Ground Beetle (Coleoptera: Carabidae) Assemblages in Apple Orchards Receiving Pheromone-based or Conventional Tortricid Management Programs[1]

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Abstract Pitfall trapping was used to assess the effect of a low-spray mating disruption program targeted against the codling moth and leafrollers on carabid communities (potential predators of codling moth, *Cydia pomonella* [L.], leafrollers [Lepidoptera: Tortricidae] and apple maggot, *Rhagoletis pomonella* [Walsh]) in the orchard ground cover. Abundance and species richness of carabids were generally higher in mating disruption blocks relative to conventionally-managed blocks. Over 2 yrs, 3,173 carabids representing 62 species in 27 genera were collected. The most common carabids (more than 5% of the total carabid population) were *Harpalus pensylvanicus* (DeGeer) (38.2%), *Harpalus erythropus* Dejean (11.4%), *Poecilus lucublandus* (Say) (10.1%), *Dicaelus elongatus* Bonelli (6.2%) and *Harpalus longicollis* LeConte (5.9%).

Key Words Carabidae, ground beetles, predators, mating disruption, apple, codling moth, leafrollers

Insecticides have been used as a primary means of pest control in apple orchards throughout the United States for many years. Recently, several important pest species, such as codling moth, *Cydia pomonella* (L.), and several leafroller (Lepidoptera: Tortricidae) species have shown varying degrees of resistance to pesticides. Codling moth and leafrollers have become candidates for control using mating disruption and environmentally-selective insecticides (Pfeiffer et al. 1993a,b). Unfortunately, the cost of pheromone dispensers is high and often does not compare with the cost of pesticides replaced if only the target insect is considered. The effects of mating disruption relative to pesticides on beneficial species and secondary pests must be evaluated to more adequately assess the cost/benefit relation between mating disruption and conventional insecticide-based management. The purpose of this research was to investigate the effect of a mating disruption IPM program, with reduced insecticidal inputs, on the carabid fauna in apple orchards. A reduced insecticide program plus mating disruption are included in this research, e.g., a conventional chemical program before bloom (2-3 sprays, generally including an organophosphate insecticide), followed by a petal fall spray (when most blossom petals had fallen) and a first cover spray, both usually including an organophosphate insecticide. The main targets of the petal fall spray are plum curculio, *Conotrachelus nenuphar* (Herbst), tarnished plant bug, *Ly-*

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gus lineolaris (Palisot de Beauvois), and various defoliators. The first cover spray targets the codling moth, serving to reduce populations to levels where mating disruption can provide control for the remainder of the season. A conventional program used in the control blocks included these sprays, plus an additional 5-7 cover sprays, mostly organophosphates (azinphosmethyl, microencapsulated methyl parathion [before loss of registration], phosmet) and a carbamate (methomyl).

Research has been conducted regarding apple orchard arthropod communities. The diversity of phytophagous arthropod communities is partially determined by management practices (Brown and Welker 1992). Although the negative effects of pesticides on orchard arthropods are widely known, many arthropods are able to recover soon after the spraying of insecticides is halted (Brown 1993). The toxic effects of orchard insecticides are often short-lived, about 2-3 wks (Hagley et al. 1980). This period is often the interval between orchard sprays in calendar-based spray programs.

While arboreal arthropods have been more intensively studied, there are many important arthropods that inhabit the orchard floor. Among these, carabids have been especially studied in fruit crops (Herne 1963, Holliday and Hagley 1978, 1979, Crane 1980, Hagley et al. 1980, Fazekas et al. 1992). The impact of low-spray mating disruption programs on nontarget populations must be evaluated to adequately assess the costs versus benefits of this IPM strategy.

Pitfall trapping is a commonly accepted technique for monitoring epigeic arthropod communities, especially carabids, owing largely to its convenience and large catches that result (Topping and Sunderland 1992, Wiedenmann et al. 1992). This technique has been much discussed as a method of accurately estimating the population size of arthropods. Trap catches are affected by various factors such as surrounding vegetation (Greenslade 1964), trap construction (Luff 1975), preservative used (Greenslade and Greenslade 1971), and climatic variables (Baars 1979, Honék 1988). Because of these factors, Greenslade (1964), Halsall and Wratten (1988) and Jarosík (1992) concluded that sampling arthropod assemblages by pitfall trapping does not accurately compare communities. However, Spence and Niemelä (1994) concluded that pitfall trapping for ecological studies may be improved if designed and interpreted with consideration for both the biology of the particular group and the deficiencies of pitfall sampling. It is used here as a relative comparison of carabid population size in paired orchard blocks.

