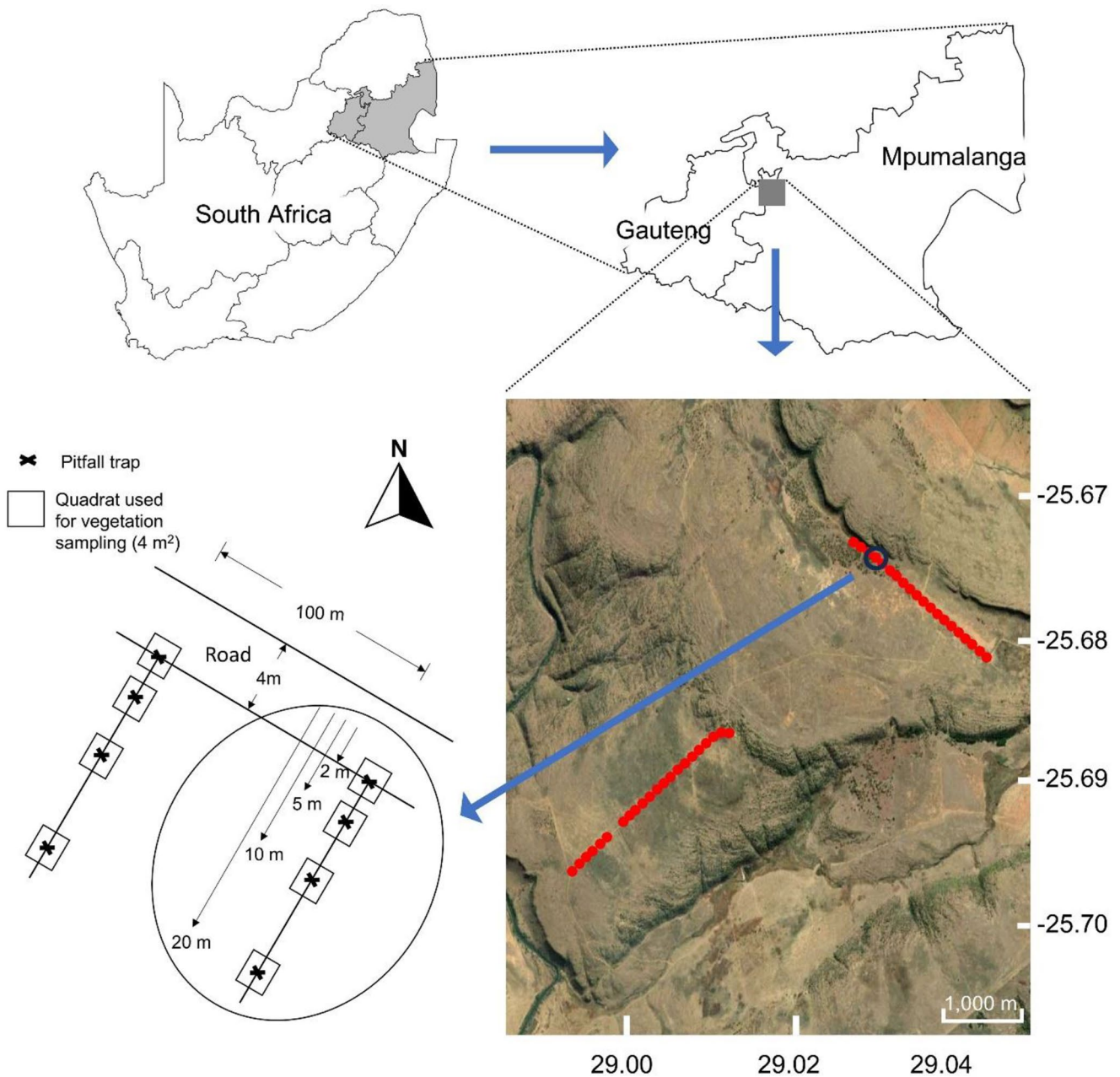


Fig. 1 The study sites. Location of the Gauteng and Mpumalanga provinces in South Africa (grey shaded area, upper left panel). Location of Telperion Nature Reserve on the borders of the Gauteng and Mpuma-

langa provinces (grey square). The 42 sampling transects (red dots) and the sampling design with distance from road (lower left panel, not drawn to scale)

Discussion

A number of studies have recorded the effects of roads on the ecology of invertebrates in the surrounding areas, also known as road-effect zones (Haskell 2000; Fitch and Vaidya 2021; Campioni et al. 2022). We intuitively expected the ecological effects of roads to be negative, but the results of these studies differ. Although the majority of studies suggest that roads indeed affect invertebrates negatively, there are

also studies that suggest negligible (Bhardwaj et al. 2019; Spiess et al. 2020), mixed (Ste-Marie et al. 2018) or even positive (Itzhak 2008; Melis et al. 2009) road effects on invertebrates. In our study there is no clear evidence of a negative road effect, with Hemiptera numbers even increasing closer to the road.

