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RESEARCH ARTICLE

The influence of land use, microhabitat and aquatic insect subsidies on predatory riparian arthropod distributions

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Abstract

Agricultural land use effects on aquatic and riparian communities are complex and multifaceted, resulting in habitat degradation and biodiversity loss in riparian and instream ecosystems. This study correlated predatory arthropod densities and species richness to abundance of potential prey (emerged aquatic insects and terrestrial dipterans) along an agricultural to forested land use gradient. Pearson's correlation coefficient was used as an effect size to measure attraction to prey, and the ratio of predator to prey was calculated to indicate potential consumption capacity of prey. Results revealed that gradients in land use and microhabitat condition, distance from the stream and season were important explanatory factors. Positive correlations between predatory arthropods and aquatic insect abundance were more apparent than those with terrestrial dipteran abundance, suggesting an overall preference of aquatic prey. However, positive correlations between predatory arthropods and adult aquatic insect subsidies were strongest in microhabitats with characteristics associated with higher moisture (e.g., greater soil organic matter and shade), particularly with increasing agricultural land use. In September, there was an indication of reduced confinement to microhabitats, likely as an effect of elevated seasonal precipitation. Overall results of this study suggest that a limited tolerance to desiccation in predatory arthropods increases spatial confinement with agricultural land use and ultimately restricts access to adult aquatic insect subsidies. The findings of this study have implications for the pathways that adult aquatic insect subsidies use to enter into riparian food webs with consequences that could cascade across trophic levels and larger spatial scales.

Keywords Agriculture · Predatory arthropods · Aquatic insect subsidies · Microhabitat · Riparian · Stream

Introduction

Predatory arthropod assemblages of beetles and spiders (Araneae) feeding on adult aquatic insect resources are a key link to the transfer of high-quality food resources into higher trophic levels in riparian food webs. Ecologists are increasingly aware of the importance of transfers of aquatic resource subsidies into terrestrial food webs for biodiversity and ecosystem function. Inputs of nutritional subsidies of emerging adult aquatic insects (e.g., Baxter et al. 2005; Gratton et al. 2008; Hoekman et al. 2011), consisting of high value proteins and lipids (Mayntz et al. 2005), can be imperative to riparian and terrestrial consumer life history, affecting abundance, territoriality, feeding behavior and reproductive success. Furthermore, subsidies of essential nutrients from aquatic environments correlate with stronger immune function in terrestrial consumers (Fritz et al. 2017; Kirschman et al. 2024). Predatory arthropod assemblages of ground beetles (Carabidae), rove beetles (Staphylinidae) and spiders (Araneae) represent a large proportion of the riparian epigeal (ground-dwelling) animal community. Epigeal predatory arthropods are often the first to intercept and feed on adult aquatic insect resources and thus are a key link to the transfer of high-quality aquatic subsidies into higher trophic levels in riparian food webs (Baxter et al. 2005). It has been hypothesized that epigeal predatory arthropod aggregations near the terrestrial/aquatic boundary are directly related to the high abundance of aquatic prey (Hering and Plachter 1997, Paetzold et al. 2005; Ramberg et al. 2020). Additionally, the degree of spatial and seasonal aggregation of riparian arthropods coincides with their proportional use of aquatic insect subsidies (Paetzold et al. 2005).

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Agricultural land use results in loss of riparian vegetation and canopy cover (Allan and Flecker 1993; Naiman and Décamps 1997; Ward 1998) often close to the stream edge (Rykken et al. 2007). Open riparian habitats are more strongly affected by solar radiation and wind effects resulting in higher ambient soil and instream water temperatures and lower relative humidity (Moore et al. 2005). Furthermore, open riparian habitats can affect the dispersal of emerging aquatic insects, confining the bulk of the adult flying insect emergence to the stream edge (Petersen et al. 1999; Winterbourn et al. 2007; Carlson et al. 2016). In addition to land use effects on riparian vegetation, intensive agricultural practices in the catchment can cause unnatural fluctuations of river discharge regimes resulting in idiosyncratic periods of inundation and drying of near-stream riparian habitats (Ward et al. 2002; Renöfält et al. 2005). As terrestrial arthropod species composition reflects shifts in local environmental conditions (Ribera et al. 2001), habitat fragmentation (Dauber et al. 2005) and the surrounding land use (Perner and Malt 2003; Vanbergen et al. 2005), warmer and dryer habitats may result in the prevalence of desiccation-tolerant species (Murgu and Rîșnoveanu 2023).

Taxonomic shifts in consumer communities may affect the magnitude of aggregation and capacity to consume aquatic prey by altering the types of foraging strategies and microhabitat requirements or their degree of seasonal specialization on aquatic insect subsidy versus in situ resources. These alterations may lead to resource-consumer asynchronies in magnitude, space and time, but their effects remain largely unexplored. An overarching key question is how the deposition of large quantities of aquatic subsidies in agricultural riparian habitats correlates with epigeal arthropod predator aggregation and consumption capacity.

Agricultural land use is a pervasive source of anthropogenic disturbance worldwide, affecting both freshwater and adjacent terrestrial ecosystems (Allan 2004); therefore, the potential to influence stream-riparian aquatic insect subsidy transfer is substantial. Agricultural land use can result in elevated nutrient concentrations that, together with increases in light associated with reductions in canopy cover, can stimulate increased primary production (Griffiths et al. 2013). Increased primary production may support higher consumer abundances in the stream environment (Carlson et al. 2013), potentially resulting in greater aquatic insect emergence (Carlson et al. 2016; Cross et al. 2006; Slavik et al. 2004). However, knowledge is limited concerning the effects of agricultural land use on the uptake of resources by epigeal predatory arthropods.

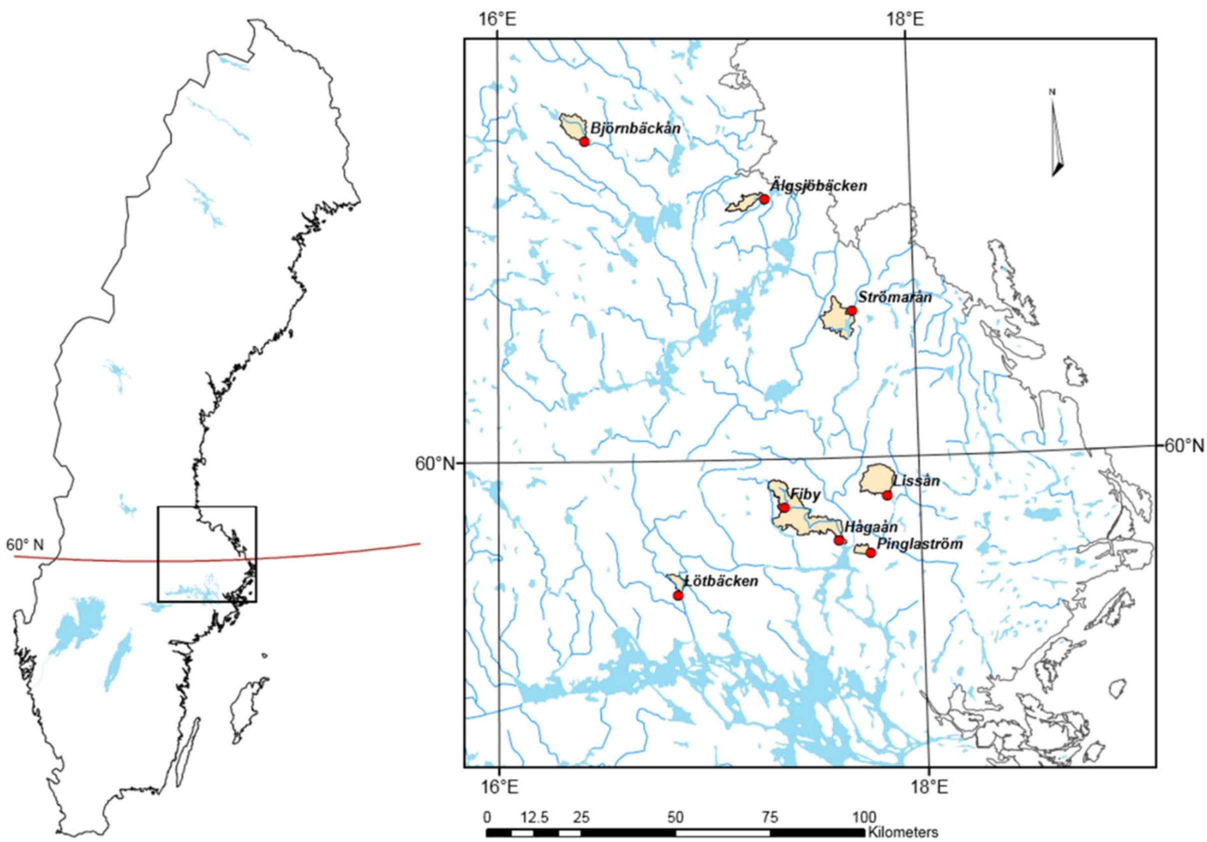

Fig. 1 Schematic diagram showing the location of the eight study streams situated in the boreal region of south-central Sweden

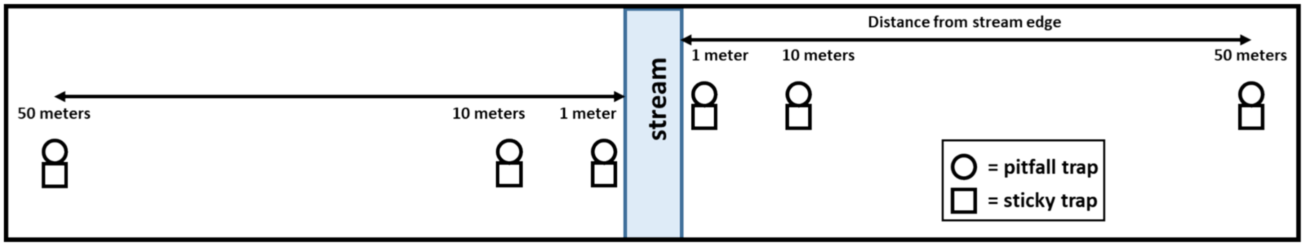

Fig. 2 Schematic diagram showing the location of pitfall and sticky trap transects with distance from stream edge at each site

We propose that the importance of aquatic insect subsidies for predatory arthropods is correlated with the aggregation of predators in terms of their density and species richness in relation to prey abundance and that these measures of aggregation indicate, at least partially, the potential for aquatic insect resource subsidies to enter riparian food webs via epigeal predatory arthropods. We consider two measures of aggregation as important determinants of the potential consumption of aquatic insect subsidies by predatory arthropods: attraction of predators to aquatic insects (Pearson's correlation coefficient between predator densities/species richness and aquatic insect abundances) and capacity of predators to consume prey (the ratio of predator individuals and species to aquatic insect abundances). Examining how these two measures of aggregation change along subsidy gradients can provide insight into pathways through which aquatic insects enter the riparian food web and how land use can affect these pathways. We utilize eight streams along an agricultural-forested land use gradient and analyze responses separately for four assemblage groups of arthropod predators (ground beetles, rove beetles, sheet-web spiders and ground hunting spiders) and include the influence of microhabitat conditions across three seasons (spring, summer, autumn) and three distances from the stream edge (1, 10, 50 m) in our analyses. Furthermore, we analyze and compare aggregation and consumption capacity for in situ prey resources (terrestrial dipterans).

We predict that for all assemblage groups of arthropod predators, aggregation and consumption capacity of adult aquatic insect subsidies will decrease with increasing agricultural land use because of sparsity of microhabitat patches with adequate environmental conditions for sensitive predatory arthropod taxa. At closer distance from the stream edge and in autumn when precipitation is greatest in the study region, we anticipate that aggregation to and consumption capacity of aquatic subsidies will increase in agricultural settings because of increased abundance of microhabitats with adequate moisture. Furthermore, we expect overall arthropod densities to have stronger positive correlations with aquatic insect abundance compared to in situ prey. It is furthermore anticipated that the importance of each factor will differ among arthropod groups. For example, spiders are strictly predatory, which may contribute to stronger correlations with distributions of aquatic insect subsidies. In contrast, coleopterans are an ecologically diverse group comprised of many feeding guilds (Gerlach et al. 2013) and are more likely to vary in their attraction to aquatic insect subsidies compared to habitat conditions, given that many carabid taxa are known to prevail in agricultural landscapes (Gailis and Turka 2013), while most staphylinid beetles prefer more shaded and moister habitats (Bohac 1999). We expect that aggregation to adult aquatic insect abundance in the latter would be more limited because of habitat preference.

Methods

Study area

The study area consisted of eight lowland streams [11–191 m above sea level (m a.s.l.)] in central Sweden representing an agricultural to forested land use gradient (Fig. 1). The streams were small to medium sized (stream orders 2–4, catchment areas from 9 to 156 km^2) and circumneutral (mean pH 6.3–8.3) and ranged from nutrient poor (mean 9 µg TP/L and 18 µg NO2-NO3-N/L) to nutrient rich (mean 198 µg TP/L and 1824 µg NO2-NO3 N/L). The riparian microhabitat factors followed the catchment gradient where the most undisturbed forested streams had continuous riparian vegetation beyond the riparian zone consisting almost entirely of mature mixed-boreal forests, dominated by pine (*Pinus sylvestris*) and spruce (*Picea abies*), with birch (*Betula* sp.) also common. Increase in agricultural land use within the catchment led to riparian environments consisting of relatively young broadleaf and mixed forests and increasingly reduced forested width (6 m) and a higher percentage of grass/brush and closer proximity to grain fields.

Epigeal riparian predatory arthropods

Ground beetles (Carabidae), rove beetles (Staphylinidae), ground-hunting spiders (Lycosidae, Liocranidae, Zoridae, Corinnidae, Gnaphosidae) and sheet-web building spiders (Linyphiidae) were collected using pitfall traps, which consisted of glass jars (60 × 70 mm) sunk into the ground, with the open top of the jar level with the ground surface and covered by a 15 × 15 mm piece of plywood supported by nails. Arrays ($n = 48$) consisting of five jars covering an area of 1 m^2, with 10-cm high plastic garden edging to guide arthropods into the five jars, were placed at 1, 10 and 50 m distances perpendicular to the wetted stream edge on both sides of each stream (Fig. 2, Appendix B). A mixture of ethanol and glycol was used to fill the bottom half of the jars. Traps were deployed in two transects (one on each side of the stream) no further than 50 m from one another at each stream over repeated 4-day sampling periods for 3 months: in July and September in 2009 and in April 2010. Upon collection, each group of five jars was combined into one composite sample per array (e.g., 1, 10 and 50 m) and preserved in 70% ethanol for subsequent sorting and identification. In the laboratory, most individuals were identified to species level.

Aquatic and terrestrial prey abundance

The availability of aquatic (aquatic Diptera, EPT) and terrestrial (terrestrial Diptera) resources was previously characterized with data reported (Carlson et al. 2016). Sticky traps were used to capture potential aquatic prey near the ground at the same locations as the pitfall trap transects (Fig. 2). The sampling dates of aquatic and terrestrial prey abundance coincided with sampling dates of epigeal riparian predatory arthropods. Insects were identified, mostly to family level, with a total of 7554 individual aquatic dipterans, 433 individuals of EPT taxa and 109,067 individuals of terrestrial dipterans collected and identified from sticky traps adjacent to the 144 individual pitfall samples.

Calculation of measures of epigeal riparian predatory arthropod response to prey

Attraction to prey: Pearson's R.

