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Abundance of aerially-dispersing spiders declines with increasing road traffic

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ABSTRACT
Roads and traffic have been implicated in population declines in a number of taxonomic groups. However, there is little research into the potential effects of roads or traffic on spiders. Here, we tested the prediction that there would be fewer aerially-dispersing (i.e., ballooning) spiders at high-traffic than low-traffic roads. We used custom-made sticky traps attached to a vehicle to collect ballooning spiders along 10 high-traffic–low-traffic rural road pairs in southeastern Ontario, Canada. We collected half as many spiders at high-traffic than low-traffic roads. This provides the first published evidence of negative traffic effects on ballooning spiders. Although consistent with our prediction that ballooning spiders are less abundant at high-traffic roads, there are several possible explanations for this finding. Further study is needed to investigate these explanations, including whether the observed traffic effect reflects reduced population sizes near high-traffic roads or reduced ballooning behaviour near high-traffic roads. If the former, then roads may represent a significant conservation concern for ballooning spider species.

RÉSUMÉ
Les routes et le trafic sont impliqués dans le déclin des populations de plusieurs groupes taxonomiques. Cependant, peu de recherches ont été effectuées sur l'effet potentiel des routes ou du trafic sur les araignées. Nous avons testé la prédiction qu'il y aurait moins d'araignées dispersées par le vent sur les routes à trafic élevé que sur celles à faible trafic. Nous avons utilisé des trappes collantes attachées à un véhicule pour collecter les araignées dispersées par le vent le long de 10 paires de routes rurales à trafic élevé-faible dans le sud-est de l'Ontario, Canada. Nous avons collecté moitié moins d'araignées sur les routes à trafic élevé et fournissons ainsi la première preuve publiée d'un effet négatif du trafic sur les araignées à dispersion aérienne. Toutefois, des recherches supplémentaires sont requises pour évaluer les explications possibles, par exemple si l'effet du trafic reflète une taille de population réduite près des routes à trafic élevé ou une diminution du comportement de dispersion aérienne. Si la première explication s'avérait être la bonne, les routes représenteraient alors un enjeu de conservation pour les araignées à dispersion aérienne.

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Introduction

Effects of roads and traffic on wildlife have been extensively studied in vertebrates (Fahrig and Rytwinski 2009; Rytwinski and Fahrig 2012), and there is a growing body of work looking at their effects on insects (Muñoz et al. 2015). For example, Fahrig et al. (1995) studied the effects of traffic intensity on the frequency of road kill and on local abundances of frogs and toads. Skórka et al. (2013) similarly studied effects of traffic intensity, as well as road width, on road kill frequency and local abundances of butterflies. Effects of roads on animal behaviour have also been studied. For example, Ford and Fahrig (2008) experimentally tested for effects of traffic intensity on the likelihood that a translocated chipmunk (*Tamias striatus*) would avoid crossing a road.

However, to date there has been little research into the potential for negative effects of roads and traffic on spiders (Araneae). A few road kill studies confirm that spiders are killed on roads (Seibert and Conover 1991; Seshadri and Ganesh 2011), and Maurer (1974) reported that spider species richness was lower along high-traffic than low-traffic roads.

In this study we focus on the potential effect of traffic intensity on the abundance of aerially-dispersing spiders, because spiders making long-distance dispersal movements are more likely to interact with roads than those making short-distance non-dispersal movements. Aerially-dispersing spiders move passively through the air by 'ballooning', i.e., by releasing one to several silk lines into the wind which allow the individual to achieve the drag-

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induced lift necessary to become (and stay) airborne (Bell et al. 2005).

Roads and traffic could negatively affect ballooning spider species in a number of ways, the most direct of which is that spiders are killed on roads (Seibert and Conover 1991; Seshadri and Ganesh 2011). Simulation modeling of linyphiid spider population dynamics in agricultural landscapes demonstrated that sufficiently high probabilities of mortality during ballooning could reduce the probability of population persistence (Johnson 2010). Theoretical study has also shown that if road kill represents a sufficiently large proportion of the local population, over time it could depress the local population size (Zimmermann Teixeira et al. 2017). Empirical studies similarly suggest that road mortality can have population-level effects in a number of taxonomic groups, including birds (Jack et al. 2015), amphibians (Fahrig et al. 1995), and insects (Martin et al. 2018). Thus road mortality could similarly affect spiders by depressing local population sizes.

