SHORT COMMUNICATION

Assessing the dispersal of spiders within agricultural fields and an adjacent mature forest

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Abstract.   A manipulative experiment was done in corn fields and their adjacent forests using enclosures that restricted access to ground-dwelling spiders. Enclosures were either closed from the adjacent habitat but open to ballooning and ground-dwelling spiders (using holes cut in the side of enclosures) or were open plots (controls). This allowed us to test the role of ballooning compared to cursorial dispersal of ground-dwelling spiders within these habitats. A reciprocal substrate treatment was included in which leaf-litter was added to cornfields and removed from forests to test the interaction between mode of dispersal and habitat use. Ninety species were collected using visual surveys and with pitfall traps. More species were collected in cornfields, and more individuals were collected in litter-addition plots, but we uncovered no interaction between substrate treatment and enclosure type. However, enclosures that excluded cursorial spiders had fewer mature and immature spiders, suggesting that cursorial activity (at a small spatial scale) is an important mode of dispersal within both types of habitats.

Keywords: Agroecosystems, ballooning, dispersal, substrate manipulation

Understanding how spiders (Araneae) colonize agroecosystems is important since sustaining viable populations of generalist predators is a key attribute of effective integrated pest management (e.g., Snyder & Wise 1994; Schmidt et al. 2004). Spiders (Araneae) are ideal for such research since they have distinct methods of dispersal (i.e., cursorial or ballooning) that allow for experimental manipulation. Manipulative experiments to quantify their mode of dispersal and to assess their need for surrounding habitats as permanent refuge are required.

It has been suggested that spiders normally found in agroecosystems take refuge in surrounding natural landscapes during periods of cultivation and disturbance (e.g., Halley et al. 1996; Wissinger 1997), and the colonization of spiders from natural habitat to agroecosystems is thought to be significant. For example, spiders common to agroecosystems have been found to move from weed strips to cereal fields in the spring (Lemke & Poehing 2002) and the proportion of spider webs in cereal fields correlates with the proportion of surrounding non-crop habitat (Schmidt & Tscharntke 2005a). There is some evidence for differences in spider assemblage patterns in natural landscapes such as woodland and old-fields adjacent to cultivated land (Riechert & Bishop 1990; Samu & Szinetar 2002) bringing the importance of such landscapes as spider reservoirs in doubt. Assemblage differences, however, can fluctuate depending on the time of year. For instance, dominant arable species have been found to be more abundant in permanent grassland in early spring indicating a dependence on natural habitat (Schmidt & Tscharntke 2005b).

Spider colonization of agroecosystems may occur more commonly via long distance colonization events (i.e., ballooning) rather than short distance methods (cursorial) (Bishop & Riechert 1990; Schmidt & Tscharntke 2005b). Conservation biological control has also been promoted as a method for increasing populations of spiders in agroecosystems (e.g., by providing artificial habitat refuges, see Halaj et al. 2000). However, whether movement of spiders into agroecosystems is via ballooning compared to cursorial activity requires further study. It is therefore of interest to understand the interaction between habitat refugia and dispersal mode within agroecosystems, and to test if dispersal differs in natural habitats compared to agricultural fields.

We studied the modes of dispersal by spiders and their effects on community structure and abundance within cornfields and adjacent mature deciduous forests in SW Quebec. We tested whether spider assemblages used cursorial or ballooning as a main method for dispersal within these habitat types. We also included a reciprocal substrate treatment to establish whether an interaction occurred between substrate type and mode of dispersal. This treatment is included in light of the use of habitat refugia to promote spiders in agroecosystems (e.g., Halaj et al. 2000), and since some spider species in agroecosystems show affinities to such refugia (Buddle & Rypstra 2003).