The most likely mechanism via which we believed the road at Telperion could affect invertebrate abundance, and which formed the impetus of our study, is through roads acting as barriers to dispersal (Haskell 2000; Bhattacharya

Fig. 2 Variation in insect abundance with distance from road (means \pm standard error) for **a** Hymenoptera **b** Hemiptera and **c** Coleoptera. Only Hemiptera showed a significant relationship between abundance and distance from road (GLM, $p < 0.05$). Values in italics above each bar show the number of sampling sites at which the group was present (total possible = 41)

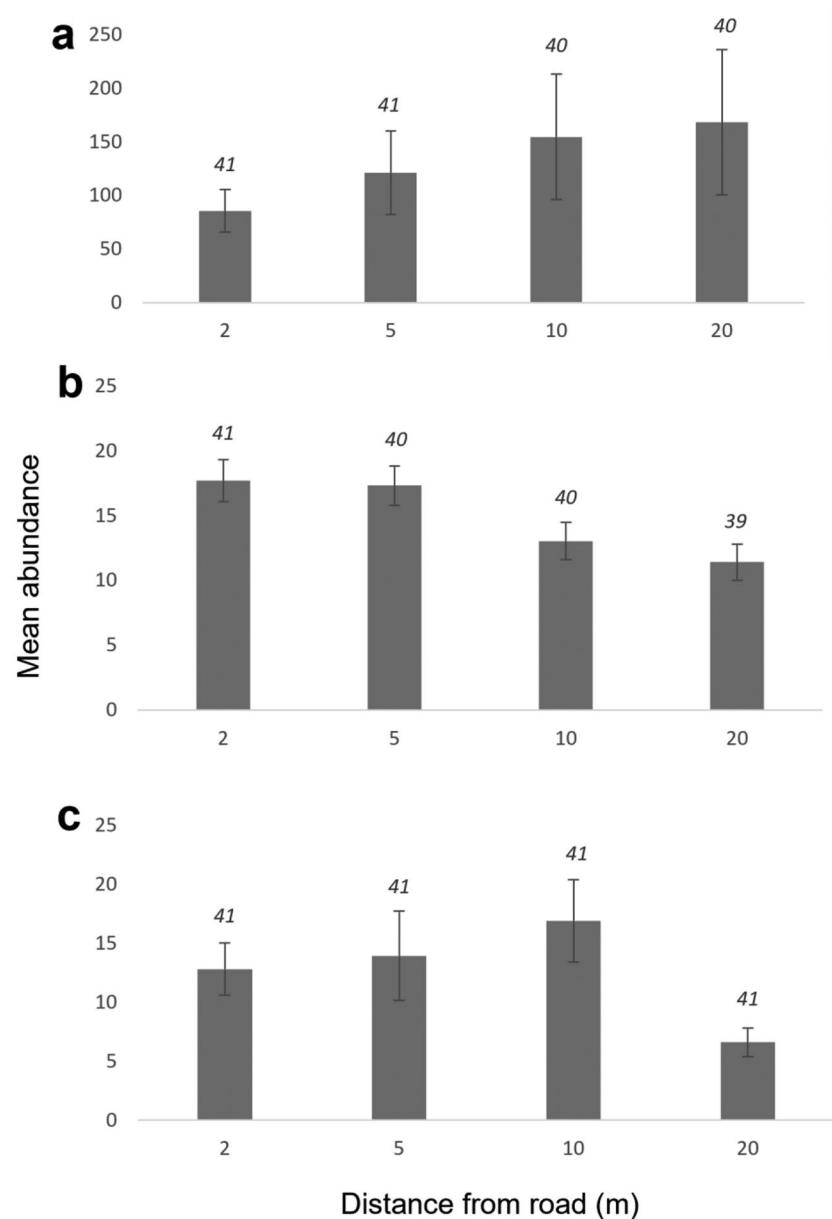


Table 1 GLM results for the three most common ground-dwelling insect orders

	Predictor							
	Distance from road				Vegetation ground cover			
	Coefficient	χ^2	df	<i>p</i>	Coefficient	χ^2	df	<i>p</i>
Hymenoptera	-0.002	0.33	1.161	0.568	0.002	2.52	1.162	0.112
Hemiptera	-0.028	75.42	1.161	<0.001	0.002	2.20	1.162	0.138
Coleoptera	-0.015	3.33	1.161	0.068	-0.002	0.49	1.162	0.484

Bold numbers highlight statistical significance at $p < 0.05$

et al. 2003; Fitch and Vaidya 2021), thereby fragmenting habitats. Beetles in particular have often been documented to struggle crossing roads (Koivula and Vermeulen 2005; Noordijk et al. 2006; Yamada et al. 2010). Fragmentation can also affect beetle abundance by changing the composition of edge and interior species near road sides (Knapp et al.

