Seasonal Abundance of Ground Beetles in Highbush Blueberry (*Vaccinium corymbosum*) Fields and Response to a Reduced-Risk Insecticide Program

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ABSTRACT Seasonal patterns of ground beetle activity were examined at six highbush blueberry (*Vaccinium corymbosum* L.) farms in southwestern Michigan. On each farm, pitfall traps were used to monitor ground beetle activity in two adjacent fields: one managed under a conventional insecticide program (grower standard) and the other with reduced-risk insecticides. Overall, more active ingredient was applied in grower standard than reduced-risk fields, with the greatest amount used in June and July. During the 6-mo sampling period, we collected 11,322 ground beetles comprised of 34 species, with *Harpalus pensylvanicus* DeGeer representing 70.7% of the total beetles collected. The greatest amount of ground beetle activity occurred in August and September, mostly because of increased captures of the autumn breeding species *H. pensylvanicus* and *H. erraticus* Say. Only *H. erraticus* responded to the different insecticide programs, with eight-fold greater captures in reduced-risk compared with grower standard fields. Because *H. erraticus* are in the soil as larvae or pupae during June and July, we suggest that greater insecticide use in the grower standard fields resulted in increased mortality of immature *H. erraticus*. At one farm, where ground cover was absent between blueberry rows, *H. erraticus* activity did not respond to the difference in insecticide program. This suggests that enhancement of ground beetle activity may require suitable habitat in addition to a reduction in broad-spectrum insecticide use.

KEY WORDS Carabidae, conservation, biological control, *Harpalus*, *Amara*

HIGHBUSH BLUEBERRIES, *Vaccinium corymbosum* L., are the most significant small fruit crop grown in Michigan, producing ≈32 million kilograms of fruit annually on 7,300 ha. Harvested fruit is primarily for the processing market, although ≈25% of the fruit is sold fresh. The key insect pests include cranberry fruitworm (*Acrobasis vaccinii* Riley), blueberry maggot (*Rhagoletis mendax* Curran), and Japanese beetle (*Popillia japonica* Newman). The zero tolerance for fruit contamination with insects forces many growers to make multiple foliar applications of organophosphate and carbamate insecticides before harvest. Because these pests spend part of their life overwintering on the soil surface (*A. vaccinii*) or in the soil (*R. mendax* and *P. japonica*), predation by ground beetles (Coleoptera: Carabidae) may be an important source of biological control of these pests.

Ground beetles are generalist arthropod predators that are natural enemies of several insect pests (Sunderland 2002). Increasing ground beetle activity under blueberry bushes has been shown to result in greater removal of sentinel Dipteran pupae prey (O'Neal et al. 2005), suggesting that conserving these natural enemies may enhance existing biological control of blueberry pests. Conservation of natural enemy abundance through habitat management has reduced pest pressure within certain agroecosystems (Landis et al. 2000). Identifying what species of ground beetles are present and when they are active on the soil surface is essential for designing successful conservation strategies.

Review of the registrations of insecticides by the U.S. Environmental Protection Agency in response to the Food Quality Protection Act (Anonymous 1996) will likely limit the use of many broad-spectrum insecticides. Organophosphate and carbamate insecticides are among the first to be reviewed, with an anticipated reduction in their use in minor crops (crops grown on <300,000 ha). Highbush blueberries are one such minor crop in which organophosphates are important tools for management of several key pests (Pritts and Hancock 1992). New classes of reduced-risk insecticides, including neonicotinoids, insect growth regulators, naturalytes, and botanicals, have been registered for use in blueberries. These products have inherently different modes of action from conventional insecticides and may have reduced

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impacts on nontarget organisms such as natural enemies (Atanassov et al. 2003) and pollinators.

Previous research has shown contrasting responses of ground beetles to changes in insect management programs. Ground beetle activity was increased in apple orchards when broad-spectrum insecticides were replaced with a pest management program based on mating-disruption alone (Epstein et al. 2001). Other studies have shown that ground beetle activity can increase in insecticide-treated orchards. For example, Riddick and Mills (1995) observed greater ground beetle activity after applications of codling moth granulosis virus compared with untreated controls in apple orchards, and Dixon and McKinlay (1992) observed a similar effect in potatoes. The authors of both of these studies suggested that increased availability of prey caused by insecticide applications resulted in increased ground beetle activity. In perennial fruit production systems, there is no consistent trend in ground beetle response to differences in insecticide programs. In separate studies comparing orchards under integrated pest management (IPM) programs to those using organic pest management programs, Labrie et al. (2003) observed an increase in activity of *Pterostichus melanarius* Illiger, but Pearsal and Walde (1995) saw no difference in overall ground beetle activity.