METHODS

Our study area is located adjacent to the Morgan Arboretum (Ste-Anne-de-Bellevue, QC Canada, approximately 45.42°N, 73.95°W). The experiment used three mature deciduous forest sites (approximately 50 years old, dominated by *Acer saccharum, A. rubrum*, and *Fagus grandifolia*; sites were greater than 300 m apart) bordering operational cornfields (operated by the Macdonald Campus Farm, McGill University). The cornfields were subject to early and mid-season herbicide applications and conventional tillage in the spring and fall.

To assess mode of dispersal, we used circular aluminium enclosures (30 cm height, diameter of 0.70 m, 0.38 m^2 in area) dug into the ground so 25 cm remained aboveground. The upper ring (a band 3 cm wide) was treated with TangleFoot®. We had three levels of this treatment: no holes (to prevent cursorial dispersal but allow ballooning spiders), holes (triangles with 5 cm sides were cut at ground level to allow for cursorial dispersal in addition to ballooning; six of these were cut, meaning about 18% of the perimeter was open to cursorial spiders), and control (no enclosures). These treatments were replicated twice within the forest and field and at three different sites. The enclosures were placed between rows of corn just after planting. The above treatment was nested with two substrate treatments to test the effect of substrate type on the overall assemblage, and to test for potential interactions between dispersal mode and substrate type. Therefore, each set of three enclosures was placed within an area of 8.1 × 3.7 m. The substrate treatment was

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reciprocal, and had two levels: Litter addition (leaf litter was moved from the forest and added to the field), and litter removal (litter was removed from the forest, by raking away all detritus, LFH layer). Litter was sifted and kept overnight before addition to the field. Some spiders, therefore, may have been accidentally introduced in the field but observations suggest these were minimal. Thus, there were 72 enclosures in total: three enclosure treatments × two substrate treatments × two replicates × three sites × two habitat types. Vertical structure increased over the growing season due to corn and weed growth, and this structure likely interfered with dispersal of spiders into enclosures. Therefore, ballooning and cursorial spider activity may have been underestimated in the field compared to the forest as vertical structure in the forest varied less over time.

Spiders were sampled using pitfall traps and with visual surveys. One pitfall trap (circular, transparent plastic: 7 cm diameter, 9.5 cm height, filled with 2–3 cm of propylene glycol diluted 3:1 with water) was placed in the center of each enclosure. Traps were accommodated with a circular shelter 10 cm in diameter, held above the traps using nails. The traps were installed on 4 June 2004, and collected on a bi-weekly basis from 16 June–25 August 2004 (i.e., 71 days of continual trapping). Visual collections were done weekly (10 min per enclosure) using an aspirator, and we attempted to perform all visual surveys between 06:00–12:00 h. Samples were sorted and stored in 70% ethanol. All adult spiders were identified to species (nomenclature followed Platnick 2007) and immature spiders were identified to family, primarily using the key by Paquin & Dupérré (2003). Voucher specimens have been deposited in McGill University's Lyman Entomological Museum (Ste-Anne-de-Bellevue, Quebec, Canada).

We used a 3-Factor nested ANOVA (i.e., enclosure treatments nested within substrate treatment and substrate treatment nested within habitat) to test our response variables (total abundance, immature abundance and mature abundance). Fixed factors were habitat (forest or corn field), substrate type (litter addition/removal or control) and enclosure type (holes, no-holes, control), and all possible interaction terms were tested. Data were tested for normality, and log-transformed when necessary. SAS for Windows (Version 5.1, SAS Institute, Cary, North Carolina) was used for ANOVA analyses, and post-hoc comparisons of means was done using Tukey's test ($P = 0.05$). Rarefied estimates of species richness were compiled to compare the influence of the treatments on species richness standardized to sampling effort (number of individuals) (Gotelli & Colwell 2001; Buddle et al. 2005); ECOSIM (Gotelli & Entsminger 2004) was used to calculate rarefaction curves. Ordination analysis (non-metric multidimensional scaling, NMS) was completed on species presence-absence data, to determine patterns of similarity in community composition in relation to treatment types. This was done with the software program PCOrd (McCune & Mefford 1999).