2013). In contrast to these studies, we found no significant change in beetle numbers with distance from road. Similarly, although mean ant numbers seemed to increase with distance from road, this was mostly the result of two exceptionally high samples, one at ten and the other at twenty

meters, and ant numbers were therefore not significantly affected by distance from road.

The road at Telperion is not very wide, with relatively low vehicle traffic. Although road effects on invertebrate movement (Fitch and Vaidya 2021), abundance (Luce and Crowe 2001) and composition (Melis et al. 2009) have also been recorded on relatively narrow or quiet roads and paths, such as ours, wider, busier roads typically have larger impacts (Dunn and Danoff-Burg 2007; Fitch and Vaidya 2021). Therefore, the severity of road impacts often depends on the characteristics of the road, which could explain the absence of negative effects in our study.

Road effects are also likely to vary depending on road type, i.e., gravel roads compared to paved roads. For example, Samways et al. (1997) attributed the high ant abundance, richness and diversity at a busy South African highway to roadkills, which attract ants. However, road kill is not associated with the relatively quiet gravel road at Telperion, which explains why we did not find similar ant effects. Beetles also appear to be quite tolerant to gravel roads, compared to paved roads (Dunn and Danoff-Burg 2007). Lastly, the road at Telperion was not constructed recently and disturbance associated with the road construction process itself therefore did not play a role. This could further explain the absence of a negative road effect in this study.

Interestingly, in our study, Hemiptera numbers increased closer to the road, implying a positive road effect for this order. There are relatively few relevant studies on Hemiptera specifically, as most studies either focus on insects in general, or on the more charismatic orders, such as Odonata, Lepidoptera and Coleoptera (Muñoz et al. 2015). However, our Hemiptera findings are comparable to a number of other studies in other geographic regions. For example, Luce and Crowe (2001) also found increased Hemiptera abundance closer to a quiet gravel forest road in Canada, and Martinez and Wool (2006) found increased aphid numbers next to a relatively low traffic road in a Mediterranean forest in Israel.

Roadsides seem to benefit aphids specifically (Przybylski 1979; Braun and Flückiger 1984, 1985; Martinez and Wool 2006; Cohen et al. 2021). In fact, Przybylski (1979) describes aphids and members of Heteroptera, both groups within the Hemiptera order, as “flourishing” close to roads (Przybylski 1979, page 161). Increasing insect numbers next to roads have been attributed to the redistribution of water– and as a consequence vegetation– next to roads (Cohen et al. 2021), biochemical changes within plants closer to roads (Przybylski 1979; Braun and Flückiger 1984, 1985), changes to interspecific competition next to roadsides (Samways et al. 1997), as well as reduced predator efficiency next to roads (Przybylski 1979; Braun and Flückiger 1984, 1985).

The applicability of our findings to other systems may depend on factors such as local vegetation type and insect

community composition. Although we did not find local vegetation type (shrub, tree, grass and bare soil cover) to affect insect abundance in any of the orders in our study, shrub cover plays an important role in severely water-limited systems, such as the Negev Desert (Cohen et al. 2021). In these systems, roads can redistribute water, increasing shrub cover next to the road and attracting aphids. In terms of community composition, disturbance-tolerant species tend to dominate roadsides, which would naturally lead to an increased road effect in systems dominated by such species.

We were not able to identify samples to species level in this study. This is a limitation of our study. If we had been able to key individuals to species, or even family level, we may have been able to shed light on the reasons behind our own Hemiptera findings. Future studies should incorporate species- or preferably family-level identifications. However, our results are in general alignment with previous studies and support this notion that roadsides may be favourable habitats for species within the Hemiptera order.

In conclusion, the results presented here suggest that relatively quiet dirt roads do not affect insect abundance of the orders Hymenoptera or Coleoptera, but increase abundance within the order Hemiptera. This was contrary to our initial expectations that roads would have negative effects, but in line with previous studies. Although our study is a relatively small case study, it contributes toward necessary research on the most diverse, but understudied group of animals within roadside ecology– the insects.

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Declarations

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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