This study describes the ground beetle community and its seasonal abundance within highbush blueberry fields in southwest Michigan. We also compared ground beetle activity/density between fields receiving pest management programs based on grower's standard broad-spectrum insecticides or reduced-risk insecticides applied to control key insect pests.

Table 1. Insecticides used on blueberry fields at six farms during 2003 in a comparison of a grower standard program to one that replaces broad-spectrum with reduced-risk insecticides

Date	Active ingredient[a]	
	Reduced-risk	Grower standard
May	*B. t.* var kurstaki[b] (1)	*B. t.* var kurstaki (1)
	Tebufenozide[c] (1)	
June	Tebufenozide (6)	Azinphosmethyl[d] (5)
	Azadirachtin[e] (5)	Methomyl[f] (2)
	Imidacloprid[g] (2)	Malathion[h] (1)
		B. t. var kurstaki (1)
July	Imidacloprid[g] (6)	Phosmet[i] (6)
	Imidacloprid[j] (4)	Methomyl (2)
	Tebufenozide (2)	Carbaryl[k] (2)
	Carbaryl (2)	Esfenvalerate (2)
	Spinosad[l] (1)	Azinphosmethyl (1)
	Azadirachtin (1)	
Aug.	Pyrethrins with piperonyl butoxide[m] (2)	Malathion (3)
	Phosmet (1)	Phosmet (2)
	Carbaryl (1)	
Sept.	Esfenvalerate[n] (1)	Esfenvalerate (1)

[a] Number of the six farms that used an insecticide with that active ingredient is given in parentheses.
[b] Dipel DF (Valent, Walnut Creek CA).
[c] Confirm 2F (Dow Agrosciences, Indianapolis, IN).
[d] Guthion 50WP (Bayer CropScience, Kansas City, MO).
[e] Azadirect (Gowan Company, Yuma, AZ).
[f] Lannate 2.4 LV (DuPont, Wilmington, DE).
[g] Admire 2F (Bayer CropScience) applied to soil per Section 18 emergency exemption for Japanese beetle grub control.
[h] Aqua Malathion 8EC (Gowan Company).
[i] Imidan 70 WP (Gowan Company).
[j] Provado 1.6F (Bayer CropScience) applied to plants per Section 18 emergency exemption for Japanese beetle adult control.
[k] Sevin XLR plus (Bayer CropScience).
[l] SpinTor 2EC(Dow Agrosciences).
[m] Evergreen EC 60-6 (MGK Golden Valley, MN).
[n] Asana XL (DuPont).

Materials and Methods

Pest Management Program. This study was conducted at six commercial farms in the main blueberry-producing region of southwest Michigan, in Van Buren and Ottawa counties. In each county, we were assisted by three growers who selected two 1.62- to 8.09-ha fields of irrigated, mature *V. corymbosum* plantings (Bluecrop or Jersey cultivars). One of these fields received a season-long insect management program dominated by reduced-risk insecticides (RR; Table 1), whereas the other received a grower-standard program employing broad-spectrum insecticides (GSTD; Table 1). Beginning in May 2003, we monitored key insect pests (cranberry fruitworm, cherry fruitworm, Japanese beetle, and blueberry maggot) each week to determine their abundance (results to be published elsewhere). In the GSTD fields, growers' response to pest information was restricted to use of broad-spectrum insecticides, although no guidance was provided on which products to use. Growers were informed of pest pressure in both fields after each sample. If pest populations reached a critical level in the RR fields, recommendations for application of appropriate reduced-risk insecticides were made. Two growers who experienced heavy infestations of Japanese beetles late in the season, and were not satisfied with the performance of reduced-risk insecticides, were allowed to use a broad-spectrum insecticide in their RR field.

