Rove beetles (Coleoptera: Staphylinidae) in Ontario, Canada soybean agroecosystems: assemblage diversity, composition, seasonality, and habitat use

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Abstract—Rove beetles (Coleoptera: Staphylinidae) are recognised as important components of agroecosystems and are best known for their contribution to biological control as predators of arthropod pests. Unfortunately, knowledge of their bionomics in North American agroecosystems is sparse. Therefore, soybean-hedgerow agroecosystems in Ontario, Canada, were surveyed in 2009–2010 to identify common, widespread members of the assemblage and characterise their seasonal activity patterns. The potential for refuge habitat in adjacent hedgerows was assessed outside of the growing season. The rove beetle assemblage of soybeans during the growing season was found to be a less diverse subset of that found in surrounding hedgerow areas, especially with respect to native species. Both native and non-native species were common (>1% activity density). Based on literature records, most common species were predaceous, univoltine, and adult overwintering. Most common species exhibited the highest activity density midway through the growing season and all were detected in hedgerow habitats outside the growing season. Comparisons with the staphylinid fauna of other North American agroecosystems revealed several common species to dominate assemblages under a wide variety of conditions. This research provides a framework for future agroecological studies of this poorly understood, but abundant and diverse, assemblage of beetles.

Introduction

Rove beetles (Coleoptera: Staphylinidae) are recognised as important components of agroecosystems worldwide and are mostly known for their mitigation of agricultural yield loss by predation of diverse pest arthropods, such as spider mites in Japan (Kishimoto and Adachi 2008), cereal aphids in central Europe (Dennis and Wratten 1991), horn flies in Florida (Hu and Frank 1995), and cabbage maggots in central Canada (Andreassen *et al*. 2010). Most of our knowledge about staphylinids in agroecosystems is based on research in Europe (*e.g.*, Clough *et al*. 2007; Balog *et al*. 2008), where the rove beetle assemblages are comprised mostly of generalist predators. Agroecosystems, especially annual crop habitats, have been described as unstable, ephemeral habitats that challenge predators with frequent disturbance and unpredictable populations of specific prey species (Wiedenmann and Smith 1997). At least in Europe, agroecosystem assemblages share several predictable staphylinid species (reviewed by Andersen 1991), apparently possessing attributes that pre-adapt them to these habitats (Wiedenmann and Smith 1997). In response to annual disturbance of the habitat, such as is caused by tillage and harvesting, some staphylinid species overwinter in unmanaged areas nearby (Holland *et al*. 2009). In addition, most

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dominant staphylinids in European agroecosystems are univoltine, are most active early in the growing season, and overwinter as adults (*e.g.*, Andersen 1982; Balog and Markó 2007).

There are relatively few studies of rove beetle assemblages in North American agroecosystems compared to other beetle groups, such as the Carabidae (*e.g.*, references in Goulet 2003; Firlej *et al.* 2012) and Coccinellidae (*e.g.*, Mignault *et al.* 2006). Most previous studies have been limited to partial surveys due to difficulties in identification at the species level (*e.g.*, Levesque and Levesque 1996). Levesque and Levesque (1996) is the only study to include detailed phenological information. Habitat use by Staphylinidae has not been studied within the agricultural landscape of North American annual crop systems. Furthermore, even a preliminary comparison of assemblages between different North American agroecosystems is lacking. Fortunately, recent taxonomic research in the difficult subfamily Aleocharinae (*e.g.*, references within Brunke *et al.* 2012) has made complete surveys more tractable in North America: Byers *et al.* (2000) characterised the assemblage of dairy cattle pastures; Leslie *et al.* (2007) reported dominant species and their affiliation with different crops; and Renkema *et al.* (2012) demonstrated species-level responses to mulching in high bush blueberries.

To improve understanding of rove beetle agroecology in North America, a species-level investigation was conducted in the soybean agroecosystem, an important annual crop in northeastern United States of America and Canada (Ontario Ministry of Agriculture, Food and Rural Affairs 2011), to elucidate the composition and diversity of the assemblage, the seasonal activity of its common species, and their use of non-crop habitat (*i.e.*, hedgerows) outside of the growing season. Finally, the available literature on staphylinids in northeastern North American agroecosystems was reviewed to elucidate whether some species are dominant in assemblages under a broad range of human-influenced conditions.

Materials and methods

Study sites

Twelve sites (six in each year), each consisting of a soybean field and corresponding hedgerow, were selected for study in southern Ontario, Canada in 2009 and 2010 (Table 1). Sites were selected equally from two different regions of southern Ontario (*i.e.*, Wellington-Waterloo centrally, and Huron county to the west), to reduce potential effects of localised species pools. All fields were operational soybean fields cultivated under agronomic practices determined by each grower. Fields at all sites were not tilled, except site 12, and were planted to corn in the previous year, except site 3, which was planted to soybean. All sites were planted with seed-treated soybean (thiamethoxam + fludioxonil + metalaxyl-M, CruiserMaxx, Syngenta, Guelph, Ontario, Canada). At all sites, soil in hedgerows contained more dry organic matter than that in soybean fields, as determined by the Walkley-Black method (Walkley and Black 1934) (Table A1). Except for site 5, fields were not sprayed with insecticides; herbicides were not used at any site. Site 5 was sprayed once in the week of 27 August 2009 with a broad-spectrum insecticide (λ-cyhalothrin, Matador 120EC, Syngenta, Guelph, Ontario, Canada) to control soybean aphid populations; however, our sampling area and a 5 m buffer were left unsprayed.

Sampling protocol

Within a given habitat, field sites were sampled for one week, every other week to ameliorate trapping pressure on invertebrates. Sampling in hedgerows began in the last week of April in both years. Spring sampling in hedgerows was continued until ~50% of soybean plants in the adjacent field were at stage V1 (one node on main stem, with fully developed trifoliates; Pederson 2009); soybean sampling began at this time or one week later, (Table 1). Sampling in soybean fields continued until 50% or more plants had begun senescence, characterised by yellowed leaves, which drop from the plant (stage R7, Pedersen 2009). Fall hedgerow sampling was initiated at this time or one week later and continued until canopy traps failed to capture rove beetles for two consecutive sampling dates. Simultaneous sampling of hedgerows and soybean fields was not possible under the logistical constraints of this study, however our sampling protocol allowed for a greater number and variety of field sites than would have otherwise been possible, and was sufficient to address the

Table 1. Summary of southern Ontario, Canada field site locations and sampling periods.

Year	Site	Location	County	GPS coordinates	Field area (km^2)	Sampling period by habitat		
						Spring hedgerow	Soybean	Fall hedgerow
2009								
	1	Cambridge	Waterloo	43.374, −80.397	0.047	28 April–16 June	16 June–15 September	21 September–24 November
	2	Cambridge	Waterloo	43.390, −80.374	0.306	28 April–16 June	16 June–15 September	21 September–24 November
	3	Guelph	Wellington	43.589, −80.274	0.040	28 April–16 June	16 June–15 September	15 September–17 November
	4	Auburn	Huron	43.729, −81.528	0.132	4 May–22 June	22 June–21 September	20 September–23 November
	5	Brucefield	Huron	43.509, −81.517	0.093	4 May–8 June	15 June–14 September	14 September–23 November
	6	Benmiller	Huron	43.691, −81.610	0.035	4 May–22 June	22 June–21 September	20 September–23 November
2010								
	7	Eramosa	Wellington	43.616, −80.215	0.036	27 April–1 June	8 June–7 September	14 September–2 November
	8	Cambridge	Waterloo	43.370, −80.364	0.226	27 April–1 June	8 June–7 September	14 September–2 November
	9	Cambridge	Waterloo	43.369, −80.359	0.101	27 April–1 June	8 June–7 September	14 September–2 November
	10	Auburn	Huron	43.745, −81.508	0.110	5 May–9 June	16 June–1 September	8 September–10 November
	11	Auburn	Huron	43.743, −81.514	0.110	5 May–9 June	16 June–1 September	8 September–10 November
	12	Auburn	Huron	43.736, −81.507	0.068	5 May–9 June	16 June–1 September	8 September–10 November

Note: Sampling periods indicate the first and last dates on which traps were active in each field.

objective of detecting hedgerow activity of staphylinids outside of the growing season.