RESULTS

A total of 1891 individual spiders representing 90 species was collected (A.C. Hibbert & C.M. Buddle. 2007. List of spider species collected at the Morgan Arboretum, available online at http://insectecology.mcgill.ca/spider_list.pdf). Visual surveys accounted for over half of the spiders collected compared to pitfall traps (1230 and 661 individuals, respectively). Of the total number of individuals, 70% were immature spiders. Immature spiders represented approximately 70% of the total abundance in enclosures with no holes, indicating immature spiders were the most common ballooning colonizers, an inference supported in the literature (Greenstone et al. 1987). Most species were rarely collected, given that an average of 6 specimens per species was found.

ANOVA results indicated non-significant interaction terms for both immature and mature spider catch rates. Habitat type (forest versus corn field) had no effect on catch rates of immature or adult spiders ($P = 0.684$ and $P = 0.968$, respectively), but substrate treatment and enclosure type had significant main effects on catch
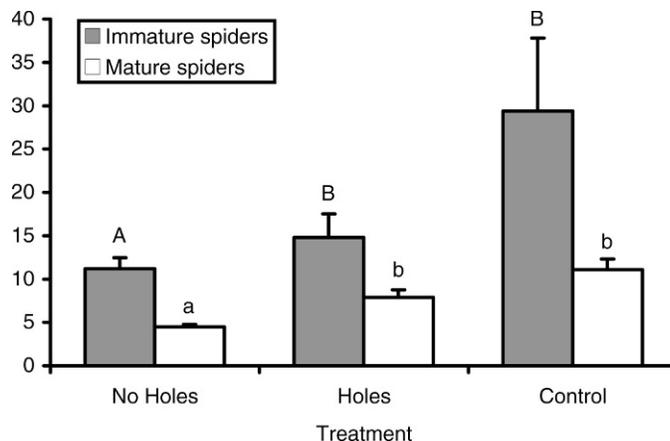

Figure 1.—Mean (± SE n = 24) number of spiders collected by pitfall traps and visual surveys (pooled by collection time), by enclosure type (control: no enclosure; holes: enclosure in place but accommodated with holes for access from ground-dwelling spiders; no-holes: enclosures in place but no access for ground-dwelling spiders). Significant difference of means (Tukey's post-hoc test) indicated by different letters for comparisons between treatments for each response variable (immature or mature spiders) analyzed separately. In this Figure, data from field compared to forest samples and substrate treatments are pooled since non-significant interactions were uncovered.

rates. Immature spiders were most commonly collected in substrate treatments with leaf litter compared to no-litter treatments (mean ± SE: litter, 25.5 ± 6.03 spiders; no litter, 11.42 ± 2.58 spiders; $F_{1,8} = 7.92$; $P = 0.023$, $n = 36$). There was no effect of substrate type on adult spiders (litter, 9.11 ± 0.78 spiders; no litter, 6.5 ± 0.87 spiders; $F_{1,8} = 4.69$; $P = 0.062$, $n = 36$). Fewer immature and adult spiders were collected in enclosures without holes compared to holes and control (Fig. 1).

Rarefied estimates of species richness demonstrated that the number of species was not affected by substrate type (mean ± S.D: litter, 63.02 ± 2.34 species; no litter, 61.57 ± 0.61 species, sample effort of 230 individuals) or enclosure treatment (control, 41.70 ± 2.84; holes, 37.39 ± 2.32; no holes, 46.34 ± 1.12, sample effort of 100 individuals). The number of species (observed) was affected by habitat type, as more species were collected in the cornfield (64 species) compared to the forest (57 species), a pattern supported by rarefied estimates of species richness (cornfield, 62.74 ± 1.60 species; forest, 56.10 ± 0.92, sample effort of 270 individuals). The NMS ordination analysis found a weak pattern (i.e., high final stress, only 59% variance explained by three axes) demonstrating that species assemblages within the forest and cornfield differ from each other (Fig. 2); when coded according to treatment types, no structure to the species data was discovered (not shown).