We report which classes of insecticides growers used each month in the GSTD and RR fields based on their pesticide usage records at the end of the growing season (Table 1). From these records, we calculated the amount (kilograms) of active ingredient applied per hectare for each plot. The monthly total amount of active ingredient for all insecticide classes and for broad-spectrum insecticides in the GSTD and RR fields was calculated. A split-split plot analysis of variance (ANOVA) was used to determine if the amount of active ingredient applied differed between the two programs, with time (month) and farm as the first and second split factors, respectively. Monthly differences in amount of active ingredient used between GSTD and RR fields were determined from least-square means tests after slicing data by date using the date by treatment interaction as the error term. Statistical analyses were performed with SAS (PROC GLM, SAS Institute 2000), and means were considered significantly different if $P < 0.05$.

Pitfall Traps. Adult ground beetles were monitored in each field with pitfall traps (13.5 cm height by 11 cm diameter plastic cups; Sweetheart Cup Company, Chicago, IL) placed in the soil between blueberry bushes with the rim 1 cm below the soil surface. Pitfall traps were comprised of an inner and an outer plastic cup with holes punched in the bottom of the outer cup to allow water drainage. A rain guard measuring 18.7 by 15.2 cm supported by four 8.9-cm-long nails covered each trap. Approximately 200 ml of ethylene glycol was placed in each pitfall trap and refilled throughout the season as needed.

Six pitfall traps were deployed in each RR and GSTD plot: three along a field edge adjacent to a wooded border and three 50 m within the interior. The traps were evenly spaced six to eight rows apart across the plot. Traps were emptied once a week beginning on 8 May 2003 and ending 12 October 2003. All ground beetles were identified to morpho-species, and voucher specimens were collected, identified to species, and deposited in the A. J. Cook Arthropod Research Collection at Michigan State University.

To describe ground beetle activity throughout the season, we combined the beetle catches by month and report mean captures per field per month. To determine the effects of insecticide program on carabid beetle activity/density, a mixed-model, repeated measures ANOVA was used to determine the effect of insecticide program with the compound symmetry option (cs type within the repeated statement of SAS PROC MIXED; SAS Institute 2000) selected to estimate the repeated measures covariance structure. This analysis was performed on the entire carabid community and on the eight most abundant species.

Results

Insecticides were applied to the foliage of blueberry bushes, except for the soil-applied formulation of the neonicotinoid imidacloprid (Admire; Bayer CropScience, Kansas City, MO), which was applied to the sod row middles and drivelanes around the RR fields only. This was applied in late June or early July to reduce Japanese beetle populations in these fields. An average of two more insecticides were applied in the RR than GSTD fields (7.5 and 5.8 applications per field, respectively), but a greater amount of active ingredient was applied in the GSTD than RR fields ($F = 8.56$; df = 1,20; $P < 0.01$; Fig. 1). The amount of active ingredient varied significantly across the six farms ($F = 5.94$; df = 5,20; $P < 0.01$) and 5-mo growing season ($F = 16.64$, df = 4,20; $P < 0.01$). More active ingredient was applied in GSTD fields in June ($F = 7.23$, df = 1,20; $P = 0.01$) and July ($F = 6.31$; df = 1,20; $P = 0.02$) than in the RR fields (Fig. 1a).

There was some overlap between the two programs early in the season, with a few growers using reduced risk insecticides (Table 1; tebufenozide and Bt) in their GSTD fields during bloom when such products are used because pollinators are present. Two growers used broad-spectrum insecticides for managing Japanese beetles in their RR fields. Despite this overlap, the total amount of active ingredients from broad-spectrum insecticides applied in GSTD fields was greater than that in the RR fields ($F = 22.4$; df = 5,20; $P < 0.01$; Fig. 1b). Monthly total amount of broad-spectrum active ingredient was significantly different between the two programs in June ($F = 11.89$; df = 1,20; $P < 0.01$) and July ($F = 16.25$; df = 1,20; $P < 0.01$), but not in August ($F = 3.95$; df = 1,20; $P = 0.06$), when many fields were completing harvest.