Rove beetles were sampled using canopy traps (*i.e.*, raised pan traps) and unfenced pitfall traps, placed in pairs (hereafter as "trap pairs") successively along a transect. This combination of trap types was selected in order to reduce biases associated with pitfall trapping alone (Lang 2000). Both trap types were constructed from clear plastic Polypro Deli Containers (10 cm diameter × 7 cm height) (Solo Cup Company, Lake Forest, Illinois, United States of America) that acted as catch basins, filled one-quarter with 50% propylene glycol (Alchem, Alachua, Florida, United States of America). Canopy traps were held on an adjustable support attached to a wooden stake (Fig. 1). Pitfall traps were placed in the soil with the top lip level with or slightly below the soil surface, and protected from weather with a roof made from the container lid and supported by wire pegs ~10 cm above the trap lip. The interface between pitfall trap and soil was actively maintained each sampling period to prevent exposure of the container lip above the soil surface as a result of erosion by rainfall. Canopy traps were held on an adjustable support attached to a wooden stake and were not protected from above as these structures were found to interfere with capture efficacy.

In hedgerows, traps were placed in association with buckthorn shrubs to gain insight into potential interactions with the soybean aphid (Brunke 2011), which uses buckthorn as an overwintering host (Bahlai *et al.* 2007). Traps were placed in a single transect along the hedgerow. Canopy traps were placed among buckthorn branches at ~1 m height, but were never placed higher than the nearest buckthorn plants. A pitfall trap was placed ⩽ 2 m of its paired canopy trap, under another buckthorn shrub, if possible. Adjacent trap pairs were separated by ⩾ 5 m, according to the density of buckthorn plants. Fifteen trap pairs (30 traps) were deployed in hedgerows, except at sites 4 (14 pairs) and 5 (10 pairs), where there was insufficient buckthorn.

In each soybean field, 15 trap pairs were arranged in three transects (5, 20, and 35 m from the field edge) to reduce microhabitat effects on assemblage composition. Five trap pairs were placed along each transect, with 5 m between adjacent trap pairs. Canopy traps were adjusted throughout the sampling period so that they were always positioned within the top third of the crop canopy.

Specimen identification and species characterisation

Trap contents were washed gently with water through coarse (425 μm mesh) and fine (180 μm mesh) sieves (Fisher Scientific, Ottawa, Ontario, Canada). Staphylinids were transferred to 70% ethanol and identified by A.J.B., with some exceptions noted below. All aleocharine staphylinids were dissected and sorted on the basis of genitalic characters. Specimens of Aleocharinae were identified by J.K. and some Omaliinae were identified by M. Thayer (Field Museum of Natural History, Chicago, Illinois, United States of America). The unrevised and taxonomically difficult genera *Amischa* Thompson and *Acrotona* Thompson were not treated at the species level. Voucher specimens were deposited in the University of Guelph Insect Collection, Guelph, Ontario, Canada. "Common" beetle species were defined as those that comprised ⩾ 1% of the total number of individuals captured in soybean. As the number of individuals captured in passive traps depends on both their activity and density, their abundance is hereafter referred to as activity density (Saska *et al.* 2008). The lower limit of 1% was chosen to ensure inclusion of those species that were characteristic of the soybean field assemblage but that may not have been effectively sampled with pitfall and canopy traps, as well as to exclude those species with too few individuals to discern statistically significant patterns. To elucidate general, species-level patterns in seasonality for common staphylinids in soybean assemblages, the total number of individuals captured each sampling date, within sampling year, was standardised by the number of non-compromised traps and plotted. To provide a visualisation of activity density, a Gaussian smoothing curve was generated as a measure of central tendency, with a span of four sequential observations (by day of year). Sampling dates that differed by one day were combined to minimise site effects in the summary figures and to maintain equivalent weights for the smoothing curve. Common species were categorised according to peak seasonal activity, hedgerow inhabitation, feeding preference (literature-based), and microhabitat preference (literature and specimen record-based).

Fig. 1. Rarefaction curves for soybean fields and their adjacent hederows sampled for Staphylinidae in 2009 and 2010. Curves result from plotting the number of species predicted by simulation at varied numbers of samples from raw capture data. Curves approaching an asymptote suggest sampling adequately characterises species richness within the sampling area. Rarefaction curves are given by sampling habitat and season: (A) spring hedgerows, (B) summer soybean, and (C) fall hedgerows.
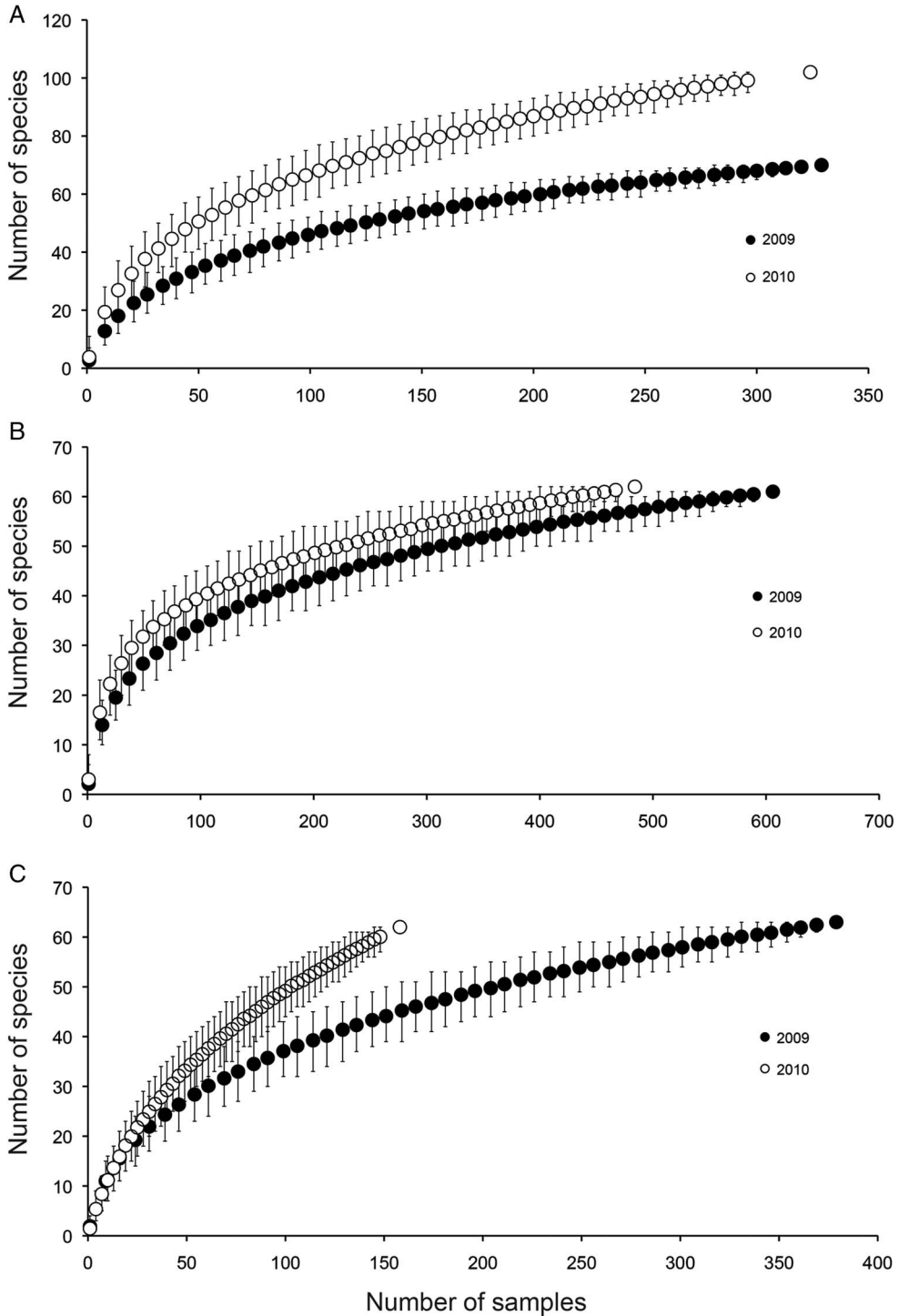
Analyses of species assemblages