Pearson's correlation coefficient "*R*" was used as an effect size to measure arthropod predator aggregation to aquatic insect subsidies and terrestrial dipterans in terms of correlation of the number of individuals (density) and species richness within each predatory arthropod group to aquatic insect and terrestrial dipteran abundance (number of individuals). Values of R range from -1 to 1 with values closer to -1 and 1 indicating a stronger relationship. Effect sizes were calculated separately for each stream and with factors of distance from stream edge (1, 10 and 50 m) and with factors of season (months of April, July and September).

For analysis with factors of distance or season, each Pearson's correlation coefficient R effect size was calculated by including all seasons for each distance or all distances for each season resulting in 24 effect sizes, respectively, for the 8 streams.

Potential consumption capacity: P/A.

Table 1 Description of variables and values for the three broad categories (substrate, ground vegetation and trees)

Category	Description
Substrate category	
Boulder	Stones > 250 mm diameter
Cobble	Stones 25–249 mm diameter
Gravel	Stones 2–24.9 mm diameter
Sand	Particles 0.05–1.9 mm diameter
Soil	< 0.05 mm grain size rich with organic matter
Ground vegetation category	
Moss	Moss
Shrubs	Any non-tree woody plant > 50 cm but < 2 m in height
Ferns	Ferns with fronds > 30 cm long
High forbs	Forbs > 10 cm high
Low forbs	Forbs < 10 cm high
Tall grass	Grass > 10 cm high
Short grass	Grass < 10 cm high
Tree category	
Small coniferous trees	0–5 cm width
Medium coniferous trees	5–20 cm width
Large coniferous trees	> 20 cm width
Small deciduous trees	0–5 cm width
Medium deciduous trees	5–20 cm width
Large deciduous trees	> 20 cm width

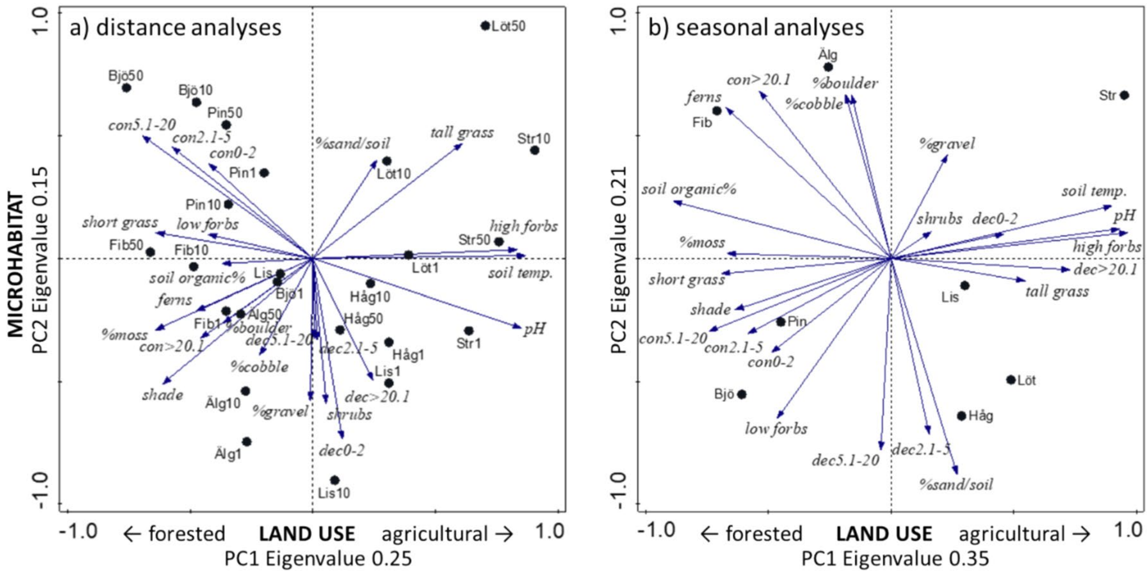

Fig. 3 Principal component analysis (PCA) of the 23 microhabitat descriptors for analysis with factors of (**a**) distance and (**b**) season. Tree types are denoted as: *con* = coniferous trees and *dec* = deciduous trees, both followed by the trunk width range. Sites with catchments dominated by forest land use are denoted as Älgsjöbäcken (Älg), Björnbäckån (Bjö), Pinglaström (Pin) and Fiby (Fib). Sites with catchments increasing agricultural land use (6.4–38% coverage) are denoted as Strömarån (Str), Hågaån (Håg), Lissån (Lis) and Lötbäcken (Löt)

The proportion of predator to prey "*P/A*" was calculated to indicate potential consumption capacity in terms of the number of individuals (density) or species richness of predatory arthropod group relative to aquatic insect and terrestrial dipteran abundance (number of individuals). Higher *P/A* values indicate more individuals or species of predator that have the potential to consume aquatic insects or terrestrial dipterans relative to aquatic insect abundance; thus, higher *P/A* values are indicative of higher potential capacity to consume aquatic insect or terrestrial dipteran abundance.

Proportion of predator density (P_d/A) or species richness to prey (P_r/A) was calculated as the $\sqrt{(\sum \text{predator}/\sum \text{aquatic}/\text{terrestrial})}$ where predator refers to density or species richness within an arthropod group and aquatic or terrestrial to insect prey abundance. For calculation of distance, the sum refers to the sum over all seasons within a distance ($n = 6$), while for analysis with factors of season, the sum refers to the sum over all distances within a season ($n = 6$), resulting in three measurements of *P/A* of distance and season across all eight streams for a total of $n = 24$ measures of *P/A* each for distance and season. The square root of the proportion was used to reduce skew in distribution of proportions.

Since calculation of effect size *R* and *P/A* for season sacrificed data from distances, and vice versa, we were not able to include factors of both season and distance in the same statistical model; thus, any potential effects of the interaction between season and distance were examined ad hoc within the discussion.

Environmental variables

Shading was measured using a LI-COR Leaf Area Index (LAI) meter (LAI-2000 model, Lincoln, NE, USA). Four measurements were taken at 1.3 m above the ground on each side of each "pitfall trap" location and averaged. All LAI measurements were made on a single clear day in early autumn, i.e., when foliage cover was maximal. LAI values range from 0 (bare ground) to > 10 (dense forest), expressed as m^2 foliage area/m^2 ground area.

Soil surface temperature was recorded at all sampling sites during each sampling event every 4 h using smart button temperature data loggers (ACR Systems Inc.). Soil samples were taken within each of the 1-m^2 pitfall arrays once during August 2010 and were analyzed for pH and organic content. Soil pH was measured on the clear water phase (supernatant) of a soil sample (ca. 45 ml) mixed with 60 ml of distilled water, shaken for 1 h, centrifuged and measured using a pH meter (Radiometer Copenhagen, TIM 800 titration manager). Organic matter, as ash-free dry weight, was calculated by weighing an approximately 15 ml soil sample to the nearest 0.001 g into a ceramic cup and then combusting it for 6 h at 550 °C and reweighing the sample.

Terrestrial microhabitat descriptors were measured within a plot with a radius of 1.785 m from the center of each pitfall array covering a total area of 10 m^2. Within each plot, information was assessed for three broad descriptor categories:

Table 2 Parameter estimates of GLMM results of ground beetle and aquatic insect abundance

Ground beetle density	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance					
Intercept	0.39	0.09	5.98	4.17	**0.0059**
Distance 1 m	0.25	0.13	11.00	1.96	*0.0764*
Distance 1 m*PC2	0.14	0.08	8.90	1.84	*0.0989*
Distance 10 m*PC2	− 0.12	0.06	9.17	− 1.99	*0.0776*
PC1*PC2	0.08	0.04	11.37	2.07	*0.0623*
Pearson R season					
Intercept	0.24	0.11	4	2.17	*0.0959*
September*PC1	0.13	0.05	8	2.84	**0.0217**
P/A distance					
Intercept	0.41	0.07	6.35	5.66	**0.0011**
Distance 10 m*PC1	− 0.04	0.02	7.62	− 1.89	*0.0972*
PC1*PC2	0.04	0.01	8.30	2.51	**0.0352**
Distance 50 m*PC1*PC2	− 0.02	0.01	8.28	− 1.88	*0.0955*
P/A season					
Intercept	0.36	0.05	4	7.8	**0.0015**
Ground beetle richness					
Pearson R distance					
Intercept	0.43	0.06	8.50	6.66	**0.0001**
Distance 1 m*PC2	0.18	0.09	10.82	2.02	*0.0691*
PC1*PC2	0.09	0.03	6.96	3.31	**0.0130**
Pearson R season					
Intercept	0.25	0.08	4	3.14	**0.0350**
PC1*PC2	− 0.03	0.01	4	− 2.2	*0.0930*
P/A distance					
Intercept	0.35	0.03	6.25	12.08	**< 0.0001**
PC1	− 0.04	0.02	10.40	− 2.49	**0.0309**
P/A season					
Intercept	0.27	0.02	4	14.34	**0.0001**
PC1	− 0.02	0.01	4	− 3.13	**0.0353**

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

substrate, ground vegetation and trees (Table 1). Substrate was classified by size and type (percent coverage), ground vegetation by percent type and trees by number (Table 1).

Statistical analyses

Principal component analysis (PCA) on centered and standardized variables was conducted to capture most of the environmental variation of the 23 microhabitat descriptors in two microhabitat variables (Table 1, Appendix B). The first and second PCs were retained from the PCA and used as variables to characterize the land use gradient (PC1), while PC2 was used to characterize the microhabitat gradient not correlated with land use (i.e., PC1 is orthogonal to PC2). PC1 and PC2 were used in subsequent analyses to construct a general linear mixed model (GLMM) (see below). As calculation of response variables for season required combining data over all distances, a separate PCA was conducted that used microhabitat descriptors composed of the mean value over all distances within each stream. All analyses were done using Canoco 5 (ter Braak and Šmilauer 2012).

We used general linear mixed models (GLMM) that included PC1, PC2 and either distance from stream or season (see above) as explanatory variables and the effect size *R* or *P/A* as response variables (see above). Since several samples were collected at the same site (stream), but at different distances from the stream or season, random intercept models were used to include the random factor 'stream' (8 levels), which accounted for non-independence. All analyses were done using JMP 8.0.1 (SAS Institute Inc. 2009).

Table 3 Parameter estimates of GLMM results of ground beetle and terrestrial dipteran abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Ground beetle density					
Pearson R distance					
Intercept	− 0.06	0.06	5.91	− 1.05	0.3361
PC1	0.13	0.04	8.54	3.26	**0.0106**
Distance 10 m*PC2	− 0.10	0.06	10.07	− 1.83	*0.0967*
Pearson R season					
Intercept	− 0.03	0.06	4.00	− 0.56	0.6052
PC1	0.07	0.02	4.00	2.95	**0.0420**
P/A distance					
Intercept	0.27	0.03	6.17	7.92	**0.0002**
Distance 1 m	0.07	0.03	10.64	2.27	**0.0451**
Distance 50 m	− 0.06	0.03	10.27	− 2.30	**0.0437**
PC2	0.04	0.02	11.70	2.30	**0.0411**
P/A season					
Intercept	0.25	0.05	4.00	5.23	**0.0064**
April	− 0.12	0.04	8.00	− 3.28	**0.0113**
July	0.11	0.04	8.00	2.99	**0.0173**
July*PC1	− 0.04	0.01	8.00	− 2.57	**0.0329**
Ground beetle richness					
Pearson R distance					
Intercept	− 0.08	0.10	5.72	− 0.83	0.4397
Pearson R season					
Intercept	− 0.05	0.06	4.00	− 0.86	0.4370
P/A distance					
Intercept	0.91	0.08	6.12	11.03	**< 0.0001**
Distance 1 m	− 0.18	0.07	10.46	− 2.48	**0.0317**
Distance 10 m	0.11	0.05	7.13	2.23	*0.0603*
Distance 1 m*PC1	− 0.09	0.05	9.14	− 1.90	*0.0887*
PC2	− 0.09	0.05	11.90	− 1.91	*0.0800*
P/A season					
Intercept	0.76	0.04	4.00	17.53	**< 0.0001**
April	0.14	0.04	8.00	3.52	**0.0079**
July	− 0.10	0.04	8.00	− 2.61	**0.0312**

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

Results

Principal component analysis (PCA) with factors of distance and season both resulted in the first principal component (PC1) characterizing the land use gradient from agricultural (positive values) to forested (negative values) (Fig. 3). Increasing agricultural impact was positively correlated with higher soil temperatures and pH and with vegetation consisting of high forbs and tall grass and negatively correlated with shade, soil organic matter and vegetation consisting of coniferous trees, mosses, low forbs, short grass and ferns (Fig. 1). PC2 with factors of distance characterized a gradient from nearer the stream edge (negative values) of larger trees (> 20 cm width), smaller deciduous trees (0–2 cm width), shrubs, increasing shade and increasing percentage of gravel and cobble substrates (Fig. 3a). PC2 with factors of season characterized a gradient from deciduous trees from 2–20 cm width, low forbs and the percent sand/soil substrate (negative values) to increasing percent boulder and cobble substrate, large conifer trees (> 20.1 cm) and ferns (positive values) (Fig. 3b).

Ground beetles (Carabidae).

Correlation and proportion to aquatic insect abundance

The mean correlation of ground beetle density and richness to aquatic insect abundance was positively associated with distance (significant intercept, est. 0.39, $p = 0.0059$; est. 0.43, $p = 0.0001$, respectively) (Table 2, Table 10 in Appendix A) and also analyses with season for richness (significant intercept, est. 0.25, $p = 0.0350$) (Table 2, Table 10 in Appendix A). Positive correlation between ground beetle richness and aquatic insect abundance increased with agricultural land use in microhabitats increasingly characterized by smaller substrate size, few deciduous trees, tall grasses and decreasing shade (significant interaction PC1*PC2 with factors of distance, est. 0.09, $p = 0.0130$) (Table 2, Fig. 3, Table 10 in Appendix A). Positive correlation between ground beetle density and aquatic insect abundance increased with agricultural land use in September (significant interaction PC1*September, est. 0.13, $p = 0.0217$) (Table 2, Table 10 in Appendix A). The proportion of ground beetle species richness to aquatic insect abundance increased in riparian habitats associated with forested land use (significant PC1 with distance and season, est. − 0.04, $p = 0.0309$; est. − 0.02, $p = 0.0353$, respectively) (Table 2, Table 10 in Appendix A).