Materials and Methods

The apple orchards studied were located in two regions of Virginia. In this study, “orchard” denotes the larger planting that contains a representative treatment and control area, and “block” denotes the part of an orchard assigned to a given management program, i.e., pheromone and control blocks. Two orchards, at Daleville and Fincastle, were located on the western side of the Blue Ridge Mountains in Botetourt Co. Two other orchards, at Tyro and Spring Valley, were located on the eastern side of the Blue Ridge Mountains in Nelson Co. and Albemarle Co., respectively. Each orchard contained a 2-ha (Daleville and Fincastle) or a 4-ha (Tyro and Spring Valley) pheromone-treated block and a conventionally-treated control block of approximately the same size. The Daleville blocks were separated by approx. 1.6 km of woodland, commercial district, highway and commercial orchard, and the Fincastle blocks by approx. 100 m of pasture. The Spring Valley blocks were separated by approx. 100 m of grassland, pond and road; the Tyro blocks adjoined. The Daleville, Fincastle and Spring Valley orchards were composed of 'Delicious' and 'Golden Delicious' varieties on M.111 rootstocks. The Tyro orchard was composed of the varieties 'Delicious', 'Golden Delicious' and 'Lodi'. Most of the trees in the orchards were approx. 5 m tall. Ground cover was similar in paired blocks. Grass was closely mown (5-10 cm) and an herbicide-treated strip was maintained in Fincastle and Tyro; mowing was moderate (10-30 cm) in Daleville and Spring Valley.

Habitats surrounding the orchards varied. Both Tyro blocks, Daleville control and Fincastle control blocks were surrounded by other apple orchards and fields. The Daleville pheromone block was surrounded by a woodlot and an abandoned orchard. The Fincastle pheromone block was surrounded by pasture land and woods. The Spring Valley blocks were bordered by woods and a farm road.

The duration of time under a reduced insecticide plus mating disruption program varied. The Daleville and Fincastle pheromone blocks had undergone a total of 4 and 3 yrs, respectively, by 1992, the first year of the study. The Spring Valley block had undergone 3 yrs of disruption by 1993, the only year it was sampled. Mating disruption at the Tyro block was initiated in 1992.

The pheromone blocks were treated in midApril of each year using a set of dispensers each for codling moths [(*E,E*)-8,10-12:OH (52.9%), 12:OH (29.7%), 14:OH (6.0%) and inert (11.4%) (165 mg/dispenser)] and leafrollers, primarily tufted apple bud moth, *Platynota idaeusalis* (Walker), and variegated leafrollers, *Platynota flavedana* Clemens [*P. idaeusalis*: *E*11-14:OH (50%) and *E*11-14:Ac (50%); *P. flavedana*: *E*11-14:OH (90%), *Z*11-14:OH (10%)] (leafroller dispensers contained 190 mg/dispenser) (Pfeiffer et al. 1993a,b). Both codling moth and leafroller dispensers were obtained from Pacific Biocontrol (Davis, CA) and were placed at the rate of 1000/ha. Normal sprays were applied in pheromone blocks at prebloom (generally a pyrethroid followed by an organophosphate, typically chlorpyrifos, methidathion or azinphosmethyl), followed by organophosphate sprays (typically azinphosmethyl or phosmet) at petal fall and first cover (7-10 d after petal fall) periods. Fungicides were applied as normal. Control blocks received these sprays plus conventional organophosphate/carbamate sprays (typically azinphosmethyl, methyl parathion, chlorpyrifos, sometimes supplemented with the carbamate methomyl) at approx. 2-wk intervals until shortly before harvest (late August to mid-September).

Pitfall traps were constructed of 270-ml plastic cups, with a top diam and depth each of approximately 10 cm. A first cup had drain holes placed in its base and side, before being placed in the soil. A second cup was then placed inside the first cup and was level with the soil surface. This was similar to a design by Morrill (1975). The traps were then filled with 3 cm of a 4% aqueous formaldehyde solution. The formaldehyde acted as both a killing agent and as a deterrent to small rodents (Bell 1990). Three bamboo rods, approx. 7 cm, were then placed in the soil, surrounding the cups. These supported a 14.5-cm diam plastic Petri dish at approx. 3 cm above the tops of the cups, preventing rain and debris from entering the trap. Stones were placed on the lids, preventing them from being blown off. A trapping station comprised a pair of abutting traps as described above. This provided a larger trapping area for the arthropods to enter. Each station was located approx. 0.5 m from the base of a tree and was in line with the tree row, protecting traps from orchard machinery; traps close to trees also collect more carabids (Holliday and Hagley 1979). Six trapping stations were located in each orchard block studied, allocated such that two stations were near the block center, and the other 4 were in the respective quadrants of the block. The traps in each orchard were evenly distributed so that they would collect over the widest possible area, to prevent bias in sampling a particular section of orchard. Pitfall traps were checked at approx. weekly intervals from late April through September to retrieve the contents and replace the formalin solution. The contents of the traps were placed in plastic vials for transport and storage pending sorting and identification.