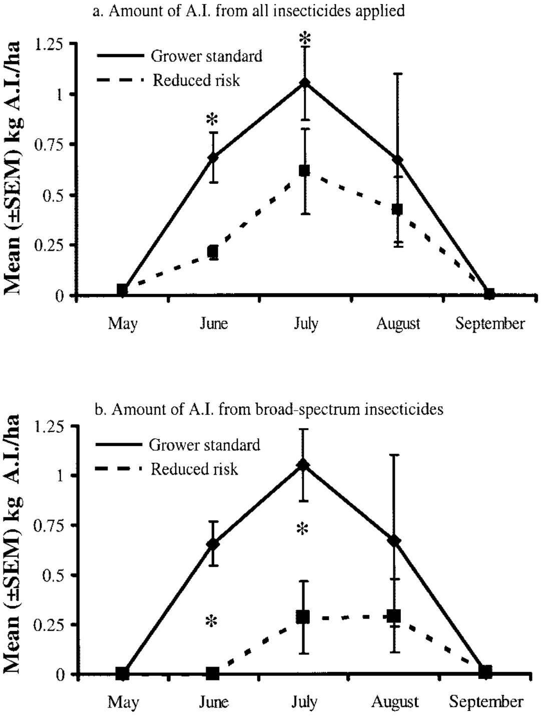

Fig. 1. Comparison of (a) the total amount of insecticide used (kilogram of active ingredient per hectare) and (b) amount of broad-spectrum insecticide (kilogram per hectare of organophosphate, carbamate, and pyrethroid) in blueberry fields receiving a pest management program based on broad-spectrum or reduced-risk insecticides. *Months with a significant difference between the two programs.

During the 6-mo sampling period, we collected 11,322 ground beetles comprised of 34 species (Table 2). *H. pensylvanicus* was the most common species collected, representing 70.7% of the total beetles collected. There was little difference in the ground beetle community between the GSTD and RR fields, with the same eight species [*H. pensylvanicus*, *H. erraticus*, *Pterostichus mutus* Say, *Amara aenea* De Geer, *Poecilus lucublandus* (Say), *Scarites* species, *Patrobus longicornis* (Say), and *Stenolophus ochropezus* (Say)] comprising 97.5% of the beetles collected in each program.

We observed the greatest amount of ground beetle activity in August and September (Fig. 2a), mostly because of the presence of two autumn breeding species, *H. pensylvanicus* (Fig. 2b) and *H. erraticus* (Fig. 2c). Four of the eight most common ground beetle species were most active in May and June (*A. aenea*, *P. lucublandus*, *S. ochropezus*, and *Scarites* species shown in Fig. 2d, e, f, and g, respectively) and

Table 2. Ground beetle community in highbush blueberry farms of southwest Michigan during 2003 in fields exposed to broad-spectrum or reduced-risk insecticide programs

Grower standard (N = 5,780)		Reduced-risk (N = 5,542)	
Species	N	Species	N
Harpalus pensylvanicus (DeGeer)	4,606	*Harpalus pensylvanicus* (DeGeer)	3,397
Pterostichus mutus (Say)	353	*Harpalus erraticus* Say	1,128
Amara aenea (DeGeer)	303	*Amara aenea* (DeGeer)	386
Harpalus erraticus Say	164	*Pterostichus mutus* (Say)	283
Poecilus lucublandus (Say)	69	*Patrobus longicornis* (Say)	72
Scarites species[a]	67	*Stenolophus ochropezus* (Say)	51
Patrobus longicornis (Say)	51	*Poecilus lucublandus* (Say)	49
Stenolophus ochropezus (Say)	24	*Scarites* species[a]	35
Anisodactylus harrisii LeConte	21	*Anisodactylus harrisi* LeConte	22
Harpalus herbivagus Say	15	*Pterostichus stygicus* (Say)	20
Anisodactylus rusticus (Say)	11	*Harpalus herbivagus* Say	15
Harpalus caliginosus F.	11	*Amara avida* (Say)	10
Pterostichus stygicus (Say)	11	*Harpalus affinis* (Schrank)	6
Amara avida (Say)	8	*Stenolophus conjunctus* (Say)	5
Stenolophus lineola (Say)	7	*Anisodactylus rusticus* (Say)	5
Anisodactylus sanctaecrucis (F.)	5	*Harpalus indianus* Csiki	4
Agonum cupripenne (Say)	3	*Ophonus puncticeps* Stephens	3
Agonum octopunctatum (F.)	3	*Harpalus caliginosus* F.	3
Bradycellus rupestris (Say)	3	*Bradycellus rupestris* (Say)	3
Harpalus affinis (Schrank)	3	*Poecilus chalcites* (Say)	2
Poecilus chalcites (Say)	3	*Bembidion impotens* Casey	2
Stenolophus conjunctus (Say)	3	*Agonum octopunctatum*	2
Notiobia terminata (Say)	2	*Chlaenius tricolor* Dejean	1
Amara exarata Dejean	1	*Sphaeroderus stenostomus* Dejean	1
Ophonus puncticeps Stephens	1	*Notiobia terminata* (Say)	1
Sphaeroderus stenostomus Dejean	1	*Cymindis platicollis* (Say)	1
Unidentified	31	*Calosoma scrutator* (F.)	1
		Brachinus janthinipennis (Dejean)	1
		Anisodactylus sanctaecrucis	1
		Anisodactylus merula (Germar)	1
		Agonum cupripenne (Say)	1
		Acupalpus partiarius (Say)	1
		Unidentified	29