Correlation and proportion to terrestrial dipteran abundance

Positive correlation between ground beetle density and terrestrial dipteran abundance increased with an increase in agricultural land use (significant PC1 with distance and season, est. 0.13, $p = 0.0106$; est. 0.07, $p = 0.042$, respectively) (Table 3, Table 14 in Appendix B). At 1 m distance the proportion of ground beetle density to terrestrial dipteran abundance was higher, and species richness to terrestrial dipteran abundance was lower (significant distance 1 m, est. 0.07, $p = 0.0451$; est. − 0.18, $p = 0.0317$, respectively) (Table 3, Table 14 in Appendix B). The proportion of ground beetle density to terrestrial dipteran abundance increased in microhabitats increasingly characterized by smaller substrate

Table 4 Parameter estimates of GLMM results of rove beetle and aquatic insect abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Rove beetle density					
Pearson R distance					
Intercept	0.24	0.19	5.35	1.25	0.2646
Pearson R season					
Intercept	0.07	0.18	4	0.4	0.7126
April	0.14	0.07	8	1.93	*0.0891*
April*PC1	– 0.06	0.03	8	– 2.14	*0.0647*
September*PC2	0.10	0.03	8	3.03	**0.0163**
P/A distance					
Intercept	0.47	0.04	4.91	11.07	**0.0001**
PC1	– 0.06	0.03	7.85	– 2.02	*0.0782*
P/A season					
Intercept	1.01	0.16	4	6.29	**0.0033**
April	0.71	0.23	8	3.1	**0.0146**
PC1	– 0.25	0.06	4	– 4.12	**0.0146**
April*PC1	– 0.27	0.09	8	– 3.02	**0.0165**
Rove beetle richness					
Pearson R distance					
Intercept	0.18	0.14	5.88	1.31	0.2378
Pearson R season					
Intercept	0.04	0.16	4	0.26	0.8044
P/A distance					
Intercept	1.57	0.26	6.09	6.12	**0.0008**
Distance 10 m*PC1*PC2	– 0.13	0.07	8.22	– 1.91	*0.0910*
P/A season					
Intercept	0.53	0.05	4	10.02	**0.0006**
April	0.34	0.10	8	3.45	**0.0088**
July	– 0.21	0.10	8	– 2.07	*0.0717*
PC1	– 0.11	0.02	4	– 5.47	**0.0054**
April*PC1	– 0.12	0.04	8	– 3.09	**0.0150**
July*PC1	0.07	0.04	8	1.91	*0.0932*

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

size, few deciduous trees, tall grasses and decreasing shade (significant PC2, est. 0.04, $p = 0.0411$) (Table 3, Table 14 in Appendix B). In April, the proportion of ground beetle density to terrestrial dipteran abundance was lower, and the proportion of ground beetle species richness to terrestrial dipteran abundance was higher (significant season April, est. – 0.12, $p = 0.0113$; est. 0.14, $p = 0.0079$, respectively), while in July the proportion of ground beetle density to terrestrial dipteran abundance was higher, and the proportion of ground beetle species richness to terrestrial dipteran abundance was lower (significant season July, est. 0.11, $p = 0.0173$; est. – 0.10, $p = 0.0312$, respectively) (Table 3, Table 14 in Appendix B). In July, the proportion of ground beetle density to terrestrial dipteran abundance increased in riparian habitats increasingly associated with forested land use (significant interaction season July*PC1, est. – 0.04, $p = 0.0329$) (Table 3, Table 14 in Appendix B).

Rove beetles (Staphylinidae).

Correlation and proportion to aquatic insect abundance

Positive correlation of rove beetle density and aquatic insect abundance increased in September in microhabitats increasingly characterized by fewer deciduous trees, decreasing percentage of shrubs, increased substrate sizes and minimal shade (significant interaction season September*PC2, est. 0.10, $p = 0.0163$) (Table 4, Table 11 in Appendix A, Fig. 3). The proportion of rove beetle density and species richness to aquatic insect abundance increased in riparian habitats that were associated with forested land use in April (significant interaction season April* PC1, est. – 0.27, $p = 0.0165$; est. – 0.12,

Table 5 Parameter estimates of GLMM results of rove beetle and terrestrial dipteran abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Rove beetle density					
Pearson R distance					
Intercept	0.07	0.07	7.06	1.03	0.3363
PC1	0.13	0.05	7.91	2.55	**0.0343**
PC2	− 0.09	0.03	2.48	− 2.61	*0.0973*
Pearson R season					
Intercept	0.12	0.10	4.00	1.18	0.3021
P/A distance					
Intercept	2.37	0.45	5.48	5.27	**0.0025**
Distance 10 m*PC2	− 0.20	0.09	5.71	− 2.22	*0.0705*
P/A season					
Intercept	3.34	0.70	4.00	4.77	**0.0088**
April	1.17	0.34	8.00	3.41	**0.0092**
September	− 0.66	0.34	8.00	− 1.94	*0.0881*
Rove beetle richness					
Pearson R distance					
Intercept	− 0.01	0.09	5.27	− 0.08	0.9407
Distance 10 m	− 0.27	0.13	7.02	− 2.03	*0.0813*
Distance 50 m	0.27	0.14	9.09	1.99	*0.0780*
Pearson R season					
Intercept	0.07	0.06	4.00	1.23	0.2849
P/A distance					
Intercept	0.70	0.06	3.98	12.24	**0.0003**
P/A season					
Intercept	0.57	0.03	4.00	19.36	**< 0.0001**

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

$p = 0.0150$, respectively) (Table 4, Table 11 in Appendix A, Fig. 3).

Correlation and proportion to terrestrial dipteran abundance

Correlation of rove beetle density with terrestrial dipteran abundance was increasingly positive with increase in agricultural land use and increasingly negative with increase in forested land use (significant PC1 with distance, est. 0.13, $p = 0.0343$) (Table 5, Table 15 in Appendix B, Fig. 3). The proportion of rove beetle density to terrestrial dipteran abundance was greater in April (significant season April, est. 1.17, $p = 0.0092$) (Table 5, Table 15 in Appendix B).

Sheet-web spiders (Linyphiidae)

Correlation and proportion regarding aquatic insect abundance

Positive correlation of sheet-web spider species richness with aquatic insect abundance at 1 m distance was observed and increased in riparian habitats associated with agricultural land use, while at 10 m distance positive correlation was observed and increased only in riparian habitats associated with forested land use (significant interaction distance 1*PC1, 10*PC1, est. 0.22, $p = 0.0047$; est. − 0.17, $p = 0.0053$, respectively) (Table 6, Table 12 in Appendix A, Fig. 3). Positive correlation of sheet-web spider species richness to aquatic insect abundance at 10 m distance increased in microhabitats with a greater number of deciduous trees, percent coverage of shrubs and abundant shade (significant interaction between distance 10*PC2, est. − 0.10, $p = 0.0398$) (Table 6, Table 12 in Appendix A, Fig. 3). The proportion of sheet-web spider density and species richness to aquatic insect abundance was greatest in April and increased in riparian habitats increasingly associated with forested land use (significant interaction season April*PC1, est. − 0.11, $p = 0.0133$; est. − 0.09, $p = 0.004$, respectively) (Table 6, Table 12 in Appendix A, Fig. 3).

Correlation and proportion to terrestrial dipteran abundance

Negative correlation of sheet-web spider density to terrestrial dipteran abundance was observed in April (significant season April, est. − 0.25, $p = 0.0461$) (Table 7, Table 16 in Appendix B). Positive correlation of sheet-web spider density to terrestrial dipteran abundance increased with an increase in agricultural land use in September (significant interaction season September*PC1, est. 0.1, $p = 0.039$) (Table 7, Table 16 in Appendix B, Fig. 3). The proportion of sheet-web spider density to terrestrial dipteran abundance increased with an increase in agricultural land use (significant PC1 with distance and season, est. 0.08, $p = 0.038$; est. 0.09, $p = 0.0219$, respectively) (Table 7, Table 16 in Appendix B, Fig. 3). The proportion of sheet-web spider species richness to terrestrial dipteran abundance decreased with an increase in agricultural land use (significant PC1 with distance and season, est. − 0.06, $p = 0.0496$; est. − 0.02, $p = 0.0458$, respectively) (Table 7, Table 16 in Appendix B, Fig. 3). The proportion of sheet-web spider species richness to terrestrial dipteran abundance in April was increasingly lower in microhabitats associated with smaller substrate sizes, increased number of deciduous trees 2.1–20 cm and higher percentage of low

Table 6 Parameter estimates of GLMM results of sheet-web spiders and aquatic insect abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Sheet-web spider density					
Pearson R distance					
Intercept	− 0.35	0.11	1.73	− 3.37	*0.0954*
Pearson R season					
Intercept	− 0.04	0.07	4	− 0.58	0.5926
P/A distance					
Intercept	1.41	0.12	5.74	11.85	**< 0.0001**
Distance 50 m*PC2	− 0.09	0.04	7.12	− 1.95	*0.0911*
Distance 1 m*PC1*PC2	0.09	0.05	9.20	1.84	*0.0985*
P/A season					
Intercept	0.55	0.06	4	9.82	**0.0006**
April	0.50	0.09	8	5.43	**0.0006**
July	− 0.24	0.09	8	− 2.64	**0.0299**
September	− 0.26	0.09	8	− 2.8	**0.0233**
PC1	− 0.08	0.02	4	− 3.82	**0.0188**
April*PC1	− 0.11	0.04	8	− 3.17	**0.0133**
Sheet-web spider richness					
Pearson R distance					
Intercept	− 0.15	0.07	5.83	− 2.14	*0.0777*
Distance 1 m*PC1	0.22	0.06	11.04	3.53	**0.0047**
Distance 10 m*PC1	− 0.17	0.05	10.03	− 3.54	**0.0053**
Distance 1 m*PC2	0.11	0.05	8.71	2.01	*0.0766*
Distance 10 m*PC2	− 0.10	0.04	8.88	− 2.41	**0.0398**
Distance 10 m*PC1*PC2	− 0.06	0.03	9.54	− 2.01	*0.0736*
Pearson R season					
Intercept	0.02	0.11	4	0.15	0.8851
P/A distance					
Intercept	0.57	0.06	2.78	8.79	**0.0042**
P/A season					
Intercept	0.39	0.03	4	11.81	**0.0003**
April	0.30	0.06	8	5.37	**0.0007**
July	− 0.15	0.06	8	− 2.58	**0.0325**
September	− 0.16	0.06	8	− 2.78	**0.0238**
PC1	− 0.07	0.01	4	− 5.16	**0.0067**
April*PC1	− 0.09	0.02	8	− 4	**0.0040**
July*PC1	0.05	0.02	8	2.22	*0.0574*

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

forbs (significant interaction season April*PC2, est. 0.03, $p = 0.0105$) (Table 7, Table 16 in Appendix B, Fig. 3). The proportion of sheet-web spider species richness to terrestrial dipteran abundance was greater in July and September (significant season July and September, est. 0.05, $p = 0.0451$; est. 0.05, $p = 0.0356$, respectively) (Table 7, Table 16 in Appendix B).

Ground-hunting spiders (Lycosidae, Liocranidae, Zoridae, Corinnidae, Gnaphosidae).

Correlation and proportion to aquatic insect abundance

The mean correlation of ground-hunting spider density and richness with aquatic insect abundance was negative in analysis with factors of distance (significant intercept, est. − 0.34, $p = 0.0023$; est. − 0.34, $p = 0.0177$, respectively) (Table 8, Table 13 in Appendix A). Positive correlation of ground-hunting spider density with aquatic insect subsidies increased in agricultural land use in habitats with increasing substrate size and decreasing number of deciduous trees 2–20 cm width

Table 7 Parameter estimates of GLMM results of sheet-web spiders and terrestrial dipteran abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Sheet-web spider density					
Pearson R distance					
Intercept	0.05	0.13	5.53	0.37	0.7257
PC1	− 0.18	0.08	8.22	− 2.25	*0.0539*
Distance 1 m*PC1*PC2	− 0.17	0.09	10.60	− 1.92	*0.0818*
Distance 10 m*PC1*PC2	0.13	0.06	9.76	2.17	*0.0560*
Pearson R season					
Intercept	0.11	0.06	4.00	1.85	0.1373
April	− 0.25	0.11	8.00	− 2.36	**0.0461**
September	0.24	0.11	8.00	2.21	*0.0585*
September*PC1	0.10	0.04	8.00	2.46	**0.0390**
PC2	0.08	0.03	4.00	2.68	*0.0552*
September*PC1*PC2	− 0.04	0.02	8.00	− 2.16	*0.0623*
P/A distance					
Intercept	0.95	0.06	6.04	16.50	**< 0.0001**
PC1	0.08	0.03	8.54	2.45	**0.0380**
P/A season					
Intercept	1.11	0.06	4.00	17.48	**< 0.0001**
April	0.32	0.11	8.00	2.99	**0.0173**
September	− 0.26	0.11	8.00	− 2.48	**0.0380**
PC1	0.09	0.02	4.00	3.64	**0.0219**
Sheet-web spider richness					
Pearson R distance					
Intercept	0.20	0.13	5.27	1.46	0.2025
Pearson R season					
Intercept	0.21	0.08	4.00	2.73	*0.0524*
P/A distance					
Intercept	0.89	0.04	5.79	20.82	**< 0.0001**
PC1	− 0.06	0.03	8.31	− 2.30	**0.0496**
P/A season					
Intercept	0.75	0.02	4.00	39.49	**< 0.0001**
April	− 0.10	0.02	8.00	− 4.90	**0.0012**
July	0.05	0.02	8.00	2.37	**0.0451**
September	0.05	0.02	8.00	2.52	**0.0356**
PC1	− 0.02	0.01	4.00	− 2.86	**0.0458**
April*PC2	0.03	0.01	8.00	3.32	**0.0105**
September*PC2	− 0.02	0.01	8.00	− 2.24	*0.0551*

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

(significant interaction PC1*PC2, est. − 0.01, $p = 0.0339$) (Table 8, Table 13 in Appendix A, Fig. 3). The proportion of ground-hunting spider density and species richness to aquatic insect abundance was highest in April and increased in riparian habitats increasingly associated with forested land use (significant interaction season April*PC1, est. – 0.11, $p = 0.022$; est. − 0.06, $p = 0.0121$, respectively) (Table 8, Table 13 in Appendix A, Fig. 3).

Correlation and proportion with terrestrial dipteran abundance

No significant relationships were detected between ground-hunting spiders and terrestrial dipteran abundance. The proportion of ground-hunting spider density to terrestrial dipteran abundance was greater with increasing forested land use in April (significant interaction season April*PC1, est. − 0.04, $p = 0.0283$) (Table 17 in Appendix B, Fig. 3). The proportion of ground-hunting spider density to terrestrial

Table 8 Parameter estimates of GLMM results of ground-hunting spiders and aquatic insect abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Ground-hunting spider density					
Pearson R distance					
Intercept	− 0.34	0.07	7.28	− 4.58	**0.0023**
Pearson R season					
Intercept	− 0.02	0.00	1.00	− 8.64	*0.0733*
PC1	0.03	0.00	1.00	43.69	**0.0146**
PC2	− 0.05	0.00	1.00	− 41.95	**0.0151**
PC1*PC2	− 0.01	0.00	1.00	− 18.76	**0.0339**
P/A distance					
Intercept	0.52	0.09	5.29	5.57	**0.0021**
Distance 50 m	0.15	0.08	9.91	1.97	*0.0775*
P/A season					
Intercept	0.37	0.11	4.053	3.44	**0.0256**
April	0.41	0.10	5.297	4.19	**0.0076**
April*PC1	− 0.11	0.03	5.105	− 3.25	**0.0220**
Ground-hunting spider richness					
Pearson R distance					
Intercept	− 0.34	0.09	3.91	− 3.94	**0.0177**
Pearson R season					
Intercept	− 0.14	0.02	0.98	− 6.95	*0.0949*
P/A distance					
Intercept	0.60	0.08	5.31	7.34	**0.0006**
P/A season					
Intercept	0.25	0.05	4.226	4.93	**0.0068**
April	0.23	0.05	5.552	4.82	**0.0036**
July	− 0.13	0.06	5.608	− 2.36	*0.0596*
September	− 0.10	0.05	5.29	− 2.05	*0.0929*
PC1	− 0.05	0.02	3.742	− 3.02	**0.0428**
April*PC1	− 0.06	0.02	5.356	− 3.72	**0.0121**

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

Table 9 Parameter estimates of GLMM results of ground-hunting spiders and terrestrial dipteran abundance

	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Ground-hunting spider density					
Pearson R distance					
Intercept	0.14	0.17	5.94	0.79	0.4617
Distance 10 m	− 0.22	0.11	6.34	− 2.00	*0.0901*
Pearson R season					
Intercept	0.00	0.18	3.37	− 0.01	0.9892
April*PC2	0.17	0.07	4.49	2.42	*0.0656*
July*PC2	− 0.16	0.07	4.17	− 2.22	*0.0879*
P/A distance					
Intercept	0.62	0.11	5.79	5.48	**0.0017**
Distance 50 m*PC2	0.09	0.05	7.33	2.08	*0.0747*
P/A season					
Intercept	0.84	0.13	4.02	6.23	**0.0033**
April	0.15	0.03	4.08	4.48	**0.0105**
September	− 0.10	0.03	4.05	− 2.96	**0.0407**
April*PC1	− 0.04	0.01	4.07	− 3.34	**0.0283**
Ground-hunting spider richness					
Pearson R distance					
Intercept	0.05	0.16	5.65	0.32	0.7617
Pearson R season					
Intercept	− 0.03	0.17	2.48	− 0.18	0.8720
April*PC2	0.18	0.07	3.74	2.56	*0.0667*
P/A distance					
Intercept	1.11	0.15	6.20	7.53	**0.0002**
P/A season					
Intercept	0.79	0.06	3.92	14.08	**0.0002**
April	− 0.11	0.03	4.36	− 3.37	**0.0245**

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

dipteran abundance was lower in September (significant season September, est. − 0.10, $p = 0.0407$) (Table 17 in Appendix B). The proportion of ground-hunting spider species richness to terrestrial dipteran abundance was lower in April (significant season April, est. − 0.11, $p = 0.0245$) (Table 17 in Appendix B) (Table 9).