Carabid identification. Several sources were used for carabid identification (Blatchley 1910, Bell 1960, 1990, Larochelle 1976, Lindroth 1961, 1963, 1966, 1968, 1969a,b, Noonan 1991). The taxonomic arrangement of Bousquet and Larochelle (1993) is followed here.

Statistical analyses. Although multiple orchard blocks were used, they were not treated as replicates in statistical analyses; we controlled the nature of the pheromone treatments, but treatment of the control blocks was left to the standard practice of the orchardist. Therefore, descriptive statistics were used instead of inferential statistics (Hurlbert 1984).

Several statistical methods were used to analyze the pitfall capture data. The first was the total abundance of individuals collected. Species richness was then determined (the total number of species collected). The Shannon diversity statistic, H′ (Shannon 1948, Ludwig and Reynolds 1988, Brower et al. 1990), was used to determine species diversity in each block. Because H′ describes the probability of two individuals drawn at random from a population being of the same species, this probability would be affected both by the number of species and the relative similarity of their numbers (evenness or Shannon's J). Sometimes there can be unanticipated interactions. If most species are at low densities, evenness is high, artificially inflating H′. The three indices must be evaluated together.

Although the use of H′ as an indicator of species diversity has been criticized (Hurlbert 1971, Washington 1984), Pielou (1984) supported the use of H′ and it remains a heavily-used diversity statistic. H′ can be compared between assemblages (Hutcheson 1970, Brower et al. 1990). Evenness (Shannon's J′) can also be calculated for each community. Evenness is defined as the distribution of *n* individuals among the *s* taxa/species. Evenness ranges from 0-1.

Communities also may be compared using community similarity indices. The Horn index of community similarity (Horn 1966, Brower et al. 1990), as modified by Rejmánek (1981), was used in determining relationships between various orchard blocks, because of the use of H′ in determining taxa/species diversity. Horn's index ranges from 0-1.

The data also were analyzed using hierarchical cluster analysis, a multivariate technique. The strategy used for the hierarchical cluster analysis was the group average unweighted method (Lance and Williams 1967, Pielou 1984, Ludwig and Reynolds 1988). The distance measure used in the group average strategy was the Bray-Curtis Percentage of Similarity (Bray and Curtis 1957).

Results

Carabid species and diversity. Table 1 lists all Carabidae collected in the various apple orchards. Species totals are presented for each year of the study as well as by treatment. Carabids were the most common beetles collected. Over 2 yrs, 3,173 carabids, representing 62 species in 27 genera were collected. The most common carabids (more than 5% of the total carabid population) were *Harpalus pensylvanicus*

Table 1. List of Carabidae collected in pitfall traps in apple orchards under pheromone-based and insecticide-based tortricid management programs (four orchards in 1992, five in 1993)

Species	Total 1992	Total 1993	Pheromone	Control
Tribe Notiophilini				
Notiophilus semistriatus Say	1	1	2	0
Tribe Cicindelini				
Cicindela punctulata Olivier	0	12	12	0
Cicindela sexguttata Fabricius	0	9	4	5
Tribe Carabini				
Calosoma scrutator (Fabricius)	0	1	0	1
Tribe Cychrini				
Scaphinotus webbi Bell	0	1	0	1
Tribe Scaratini				
Scarites subterraneus Fabricius	14	11	21	4
Tribe Pterostichini				
Poecilus lucublandus (Say)	27	291	178	140
Pterostichus coracinus Newman	105	44	128	21
Pterostichus mutus (Say)	13	1	9	5
Pterostichus sculptus LeConte	0	1	0	1
Pterostichus tristis (Dejean)	0	1	1	0
Tribe Zabriini				
Amara aenea (DeGeer)	5	0	4	1
Amara aeneopolita Casey	0	1	0	1
Amara cupreolata Putzeys	1	8	7	2
Amara exarata Dejean	0	1	1	0
Amara familiaris Duftschmid	9	5	10	4
Amara impuncticollis (Say)	2	0	2	0
Amara littoralis Mannerheim	6	22	28	0
Amara pennsylvanica Hayward	0	1	0	1
Tribe Chlaeniini				
Chlaenius emarginatus Say	26	31	44	13
Tribe Licinini				
Dicaelus dilatatus Say	0	3	0	3
Dicaelus elongatus Bonelli	29	166	153	42
Dicaelus furvus Dejean	1	1	2	0
Dicaelus purpuratus Bonelli	0	2	2	0

Table 1. Continued.