Individuals captured, species richness and Shannon's H index of diversity were calculated and used to compare the staphylinid assemblages of hedgerows and soybean fields. These analyses were performed using EcoSim Professional v. 1.2d (Acquired Intelligence Inc., www.garyentsminger. com/ecosim/index.htm). Rarefied captures, species richness and Shannon diversity indices for native and total staphylinids captured were computed using sample-based rarefaction for spring hedgerows, summer soybean, and fall hedgerows (Buddle *et al.* 2005). Individual traps, rather than site totals, were used as the sampling unit to remove bias associated with compromised traps. Each diversity estimation was performed using 1000 iterations and using rarefaction curves as the randomisation algorithm. Diversity measures were rarefied to 150 samples for whole community analyses, and 50 samples for native-species-only analyses, and then season-long rarefied diversity measures, accompanied by their computed standard errors, were compared using analysis of variance followed by means separations using Tukey's honest significant difference test, with $\alpha = 0.05$.

Results

Assemblage abundance, richness, diversity, and origin

One hundred and fifty-four species of Staphylinidae were captured in southern Ontario, Canada soybean-hedgerow landscapes. A total of 7306 individuals representing 80 species were captured in southern Ontario soybean fields (Table A2). Only 10 species were captured exclusively in soybean fields, with eight of these being singletons or infrequent captures; none were common species. Of the 80 species collected in soybean fields, 36 were non-native and comprised 43.1% of all individuals. A total of 6733 individuals representing 144 species were captured in hedgerows adjacent to soybean fields (Table A3); 75 were unique to hedgerows. Of these 144 species, 50 were non-native and comprised 73.1% of all individuals. Less than half (47%) of the species occurring in hedgerows were also detected in soybean fields.

Hedgerows and soybean fields did not significantly differ in the total number of individuals captured (Table 2). Abundance and diversity varied between sites (Kruskal–Wallis test, abundance: $H_{(11)} = 121.1$, $P < 0.001$; diversity: $H_{(11)} = 186.7$, $P < 0.001$), but this variation was not explained by sampling region (Mann–Whitney test, abundance: $U = 140869$, $P = 0.114$; diversity: $U = 142076$, $P = 0.173$), and thus sites were grouped for analysis. Species accumulation curves reached an asymptote in all habitats, seasons, and years, except 2010 sampling of fall hedgerow assemblages (Fig. 1). Relatively few staphylinids were captured in fall hedgerow samples in 2010 and very few traps captured rove beetles (Table 2). Significant and sometimes marked differences in richness and diversity were found between years in hedgerows, but not soybean fields (Table 2). In 2010, the fall and spring assemblages in hedgerows were significantly more species rich and diverse than that of soybean fields during the growing season (Table 2). In 2009, only the spring hedgerow assemblage was significantly more species rich and diverse than the soybean field assemblage, although both spring and fall hedgerow assemblages were numerically more diverse and species rich (Table 2). Patterns in native species richness were similar to those observed in the full community, but native species were consistently, less diverse in soybean fields during the growing season (Table 2). Significantly more individuals of native species were captured in soybean fields during the growing season than hedgerows outside of the growing season in 2009; this was due to relatively high numbers of *Strigota obscurata* Klimaszewski and Brunke in soybean during that year.

Common species

Fifteen species of the soybean field assemblage were considered common (Table 3). The native species *Strigota obscurata* accounted for more than one-third of all individuals captured. *Apocellus sphaericollis* (Say), also native, had the second highest activity density but was spatiotemporally localised as nearly all individuals were captured at sites 10–12 (2010 only). Based on information in the literature, approximately half of the common species were non-native (Klimaszewski *et al.* 2013) and most were predaceous, though the diet of some species is unknown or poorly known (Table 3, and references therein).

Table 2. Observed and rarefied estimates of captured individuals, species richness and Shannon's H diversity index of hedgerow and soybean field staphylinid assemblages, generated from sample-based rarefaction to 150 (all species) or 50 (native species) samples.

All species

Year	Season	Habitat	Samples	Captures		Richness		Shannon's H Diversity	
				Observed	Rarefied	Observed	Rarefied	Observed	Rarefied
2009	Spring	Hedgerow	329	1998	914 ± 58 bc	70	54 ± 3 bc	2.67	2.62 ± 0.07 bc
2009	Summer	Soybean	606	3918	973 ± 86 b	61	39 ± 3 d	2.17	2.13 ± 0.11 d
2009	Fall	Hedgerow	379	1589	627 ± 56 c	63	44 ± 3 d	2.29	2.25 ± 0.15 cd
2010	Spring	Hedgerow	324	2840	1315 ± 107 a	102	78 ± 4 a	2.90	2.87 ± 0.09 ab
2010	Summer	Soybean	484	3382	1047 ± 75 ab	62	45 ± 3 cd	2.50	2.48 ± 0.08 cd
2010	Fall	Hedgerow	158	305	290 ± 5 d	62	60 ± 1 b	3.07	3.06 ± 0.04 a

Native species

Year	Season	Habitat	Samples	Captures		Richness		Shannon's H Diversity	
				Observed	Rarefied	Observed	Rarefied	Observed	Rarefied
2009	Spring	Hedgerow	195	620	158 ± 21 bc	47	26 ± 3 ab	2.40	2.22 ± 0.17 bc
2009	Summer	Soybean	479	2808	294 ± 54 a	33	14 ± 2 c	1.39	1.33 ± 0.17 d
2009	Fall	Hedgerow	214	396	92 ± 11 bd	37	22 ± 2 bc	2.77	2.57 ± 0.14 b
2010	Spring	Hedgerow	211	821	194 ± 31 ab	58	35 ± 3 a	2.83	2.68 ± 0.17 ab
2010	Summer	Soybean	412	2418	294 ± 42 a	31	17 ± 2 bc	1.72	1.67 ± 0.12 cd
2010	Fall	Hedgerow	59	74	63 ± 1 c	35	32 ± 1 a	3.23	3.16 ± 0.06 a

Note: Results of analysis of variance for multiple comparisons: all species (captures, $F = 25$, df = 5894, $P < 0.0001$; richness, $F = 23$, df = 5894, $P < 0.0001$; Shannon's H, $F = 13.74$, df = 5894, $P < 0.0001$) and native species only (captures, $F = 9.3$, df = 5294, $P < 0.0001$; richness, $F = 13.2$, df = 5294, $P < 0.0001$; Shannon's H, $F = 22.2$, df = 5294, $P < 0.0001$). Within a category and column, means followed by the same letter are not significantly different, Tukey's honest significant difference, $\alpha = 0.05$.

Table 3. Percent total and peak activity density, season of highest hedgerow activity, typical microhabitat, and reported diet of common species (⩾1% of total individuals captured) collected in pitfall and canopy traps (pooled) in soybean fields in 2009–2010.