Alternatively, roads and traffic could influence spider behaviour by affecting the propensity of spiders to disperse via ballooning. For example, ballooning is strongly dependent on meteorological conditions, including wind speed, air temperature, and humidity (Rensch et al. 2008; Simonneau et al. 2016), and road traffic may decrease dispersal propensity by disrupting the microclimatic conditions necessary for initiation of ballooning. For example, frequent vehicle passage results in turbulence and higher local wind speeds. This could reduce the probability of ballooning because spiders do not typically disperse at wind speeds greater than ~3 m/s (e.g., Suter 1999; Simonneau et al. 2016).

We predicted fewer ballooning spiders at high-traffic than low-traffic roads. To test this prediction we sampled ballooning spiders at 10 pairs of road segments in rural southeastern Ontario, Canada. Each road pair included one high-traffic and one low-traffic road. Roads within pairs had similar road characteristics and similar surrounding landscape context. We used custom-made sticky traps attached to a pickup truck (Figure 1) to collect ballooning spiders moving directly over the roads at approximately vehicle height, to index relative abundance of ballooning spiders at risk of vehicle collisions. For a given traffic volume, the number of spiders colliding with a vehicle should be lower when there are fewer ballooning spiders in the local population or when ballooning rates are reduced. Thus our prediction would be supported if there were fewer spiders collected per vehicle on high-traffic than low-traffic roads.

Figure 1. Vehicle-mounted sticky traps attached to the front grill (0.5 × 1.2 m area) and roof (0.3 × 1.2 m) of a pickup truck. A sticky trap had a plywood frame which was secured to the truck using ratcheting straps. We inserted a thin board covered in heavy plastic wrap into that frame and applied Pestick (Phytotronics, Inc., Earth City, Missouri, USA) to the exposed area of plastic wrap. The surface area of each trap was subdivided into six equal-area portions.

Materials and methods

Site selection

We selected 10 pairs of roads with contrasting traffic intensities, but similar road characteristics and landscape context (see also Martin et al. 2018). To do this, we first selected the 10 high-traffic road segments (where a road segment is a stretch of road between two cross-streets). Each segment was 1–3 km long, 2-lane, paved, and in a rural area with < 15 houses/km^2 within a 250 m radius around the road segment. Then we selected a low-traffic road segment to pair with each high-traffic segment, ensuring that the low-traffic road segment met the following criteria. First, it had to be 1–3 km long, 2-lane, paved, and rural. Second, it had to have a similar landscape context to its paired high-traffic road segment, i.e., a ≤ 0.1 difference in the proportion of forest, ≤ 0.1 difference in the proportion of wetland, ponds, streams, and rivers, and ≤ 5 houses/km^2 difference in the number of houses within a 250 m radius around the road segment.

Third, it had to be < 10 km from its paired high-traffic road segment. The thresholds used to select paired roads represented a trade-off between minimizing differences between roads within a pair and the likelihood of finding at least 10 road pairs that met our criteria within the study area. Road segment lengths, forest cover, water cover, and housing density were derived from land cover data obtained from the Ontario Ministry of Natural Resources and Forestry (Peterborough, ON, Canada). We estimated traffic volumes at each road segment during the field season, and confirmed that high-traffic roads had significantly greater traffic volumes than low-traffic roads within our 10 road pairs (two-tailed, paired $t_9 = -4.66$, $P < 0.001$; Martin et al. 2018).

Spider sampling

We sampled ballooning spiders along each road segment, using two custom-made sticky traps attached to a pickup truck (Figure 1). We attached one sticky trap to the front grill of the truck and the other to the roof. The front grill and roof sticky trap dimensions were 0.5 × 1.2 m and 0.3 × 1.2 m, respectively. A sticky trap had a plywood frame secured to the vehicle using ratcheting straps. We inserted a thin board covered in heavy plastic wrap into that frame and applied Pestick (Phytotronics, Inc., Earth City, Missouri, USA) to the exposed area of plastic wrap.

Each road segment was sampled once between June and mid-July 2014 and again between mid-July and September 2014, between 1200 and 1700 on rain-free days with a temperature > 15°C and wind speed < 20 km/h. Paired road segments were sampled within one week of each other, and the order in which pairs – and road segments within pairs – were sampled was random. Sampling order within a given day was also randomized. Thus there were no systematic differences in sampling dates or times between high-traffic and low-traffic roads. Road segments were driven twice per survey at a consistent speed – ~80 km/hr – to keep sampling conditions between the high-traffic and low-traffic roads as consistent as possible. However, we were unable to keep road segment lengths consistent across roads: road segment lengths ranged from 1–3 km. Therefore, the distance driven per survey per road segment varied from 2–6 km.