[a] *Scarites* species complex composed of either *S. subterraneus* F. or *S. quadriceps* Chaudoir.

are apparently spring breeders. Two species (*P. mutus* and *P. longicornis* shown in Fig. 2h and i, respectively) were present as adults throughout most of our sampling period. *P. longicornis* seemed to undergo a summer aestivation from July to August (Fig. 2i).

Only *H. erraticus* responded to the different insecticide programs (Table 3). Compared with the GSTD program, there was an eight-fold increase in the number of *H. erraticus* collected throughout the season in the RR fields (Table 4), with the greatest difference occurring in September (Fig. 2b). Captures of this species were greater in the RR fields in five of the six farms, with varying degrees of difference between programs among farms.

Discussion

We measured a reduction in the amount of active ingredient applied when reduced-risk insecticides replaced broad-spectrum insecticides. Because less broad-spectrum insecticide was used in the RR fields, we expected ground beetle activity to be greater in the RR fields. However, the impact of the change in insecticide program was limited to one species and did not significantly affect the overall ground beetle activity/density. Most of the insecticides used in both programs were applied to the foliage of blueberry bushes. To what extent these foliar applications affect ground beetles in larval and adult stages is not clear. Adult ground beetles may be able to avoid contacting an insecticide, as many species of ground beetles are highly mobile, moving 10–40 m/d (Wallin and Ekbom 1994). Dixon and McKinlay (1992) found that foliar applications of an organophosphate to potatoes did not produce significant mortality to adult *Pterostichus* species. The nonclimbing, nocturnal behavior of our most abundant ground beetle, *H. pensylvanicus,* may allow it to minimize exposure to foliar applied insecticides, as suggested by Dixon and McKinlay (1992) for *Pterostichus* species.

Each RR field received an application of the soil-applied formulation of imidacloprid for Japanese beetle grub control followed by overhead irrigation. Imidacloprid has been shown to be toxic to *H. pensylvanicus,* but irrigation after the application to turf helped reduce the impact of this insecticide on adult ground beetles in golf course roughs (Kunkel 1998). This may explain why imidiacloprid applied for Japanese beetle grub control did not reduce ground beetle activity in the RR fields.

Harpalus erraticus was the only species that responded to the difference in insecticide programs.