Discussion

Gradients in land use and in microhabitat conditions, distance from the stream and season were important factors in terms of correlations between predatory arthropod and aquatic insect abundance. Positive correlations between predatory arthropods and aquatic insect abundance was more apparent compared to terrestrial dipteran abundance, suggesting an overall preference of aquatic prey. However, positive correlations of ground beetle and rove beetle density with terrestrial dipterans increased with increase in agricultural land use, which may reflect a shift in communities with taxa having less specialization or preference for aquatic insect prey. The overall results indicated that a sensitivity to desiccation may be one of the strongest drivers of distribution in riparian predatory arthropods and can restrict access to adult aquatic insect subsidies. Positive correlations of riparian predatory arthropods with aquatic insect subsidies were generally more confined to microhabitats with characteristics associated with higher moisture (e.g., greater soil organic matter and shade), particularly with increasing agricultural land use. In September, there was indication of reduced confinement to microhabitats, likely as an effect of elevated seasonal precipitation.

Ground beetles exhibited the strongest positive correlations with aquatic insect abundance in terms of both number of individuals and species, but not spiders as was anticipated. Ground beetles appeared to be least sensitive to microhabitat gradients. In fact, positive correlation between ground beetle species richness and aquatic insect abundance increased in open, tall grass-dominated microhabitats associated with agricultural land use. Other studies have shown that ground beetles have the collective ability to occupy a high diversity of habitats including both specialists and generalists, many of which prefer and thrive in the relatively dry and open habitats associated with agricultural landscapes (Rykken et al. 1997). However, results of this study advocate some degree of microhabitat confinement. First, positive correlation between ground beetle density and aquatic insect abundance in agricultural settings increased during the season of increased precipitation in September. Second, with increasing agricultural land use at 50 m from the stream edge, the number of ground beetle species relative to aquatic insect abundance increased but the number of species with attraction to aquatic insect subsidies was lower. Lastly, we found that with increasing forested land use, the number of ground beetle species with attraction to aquatic subsidies increased in more shaded microhabitats dominated by shrub vegetation. Nonetheless, ground beetles displayed a positive mean effect size in all analysis of aggregation to aquatic insect abundances. This observation, combined with significantly higher positive effect size in densities at the stream boundary, suggests their utilization of aquatic insect subsidies was greater than the other predatory arthropod groups.

Rove beetle species and number of individuals relative to aquatic insect abundance increased with forested land use, even more so in spring and in microhabitats with greater shade and a higher percentage of shrubs. Other studies have indicated rove beetle sensitivity to higher temperatures, soil moisture and humidity and preference for dark or shaded habitats (e.g., Centeno et al. 2002; Bohac 1999). However, positive relationships of rove beetles to aquatic insect subsidies were more apparent in agricultural settings. In fact, with increasing forested land use the number of species were negatively correlated with adult aquatic insect subsidies in spring when the consumption capacity was found to be the greatest. In contrast, the number of species displaying attraction to aquatic insect subsidies increased in agricultural settings in spring, but only in microhabitats with characteristics associated with higher soil moisture. Furthermore, more rove beetle species relative to aquatic insect abundance were observed in microhabitats associated with increasing agricultural land use at 10 m distance from the stream edge. Microhabitats associated with higher soil moisture were associated with increased rove beetle species attraction to aquatic insect subsidies in July while negative relationships were observed in September. Conversely, microhabitats associated with less soil moisture were associated with increased rove beetle species attraction to aquatic insect subsidies in September, while negative correlations were observed in July. As was observed for ground beetles, these results suggest rove beetle species attraction to aquatic insect subsidies was not restricted to microhabitats characteristic of having higher soil moisture in September when precipitation is usually highest in the study region.

Results for both ground-hunting and sheet-web spider were consistent with beetles in terms of a limited tolerance to desiccation that may limit their consumption of the aquatic insect subsidy. Other studies have shown that gradients of soil moisture drive ground-hunting spider distributions (i.e., Lycosidae; Graham et al. 2003; DeVito et al. 2004). Positive relationships of spiders to aquatic insect subsidies were mostly limited to riparian habitats associated with forested land use. Furthermore, the number of sheet-web spider species with attraction increased at 1 m in agricultural settings while in forested settings species attraction increased at 10 m from the stream edge. However, the higher attraction observed at 1 m distance in microhabitats with greater soil moisture in agricultural settings was represented by a proportionally lower number of species. Higher soil moisture nearer the stream edge could explain the positive correlation of sheet-web spider species richness to aquatic insect abundance at 10 m distance with increasing forested land use but was limited to 1 m distance in agricultural settings.

Compared to beetles, positive associations of spiders with aquatic insect subsidies were most apparent in April. In April, both ground-hunting and sheet-web spider consumption capacity of aquatic insects in terms of the number of individuals and species richness was greater with increasing forested land use. In agricultural settings, positive relationships were observed between the number of ground-hunting spider individuals and aquatic insects in microhabitats with fewer shrubs and higher soil moisture in April and in microhabitats with a high percentage of shrubs and lower soil moisture in July. Our finding that sheet-web spider consumption capacity in terms of individuals and species was greatest in spring was not surprising as this is typically when sheet-web spiders are at their highest activity in Europe (Foelix 1996). Our results follow a similar pattern of seasonal

Table 10 Parameter estimates of GLMM results of ground beetle and aquatic insect abundance

Ground beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > $\lvert t \rvert$	Estimate	Std error	DFDen	*t* ratio	Prob > $\lvert t \rvert$
Pearson R distance										
Intercept	0.39	0.09	5.98	4.17	**0.0059**	0.43	0.06	8.50	6.66	**0.0001**
Distance 1 m	0.25	0.13	11.00	1.96	***0.0764***	0.21	0.13	10.33	1.62	0.1358
Distance 10 m	− 0.07	0.10	7.88	− 0.71	0.4997	− 0.10	0.12	9.22	− 0.81	0.4407
Distance 50 m	− 0.17	0.11	10.38	− 1.52	0.1582	− 0.11	0.12	9.98	− 0.92	0.3801
PC1	− 0.02	0.06	8.61	− 0.33	0.7479	− 0.05	0.05	9.58	− 1.05	0.3206
Distance 1 m*PC1	0.07	0.09	11.34	0.74	0.4764	0.00	0.08	11.68	− 0.02	0.9834
Distance 10 m*PC1	− 0.06	0.07	10.36	− 0.83	0.4231	− 0.10	0.07	11.29	− 1.36	0.2004
Distance 50 m*PC1	− 0.01	0.06	9.48	− 0.11	0.9164	0.10	0.07	11.72	1.44	0.1765
PC2	0.03	0.06	6.82	0.51	0.6279	0.06	0.03	4.05	1.85	0.1373
Distance 1 m*PC2	0.14	0.08	8.90	1.84	***0.0989***	0.18	0.09	10.82	2.02	***0.0691***
Distance 10 m*PC2	− 0.12	0.06	9.17	− 1.99	***0.0776***	− 0.11	0.07	11.64	− 1.69	0.1174
Distance 50 m*PC2	− 0.02	0.06	8.24	− 0.38	0.7106	− 0.07	0.07	11.12	− 0.91	0.3824
PC1*PC2	0.08	0.04	11.37	2.07	***0.0623***	0.09	0.03	6.96	3.31	**0.0130**
Distance 1 m*PC1*PC2	0.09	0.06	10.79	1.43	0.1801	0.06	0.06	11.93	0.95	0.3606
Distance 10 m*PC1*PC2	− 0.05	0.04	10.04	− 1.12	0.2868	0.01	0.05	11.06	0.13	0.9011
Distance 50 m*PC1*PC2	− 0.04	0.04	10.88	− 0.98	0.3487	− 0.07	0.04	11.89	− 1.7	0.1157
Pearson R season										
Intercept	0.24	0.11	4	2.17	***0.0959***	0.25	0.08	4	3.14	**0.0350**
April	0.11	0.12	8	0.94	0.3768	0.09	0.12	8	0.77	0.4633
July	− 0.10	0.12	8	− 0.85	0.4200	− 0.07	0.12	8	− 0.6	0.5620
September	− 0.01	0.12	8	− 0.09	0.9339	− 0.02	0.12	8	− 0.17	0.8728
PC1	0.03	0.04	4	0.73	0.5053	− 0.01	0.03	4	− 0.35	0.7466
April*PC1	− 0.06	0.05	8	− 1.27	0.2393	− 0.02	0.05	8	− 0.4	0.6989
July*PC1	− 0.07	0.05	8	− 1.57	0.1544	0.00	0.05	8	− 0.07	0.9491
September*PC1	0.13	0.05	8	2.84	**0.0217**	0.02	0.05	8	0.47	0.6531
PC2	− 0.04	0.05	4	− 0.85	0.4422	− 0.07	0.04	4	− 1.77	0.1517
April*PC2	− 0.03	0.06	8	− 0.52	0.6141	0.00	0.05	8	0	0.9964
July*PC2	0.00	0.06	8	− 0.01	0.9907	− 0.02	0.05	8	− 0.3	0.7746
September*PC2	0.03	0.06	8	0.54	0.6062	0.02	0.05	8	0.29	0.7781
PC1*PC2	− 0.03	0.02	4	− 1.45	0.2201	− 0.03	0.01	4	− 2.2	***0.0930***
April*PC1*PC2	− 0.02	0.02	8	− 0.82	0.4376	− 0.01	0.02	8	− 0.65	0.5338
July*PC1*PC2	− 0.01	0.02	8	− 0.26	0.7982	0.00	0.02	8	− 0.11	0.9139
September*PC1*PC2	0.02	0.02	8	1.08	0.3110	0.02	0.02	8	0.76	0.4681
P/A distance										
Intercept	0.41	0.07	6.35	5.66	0.0011	0.35	0.03	6.25	12.08	< 0.0001
Distance 1 m	0.00	0.05	9.55	− 0.07	0.9451	− 0.03	0.02	9.49	− 1.29	0.2289
Distance 10 m	− 0.01	0.03	6.77	− 0.43	0.6814	0.00	0.01	6.67	0.16	0.8786
Distance 50 m	0.02	0.04	9.34	0.39	0.7069	0.02	0.02	9.28	1.35	0.2087
PC1	− 0.03	0.04	10.45	− 0.89	0.3924	− 0.04	0.02	10.40	− 2.49	**0.0309**
Distance 1 m*PC1	0.04	0.03	8.23	1.31	0.2250	− 0.01	0.01	8.15	− 0.78	0.4585
Distance 10 m*PC1	− 0.04	0.02	7.62	− 1.89	***0.0972***	0.00	0.01	7.53	− 0.37	0.7224
Distance 50 m*PC1	0.00	0.02	7.39	0.16	0.8772	0.01	0.01	7.30	1.63	0.1462
PC2	− 0.01	0.03	11.39	− 0.23	0.8192	− 0.01	0.01	11.37	− 0.71	0.4897
Distance 1 m*PC2	− 0.01	0.03	7.62	− 0.47	0.6504	0.00	0.01	7.53	0.31	0.7663
Distance 10 m*PC2	0.02	0.02	7.46	1.07	0.3194	0.01	0.01	7.37	0.91	0.3901
Distance 50 m*PC2	− 0.01	0.02	7.04	− 0.46	0.6583	− 0.01	0.01	6.95	− 1.36	0.2157
PC1*PC2	0.04	0.01	8.30	2.51	0.0352	0.01	0.01	8.22	1.69	0.1290

Table 10 (continued)

Ground beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Distance 1 m*PC1*PC2	0.03	0.02	8.55	1.48	0.1745	0.01	0.01	8.47	0.62	0.5520
Distance 10 m*PC1*PC2	− 0.01	0.01	7.57	− 0.48	0.6472	0.00	0.01	7.48	0.07	0.9495
Distance 50 m*PC1*PC2	− 0.02	0.01	8.28	− 1.88	0.0955	− 0.01	0.01	8.19	− 1.07	0.3170
P/A season										
Intercept	0.36	0.05	4	7.8	0.0015	0.27	0.02	4	14.34	0.0001
April	− 0.01	0.06	8	− 0.24	0.8170	0.05	0.03	8	1.68	0.1314
July	0.04	0.06	8	0.74	0.4816	− 0.02	0.03	8	− 0.82	0.4375
September	− 0.03	0.06	8	− 0.5	0.6312	− 0.03	0.03	8	− 0.86	0.4131
PC1	− 0.02	0.02	4	− 1.15	0.3154	− 0.02	0.01	4	− 3.13	**0.0353**
April*PC1	0.00	0.02	8	− 0.17	0.8685	− 0.02	0.01	8	− 1.3	0.2297
July*PC1	0.00	0.02	8	− 0.21	0.8402	0.01	0.01	8	0.67	0.5189
September*PC1	0.01	0.02	8	0.38	0.7144	0.01	0.01	8	0.63	0.5490
PC2	0.01	0.02	4	0.47	0.6659	0.01	0.01	4	0.81	0.4650
April*PC2	0.01	0.03	8	0.35	0.7321	0.01	0.01	8	0.68	0.5166
July*PC2	0.01	0.03	8	0.43	0.6791	0.00	0.01	8	− 0.12	0.9050
September*PC2	− 0.02	0.03	8	− 0.78	0.4558	− 0.01	0.01	8	− 0.56	0.5939
PC1*PC2	0.00	0.01	4	0.15	0.8896	0.00	0.00	4	0.26	0.8053
April*PC1*PC2	0.01	0.01	8	0.69	0.5120	0.01	0.01	8	0.99	0.3514
July*PC1*PC2	0.00	0.01	8	− 0.35	0.7332	0.00	0.01	8	− 0.36	0.7293
September*PC1*PC2	0.00	0.01	8	− 0.33	0.7476	0.00	0.01	8	− 0.63	0.5455