Species	Native species	Per cent activity density	Peak adult activity	Hedgerow activity	Microhabitat affinity	Diet
Strigota obscurata Klimaszewski and Brunke	X	35.4	Middle	Spring (low)	Edaphic	Unknown
Apocellus sphaericollis (Say)	X	13.3	Middle	Spring (low)	Variable	Predaceous[1]
Drusilla canaliculata (Fabricius)	–	9.1	Late	Spring	Variable	Predaceous[2]
Dinaraea angustula (Gyllenhal)	–	5.9	Middle	Spring	Saprophilic	Predaceous[3]
Hoplandria lateralis (Melsheimer)	X	4.9	Late	Fall (low)	Saprophilic	Predaceous?[4]
Aleochara verna Say	X	4.9	Middle	Fall (low)	Saprophilic	Predaceous/Parasitoid[5]
Strigota ambigua (Erichson)	X	4.4	Variable	Spring (low)	Edaphic	Unknown
Oxypoda brachyptera (Stephens)	–	2.6	Variable	Spring (low)	Edaphic	*Predaceous[6]
Anotylus tetracarinatus (Block)	–	2.1	Middle	Spring	Saprophilic	Omnivorous[7]
Anotylus insecatus (Erichson)	–	1.8	Middle	Spring	Saprophilic	Predaceous[8]
Amischa species	?[10]	1.6	Middle	Spring and Fall	Unknown	Unknown
Anotylus rugosus (Fabricius)	–	1.5	Middle	Spring (low)	Saprophilic	Omnivorous[7]
Stethusa spuriella (Casey)	X	1.5	Variable	Spring (low)	Saprophilic	Unknown
Scopaeus minutus Erichson	–	1.1	Middle	1 individual	Edaphic	*Predaceous[9]
Tachinus corticinus Gravenhorst	–	1.0	Early	Spring and Fall	Variable	*Omnivorous[7]

Note: Species with activity density peaks in June, mid June through to late July, and August were categorised as "early", "middle", and "late", respectively. Data on microhabitats are derived from museum specimen records and diet from the literature. Saprophilic species are attracted to rapidly decaying organic matter such as carrion, decaying fungi, compost and/or dung. Edaphic species are rarely attracted to rapid decay and occur at or just below the soil surface.1, Jo and Smitley (2003); 2, Andersen *et al.* (1983); 3, Balduf (1935); 4, Thayer *et al.* (2004); 5, Klimaszewski (1984); 6, Dennison and Hodkinson (1983); 7, Good and Giller (1991), and references therein; 8, Majka and Klimaszewski (2008a); 9, Thayer (2005): all Paederinae are considered to be primarily predaceous; 10, It is unknown which species of this unrevised genus, if any, are native to North America.

*Diet records available only for related species.

Fig. 2. Average number of individuals ($\pm$ SE) of *Tachinus corticinus* Gravenhorst, *Aleochara verna* Say, and *Amischa* species captured per trap on by pitfall and canopy traps in southern Ontario, Canada soybean fields and their adjacent hedgerows in 2009 and 2010. Smoothing lines presented in figure are Gaussian smoothers with a span of four observations, used to visualise trends, and applied to all data points sequentially by ordinal date.
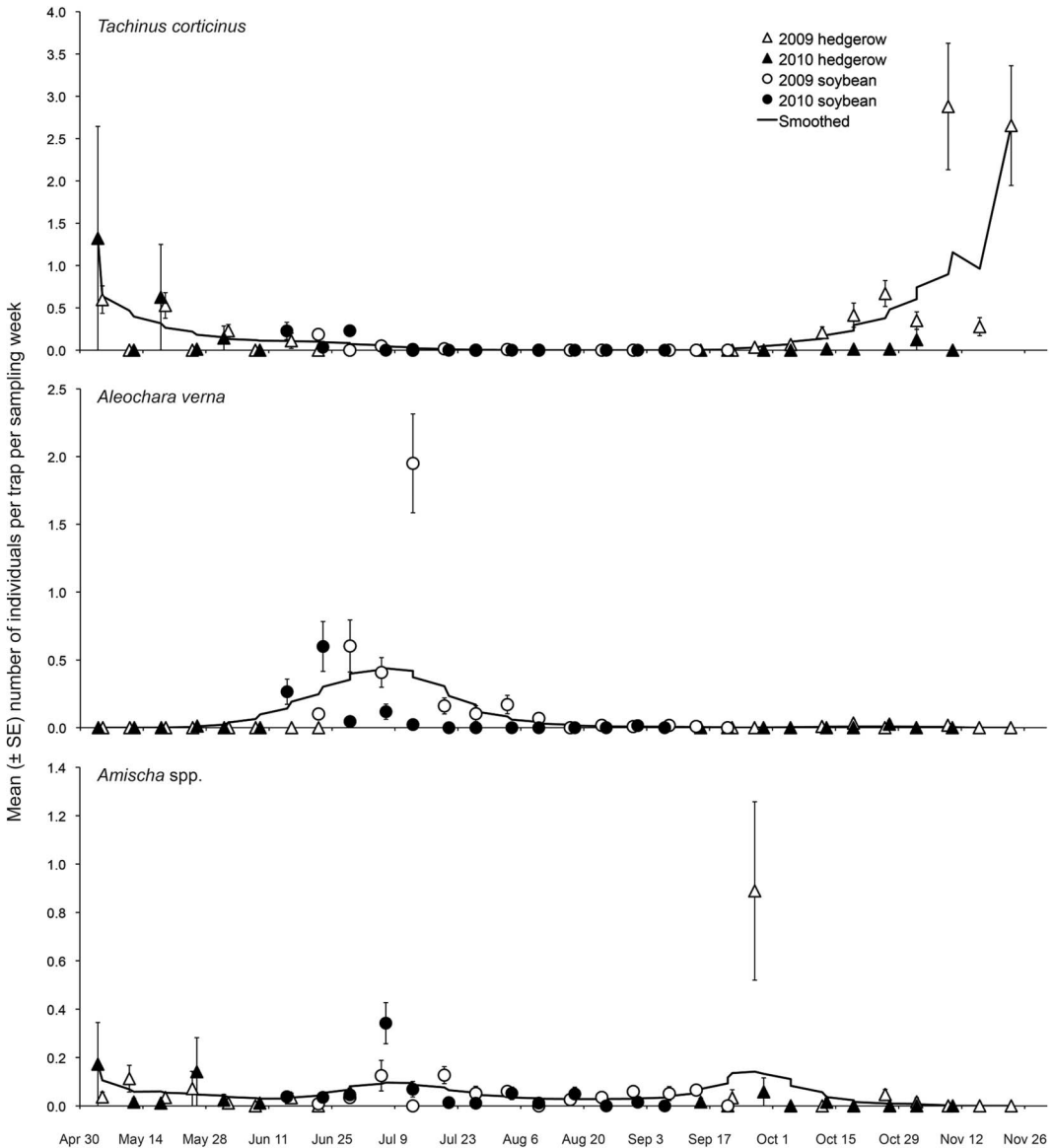

Seasonality and habitat use of species common in soybean field assemblages

Tachinus corticinus Gravenhorst was restricted to the beginning of the growing season in soybean, with low activity density compared with hedgerows in the spring and fall (Fig. 2). *Aleochara verna* Say, *Amischa* species, *Anotylus insecatus* (Erichson), *Anotylus rugosus* (Fabricius), *Anotylus tetracarinatus* (Block), *Apocellus sphaericollis*, *Dinaraea angustula* (Gyllenhal), *Scopaeus minutus* Erichson, and *Strigota obscurata*, were most active in soybean fields during June and July; activity generally decreased over the soybean growing season, especially after canopy closure occurred in early August (Figs. 2–5). The highest activity densities