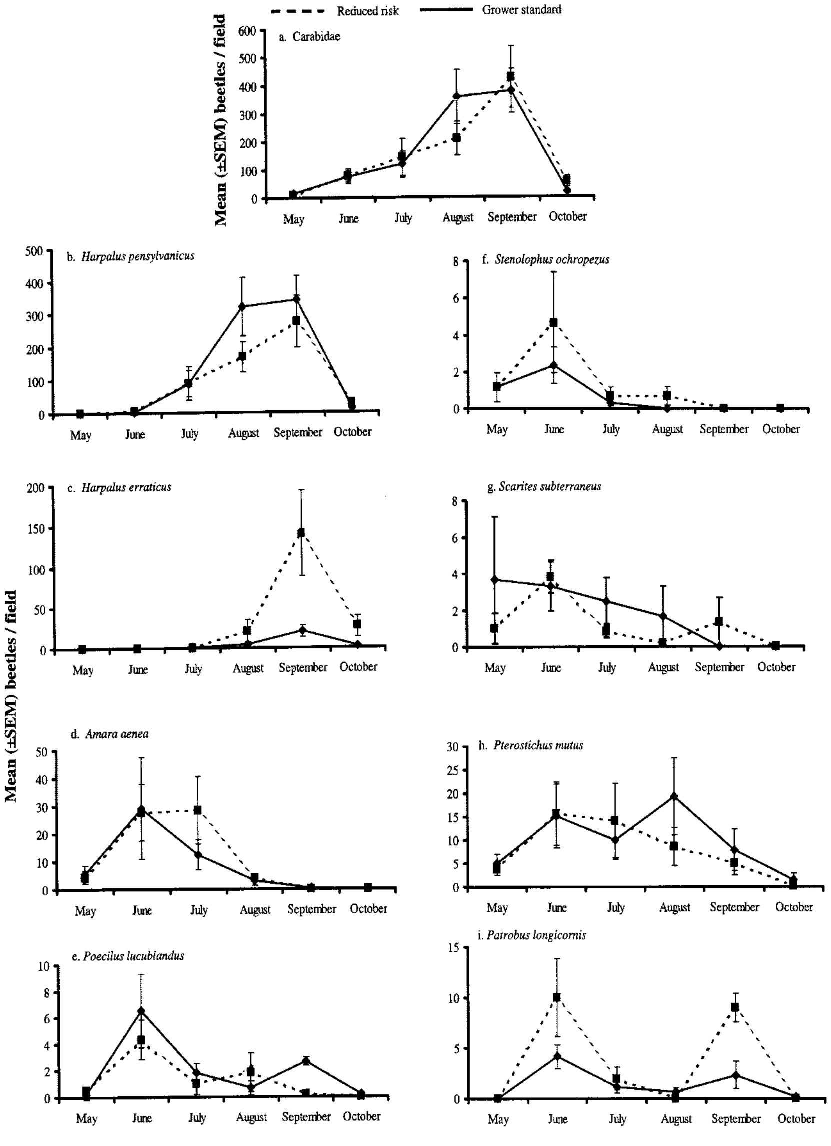

Fig. 2. Mean activity/density of (a) all ground beetles and (b–i) individual species in blueberry fields receiving a pest management program based on broad-spectrum or reduced-risk insecticides.

More *H. erraticus* were collected in RR than GSTD in September, when insecticide use in RR and GSTD was low. The greatest amount of broad-spectrum insecticide use occurred in June and July, when *H. erraticus* are in the soil as larvae or pupae (Kirk 1974). We suggest that foliar applications of these products increased mortality of immature *H. erraticus* in the GSTD fields. When applied as soil insecticides, organophosphates (Brust et al. 1985, Lee et al. 2001) and carbamates (Kunkel et al. 1999, Kunkel et al. 2001) are lethal to ground beetles, reduce adult activity/density, and can disrupt predation (Terry et al. 1993).

Indirect effects of insecticides on predators may also contribute to the measured response of ground beetles to the different insecticide programs (Dixon and McKinlay 1992, Riddick and Mills 1995). Compared with untreated controls, Riddick and Mills (1995) observed greater *H. pensylvanicus* activity on the soil surface in fields where a granulosis virus targeting *Cydia pomonella* L. was applied. Riddick and Mills (1995) speculated that *H. pensylvanicus* responded to higher concentrations of dying caterpillars falling to the ground after infection with the virus. A similar mechanism was invoked by Dixon and McKinlay (1992), who suggested that predation by *P. melanarius* on aphids falling to the ground after an insecticide application resulted in greater beetle abundance compared with an untreated control. Such

Table 3. Impact of two insecticide programs, one comprised of broad-spectrum and the other of reduced-risk insecticides, on activity/density of the ground beetle community

Species	*F* value				
	Farm	Date	Farm by date	Treatment	Date by treatment
Carabidae	5.92^b	22.85^b	1.34	0.05	1.23
Harpalus pensylvanicus	5.75^b	30.02^b	2.12^a	2.86	1.81
Harpalus erraticus	2.51^a	8.71^b	1.12	9.59^b	4.85^b
Amara aenea	7.13^b	12.95^b	3.11^b	0.73	1.06
Pterostichus mutus	8.02^b	6.28^b	2.55^b	1.05	1.14
Poecilus lucublandus	9.37^b	14.06^b	2.97^a	1.45	0.38
Scarites subterraneus	4.14^b	6.51^b	0.95	1.93	0.33
Patrobus longicornis	3.15^a	5.02^b	0.97	0.64	0.25
Stenolophus ochropezus	3.01^a	5.54	1.37	1.44	0.64
Df	5	5	25	1	5