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

Table 11 GLMM results of rove beetle and aquatic insect abundance

Rove beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance										
Intercept	0.24	0.19	5.35	1.25	0.2646	0.18	0.14	5.88	1.31	0.2378
Distance 1 m	0.12	0.22	10.85	0.54	0.6025	0.22	0.22	10.43	0.99	0.3435
Distance 10 m	− 0.27	0.16	7.00	− 1.69	0.1347	− 0.33	0.19	7.69	− 1.74	0.1216
Distance 50 m	0.15	0.19	10.26	0.8	0.4396	0.11	0.20	9.75	0.57	0.5790
PC1	0.00	0.11	7.93	− 0.04	0.9680	0.00	0.09	8.73	− 0.05	0.9640
Distance 1 m*PC1	0.09	0.15	10.18	0.59	0.5710	0.06	0.15	11.61	0.42	0.6815
Distance 10 m*PC1	− 0.11	0.11	9.12	− 0.96	0.3624	− 0.08	0.12	10.64	− 0.64	0.5347
Distance 50 m*PC1	0.02	0.10	8.16	0.22	0.8294	0.02	0.12	10.09	0.13	0.8982
PC2	0.05	0.12	9.01	0.38	0.7132	0.05	0.09	4.66	0.63	0.5573
Distance 1 m*PC2	0.16	0.12	8.11	1.3	0.2289	0.18	0.14	8.85	1.28	0.2322
Distance 10 m*PC2	− 0.05	0.09	8.13	− 0.55	0.5952	− 0.04	0.11	9.55	− 0.36	0.7302
Distance 50 m*PC2	− 0.11	0.09	7.23	− 1.14	0.2911	− 0.14	0.11	8.44	− 1.25	0.2439
PC1*PC2	0.05	0.07	11.77	0.66	0.5192	0.06	0.06	8.72	0.99	0.3473
Distance 1 m*PC1*PC2	− 0.03	0.10	9.78	− 0.33	0.7497	0.02	0.11	11.27	0.19	0.8565
Distance 10 m*PC1*PC2	0.03	0.07	8.54	0.45	0.6636	0.02	0.08	11.16	0.27	0.7937
Distance 50 m*PC1*PC2	0.00	0.06	9.65	0.03	0.9795	− 0.04	0.07	11.50	− 0.61	0.5563
Pearson R season										
Intercept	0.07	0.18	4	0.4	0.7126	0.04	0.16	4	0.26	0.8044
April	0.14	0.07	8	1.93	***0.0891***	− 0.04	0.06	8	− 0.6	0.5661
July	− 0.10	0.07	8	− 1.45	0.1855	− 0.03	0.06	8	− 0.44	0.6700

Table 11 (continued)

Rove beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
September	− 0.03	0.07	8	− 0.49	0.6398	0.06	0.06	8	1.04	0.3284
PC1	− 0.02	0.07	4	− 0.31	0.7732	0.00	0.06	4	− 0.02	0.9871
April*PC1	− 0.06	0.03	8	− 2.14	***0.0647***	0.04	0.02	8	1.64	0.1388
July*PC1	0.04	0.03	8	1.34	0.2160	− 0.02	0.02	8	− 0.75	0.4768
September*PC1	0.02	0.03	8	0.8	0.4481	− 0.02	0.02	8	− 0.9	0.3955
PC2	− 0.02	0.08	4	− 0.29	0.7889	− 0.01	0.08	4	− 0.17	0.8719
April*PC2	− 0.04	0.03	8	− 1.21	0.2617	0.01	0.03	8	0.48	0.6427
July*PC2	− 0.06	0.03	8	− 1.82	0.1061	0.03	0.03	8	0.99	0.3520
September*PC2	0.10	0.03	8	3.03	**0.0163**	− 0.04	0.03	8	− 1.47	0.1797
PC1*PC2	− 0.03	0.03	4	− 0.92	0.4108	− 0.04	0.03	4	− 1.32	0.2565
April*PC1*PC2	0.01	0.01	8	0.91	0.3901	0.00	0.01	8	− 0.05	0.9632
July*PC1*PC2	0.01	0.01	8	0.42	0.6847	0.00	0.01	8	0.2	0.8488
September*PC1*PC2	− 0.02	0.01	8	− 1.33	0.2202	0.00	0.01	8	− 0.15	0.8850
P/A distance										
Intercept	0.47	0.04	4.91	11.07	0.0001	1.57	0.26	6.09	6.12	0.0008
Distance 1 m	0.00	0.07	10.21	− 0.04	0.9694	− 0.22	0.23	10.56	− 0.95	0.3641
Distance 10 m	0.00	0.06	6.83	− 0.08	0.9365	0.25	0.15	7.18	1.6	0.1523
Distance 50 m	0.01	0.06	9.37	0.12	0.9070	− 0.03	0.20	10.19	− 0.16	0.8777
PC1	− 0.06	0.03	7.85	− 2.02	***0.0782***	− 0.12	0.14	9.02	− 0.84	0.4239
Distance 1 m*PC1	0.04	0.05	11.40	0.8	0.4427	− 0.13	0.15	9.28	− 0.85	0.4154
Distance 10 m*PC1	− 0.03	0.04	10.12	− 0.8	0.4421	0.16	0.11	8.52	1.46	0.1797
Distance 50 m*PC1	− 0.01	0.03	9.24	− 0.2	0.8423	− 0.04	0.10	7.94	− 0.39	0.7085
PC2	0.02	0.03	4.34	0.84	0.4422	0.05	0.15	11.77	0.35	0.7348
Distance 1 m*PC2	− 0.01	0.04	8.04	− 0.34	0.7401	0.03	0.12	8.19	0.28	0.7872
Distance 10 m*PC2	0.01	0.03	8.67	0.34	0.7419	0.05	0.09	8.08	0.48	0.6411
Distance 50 m*PC2	0.00	0.03	7.47	0.1	0.9259	− 0.08	0.09	7.39	− 0.87	0.4139
PC1*PC2	0.03	0.02	9.00	1.3	0.2252	− 0.09	0.07	10.07	− 1.3	0.2217
Distance 1 m*PC1*PC2	0.01	0.03	10.78	0.44	0.6668	0.04	0.10	9.34	0.4	0.6984
Distance 10 m*PC1*PC2	0.00	0.02	10.34	0.11	0.9165	− 0.13	0.07	8.22	− 1.91	***0.0910***
Distance 50 m*PC1*PC2	− 0.02	0.02	11.05	− 0.82	0.4304	0.09	0.06	9.08	1.41	0.1923
P/A season										
Intercept	1.01	0.16	4	6.29	0.0033	0.53	0.05	4	10.02	0.0006
April	0.71	0.23	8	3.1	**0.0146**	0.34	0.10	8	3.45	**0.0088**
July	− 0.36	0.23	8	− 1.56	0.1567	− 0.21	0.10	8	− 2.07	***0.0717***
September	− 0.35	0.23	8	− 1.54	0.1624	− 0.14	0.10	8	− 1.37	0.2077
PC1	− 0.25	0.06	4	− 4.12	**0.0146**	− 0.11	0.02	4	− 5.47	**0.0054**
April*PC1	− 0.27	0.09	8	− 3.02	**0.0165**	− 0.12	0.04	8	− 3.09	**0.0150**
July*PC1	0.14	0.09	8	1.61	0.1459	0.07	0.04	8	1.91	***0.0932***
September*PC1	0.12	0.09	8	1.41	0.1959	0.05	0.04	8	1.18	0.2715
PC2	0.01	0.07	4	0.19	0.8605	0.01	0.02	4	0.51	0.6366
April*PC2	0.01	0.11	8	0.1	0.9231	0.02	0.05	8	0.42	0.6842
July*PC2	− 0.02	0.11	8	− 0.15	0.8851	− 0.02	0.05	8	− 0.36	0.7246
September*PC2	0.01	0.11	8	0.05	0.9617	0.00	0.05	8	− 0.06	0.9560
PC1*PC2	0.03	0.03	4	1.28	0.2704	0.01	0.01	4	1.3	0.2646
April*PC1*PC2	0.05	0.04	8	1.38	0.2035	0.02	0.02	8	1.14	0.2878
July*PC1*PC2	− 0.03	0.04	8	− 0.75	0.4751	− 0.01	0.02	8	− 0.7	0.5039
September*PC1*PC2	− 0.02	0.04	8	− 0.64	0.5428	− 0.01	0.02	8	− 0.44	0.6724

Significance $p < 0.05$ in bold, significance $p > 0.1$ in italics

Table 12 GLMM results of sheet-web spider and aquatic insect abundance

Sheet-web spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* Ratio	Prob > |*t*|
Pearson R distance										
Intercept	− 0.35	0.11	1.73	− 3.37	***0.0954***	− 0.15	0.07	5.83	− 2.14	***0.0777***
Distance 1 m	− 0.10	0.10	4.92	− 0.96	0.3829	− 0.02	0.09	11.03	− 0.21	0.8387
Distance 10 m	0.11	0.05	2.04	2.13	0.1646	0.11	0.07	7.68	1.62	0.1455
Distance 50 m	− 0.01	0.09	4.53	− 0.14	0.8915	− 0.09	0.08	10.44	− 1.19	0.2593
PC1	0.01	0.08	5.26	0.17	0.8682	0.03	0.04	8.39	0.81	0.4412
Distance 1 m*PC1	− 0.02	0.06	3.22	− 0.3	0.7851	0.22	0.06	11.04	3.53	**0.0047**
Distance 10 m*PC1	0.03	0.04	2.67	0.6	0.5927	− 0.17	0.05	10.03	− 3.54	**0.0053**
Distance 50 m*PC1	− 0.01	0.04	2.44	− 0.24	0.8311	− 0.05	0.04	9.09	− 1.09	0.3052
PC2	− 0.08	0.08	10.55	− 1.1	0.2959	0.04	0.05	7.63	0.85	0.4199
Distance 1 m*PC2	0.04	0.05	2.63	0.8	0.4896	0.11	0.05	8.71	2.01	***0.0766***
Distance 10 m*PC2	− 0.07	0.03	2.52	− 2.11	0.1424	− 0.10	0.04	8.88	− 2.41	**0.0398**
Distance 50 m*PC2	0.04	0.03	2.19	1.18	0.3510	− 0.01	0.04	7.97	− 0.19	0.8566
PC1*PC2	− 0.02	0.03	3.43	− 0.7	0.5290	0.05	0.03	11.88	1.74	0.1081
Distance 1 m*PC1*PC2	− 0.04	0.04	3.49	− 0.89	0.4323	0.05	0.04	10.50	1.22	0.2503
Distance 10 m*PC1*PC2	− 0.03	0.03	2.60	− 1.24	0.3145	− 0.06	0.03	9.54	− 2.01	***0.0736***
Distance 50 m*PC1*PC2	0.07	0.02	3.21	2.69	***0.0693***	0.01	0.03	10.52	0.33	0.7500
Pearson R season										
Intercept	− 0.04	0.07	4	− 0.58	0.5926	0.02	0.11	4	0.15	0.8851
April	− 0.06	0.14	8	− 0.42	0.6877	0.01	0.14	8	0.05	0.9611
July	− 0.11	0.14	8	− 0.77	0.4658	− 0.03	0.14	8	− 0.25	0.8123
September	0.16	0.14	8	1.18	0.2709	0.03	0.14	8	0.2	0.8502
PC1	− 0.05	0.03	4	− 1.73	0.1592	− 0.04	0.04	4	− 0.9	0.4199
April*PC1	− 0.05	0.05	8	− 0.89	0.3985	− 0.06	0.05	8	− 1.16	0.2802
July*PC1	− 0.02	0.05	8	− 0.47	0.6537	0.03	0.05	8	0.59	0.5735
September*PC1	0.07	0.05	8	1.36	0.2116	0.03	0.05	8	0.57	0.5834
PC2	0.05	0.03	4	1.48	0.2118	0.04	0.05	4	0.73	0.5072
April*PC2	0.02	0.06	8	0.26	0.8023	0.05	0.07	8	0.71	0.5002
July*PC2	0.02	0.06	8	0.31	0.7612	− 0.03	0.07	8	− 0.46	0.6598
September*PC2	− 0.04	0.06	8	− 0.57	0.5822	− 0.02	0.07	8	− 0.25	0.8097
PC1*PC2	0.01	0.01	4	0.43	0.6882	0.00	0.02	4	0.16	0.8816
April*PC1*PC2	− 0.01	0.02	8	− 0.38	0.7137	0.01	0.02	8	0.38	0.7148
July*PC1*PC2	− 0.01	0.02	8	− 0.25	0.8100	− 0.01	0.02	8	− 0.22	0.8320
September*PC1*PC2	0.01	0.02	8	0.63	0.5471	0.00	0.02	8	− 0.16	0.8772
P/A distance										
Intercept	1.41	0.12	5.74	11.85	< 0.0001	0.57	0.06	2.78	8.79	0.0042
Distance 1 m	− 0.11	0.11	10.50	− 1.03	0.3260	− 0.04	0.11	8.06	− 0.38	0.7141
Distance 10 m	0.04	0.07	6.90	0.59	0.5756	0.06	0.11	7.46	0.59	0.5721
Distance 50 m	0.07	0.10	10.08	0.72	0.4908	− 0.02	0.10	7.21	− 0.22	0.8351
PC1	0.04	0.07	8.67	0.59	0.5730	0.03	0.04	2.82	0.68	0.5507
Distance 1 m*PC1	0.05	0.07	9.17	0.76	0.4682	− 0.06	0.06	9.89	− 0.92	0.3809
Distance 10 m*PC1	− 0.07	0.05	8.35	− 1.32	0.2232	0.09	0.06	10.16	1.47	0.1722
Distance 50 m*PC1	0.02	0.05	7.71	0.37	0.7249	− 0.03	0.06	11.95	− 0.48	0.6411
PC2	0.08	0.07	11.59	1.13	0.2817	− 0.08	0.02	1.09	− 4.4	0.1258
Distance 1 m*PC2	0.06	0.06	7.96	1.07	0.3150	− 0.02	0.10	9.68	− 0.2	0.8436
Distance 10 m*PC2	0.02	0.04	7.85	0.51	0.6215	− 0.03	0.07	6.62	− 0.37	0.7208
Distance 50 m*PC2	− 0.09	0.04	7.12	− 1.95	***0.0911***	0.05	0.09	4.17	0.53	0.6221
PC1*PC2	0.00	0.03	10.10	− 0.01	0.9906	− 0.03	0.02	3.29	− 1.99	0.1330

Table 12 (continued)