Fig. 3. Average number of individuals ($\pm$ SE) of *Anotylus insecatus* (Erichson), *Anotylus rugosus* (Fabricius), and *Anotylus tetracarinatus* (Block) captured per trap on by pitfall and canopy traps in southern Ontario, Canada soybean fields and their adjacent hedgerows in 2009 and 2010. Smoothing lines presented in figure are Gaussian smoothers with a span of four observations, used to visualise trends, and applied to all data points sequentially by ordinal date.
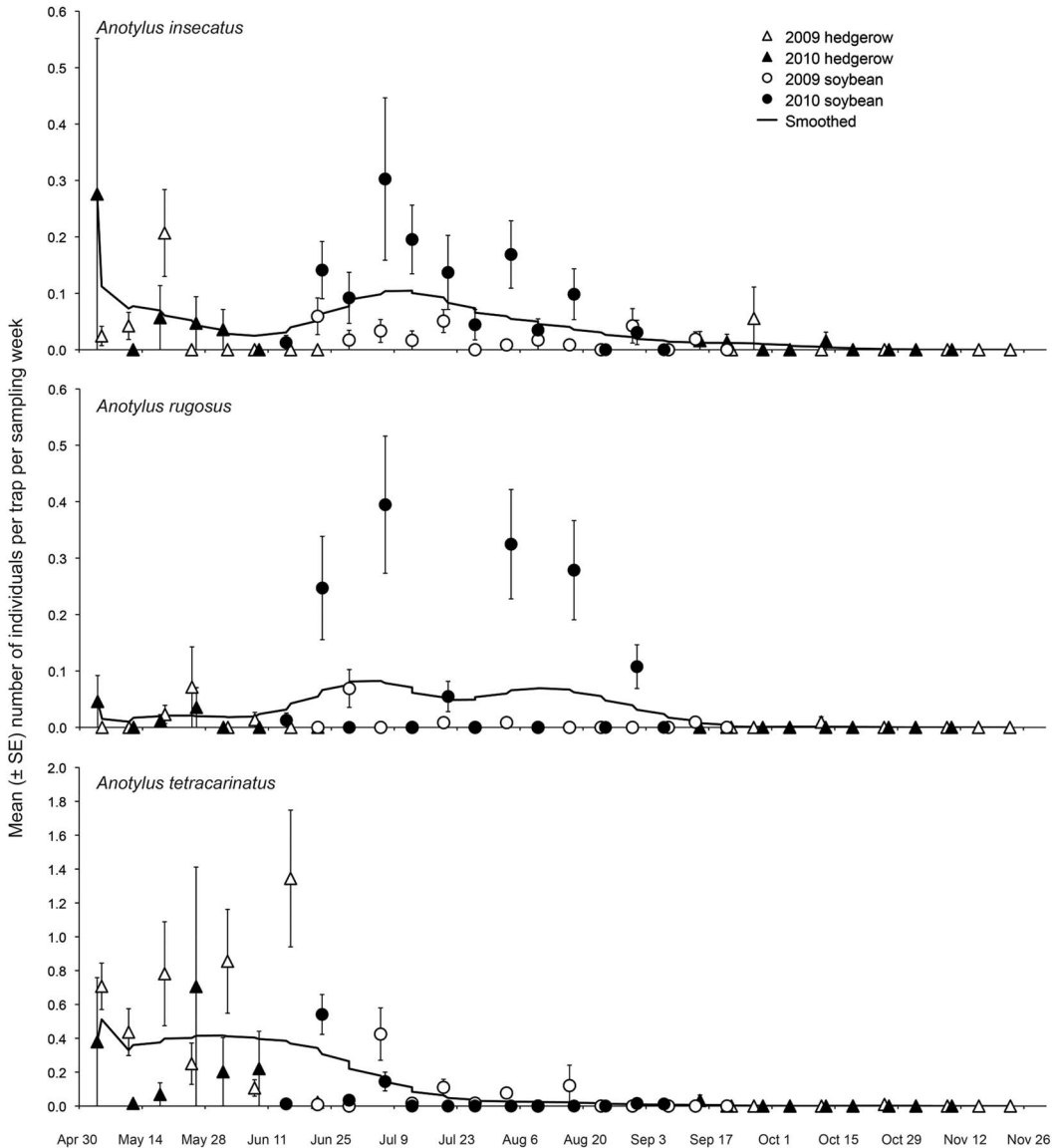

of *Drusilla canaliculata* (Fabricius) and *Hoplandria lateralis* (Melsheimer) in soybean fields were observed later, from mid-July to mid-August, after the soybean canopy had closed (Fig. 5). Activity density of *Oxypoda brachyptera* (Stephens), *Stethusa spuriella* (Casey), and *Strigota ambigua* (Erichson) in soybean fields was greatest during June and July in 2010, and July–August in 2009

(Fig. 6). All species common in soybean assemblages were detected in hedgerows outside of the growing season (Table 3). Substantial spring activity in hedgerows was observed in *Amischa* species, *Anotylus insecatus*, *Anotylus tetracarinatus*, *Dinaraea angustula*, *Drusilla canaliculata*, and *Tachinus corticinus*, such that activity densities were equal to or greater than that observed in

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Fig. 4. Average number of individuals ($\pm$ SE) of *Apocellus sphaericollis* (Say), *Dinaraea angustula* (Gyllenhal), and *Scopaeus minutus* Erichson captured per trap on by pitfall and canopy traps in southern Ontario, Canada soybean fields and their adjacent hedgerows in 2009 and 2010. Smoothing lines presented in figure are Gaussian smoothers with a span of four observations, used to visualise trends, and applied to all data points sequentially by ordinal date.
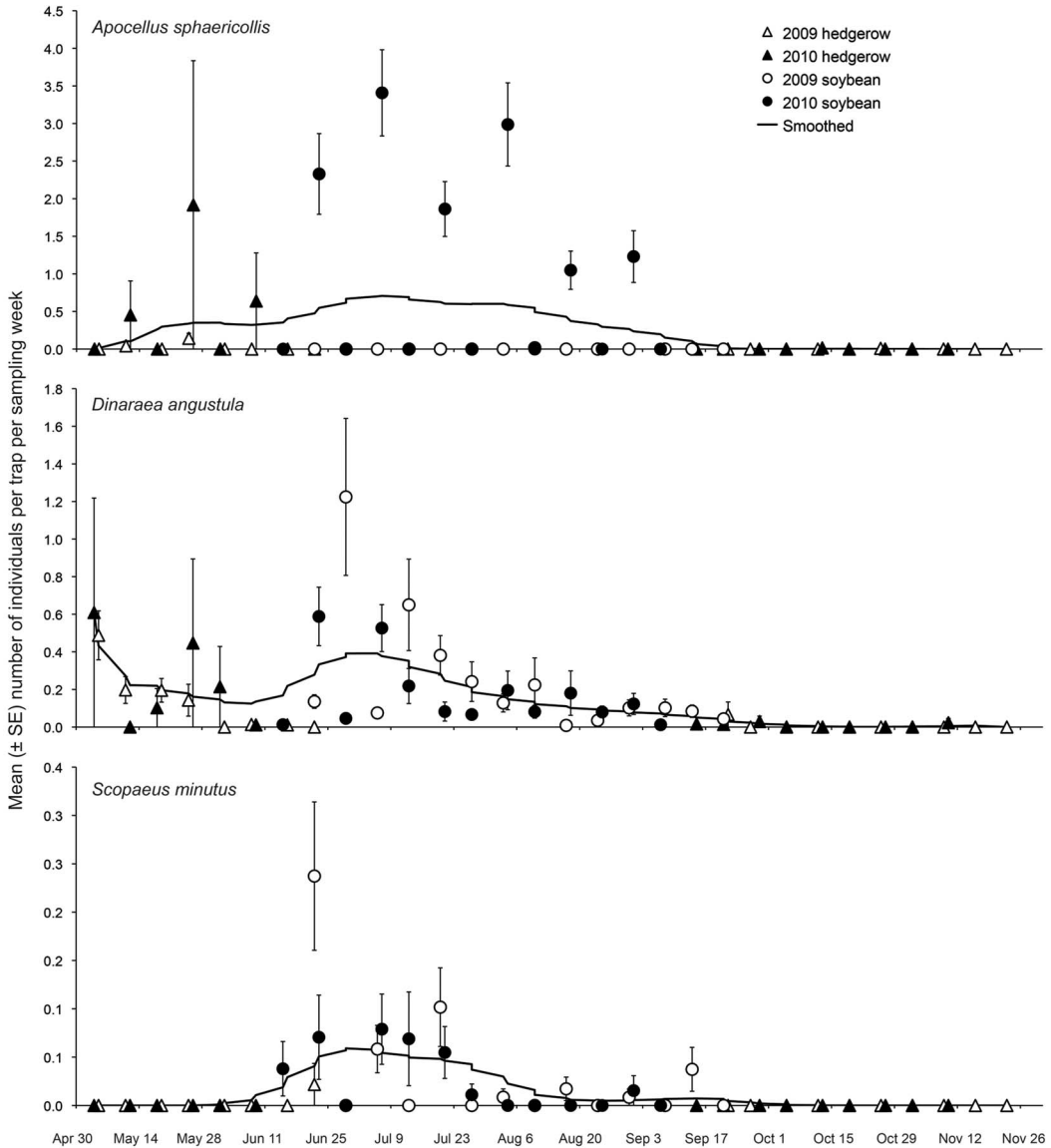
soybean fields. In the remaining species, hedgerow activity was observed at only low levels; only one individual of *Scopaeus minutus* was captured, in hedgerows during the spring. With the exception of *Tachinus corticinus* and *Amischa* species, hedgerow activity during the fall was either very low or not detected in the common soybean staphylinids.