To account for differences in road segment lengths between high-traffic and low-traffic roads, we standardized sampling effort across road segments by sampling less of the sticky trap surface area on longer road segments. We divided the surface area of each sticky trap into six equal-area portions. For each 0.5 km increase in the road segment length, we excluded one section (selected at random) of the grill sticky trap and one section (at random) of the roof sticky trap from sampling. Thus the full sticky trap area was sampled when the road was 1 km long and 1/3 of the area was sampled when the road was 3 km long. We note that there was no difference in road segment lengths between the high-traffic and low-traffic road segments within each road pair (two-tailed, paired $t_9 = -0.14$, $P = 0.89$), and no relationship between the number of collected spiders and road segment length (Spearman $\rho = -0.24$, $P = 0.31$). Thus we are confident that this subsampling procedure did not bias estimates of the relative abundance of ballooning spiders at high-traffic versus low-traffic roads.

Analysis

We tested whether there were fewer spiders captured by our vehicle-mounted sticky traps on high-traffic than low-traffic roads using a paired, one-tailed t-test assuming unequal variances (in R version 3.4.3, R Foundation for Statistical Computing, Vienna, Austria). The number of spiders collected per road segment was the summed count for the roof and grill sticky traps for the two surveys.

Results

In total, we collected 39 spiders with the vehicle-mounted sticky traps, 10 on the roof sticky trap and the other 29 on the grill sticky trap. Twenty spiders were collected during the first sampling period (June–mid-July 2014) and the other 19 during the second sampling period (mid-July–September 2014).

As predicted, there were significantly fewer spiders captured on high-traffic than low-traffic roads ($t_9 = 1.82$, $P = 0.05$); we captured half as many spiders on high-traffic roads ($n = 13$) than low-traffic roads ($n = 26$; Figure 2). Five of the 10 road pairs had fewer spiders on the high-traffic road, three had equal numbers of spiders on high-traffic and low-traffic roads, and two had more spiders on the high-traffic than low-traffic road (Figure 2).

Discussion

Ballooning spiders were less abundant at high-traffic than low-traffic roads. This is consistent with declines in the abundance of flying insects with traffic intensity that we observed at these same sites (Martin et al. 2018). We attribute the lower abundance of spiders at high-traffic than low-traffic roads to the traffic itself. This is because we controlled for potentially confounding variables that could be correlated with both traffic intensity and spider abundance, including characteristics of the road (road substrate, road width) and the local landscape context (forest cover, water cover, housing density).

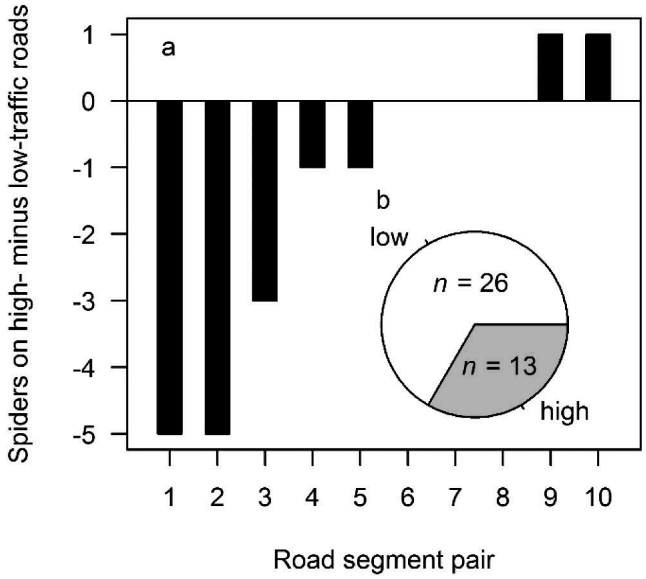

Figure 2. Effect of traffic intensity on the number of spiders collected by vehicle-mounted sticky traps, measured as: a. the difference in the number of collected spiders on high-traffic minus low-traffic roads within each of the 10 road segment pairs, where negative values indicate that there were fewer spiders at high-traffic than low-traffic roads; and b. the total number of collected spiders across all high-traffic and low-traffic roads.

The total number of spiders we captured was small (39). Thus our results must be viewed with caution until further work confirms the effect we documented. However, we also note that the effect size we observed – a 50% decline at high traffic roads – was large. Given this, and given that this is the first study of traffic effects on ballooning spiders, we feel the results merit some consideration.