Sheet-web spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* Ratio	Prob > |*t*|
Distance 1 m*PC1*PC2	0.09	0.05	9.20	1.84	***0.0985***	− 0.02	0.06	3.55	− 0.35	0.7457
Distance 10 m*PC1*PC2	− 0.04	0.03	8.01	− 1.39	0.2019	− 0.03	0.04	1.57	− 0.73	0.5599
Distance 50 m*PC1*PC2	− 0.04	0.03	8.93	− 1.44	0.1841	0.05	0.04	4.95	1.39	0.2237
P/A season										
Intercept	0.55	0.06	4	9.82	0.0006	0.39	0.03	4	11.81	0.0003
April	0.50	0.09	8	5.43	**0.0006**	0.30	0.06	8	5.37	**0.0007**
July	− 0.24	0.09	8	− 2.64	**0.0299**	− 0.15	0.06	8	− 2.58	**0.0325**
September	− 0.26	0.09	8	− 2.8	**0.0233**	− 0.16	0.06	8	− 2.78	**0.0238**
PC1	− 0.08	0.02	4	− 3.82	**0.0188**	− 0.07	0.01	4	− 5.16	**0.0067**
April*PC1	− 0.11	0.04	8	− 3.17	**0.0133**	− 0.09	0.02	8	− 4	**0.0040**
July*PC1	0.06	0.04	8	1.76	0.1164	0.05	0.02	8	2.22	***0.0574***
September*PC1	0.05	0.04	8	1.41	0.1974	0.04	0.02	8	1.78	0.1132
PC2	0.01	0.03	4	0.46	0.6724	0.01	0.02	4	0.54	0.6162
April*PC2	0.05	0.04	8	1.23	0.2554	0.03	0.03	8	1.09	0.3061
July*PC2	− 0.03	0.04	8	− 0.77	0.4651	− 0.02	0.03	8	− 0.69	0.5106
September*PC2	− 0.02	0.04	8	− 0.46	0.6591	− 0.01	0.03	8	− 0.4	0.6964
PC1*PC2	0.01	0.01	4	0.93	0.4044	0.01	0.01	4	1.32	0.2568
April*PC1*PC2	0.01	0.02	8	0.63	0.5473	0.01	0.01	8	1.42	0.1935
July*PC1*PC2	− 0.01	0.02	8	− 0.43	0.6818	− 0.01	0.01	8	− 0.83	0.4303
September*PC1*PC2	0.00	0.02	8	− 0.2	0.8443	− 0.01	0.01	8	− 0.59	0.5721

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

Table 13 GLMM results of ground-hunting spider and aquatic insect abundance

Ground-hunting spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance										
Intercept	− 0.34	0.07	7.28	− 4.58	**0.0023**	− 0.34	0.09	3.91	− 3.94	**0.0177**
Distance 1 m	0.10	0.16	9.39	0.65	0.5319	0.17	0.15	8.30	1.08	0.3106
Distance 10 m	0.02	0.14	8.00	0.13	0.9019	− 0.04	0.13	5.38	− 0.31	0.7717
Distance 50 m	− 0.12	0.14	8.94	− 0.84	0.4223	− 0.12	0.14	7.49	− 0.9	0.3938
PC1	0.04	0.06	7.84	0.81	0.4434	0.00	0.06	6.53	0.01	0.9927
Distance 1 m*PC1	0.02	0.10	10.89	0.16	0.8738	0.05	0.11	10.63	0.46	0.6541
Distance 10 m*PC1	− 0.05	0.08	10.45	− 0.64	0.5384	− 0.10	0.09	9.25	− 1.18	0.2658
Distance 50 m*PC1	0.04	0.08	10.84	0.45	0.6634	0.05	0.09	8.91	0.61	0.5569
PC2	0.04	0.04	2.54	1.09	0.3672	0.08	0.06	2.23	1.38	0.2906
Distance 1 m*PC2	− 0.08	0.11	10.32	− 0.78	0.4523	− 0.10	0.11	7.50	− 0.92	0.3883
Distance 10 m*PC2	− 0.02	0.08	10.67	− 0.26	0.7989	− 0.04	0.08	7.80	− 0.48	0.6443
Distance 50 m*PC2	0.11	0.08	9.83	1.24	0.2424	0.14	0.08	6.95	1.62	0.1492
PC1*PC2	− 0.02	0.03	4.66	− 0.7	0.5173	− 0.01	0.05	4.99	− 0.23	0.8262
Distance 1 m*PC1*PC2	− 0.04	0.08	10.42	− 0.54	0.5986	− 0.05	0.08	10.75	− 0.62	0.5477
Distance 10 m*PC1*PC2	0.02	0.06	9.29	0.41	0.6876	0.04	0.06	10.91	0.57	0.5827
Distance 50 m*PC1*PC2	0.02	0.05	10.45	0.39	0.7069	0.02	0.05	10.75	0.31	0.7647
Pearson R season										
Intercept	− 0.02	0.00	1.00	− 8.64	***0.0733***	− 0.14	0.02	0.98	− 6.95	***0.0949***
April	− 0.09	0.21	7.00	− 0.43	0.6781	− 0.22	0.22	6.93	− 1	0.3503
July	0.03	0.22	7.00	0.13	0.9014	0.09	0.23	7.01	0.38	0.7130

Table 13 (continued)

Ground-hunting spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
September	0.06	0.22	7.00	0.28	0.7877	0.13	0.23	6.91	0.56	0.5929
PC1	0.03	0.00	1.00	43.69	**0.0146**	0.01	0.01	0.97	1.78	0.3318
April*PC1	0.07	0.08	7.00	0.94	0.3799	0.07	0.08	6.90	0.82	0.4371
July*PC1	− 0.05	0.08	7.00	− 0.63	0.5489	− 0.06	0.09	6.92	− 0.65	0.5365
September*PC1	− 0.02	0.08	7.00	− 0.27	0.7950	− 0.01	0.09	6.89	− 0.14	0.8920
PC2	− 0.05	0.00	1.00	− 41.95	**0.0151**	− 0.05	0.01	0.98	− 4.91	0.1323
April*PC2	0.12	0.10	7.00	1.22	0.2633	0.11	0.10	6.93	1.13	0.2979
July*PC2	− 0.08	0.10	7.00	− 0.76	0.4702	− 0.13	0.11	7.00	− 1.18	0.2764
September*PC2	− 0.04	0.10	7.00	− 0.35	0.7340	0.02	0.11	6.91	0.15	0.8849
PC1*PC2	− 0.01	0.00	1.00	− 18.76	**0.0339**	0.00	0.00	0.97	− 0.2	0.8735
April*PC1*PC2	0.02	0.04	7.00	0.46	0.6563	0.00	0.04	6.90	− 0.11	0.9132
July*PC1*PC2	− 0.02	0.04	7.00	− 0.59	0.5722	− 0.01	0.04	6.91	− 0.29	0.7818
September*PC1*PC2	0.01	0.04	7.00	0.15	0.8861	0.02	0.04	6.89	0.4	0.7039
P/A distance										
Intercept	0.52	0.09	5.29	5.57	0.0021	0.60	0.08	5.31	7.34	0.0006
Distance 1 m	− 0.10	0.09	10.39	− 1.07	0.3092	− 0.01	0.09	10.85	− 0.15	0.8798
Distance 10 m	− 0.06	0.06	6.53	− 0.98	0.3639	− 0.06	0.07	6.99	− 0.88	0.4082
Distance 50 m	0.15	0.08	9.91	1.97	***0.0775***	0.07	0.08	10.24	0.91	0.3839
PC1	0.00	0.05	8.20	0	0.9985	− 0.07	0.05	7.89	− 1.37	0.2091
Distance 1 m*PC1	− 0.04	0.06	9.00	− 0.71	0.4944	− 0.09	0.06	10.24	− 1.46	0.1730
Distance 10 m*PC1	0.00	0.04	8.10	0.04	0.9697	0.06	0.05	9.16	1.13	0.2875
Distance 50 m*PC1	0.04	0.04	7.39	1.04	0.3322	0.04	0.04	8.18	0.88	0.4045
PC2	0.00	0.06	11.29	0	0.9989	− 0.03	0.05	8.81	− 0.6	0.5636
Distance 1 m*PC2	− 0.02	0.05	7.62	− 0.32	0.7560	0.00	0.05	8.11	− 0.04	0.9685
Distance 10 m*PC2	0.00	0.04	7.52	− 0.03	0.9751	0.00	0.04	8.14	− 0.1	0.9228
Distance 50 m*PC2	0.02	0.04	6.75	0.46	0.6587	0.01	0.04	7.23	0.15	0.8824
PC1*PC2	0.02	0.03	10.14	0.56	0.5889	− 0.01	0.03	11.83	− 0.31	0.7584
Distance 1 m*PC1*PC2	− 0.04	0.04	8.98	− 1.04	0.3236	− 0.05	0.04	9.81	− 1.09	0.3006
Distance 10 m*PC1*PC2	0.03	0.03	7.71	0.98	0.3557	0.01	0.03	8.57	0.38	0.7103
Distance 50 m*PC1*PC2	0.02	0.02	8.70	0.61	0.5573	0.04	0.03	9.69	1.3	0.2230
P/A season										
Intercept	0.37	0.11	4.053	3.44	0.0256	0.25	0.05	4.226	4.93	0.0068
April	0.41	0.10	5.297	4.19	**0.0076**	0.23	0.05	5.552	4.82	**0.0036**
July	− 0.22	0.11	5.335	− 1.91	0.1111	− 0.13	0.06	5.608	− 2.36	***0.0596***
September	− 0.19	0.10	5.033	− 1.95	0.1084	− 0.10	0.05	5.29	− 2.05	***0.0929***
PC1	− 0.08	0.04	3.583	− 2.06	0.1165	− 0.05	0.02	3.742	− 3.02	**0.0428**
April*PC1	− 0.11	0.03	5.105	− 3.25	**0.0220**	− 0.06	0.02	5.356	− 3.72	**0.0121**
July*PC1	0.06	0.04	5.027	1.57	0.1764	0.03	0.02	5.285	1.91	0.1115
September*PC1	0.05	0.03	4.914	1.58	0.1764	0.03	0.02	5.165	1.69	0.1505
PC2	0.01	0.05	4.129	0.13	0.9033	0.00	0.02	4.3	0.04	0.9721
April*PC2	0.03	0.05	5.445	0.56	0.5960	0.02	0.02	5.698	0.65	0.5398
July*PC2	− 0.02	0.05	5.353	− 0.35	0.7405	− 0.02	0.03	5.625	− 0.78	0.4644
September*PC2	− 0.01	0.05	5.062	− 0.15	0.8831	0.01	0.02	5.318	0.26	0.8046
PC1*PC2	0.02	0.02	3.573	0.96	0.3971	0.01	0.01	3.73	1.28	0.2750
April*PC1*PC2	0.02	0.02	5.124	1.38	0.2259	0.01	0.01	5.374	1.2	0.2811
July*PC1*PC2	− 0.01	0.02	4.998	− 0.62	0.5608	0.00	0.01	5.254	− 0.35	0.7397
September*PC1*PC2	− 0.01	0.02	4.91	− 0.72	0.5043	− 0.01	0.01	5.161	− 0.82	0.4467

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

Table 14 GLMM results of ground beetle and terrestrial dipteran abundance

Ground beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance										
Intercept	− 0.06	0.06	5.91	− 1.05	0.3361	− 0.08	0.10	5.72	− 0.83	0.4397
Distance 1 m	− 0.12	0.10	9.67	− 1.15	0.2771	− 0.08	0.15	10.62	− 0.53	0.6095
Distance 10 m	0.08	0.09	7.37	0.81	0.4431	0.07	0.13	7.62	0.55	0.5991
Distance 50 m	0.04	0.10	9.02	0.45	0.6664	0.01	0.14	9.92	0.06	0.9505
PC1	0.13	0.04	8.54	3.26	**0.0106**	0.09	0.06	8.54	1.47	0.1784
Distance 1 m*PC1	0.00	0.07	11.58	− 0.07	0.9453	− 0.03	0.10	11.53	− 0.28	0.7818
Distance 10 m*PC1	0.01	0.06	10.64	0.19	0.8523	− 0.01	0.08	10.49	− 0.08	0.9386
Distance 50 m*PC1	− 0.01	0.06	10.64	− 0.11	0.9147	0.04	0.08	9.74	0.46	0.6535
PC2	0.04	0.03	3.26	1.01	0.3798	0.08	0.06	5.23	1.23	0.2719
Distance 1 m*PC2	0.07	0.07	8.90	1.01	0.3407	0.07	0.09	8.73	0.74	0.4769
Distance 10 m*PC2	− 0.10	0.06	10.07	− 1.83	***0.0967***	− 0.07	0.07	9.26	− 0.93	0.3759
Distance 50 m*PC2	0.03	0.06	8.79	0.51	0.6198	0.00	0.08	8.20	− 0.02	0.9816
PC1*PC2	0.04	0.03	6.35	1.31	0.2349	0.01	0.05	9.74	0.28	0.7865
Distance 1 m*PC1*PC2	0.06	0.05	11.75	1.05	0.3139	0.03	0.07	11.02	0.37	0.7161
Distance 10 m*PC1*PC2	− 0.03	0.04	11.98	− 0.73	0.4807	0.00	0.05	10.62	0.06	0.9510
Distance 50 m*PC1*PC2	− 0.03	0.03	11.92	− 0.80	0.4410	− 0.03	0.05	11.23	− 0.66	0.5233
Pearson R season										
Intercept	− 0.03	0.06	4.00	− 0.56	0.6052	− 0.05	0.06	4.00	− 0.86	0.4370
April	0.02	0.15	8.00	0.16	0.8799	0.05	0.17	8.00	0.27	0.7936
July	0.10	0.15	8.00	0.69	0.5081	0.01	0.17	8.00	0.07	0.9467
September	− 0.12	0.15	8.00	− 0.85	0.4207	− 0.06	0.17	8.00	− 0.34	0.7430
PC1	0.07	0.02	4.00	2.95	**0.0420**	0.04	0.02	4.00	2.00	0.1164
April*PC1	− 0.05	0.06	8.00	− 0.95	0.3715	− 0.03	0.07	8.00	− 0.40	0.6992
July*PC1	0.02	0.06	8.00	0.36	0.7252	0.01	0.07	8.00	0.17	0.8670
September*PC1	0.03	0.06	8.00	0.58	0.5762	0.02	0.07	8.00	0.23	0.8256
PC2	0.02	0.03	4.00	0.63	0.5658	0.02	0.03	4.00	0.62	0.5687
April*PC2	− 0.02	0.07	8.00	− 0.27	0.7961	− 0.03	0.08	8.00	− 0.41	0.6903
July*PC2	0.06	0.07	8.00	0.91	0.3917	0.06	0.08	8.00	0.80	0.4474
September*PC2	− 0.04	0.07	8.00	− 0.64	0.5412	− 0.03	0.08	8.00	− 0.39	0.7098
PC1*PC2	− 0.02	0.01	4.00	− 2.09	0.1047	0.00	0.01	4.00	− 0.33	0.7557
April*PC1*PC2	0.01	0.02	8.00	0.43	0.6786	− 0.01	0.03	8.00	− 0.43	0.6778
July*PC1*PC2	− 0.01	0.02	8.00	− 0.28	0.7872	− 0.03	0.03	8.00	− 1.03	0.3317
September*PC1*PC2	0.00	0.02	8.00	− 0.15	0.8839	0.04	0.03	8.00	1.46	0.1813
P/A distance										
Intercept	0.27	0.03	6.17	7.92	0.0002	0.91	0.08	6.12	11.03	< 0.0001
Distance 1 m	0.07	0.03	10.64	2.27	**0.0451**	− 0.18	0.07	10.46	− 2.48	**0.0317**
Distance 10 m	− 0.01	0.02	7.29	− 0.35	0.7345	0.11	0.05	7.13	2.23	***0.0603***
Distance 50 m	− 0.06	0.03	10.27	− 2.30	**0.0437**	0.07	0.06	10.11	1.11	0.2924
PC1	0.00	0.02	9.03	0.10	0.9229	− 0.05	0.05	9.16	− 0.99	0.3461
Distance 1 m*PC1	0.01	0.02	9.41	0.35	0.7350	− 0.09	0.05	9.14	− 1.90	***0.0887***
Distance 10 m*PC1	− 0.01	0.02	8.65	− 0.80	0.4425	0.05	0.04	8.40	1.52	0.1661
Distance 50 m*PC1	0.01	0.01	8.06	0.40	0.7021	0.04	0.03	7.86	1.15	0.2837
PC2	0.04	0.02	11.70	2.30	**0.0411**	− 0.09	0.05	11.90	− 1.91	***0.0800***
Distance 1 m*PC2	0.01	0.02	8.30	0.55	0.5955	− 0.02	0.04	8.13	− 0.65	0.5363
Distance 10 m*PC2	0.00	0.01	8.20	− 0.39	0.7088	− 0.01	0.03	8.01	− 0.35	0.7325
Distance 50 m*PC2	0.00	0.01	7.50	− 0.34	0.7429	0.03	0.03	7.35	1.22	0.2585
PC1*PC2	0.00	0.01	10.24	0.44	0.6692	− 0.03	0.02	9.82	− 1.28	0.2308