Discussion

Assemblage richness, diversity, and composition

The total number of staphylinid species found in the soybean field-hedgerow landscape (154 species) was similar to a survey of apple (191 species) and pear (121 species) orchards in

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Fig. 5. Average number of individuals (± SE) of *Strigota obscurata* Klimaszewski and Brunke, *Drusilla canaliculata* (Fabricius), and *Hopandria lateralis* (Melsheimer) captured per trap on by pitfall and canopy traps in southern Ontario, Canada soybean fields and their adjacent hedgerows in 2009 and 2010. Smoothing lines presented in figure are Gaussian smoothers with a span of four observations, used to visualise trends, and applied to all data points sequentially by ordinal date.
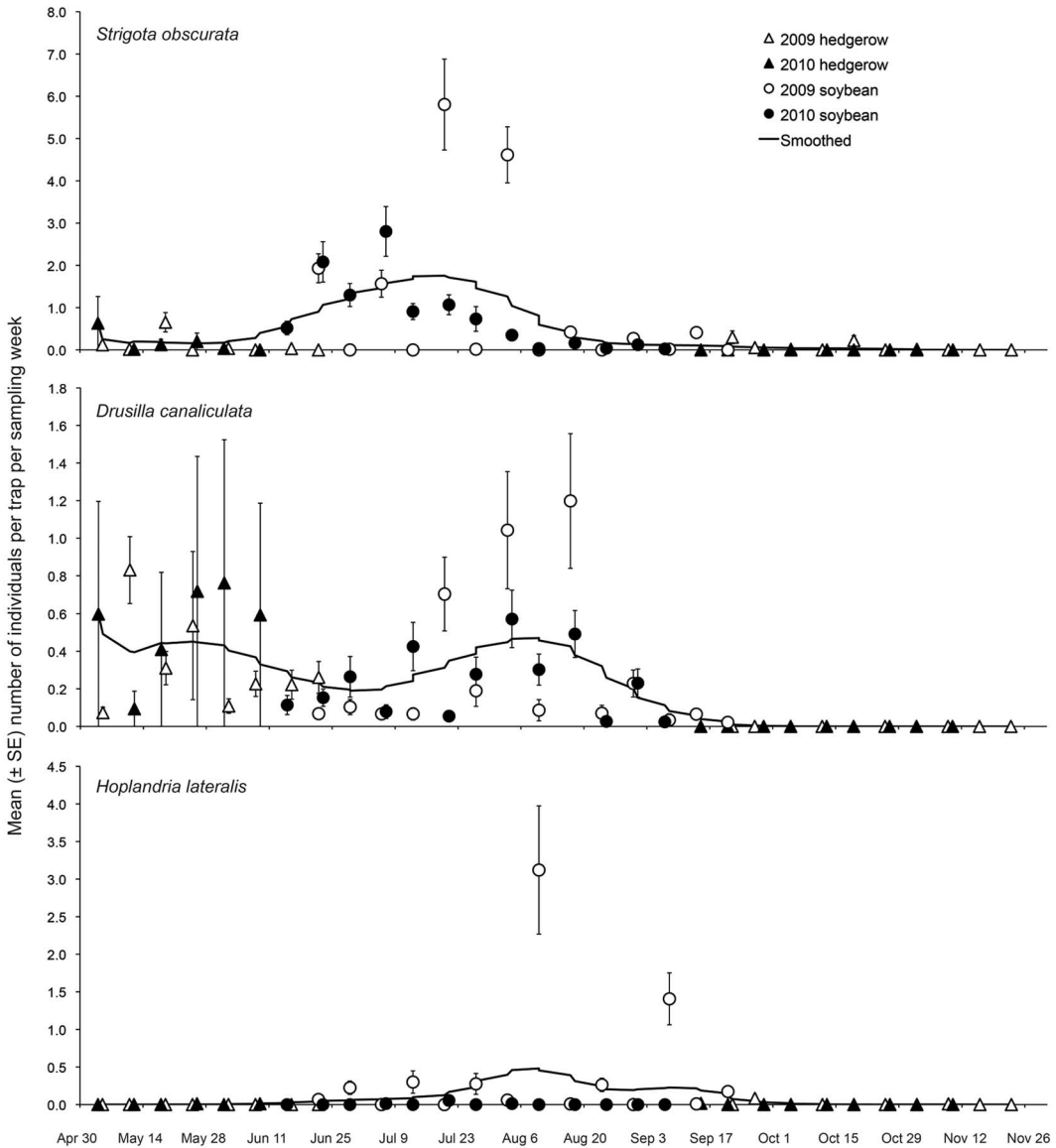
Hungary (Balog *et al.* 2008). Comparisons between assemblages of North American staphylinids are limited as the Aleocharinae are rarely identified to species (*e.g.*, Brunke *et al.* 2009). Dairy pasture assemblages, including aleocharines in the northeastern United States of America (Byers *et al.* 2000) were comparable in richness (79 species) to that of southern Ontario soybean fields in the present study (80 species). Comparisons are further limited when species richness or diversity are not corrected for differences in sampling effort (Buddle *et al.* 2005). Species richness of staphylinids in highbush blueberry fields in Nova Scotia, Canada (Renkema *et al.* 2012) was consistently lower than that found in the