There are several possible explanations for the observed negative effect of traffic on the abundance of ballooning spiders. To our knowledge, these are as-yet untested. Thus, in addition to future work to confirm the effect of traffic intensity on ballooning spiders, future study is needed to determine the mechanism(s) underlying this effect. Potential explanations are related either to an effect of road traffic on local spider abundances or to an effect of road traffic on spider behaviour. Effects on local population size could occur if greater rates of road mortality at high-traffic than low-traffic roads depress local population sizes more along high-traffic roads than low-traffic roads (Zimmermann Teixeira et al. 2017). Alternatively, higher traffic may reduce local populations due to increased local pollution levels (Wheeler and Rolfe 1979; Aldrin and Haff 2005; Gilbert et al. 2005). Indeed, abundance declines in some spider taxa have been observed with increasing proximity to heavy metal pollution (Koponen and Koneva 2005; Zolotarev 2009). If spiders are similarly sensitive to road-related pollutants, greater pollution levels at high-traffic than low-traffic roads may result in smaller local population sizes along high-traffic roads than low-traffic roads.

Reduced numbers of ballooning spiders might also result from a behavioural response to high traffic, reducing the likelihood of sampling spiders on our vehicle-mounted sticky traps. In particular, high traffic intensities may reduce the propensity of spiders to disperse via ballooning due to high air turbulence from frequent vehicle passage (Suter 1999; Simonneau et al. 2016). Turbulence caused by airflow around vehicles might also direct ballooning spiders away from roads rather than across them, reducing the number captured on our sticky traps. Other factors that could affect ballooning behaviour are food availability and habitat disturbance. Starvation may increase spider dispersal propensity (Bonte et al. 2008; Mestre and Bonte 2012). However, for this to explain our lower capture rate of spiders at high-traffic than low-traffic roads there would need to be more prey available at high-traffic roads. It is not clear whether we should expect this to be true: for example, although Melis et al. (2010) found more insects at high-traffic than low-traffic sites, Martin et al. (2018) found the opposite. Spiders may also be more likely to balloon in areas with more frequent habitat disturbance (Entling et al. 2011). For this to explain our lower capture rate of spiders at high-traffic than low-traffic roads there would need to be less frequent disturbances at high-traffic roads. We have no evidence that habitat disturbance rates are lower at our high-traffic roads.

We also note that the two groups of possible explanations – reduced population sizes and reduced ballooning behaviour at high-traffic roads – are not necessarily independent. It is possible that a reduction in ballooning behaviour could translate into a smaller population size if reduced dispersal leads to declining population growth rates through, for example, reduced access to habitat or other resources (e.g., mates; Shine et al. 2004; Eigenbrod et al. 2008), inbreeding depression resulting from population isolation (Holderegger and Di Giulio 2010), or lower rescue of small populations (Hels and Nachman 2002). Road kill could exacerbate these effects if spiders adapt to the higher risk of dispersal mortality by decreasing their propensity to disperse. Previous studies suggest that spiders reduce their dispersal propensity in response to increasing risks of dispersal. For example, Bonte et al. (2006) found that spiders were more likely to balloon if they were from a landscape with ample, contiguous habitat (i.e., 400 ha of continuous grassland) versus a landscape with less and more fragmented habitat (grassland fragments of 1.41 ha ± 0.41 SE, considered to be 'moderately' connected to one another by the authors). And spiders were least likely to balloon in the landscape with the least habitat (0.48 ha with no populations within 20 km). This is probably because ballooning is most risky in the latter landscape type: spiders are less likely to find suitable habitat when there is less habitat.

It is also possible that density-dependent ballooning behaviour – where spiders are more likely to balloon away from higher-density populations (De Meester and Bonte 2010) – could increase the apparent difference in observed abundances at high-traffic and low-traffic roads. If local spider population densities are somewhat depressed along high-traffic roads (for any of the reasons discussed above) and fewer spiders balloon in low-density populations, then the smaller number of ballooning spiders observed at high-traffic roads could reflect not only the smaller local population size but also a lower per capita dispersal propensity.

The work presented in this paper is a first step towards understanding the potential effects of traffic intensity on ballooning spiders. We offer these speculations as to the causes of the observed effect (above) in the hopes that this will inspire future research in this area. For example, to test the road mortality hypothesis the next step could be to determine whether ballooning species with the highest per capita probabilities of road mortality are also the species with the strongest declines in response to traffic intensity. If supported this would suggest that road mortality was negatively affecting the abundance of ballooning spiders.

If future study does show that traffic reduces local ballooning spider population sizes near roads then this is of conservation concern. The already extensive global network of ~21.6 million km of roads is projected to increase by 14–21% (3–5 million km) by 2050 (Meijer et al. 2018). Increasing traffic associated with this growing road network could put spider populations at risk. This is of concern not only because spiders contribute to global biodiversity but also because spiders provide ecosystem services such as pest control (Nyffeler and Sunderland 2003).

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