Table 14 (continued)

Ground beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Distance 1 m*PC1*PC2	0.00	0.01	9.45	0.23	0.8214	− 0.05	0.03	9.25	− 1.48	0.1722
Distance 10 m*PC1*PC2	0.00	0.01	8.34	− 0.05	0.9613	0.03	0.02	8.14	1.51	0.1692
Distance 50 m*PC1*PC2	0.00	0.01	9.20	− 0.32	0.7590	0.01	0.02	8.97	0.75	0.4714
P/A season										
Intercept	0.25	0.05	4.00	5.23	0.0064	0.76	0.04	4.00	17.53	< 0.0001
April	− 0.12	0.04	8.00	− 3.28	**0.0113**	0.14	0.04	8.00	3.52	**0.0079**
July	0.11	0.04	8.00	2.99	**0.0173**	− 0.10	0.04	8.00	− 2.61	**0.0312**
September	0.01	0.04	8.00	0.28	0.7842	− 0.04	0.04	8.00	− 0.91	0.3903
PC1	0.00	0.02	4.00	− 0.01	0.9921	− 0.02	0.02	4.00	− 1.15	0.3152
April*PC1	0.02	0.01	8.00	1.33	0.2196	− 0.02	0.02	8.00	− 1.18	0.2704
July*PC1	− 0.04	0.01	8.00	− 2.57	**0.0329**	0.03	0.02	8.00	1.76	0.1170
September*PC1	0.02	0.01	8.00	1.24	0.2494	− 0.01	0.02	8.00	− 0.57	0.5826
PC2	0.00	0.02	4.00	0.13	0.8996	0.00	0.02	4.00	− 0.05	0.9619
April*PC2	0.00	0.02	8.00	− 0.25	0.8099	0.00	0.02	8.00	0.19	0.8528
July*PC2	0.01	0.02	8.00	0.45	0.6647	0.01	0.02	8.00	0.30	0.7722
September*PC2	0.00	0.02	8.00	− 0.20	0.8455	− 0.01	0.02	8.00	− 0.49	0.6365
PC1*PC2	0.00	0.01	4.00	− 0.06	0.9555	0.00	0.01	4.00	− 0.19	0.8610
April*PC1*PC2	0.00	0.01	8.00	0.23	0.8242	0.00	0.01	8.00	− 0.01	0.9901
July*PC1*PC2	0.00	0.01	8.00	0.10	0.9258	0.00	0.01	8.00	− 0.73	0.4884
September*PC1*PC2	0.00	0.01	8.00	− 0.33	0.7530	0.01	0.01	8.00	0.74	0.4810

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

Table 15 GLMM results of rove beetle and terrestrial dipteran abundance

Rove beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance										
Intercept	0.07	0.07	7.06	1.03	0.3363	− 0.01	0.09	5.27	− 0.08	0.9407
Distance 1 m	0.02	0.15	9.20	0.11	0.9109	0.00	0.15	9.86	− 0.03	0.9750
Distance 10 m	− 0.14	0.14	7.89	− 1.04	0.3310	− 0.27	0.13	7.02	− 2.03	***0.0813***
Distance 50 m	0.13	0.14	8.74	0.92	0.3798	0.27	0.14	9.09	1.99	***0.0780***
PC1	0.13	0.05	7.91	2.55	**0.0343**	0.08	0.06	8.21	1.29	0.2324
Distance 1 m*PC1	0.01	0.09	11.36	0.06	0.9551	0.11	0.10	11.54	1.06	0.3096
Distance 10 m*PC1	− 0.05	0.08	10.77	− 0.69	0.5061	− 0.13	0.08	10.40	− 1.59	0.1411
Distance 50 m*PC1	0.05	0.08	11.67	0.63	0.5408	0.02	0.08	9.95	0.31	0.7643
PC2	− 0.09	0.03	2.48	− 2.61	***0.0973***	− 0.06	0.06	3.61	− 1.02	0.3722
Distance 1 m*PC2	0.00	0.11	10.46	− 0.04	0.9719	0.08	0.10	8.35	0.80	0.4450
Distance 10 m*PC2	− 0.01	0.08	11.68	− 0.07	0.9448	− 0.07	0.08	9.29	− 0.89	0.3956
Distance 50 m*PC2	0.01	0.09	11.11	0.11	0.9169	− 0.01	0.08	8.00	− 0.13	0.9015
PC1*PC2	− 0.05	0.03	5.01	− 1.52	0.1888	0.00	0.04	7.29	0.04	0.9716
Distance 1 m*PC1*PC2	0.04	0.07	11.54	0.60	0.5604	0.07	0.08	11.30	0.91	0.3811
Distance 10 m*PC1*PC2	− 0.07	0.05	9.23	− 1.22	0.2543	0.00	0.06	11.41	− 0.07	0.9445
Distance 50 m*PC1*PC2	0.02	0.05	11.53	0.49	0.6325	− 0.06	0.05	11.58	− 1.35	0.2018
Pearson R season										
Intercept	0.12	0.10	4.00	1.18	0.3021	0.07	0.06	4.00	1.23	0.2849
April	− 0.12	0.12	8.00	− 1.01	0.3412	− 0.22	0.15	8.00	− 1.41	0.1973
July	0.11	0.12	8.00	0.90	0.3951	0.20	0.15	8.00	1.33	0.2200

Table 15 (continued)

Rove beetles	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
September	0.01	0.12	8.00	0.11	0.9126	0.01	0.15	8.00	0.08	0.9416
PC1	0.03	0.04	4.00	0.71	0.5164	0.03	0.02	4.00	1.51	0.2055
April*PC1	− 0.02	0.05	8.00	− 0.44	0.6713	0.03	0.06	8.00	0.56	0.5925
July*PC1	− 0.04	0.05	8.00	− 0.77	0.4616	− 0.06	0.06	8.00	− 1.05	0.3237
September*PC1	0.06	0.05	8.00	1.21	0.2595	0.03	0.06	8.00	0.49	0.6344
PC2	− 0.01	0.05	4.00	− 0.15	0.8860	0.00	0.03	4.00	0.12	0.9074
April*PC2	0.06	0.06	8.00	1.05	0.3254	0.02	0.07	8.00	0.25	0.8113
July*PC2	− 0.10	0.06	8.00	− 1.66	0.1347	− 0.06	0.07	8.00	− 0.84	0.4234
September*PC2	0.04	0.06	8.00	0.62	0.5549	0.04	0.07	8.00	0.60	0.5672
PC1*PC2	0.00	0.02	4.00	0.26	0.8074	0.01	0.01	4.00	0.67	0.5417
April*PC1*PC2	0.02	0.02	8.00	1.19	0.2689	0.01	0.03	8.00	0.39	0.7091
July*PC1*PC2	− 0.03	0.02	8.00	− 1.39	0.2025	− 0.01	0.03	8.00	− 0.38	0.7116
September*PC1*PC2	0.00	0.02	8.00	0.20	0.8461	0.00	0.03	8.00	0.00	0.9972
P/A distance										
Intercept	2.37	0.45	5.48	5.27	0.0025	0.70	0.06	3.98	12.24	0.0003
Distance 1 m	0.06	0.24	7.36	0.23	0.8263	− 0.02	0.07	10.31	− 0.22	0.8313
Distance 10 m	− 0.04	0.14	5.26	− 0.25	0.8102	0.02	0.05	5.75	0.37	0.7269
Distance 50 m	− 0.02	0.21	7.27	− 0.09	0.9301	0.00	0.06	9.38	− 0.07	0.9481
PC1	− 0.38	0.22	11.80	− 1.70	0.1151	0.01	0.03	6.57	0.38	0.7137
Distance 1 m*PC1	0.01	0.15	6.35	0.04	0.9729	− 0.05	0.05	10.10	− 1.04	0.3222
Distance 10 m*PC1	− 0.04	0.11	5.81	− 0.37	0.7271	0.03	0.04	8.57	0.81	0.4412
Distance 50 m*PC1	0.03	0.09	5.82	0.37	0.7269	0.02	0.03	7.31	0.62	0.5566
PC2	0.23	0.17	8.50	1.35	0.2114	− 0.06	0.04	6.14	− 1.38	0.2144
Distance 1 m*PC2	0.19	0.12	5.89	1.58	0.1656	− 0.04	0.04	6.94	− 0.90	0.3965
Distance 10 m*PC2	− 0.20	0.09	5.71	− 2.22	***0.0705***	0.02	0.03	7.10	0.52	0.6173
Distance 50 m*PC2	0.01	0.09	5.57	0.13	0.9007	0.02	0.03	6.05	0.64	0.5451
PC1*PC2	− 0.04	0.07	6.05	− 0.52	0.6229	− 0.02	0.02	11.95	− 0.96	0.3559
Distance 1 m*PC1*PC2	− 0.04	0.10	6.73	− 0.44	0.6718	− 0.03	0.03	9.30	− 0.89	0.3955
Distance 10 m*PC1*PC2	0.03	0.06	5.88	0.51	0.6295	0.02	0.02	7.86	0.70	0.5019
Distance 50 m*PC1*PC2	0.01	0.06	6.50	0.19	0.8523	0.01	0.02	9.27	0.62	0.5508
P/A season										
Intercept	3.34	0.70	4.00	4.77	0.0088	0.57	0.03	4.00	19.36	< 0.0001
April	1.17	0.34	8.00	3.41	**0.0092**	0.00	0.03	8.00	0.17	0.8689
July	− 0.50	0.34	8.00	− 1.47	0.1799	− 0.05	0.03	8.00	− 1.76	0.1167
September	− 0.66	0.34	8.00	− 1.94	***0.0881***	0.04	0.03	8.00	1.59	0.1509
PC1	− 0.42	0.27	4.00	− 1.56	0.1929	0.02	0.01	4.00	1.39	0.2365
April*PC1	− 0.19	0.13	8.00	− 1.43	0.1911	0.00	0.01	8.00	− 0.35	0.7371
July*PC1	0.09	0.13	8.00	0.70	0.5019	0.01	0.01	8.00	0.50	0.6287
September*PC1	0.10	0.13	8.00	0.72	0.4891	0.00	0.01	8.00	− 0.16	0.8806
PC2	0.19	0.33	4.00	0.58	0.5928	− 0.02	0.01	4.00	− 1.18	0.3035
April*PC2	0.19	0.16	8.00	1.20	0.2651	0.00	0.01	8.00	0.24	0.8181
July*PC2	− 0.20	0.16	8.00	− 1.24	0.2508	− 0.01	0.01	8.00	− 0.48	0.6429
September*PC2	0.01	0.16	8.00	0.04	0.9692	0.00	0.01	8.00	0.24	0.8134
PC1*PC2	0.07	0.12	4.00	0.58	0.5959	− 0.01	0.01	4.00	− 1.28	0.2700
April*PC1*PC2	0.04	0.06	8.00	0.60	0.5640	0.00	0.00	8.00	0.12	0.9088
July*PC1*PC2	− 0.02	0.06	8.00	− 0.29	0.7809	0.00	0.00	8.00	− 0.04	0.9666
September*PC1*PC2	− 0.02	0.06	8.00	− 0.31	0.7615	0.00	0.00	8.00	− 0.07	0.9421

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

Table 16 GLMM results of sheet-web spider and terrestrial dipteran abundance

Sheet-web spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance										
Intercept	0.05	0.13	5.53	0.37	0.7257	0.20	0.13	5.27	1.46	0.2025
Distance 1 m	− 0.15	0.18	10.85	− 0.81	0.4352	0.02	0.21	10.36	0.09	0.9263
Distance 10 m	0.00	0.15	7.46	0.00	0.9981	− 0.03	0.18	7.18	− 0.20	0.8487
Distance 50 m	0.15	0.16	10.17	0.89	0.3921	0.02	0.19	9.58	0.08	0.9367
PC1	− 0.18	0.08	8.22	− 2.25	***0.0539***	− 0.10	0.09	8.18	− 1.11	0.2997
Distance 1 m*PC1	− 0.06	0.13	11.23	− 0.45	0.6611	0.03	0.15	11.48	0.21	0.8377
Distance 10 m*PC1	− 0.11	0.10	10.12	− 1.06	0.3121	− 0.07	0.12	10.31	− 0.60	0.5624
Distance 50 m*PC1	0.16	0.09	9.16	1.79	0.1058	0.04	0.11	9.52	0.36	0.7262
PC2	− 0.04	0.09	6.41	− 0.42	0.6862	0.02	0.09	4.61	0.27	0.8007
Distance 1 m*PC2	− 0.09	0.11	8.53	− 0.81	0.4373	− 0.02	0.13	8.35	− 0.14	0.8943
Distance 10 m*PC2	0.05	0.09	8.83	0.57	0.5802	0.01	0.10	8.97	0.09	0.9273
Distance 50 m*PC2	0.04	0.09	7.83	0.47	0.6524	0.01	0.11	7.82	0.08	0.9385
PC1*PC2	− 0.04	0.06	11.30	− 0.61	0.5553	− 0.02	0.06	9.13	− 0.25	0.8056
Distance 1 m*PC1*PC2	− 0.17	0.09	10.60	− 1.92	***0.0818***	− 0.10	0.10	10.93	− 0.98	0.3465
Distance 10 m*PC1*PC2	0.13	0.06	9.76	2.17	***0.0560***	0.05	0.08	10.56	0.63	0.5398
Distance 50 m*PC1*PC2	0.03	0.06	10.71	0.57	0.5819	0.05	0.07	11.18	0.81	0.4368
Pearson R season										
Intercept	0.11	0.06	4.00	1.85	0.1373	0.21	0.08	4.00	2.73	***0.0524***
April	− 0.25	0.11	8.00	− 2.36	**0.0461**	− 0.12	0.13	8.00	− 0.91	0.3876
July	0.02	0.11	8.00	0.15	0.8823	0.00	0.13	8.00	− 0.01	0.9958
September	0.24	0.11	8.00	2.21	***0.0585***	0.12	0.13	8.00	0.92	0.3849
PC1	− 0.03	0.02	4.00	− 1.35	0.2469	− 0.02	0.03	4.00	− 0.53	0.6244
April*PC1	− 0.04	0.04	8.00	− 0.91	0.3878	− 0.05	0.05	8.00	− 1.06	0.3186
July*PC1	− 0.06	0.04	8.00	− 1.55	0.1594	− 0.02	0.05	8.00	− 0.44	0.6722
September*PC1	0.10	0.04	8.00	2.46	**0.0390**	0.08	0.05	8.00	1.50	0.1713
PC2	0.08	0.03	4.00	2.68	***0.0552***	0.07	0.04	4.00	1.84	0.1391
April*PC2	0.02	0.05	8.00	0.48	0.6408	0.03	0.06	8.00	0.41	0.6923
July*PC2	− 0.04	0.05	8.00	− 0.85	0.4179	− 0.04	0.06	8.00	− 0.70	0.5055
September*PC2	0.02	0.05	8.00	0.37	0.7216	0.02	0.06	8.00	0.29	0.7815
PC1*PC2	0.01	0.01	4.00	1.07	0.3446	0.01	0.01	4.00	0.94	0.4011
April*PC1*PC2	0.03	0.02	8.00	1.38	0.2052	0.00	0.02	8.00	0.12	0.9106
July*PC1*PC2	0.01	0.02	8.00	0.79	0.4547	0.02	0.02	8.00	0.99	0.3499
September*PC1*PC2	− 0.04	0.02	8.00	− 2.16	***0.0623***	− 0.03	0.02	8.00	− 1.11	0.2998
P/A distance										
Intercept	0.95	0.06	6.04	16.50	< 0.0001	0.89	0.04	5.79	20.82	< 0.0001
Distance 1 m	− 0.10	0.07	11.11	− 1.40	0.1895	0.05	0.05	11.03	0.97	0.3552
Distance 10 m	0.03	0.05	7.83	0.50	0.6294	− 0.02	0.04	7.50	− 0.63	0.5501
Distance 50 m	0.07	0.06	10.56	1.12	0.2875	− 0.02	0.04	10.47	− 0.55	0.5944
PC1	0.08	0.03	8.54	2.45	**0.0380**	− 0.06	0.03	8.31	− 2.30	**0.0496**
Distance 1 m*PC1	0.02	0.05	10.97	0.39	0.7045	− 0.02	0.03	10.61	− 0.63	0.5427
Distance 10 m*PC1	− 0.03	0.04	10.01	− 0.73	0.4812	0.03	0.03	9.61	1.23	0.2479
Distance 50 m*PC1	0.01	0.03	9.11	0.26	0.8020	− 0.01	0.02	8.69	− 0.47	0.6513
PC2	0.00	0.04	8.24	− 0.04	0.9710	− 0.01	0.03	8.80	− 0.33	0.7470
Distance 1 m*PC2	0.02	0.04	8.84	0.46	0.6600	− 0.02	0.03	8.56	− 0.76	0.4651
Distance 10 m*PC2	0.04	0.03	8.96	1.21	0.2590	0.00	0.02	8.62	− 0.12	0.9057
Distance 50 m*PC2	− 0.06	0.03	8.09	− 1.78	0.1128	0.02	0.02	7.74	1.11	0.3001
PC1*PC2	0.00	0.02	11.98	0.07	0.9460	0.01	0.02	11.95	0.34	0.7416