Fig. 6. Average number of individuals ($\pm$ SE) of *Oxypoda brachyptera* (Stephens), *Stethusa spuriella* (Casey), and *Strigota ambigua* (Erichson) captured per trap on by pitfall and canopy traps in southern Ontario, Canada soybean fields and their adjacent hedgerows in 2009 and 2010. Smoothing lines presented in figure are Gaussian smoothers with a span of four observations, used to visualise trends, and applied to all data points sequentially by ordinal date.
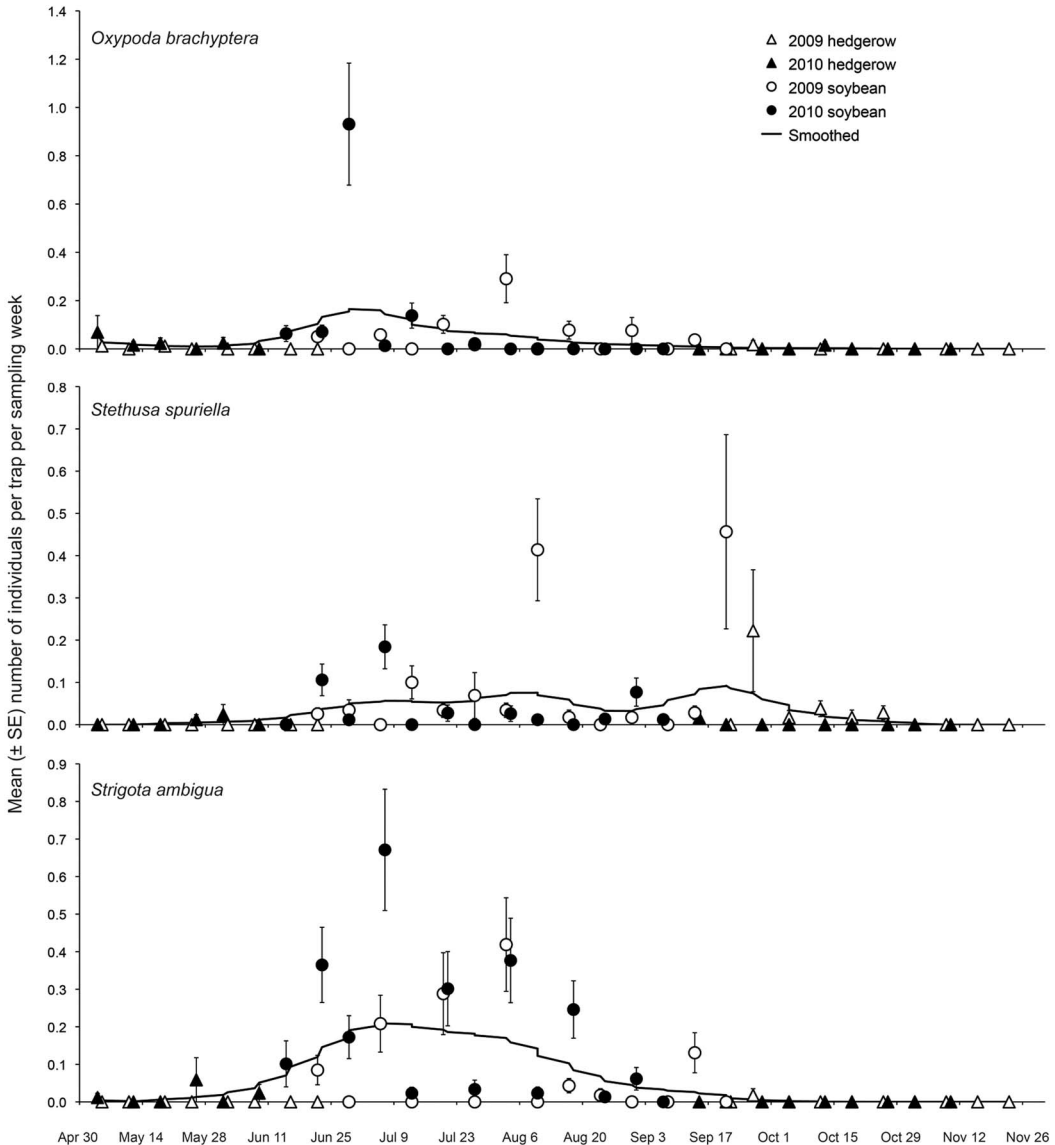
present study for soybean fields or even adjacent hedgerows, though the relative effects of geography versus crop type are difficult to surmise.

Species accumulation curves indicated that our sampling protocol adequately measured the richness and diversity of staphylinid species assemblages in hedgerows and soybean fields

(Buddle *et al*. 2005). Richness and diversity may have been underestimated in 2010 fall hedgerows, as an asymptote was not reached. However, this is of minor importance, as the 2010 fall hedgerow assemblage was shown to be more species rich and diverse than that of soybean in the same year, despite this bias. Species richness and diversity

may normally vary greatly between years as habitat-level patterns could only be detected within a given year. Comparisons between the present results and those of the only other study providing rarefied estimates of staphylinid richness and diversity (Renkema *et al.* 2012) are difficult as data was pooled across years and a different diversity index (*i.e.*, Simpson's) was used. However, large between-year variation in diversity and richness was also observed in ground beetle assemblages of Canadian soybean fields (Firlej *et al.* 2012).

Our study design allowed comparison of the staphylinid assemblages present in available habitats within and outside of the soybean growing season, but we acknowledge that the lack of simultaneous sampling in our study prevents a generalised comparison of hedgerow and soybean habitats *per se*. Although hedgerows outside of the growing season and soybean fields supported similar numbers of staphylinid individuals (Table 2), the soybean assemblage was generally found to be a subset of the spring and fall hedgerow assemblages (see Results), with lower diversity of native species, and in 2010, all species. This result suggests that fewer than half of the species occurring in the perennial hedgerows, and fewer native species have successfully overcome the challenges of the annual soybean agroecosystem, which could include the yearly disturbance of the soil and low habitat heterogeneity. Of the common staphylinid species present in this study, roughly half were non-native. A literature survey of the common species reported from other northeastern agroecosystems (Table 4) revealed that, while non-native species consistently form a significant component of assemblages, native species often represent a substantial, or occasionally the greatest, proportion of individuals captured. Other beetle assemblages in soybean show a similar pattern with high proportions of native ground beetle species in some situations (Hajek *et al.* 2007) and relatively few natives in others (Firlej *et al.* 2012).

Habitat generalists, typical of open, early succession or disturbed areas, comprised the majority of the soybean assemblage (Campbell and Tomlin 1983; Klimaszewski 1984; Andersen 1991; Levesque and Levesque 1995; Klimaszewski *et al.* 2007; Majka and Klimaszewski 2008b; Assing 2012; Brunke *et al.* 2012; Webster *et al.* 2012).

In an extensive review of rove beetle species typically found in Norwegian agroecosystems, Andersen (1991) listed the 30 most widespread species based on their dominance in a variety of annual crop types; three of these species were also common in southern Ontario soybean fields: *Anotylus rugosus*, *Dinaraea angustula*, and *Amischa* species (*Amischa analis* (Gravenhorst) was among those captured). Three recent surveys of Staphylinidae in annual and perennial agroecosystems in northeastern North America (Byers *et al.* 2000; Leslie *et al.* 2007; Renkema *et al.* 2012) have reported common species (as defined in this study) and are relatively complete at the species level, having identified at least some Aleocharinae. A comparison of these assemblages (Table 4) demonstrated a pattern similar to that of Europe, with many shared species; *Drusilla canaliculata*, *Dinaraea angustula*, *Strigota ambigua*, and *Amischa analis* were common (>1% activity density) species in the greatest number of habitats. Individual species of *Anotylus* may be more widespread in agroecosystems than apparent in Table 4, due to differences among studies in the level at which members of this genus were reported.

Seasonal activity patterns in soybean fields

While a seasonal progression of species was observed in southern Ontario soybean fields, most species were active during June and July, and generally declined in activity density toward the end of the growing season. Few staphylinids were captured at the end of soybean sampling in September. This general trend was also found in soybean assemblages of Carabidae (Hajek *et al.* 2007). *Tachinus corticinus* differed from other common species in that individuals were generally absent from soybean fields after June. Patterns of high early season activity and summer inactivity for *Tachinus corticinus* were also observed in Québec, Canada raspberry plantations (Levesque and Levesque 1996).