DISCUSSION

Catch rates of mature and immature spiders were lowest in enclosed treatments, where arrival only by ballooning was allowed to occur. This indicates that ground dispersal contributed significantly to the arrival of spiders in both habitats in this study (i.e., the same effect was uncovered in the forests as within the corn field). This is in contrast to what has been found in small garden plots (Bishop & Riechert 1990) and on Sagebrush (Ehmann 1994) where ballooning was found to be the most important means of arrival.

If cursorial activity is assumed to be an important type of short distance travel, adjacent mature forest edges have the potential to act
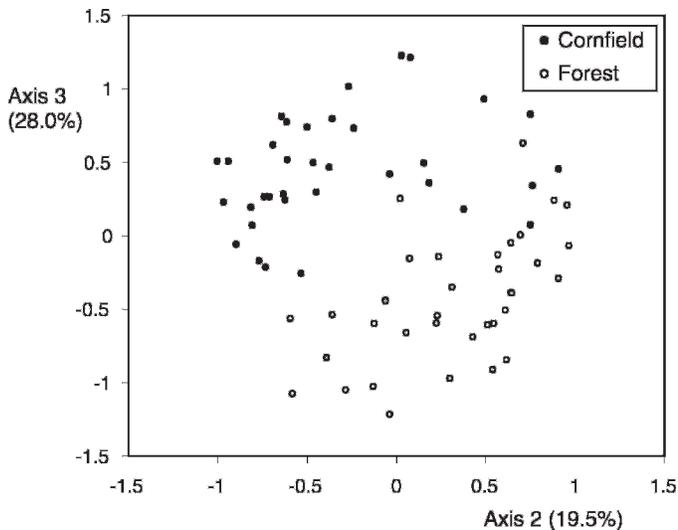
Figure 2.—Non-metric multidimensional scaling (NMS) ordination depicting samples (i.e., individual enclosures) coded by habitat (forest compared to cornfield) based on presence absence data for 90 spider species. A three dimensional NMS ordination was deemed optimal, but axis one represented 11.5% of the variation and depicting the 3-dimensional solution did not change the pattern; therefore, only axes 2 and 3 are depicted. Fifty-nine percent of the total variance is explained by the ordination; solution is based on 20 iterations with real data, 44 iterations total and final stress was 21.2. Monte-Carlo permutations ($n = 100$) indicated each axis was significantly different ($P < 0.01$) than would be expected by chance. The solution from a detrended correspondence analysis (DCA) was used as the starting coordinates for the final NMS solution.

as important ''reservoirs'' for spider dispersal within agroecosytems, at least at small spatial scales, and at this scale such reservoirs may be as critical as more distant and/or permanent refuges. This does, however, depend on the size of potential reservoirs and on the area of cultivated land. Although the ordination did reveal community composition differences between the forest and corn field, this multivariate analysis explained little of the total variation in the species by sample matrix (Fig. 2). Adjacent mature forests may therefore share enough in common with cornfields to maintain or retain populations of spiders throughout the growing season. Species data by habitat type are available as an online appendix (http://insectecology.mcgill.ca/spider_list.pdf).

Immature spiders responded positively to leaf-litter additional treatments. Leaf litter presumably provides optimal conditions for young spiders, and adding it to agroecosystems may promote their numbers, a finding consistent with Halaj et al. (2000). It is possible, however, that the abundance of immature spiders was overestimated if egg sacs had been transferred with the litter to the cornfield. Due to the difficulty in identifying immature spiders to species, assemblage differences were not fully determined, and community composition may overlap more between forests and agroecosystems if immature spiders are taken into account.

Our results indicate that dispersal by mature and immature spiders within corn fields and within mature forests bordering these fields occurred often via cursorial activity. Even though the spider assemblage of our forests was different than the corn fields, it is possible that some of the species move from the adjacent habitat to the agroecosystem and adjacent forests may play a role in facilitating short-distance faunal recolonization of agroecosystems.

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