Table 16 (continued)

Sheet-web spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Distance 1 m*PC1*PC2	0.01	0.03	10.49	0.33	0.7455	– 0.01	0.02	10.18	– 0.54	0.6030
Distance 10 m*PC1*PC2	0.00	0.02	9.52	0.14	0.8902	0.00	0.02	9.07	– 0.23	0.8208
Distance 50 m*PC1*PC2	– 0.01	0.02	10.47	– 0.68	0.5105	0.02	0.01	10.09	1.10	0.2964
P/A season										
Intercept	1.11	0.06	4.00	17.48	< 0.0001	0.75	0.02	4.00	39.49	< 0.0001
April	0.32	0.11	8.00	2.99	**0.0173**	– 0.10	0.02	8.00	– 4.90	**0.0012**
July	– 0.05	0.11	8.00	– 0.51	0.6232	0.05	0.02	8.00	2.37	**0.0451**
September	– 0.26	0.11	8.00	– 2.48	**0.0380**	0.05	0.02	8.00	2.52	**0.0356**
PC1	0.09	0.02	4.00	3.64	**0.0219**	– 0.02	0.01	4.00	– 2.86	**0.0458**
April*PC1	0.00	0.04	8.00	– 0.02	0.9818	0.00	0.01	8.00	0.27	0.7965
July*PC1	0.01	0.04	8.00	0.20	0.8463	0.00	0.01	8.00	– 0.50	0.6299
September*PC1	– 0.01	0.04	8.00	– 0.18	0.8641	0.00	0.01	8.00	0.23	0.8207
PC2	– 0.01	0.03	4.00	– 0.26	0.8069	– 0.01	0.01	4.00	– 1.05	0.3531
April*PC2	– 0.08	0.05	8.00	– 1.58	0.1522	0.03	0.01	8.00	3.32	**0.0105**
July*PC2	0.04	0.05	8.00	0.87	0.4075	– 0.01	0.01	8.00	– 1.08	0.3118
September*PC2	0.04	0.05	8.00	0.71	0.4988	– 0.02	0.01	8.00	– 2.24	***0.0551***
PC1*PC2	0.00	0.01	4.00	– 0.18	0.8695	0.00	0.00	4.00	– 0.19	0.8569
April*PC1*PC2	0.00	0.02	8.00	– 0.13	0.9020	0.00	0.00	8.00	– 0.27	0.7939
July*PC1*PC2	0.01	0.02	8.00	0.44	0.6719	0.00	0.00	8.00	0.63	0.5475
September*PC1*PC2	– 0.01	0.02	8.00	– 0.31	0.7627	0.00	0.00	8.00	– 0.36	0.7297

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

dynamics as in other habitats described elsewhere (Merrett 1967; Braun and Rabeler 1969) and may be explained by life history of spiders where the adults of most species dominate in the spring and summer (Foelix 1996).

Conclusions

The findings presented in this paper highlight the role that habitat heterogeneity may play in mediating effects of resource subsidies, pointing to the need to encompass such spatial complexity in conceptual frameworks (Power and Rainey 2000; Loreau and Holt 2004), in particular the importance of spatial patchiness at smaller scales. Future investigations of resource subsidies, both theoretical and empirical, should make land use and spatial heterogeneity of microhabitats an explicit focus to further understand food webs in landscapes. Furthermore, investigations are needed to understand the ultimate fate of the residual adult aquatic insect subsidy available in agricultural landscapes and the food web implications across trophic levels and larger spatial scales.

Appendix A

GLMM results in predatory arthropod group correlation and proportion regarding aquatic insect abundance.

See Tables 10, 11, 12 and 13.

Appendix B

GLMM results in predatory arthropod group correlation and proportion to terrestrial dipteran abundance.

See Tables 14, 15, 16 and 17.

Table 17 GLMM results of ground-hunting spider and terrestrial dipteran abundance

Ground-hunting spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Pearson R distance										
Intercept	0.14	0.17	5.94	0.79	0.4617	0.05	0.16	5.65	0.32	0.7617
Distance 1 m	0.08	0.17	9.58	0.48	0.6405	0.04	0.15	9.31	0.24	0.8149
Distance 10 m	− 0.22	0.11	6.34	− 2.00	***0.0901***	− 0.18	0.10	5.95	− 1.73	0.1347
Distance 50 m	0.14	0.14	9.23	1.00	0.3426	0.14	0.13	8.96	1.04	0.3234
PC1	− 0.09	0.10	8.61	− 0.92	0.3807	− 0.10	0.09	8.51	− 1.11	0.2979
Distance 1 m*PC1	− 0.05	0.11	8.47	− 0.44	0.6679	0.01	0.10	8.05	0.09	0.9320
Distance 10 m*PC1	− 0.04	0.08	7.79	− 0.53	0.6139	− 0.07	0.07	7.36	− 0.91	0.3914
Distance 50 m*PC1	0.09	0.07	7.12	1.29	0.2367	0.06	0.06	6.71	0.91	0.3934
PC2	− 0.03	0.10	10.68	− 0.34	0.7403	− 0.05	0.10	10.83	− 0.48	0.6385
Distance 1 m*PC2	0.06	0.09	7.08	0.66	0.5318	− 0.03	0.08	6.69	− 0.37	0.7201
Distance 10 m*PC2	− 0.06	0.07	7.06	− 0.87	0.4144	− 0.04	0.06	6.67	− 0.69	0.5128
Distance 50 m*PC2	0.00	0.07	6.51	0.00	0.9968	0.07	0.06	6.12	1.18	0.2818
PC1*PC2	− 0.02	0.05	9.24	− 0.44	0.6669	0.00	0.05	8.76	0.06	0.9503
Distance 1 m*PC1*PC2	− 0.06	0.07	8.22	− 0.80	0.4474	− 0.05	0.07	7.84	− 0.80	0.4496
Distance 10 m*PC1*PC2	0.04	0.05	7.30	0.74	0.4848	0.03	0.04	6.88	0.59	0.5762
Distance 50 m*PC1*PC2	0.02	0.05	8.06	0.48	0.6445	0.03	0.04	7.66	0.64	0.5393
Pearson R season										
Intercept	0.00	0.18	3.37	− 0.01	0.9892	− 0.03	0.17	2.48	− 0.18	0.8720
April	− 0.11	0.15	4.33	− 0.74	0.4957	− 0.09	0.15	3.57	− 0.62	0.5710
July	0.17	0.17	4.38	1.01	0.3632	0.22	0.17	3.66	1.27	0.2785
September	− 0.06	0.15	4.11	− 0.43	0.6867	− 0.13	0.15	3.34	− 0.88	0.4392
PC1	0.01	0.06	2.94	0.10	0.9264	− 0.01	0.06	2.09	− 0.21	0.8524
April*PC1	0.02	0.05	4.20	0.46	0.6712	− 0.02	0.05	3.43	− 0.39	0.7184
July*PC1	− 0.04	0.06	4.19	− 0.75	0.4906	0.00	0.06	3.44	0.04	0.9698
September*PC1	0.02	0.05	4.04	0.36	0.7354	0.02	0.05	3.26	0.35	0.7481
PC2	− 0.03	0.08	3.10	− 0.41	0.7098	− 0.03	0.08	2.21	− 0.42	0.7131
April*PC2	0.17	0.07	4.49	2.42	***0.0656***	0.18	0.07	3.74	2.56	0.0667
July*PC2	− 0.16	0.07	4.17	− 2.22	***0.0879***	− 0.15	0.07	3.40	− 2.10	0.1155
September*PC2	− 0.01	0.07	4.08	− 0.10	0.9229	− 0.03	0.07	3.30	− 0.38	0.7269
PC1*PC2	− 0.02	0.03	2.90	− 0.61	0.5886	− 0.02	0.03	2.05	− 0.61	0.6039
April*PC1*PC2	0.01	0.02	4.24	0.44	0.6841	0.02	0.02	3.46	0.76	0.4952
July*PC1*PC2	− 0.01	0.02	4.10	− 0.27	0.8016	− 0.01	0.02	3.33	− 0.24	0.8230
September*PC1*PC2	0.00	0.02	4.02	− 0.16	0.8827	− 0.01	0.02	3.24	− 0.51	0.6406
P/A distance										
Intercept	0.62	0.11	5.79	5.48	0.0017	1.11	0.15	6.20	7.53	0.0002
Distance 1 m	− 0.12	0.11	10.73	− 1.04	0.3194	0.06	0.21	10.91	0.27	0.7945
Distance 10 m	− 0.04	0.08	7.12	− 0.52	0.6219	0.04	0.18	8.08	0.21	0.8351
Distance 50 m	0.15	0.10	10.28	1.59	0.1421	− 0.09	0.19	10.29	− 0.49	0.6333
PC1	0.01	0.06	8.51	0.14	0.8951	− 0.01	0.09	8.88	− 0.16	0.8781
Distance 1 m*PC1	− 0.02	0.07	9.60	− 0.29	0.7811	− 0.07	0.15	11.54	− 0.47	0.6486
Distance 10 m*PC1	0.00	0.06	8.73	0.08	0.9394	0.05	0.12	10.63	0.46	0.6575
Distance 50 m*PC1	0.02	0.05	8.00	0.34	0.7425	0.02	0.11	9.90	0.14	0.8922
PC2	− 0.01	0.07	11.02	− 0.11	0.9132	− 0.08	0.09	6.12	− 0.89	0.4070
Distance 1 m*PC2	− 0.11	0.06	8.18	− 1.85	0.1011	− 0.06	0.13	9.09	− 0.43	0.6771
Distance 10 m*PC2	0.02	0.05	8.11	0.36	0.7285	0.00	0.10	9.50	0.04	0.9706
Distance 50 m*PC2	0.09	0.05	7.33	2.08	***0.0747***	0.05	0.11	8.54	0.50	0.6269
PC1*PC2	0.03	0.04	10.75	0.84	0.4175	− 0.06	0.06	10.53	− 0.99	0.3431

Table 17 (continued)

Ground-hunting spiders	Density					Richness				
	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|	Estimate	Std error	DFDen	*t* ratio	Prob > |*t*|
Distance 1 m*PC1*PC2	0.03	0.05	9.50	0.56	0.5875	− 0.07	0.10	11.06	− 0.68	0.5111
Distance 10 m*PC1*PC2	− 0.02	0.03	8.31	− 0.71	0.4981	0.03	0.07	10.58	0.37	0.7188
Distance 50 m*PC1*PC2	0.00	0.03	9.27	− 0.13	0.9001	0.04	0.07	11.22	0.64	0.5332
P/A season										
Intercept	0.84	0.13	4.02	6.23	0.0033	0.79	0.06	3.92	14.08	0.0002
April	0.15	0.03	4.08	4.48	**0.0105**	− 0.11	0.03	4.36	− 3.37	**0.0245**
July	− 0.05	0.04	4.07	− 1.33	0.2518	0.07	0.04	4.35	1.70	0.1590
September	− 0.10	0.03	4.05	− 2.96	**0.0407**	0.05	0.03	4.23	1.43	0.2222
PC1	0.00	0.05	3.95	− 0.04	0.9667	− 0.02	0.02	3.61	− 1.17	0.3146
April*PC1	− 0.04	0.01	4.07	− 3.34	**0.0283**	0.02	0.01	4.29	1.96	0.1169
July*PC1	0.03	0.01	4.05	2.08	0.1056	0.00	0.01	4.26	0.04	0.9664
September*PC1	0.01	0.01	4.04	1.11	0.3286	− 0.02	0.01	4.19	− 2.01	0.1114
PC2	0.05	0.06	3.99	0.76	0.4916	− 0.01	0.03	3.77	− 0.20	0.8539
April*PC2	− 0.02	0.02	4.11	− 1.02	0.3656	0.00	0.02	4.48	− 0.31	0.7695
July*PC2	0.00	0.02	4.06	− 0.19	0.8588	0.01	0.02	4.26	0.50	0.6435
September*PC2	0.02	0.02	4.05	1.22	0.2898	0.00	0.02	4.22	− 0.21	0.8462
PC1*PC2	0.00	0.02	3.95	0.21	0.8470	0.00	0.01	3.59	0.20	0.8552
April*PC1*PC2	0.00	0.01	4.07	0.09	0.9310	− 0.01	0.01	4.32	− 1.08	0.3348
July*PC1*PC2	− 0.01	0.01	4.05	− 1.96	0.1211	0.00	0.01	4.22	0.74	0.4976
September*PC1*PC2	0.01	0.01	4.04	1.94	0.1239	0.00	0.01	4.18	0.32	0.7659

Significance $p > 0.05$ in bold, significance $p > 0.1$ in bold italics

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Data availability Raw data can be provided upon request; otherwise, data are provided within the manuscript or supplementary information files.

Declarations

Conflict of interest The authors declare no conflict of interest.

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