The seasonal activity patterns observed in soybean for most species and the additional early season activity in spring hedgerows observed in some species, are consistent with the temporal dynamics of common agricultural species described by Andersen (1982), Levesque and Levesque (1996), and Balog and Markó (2007), where species were univoltine and overwintered as adults. Based on these studies, the spring

Table 4. Common species of Staphylinidae ($\geqslant$1% of total captured by pitfall traps) in agroecosystems of northeastern North America ranked from highest to lowest activity density.

Soybean (Ontario)[1]	Vegetable field crops (Pennsylvania)[2]	Blueberries (Nova Scotia)[3]	Dairy pastures (New York and Vermont)[4]
Strigota obscurata Klimaszewski and Brunke[X]	***Dinarea angustula* (Gyllenhal)**	*Stenus erythropus* (Melsheimer)[X]	*Philonthus cognatus* Stephens
Apocellus sphaericollis (Say)[X]	*Hoplandria lateralis* (Melsheimer)[X]	*Xantholinus linearis* (Olivier)	*Philonthus carbonarius* (Gravenhorst)
***Drusilla canaliculata* (Fabricius)**	***Strigota ambigua* (Erichson)[X]**	*Mocyta fungi* (Gravenhorst)	*Meronera venustula* Erichson[X]
Dinaraea angustula (Gyllenhal)	*Tachyporus nitidulus* (Fabricius)[X]	***Drusilla canaliculata* (Fabricius)**	***Amischa analis* (Gravenhorst)**
Hoplandria lateralis (Melsheimer)[X]	*Anotylus* species	*Philonthus carbonarius* (Gravenhorst)	*Stenus* species
Aleochara verna Say[X]	*Aleochara verna* Say[X]	*Octhephilium fracticorne* (Paykull)	*Anotylus tetracarinatus* (Block)
***Strigota ambigua* (Erichson)[X]**	*Neohypnus* species[X]	*Stenus semicolon* LeConte[X]	*Trichiusa* species[X]
Oxypoda brachyptera (Stephens)	*Tachinus fimbriatus* Gravenhorst[X]	*Anotylus rugosus* (Fabricius)	*Oxypoda* species
Anotylus tetracarinatus (Block)	*Aleochara curtula* (Gravenhorst)	*Gabrius picipennis* (Mäklin)[X]	*Amischa* species
Anotylus insecatus (Erichson)	*Belonuchus rufipennis* (Fabricius)[X]	*Oxypoda nigriceps* Casey[X]	***Drusilla canaliculata* (Fabricius)**
Amischa* species	*Gabrius nigritulus* (Gravenhorst)	***Dinarea angustula* (Gyllenhal)**	undetermined Aleocharinae
Anotylus rugosus (Fabricius)		*Mycetoporus horni* Berhauer and Schubert[X]	*Euaesthetus* species[X]
Stethusa spuriella (Casey)[X]		***Amischa analis* (Gravenhorst)**	*Apocellus sphaericollis* (Say)[X]
Scopaeus minutus Erichson		*Ilyobates bennetti* Donisthrope	*Anotylus* species
Tachinus corticinus Gravenhorst		*Mycetoporus consors* LeConte[X]	*Autalia rivularis* (Gravenhorst)
		***Strigota ambigua* (Erichson)[X]**	*Neohypnus* species[X]
		Quedius curtipennis Bernhauer	*Falagria dissecta* Erichson[X]
			Tachyporus jocosus Say[X]
			Tinotus species

1, Present study; 2, Leslie *et al.* (2007); 3, Renkema *et al.* (2012); 4, Byers *et al.* (2000).
Rankings for vegetable crops were estimated from bar graphs in Leslie *et al.* (2007). Species occurring in three or more agroecosystems are in **boldface**, other shared species are <u>underlined</u>. Native species are indicated by "X".
*Included at least some individuals of *Amischa analis*.

hedgerow activity should represent overwintered adults and the later activity observed in soybean should represent the emergence of new adults. However, in some species, these peaks in activity were weakly separated in time and, given our sampling methodology, difficult to distinguish from dispersal of individuals from hedgerows into soybean fields. The apparent long delay in maximal adult activity in soybean of *Hoplandria lateralis* may indicate that this species over-winters in the larval stage. Congruently, Thayer *et al.* (2004) reported larvae of a related species, *H. klimaszewskii*, occurring in Illinois, United States of America, as early as April, while adults were not collected until July.

Habitat use of Staphylinidae common in soybean

All species common in soybean assemblages were detected in hedgerows outside of the soybean growing season and six of 15 species were observed in spring at activity density levels comparable to those observed in soybean fields. At present, it is unclear whether those species detected only at low levels in hedgerows typically occur in other habitats at this time or simply do not exhibit high levels of adult activity outside of the growing season due to aestivation. Adjacent hedgerows provide important habitat to predatory beetles outside the growing season in Europe (Holland *et al.* 2009). Staphylinid species sampled during the winter in a wheat and grass field landscape were more abundant in hedgerows compared with grass fields or ploughed winter wheat in Norway (Andersen 1997). The present study demonstrated that most species common in soybean assemblages do inhabit hedgerows outside of the growing season. Dispersal of beetles between hedgerows and fields is well documented in European agroecosystems (*e.g.*, Holland *et al.* 2009) and thus it is unlikely that hedgerow and field populations of a given species were mutually exclusive. Further research comparing numbers of overwintering staphylinids between fields and hedgerows (as in Andersen 1997 or Pfiffner and Luka 2000) is needed to assess the degree to which staphylinids benefit from provision of hedgerow habitat. European staphylinid species that use hedgerows for over-wintering habitat were generally spring-active, whereas those with summer activity generally overwintered in the fields themselves (Holland *et al.* 2009). This pattern was not detected in the current study and differences in the degree of hedgerow use by soybean staphylinids may be due to habitat or host requirements rather than phenology, at least for some species. For example, *Scopaeus minutus* prefers unshaded habitats with disturbed ground (Bohac 1985), and the Diptera hosts of *Aleochara verna* (Hummel *et al.* 2010) may not occur in hedgerows at levels adequate to sustain stable populations. Further research is needed to determine whether these species over-winter in the fields themselves or elsewhere. Holland *et al.* (2009) emphasised the importance of cultural practices such as non-inversion tillage in the conservation of those species that overwintered in fields rather than hedgerows. Additional surveys are needed to establish whether hedgerow use by the above species is stable across a wider geographic area and range of annual crop systems.

Conclusions

This study identified the common staphylinid species in soybean fields, enabling a description of their spatiotemporal distributions and use of the soybean-hedgerow landscape. The staphylinid assemblage in soybean was generally most active from late June to July and was evenly comprised of native and non-native common species. All species were detected in hedgerows outside of the growing season, consistent with European assemblages, and may benefit from the provision of overwintering habitat. A review of common staphylinids in northeastern North American agroecosystems revealed a shared group of species including *Drusilla canaliculata*, *Dinaraea angustula*, *Amischa* species, and *Strigota ambigua*. *Strigota obscurata*, the most abundant species in the present study, was described only recently (Brunke *et al.* 2012) and may have gone unnoticed among individuals of *Strigota ambigua* in previous surveys. Basic knowledge of the natural history of these species in North America, including diet, is limited or non-existent but, given their widespread occurrence as dominant species, is of general interest to agroecologists. More research is needed to understand the ecology of those species that consistently form dominant components of North American agroecosystems and to elucidate the

conditions under which native or non-native species dominate rove beetle assemblages.

The current investigation represents the first species-level survey and study of Staphylinidae in soybean and in northeastern North American field crops. The use of hedgerows by staphylinid species outside of the growing season was not previously reported in annual North American agroecosystems. This study demonstrates that rove beetles are an abundant, diverse component of the soybean arthropod assemblage and their ecological significance in this and other agroecosystems deserves further research attention.

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Supplementary materials

To view supplementary material for this article, please visit http://dx.doi.org/10.4039/tce.2014.19.

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