[a] $P < 0.05$ and [b] $P < 0.01$ are significant *F* values.

scavenging behavior by ground beetles in blueberries may occur after an insecticide application. Knockdown of adult Japanese beetles from blueberry bushes is an important part of the efficacy of insecticides used in both the GSTD and RR fields. *Harpalus erraticus* has been observed to scavenge on dead or dying invertebrate prey (Kirk 1974) and may feed on Japanese beetles after an insecticide application, increasing the risk of insecticide exposure. Kunkel et al. (2001) observed that *H. pensylvanicus* suffered higher mortality and morbidity when fed dog food contaminated with a carbamate (20%) compared with food contaminated with a neonicotinoid (<1%). To what extent broad-spectrum insecticide residues on Japanese beetles could increase adult ground beetle mortality is not known, but this could contribute to the low numbers of *H. erraticus* observed in the GSTD fields.

The similarities in ground beetle relative diversity across the six farms suggest that there is a stable carabid community in Michigan blueberry fields. *Harpalus* species accounted for 82.1% and 83.0% of the ground beetles in the RR and GSTD fields (Table 2), respectively, and nearly 83% of the species across all six farms (Table 4). Although our pitfall trap data were collected in only 1 yr, this consistency is remarkable given the distance between the farms (>6 km) and across the two southwest Michigan counties in which this study was performed. Further comparisons of ground beetle communities will continue at these sites to determine long-term responses to changes in insecticide programs. This is important because some carabids, such as *H. erraticus,* require 2 yr to reach maturity (Kirk 1974), and the response of this species and other ground beetles to the reduced-risk insecticides may change over time.

Table 4. Total of all species and two most common species of ground beetles collected during 2003 on six blueberry farms in southwest Michigan[a]

Farm	Carabidae		*H. pensylvanicus*		*H. erraticus*	
	GSTD	RR	GSTD	RR	GSTD	RR
1	1,768	1,385	1,426	952	28	143
2	1,373	859	1,119	437	70	357
3	895	812	791	590	35	133
4	707	1,806	518	1,031	15	475
5	633	490	486	297	6	18
6	391	190	266	90	10	2

[a] Ground beetles were collected with six pitfall traps in two adjacent fields that received an insecticide program comprised of broad-spectrum (GSTD) or reduced-risk (RR) insecticides.

The peak ground beetle abundance in the late summer suggests that those species active as adults in the fall may play a role in pest suppression, given that blueberry maggot fall from the fruit to overwinter in the soil during this time. Several carabid species found in southwest Michigan blueberry fields are predatory on similar pest species in other agroecosystems. *Rhagoletis pomonella* (Walsh) has a similar biology as the blueberry maggot (*R. mendax*) and is preyed on by several species of ground beetles. In apple orchards, *A. aenea* and *P. lucublandus,* two species that we collected in blueberry fields, were both serologically positive to apple maggot antiserum (Allen and Hagley 1990), suggesting predation on apple maggots in the last instar or puparium stage. Several adult *Harpalus* species have been shown to feed on eggs and first instars of Japanese beetles (Terry et al. 1993), another key blueberry pest. Also, larval *H. pensylvanicus* were observed feeding on Japanese beetle grubs in laboratory assays (Hallock 1929).

While ground beetles may provide invertebrate pest suppression in blueberry fields, measurement of this effect will require careful consideration of how pest management and agronomic practices impact their contribution. O'Neal et al. (2005) observed greater ground beetle relative abundance under blueberry bushes when ground cover was maintained in the aisles than when the aisles were rotovated to remove grass. This suggests that the transition from conventional to reduced-risk insecticides may not be sufficient to enhance ground beetle activity and that maintaining a suitable habitat may be required. While this study did not determine the mechanism for greater activity of *H. erraticus* in our reduced-risk insecticide program, identifying the mechanism for this response may be critical for the conservation of ground beetles through the use of reduced-risk insecticides. Measurements will continue in these fields over four growing seasons, and are expected to provide insight into long-term changes in carabid communities as selective insecticide programs are implemented.

Acknowledgments

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