Species	Total 1992	Total 1993	Pheromone	Control
Tribe Harpalini				
Amphasia interstitialus (Say)	0	44	34	10
Anisodactylus furvus LeConte	12	96	91	17
Anisodactylus harrisii LeConte	2	81	45	38
Anisodactylus ovularis Casey	3	0	2	1
Anisodactylus nigerrimus (Dejean)	48	69	74	43
Anisodactylus rusticus (Say)	0	2	2	0
Anisodactylus sanctaecrucis (Fabricius)	0	1	0	1
Bradycellus badipennis (Haldeman)	0	3	3	0
Bradycellus congener (LeConte)	2	0	1	1
Bradycellus insulsus (Casey)	1	0	1	0
Harpalus caliginosus (Fabricius)	0	17	17	0
Harpalus erythropus Dejean	21	338	272	87
Harpalus fulgens Csiki	5	0	0	5
Harpalus herbivagus Say	1	8	2	7
Harpalus longicollis LeConte	51	131	152	30
Harpalus pensylvanicus (DeGeer)	68	1137	534	671
Harpalus somnulentus Dejean	2	0	1	1
Notiobia nitidipennis (LeConte)	2	7	5	4
Notiobia terminatus (Say)	5	0	3	2
Selenophorus opalinus (LeConte)	1	0	0	1
Stenolophus conjunctus (Say)	0	1	1	0
Stenolophus rotundatus LeConte	0	3	3	0
Trichotichnus dichrous (Dejean)	0	21	18	3
Xestonotus lugubris (Dejean)	0	1	1	0
Tribe Platynini				
Agonum melanarium Dejean	0	1	1	0
Agonum placidum (Say)	0	1	0	1
Agonum punctiforme (Say)	3	1	0	4
Agonum retractum LeConte	1	0	1	0
Calathus gregarious (Say)	7	18	16	9
Platynus cincticollis (Say)	0	1	0	1
Platynus decentis (Say)	0	2	2	0

Table 1. Continued.

Species	Total 1992	Total 1993	Pheromone	Control
Tribe Lebiini				
Apenes lucidulus (Dejean)	0	1	1	0
Cymindis americanus Dejean	0	1	1	0
Cymindis complanatus Dejean	0	1	1	0
Cymindis limbatus Dejean	0	2	1	1
Dromius piceus Dejean	0	1	1	0
Lebia viridis Say	0	2	1	1
Tribe Galeritini				
Galerita bicolor (Drury)	29	64	72	21
Number of individuals	503	2670	1968	1205
Number of species	32	52	50	40

DeGeer (38.2%), *H. erythropus* Dejean (11.4%), *Poecilus lucublandus* (Say) (usually referred to in the literature as *Pterostichus lucublandus*) (10.1%), *Dicaelus elongatus* Bonelli (6.2%) and *H. longicollis* LeConte (5.9%).

Daleville orchard. There was a large difference in the number of carabid species collected in the pheromone block relative to the control in both years (Table 2). Of the 792 individual arthropods captured in 1992, 110 represented 14 species of carabids. *Anisodactylus nigerrimus* (Dejean), *D. elongatus*, *Galerita bicolor* (Drury) and *P. lucublandus* were the most commonly collected species. Of the 331 individual arthropods collected in the control, only 14 were carabids, representing only 4 species, none of which could be considered to be common.

During 1993, of 2054 individual arthropods collected in the pheromone block, 508 were carabid beetles, representing 27 species. *Amara littoralis* Mannerheim, *Amphasia interstitialis* (Say), *Anisodactylus furvus* LeConte, *D. elongatus*, *G. bicolor*, *H. erythropus*, *H. pensylvanicus*, *Pterostichus coracinus* Newman and *P. lucublandus* were the most frequently collected species. In the corresponding control block, of 54 taxa and 679 individuals collected, 316 were carabids representing 11 species. *Harpalus pensylvanicus* was the most common carabid collected.

For both years, the pheromone block had the highest diversity (H′) of Carabidae (Table 2). Richness and evenness components were both higher in the pheromone block. This difference was more pronounced in 1993. The pheromone block evenness (J′) was 0.75 in 1992 whereas in 1993 it remained virtually unchanged at 0.72. In the control, J′ dramatically decreased from 0.71 in 1992 to 0.58 in 1993. The Horn Index of Similarity was low for the comparison between blocks in both 1992 and 1993. In 1992, the blocks had a Horn similarity value of 0.33 whereas in 1993, the blocks had a similarity value of 0.59. Similarity, between years for the pheromone block comparison was 0.71, which was similar to the control block's between-year similarity (0.76).

Fincastle orchard. The pheromone block yielded a greater number of individuals and species than the control block, for both years. In 1992, of 633 individual arthro-

Table 2. Carabid diversity comparisons for pitfall traps in apple orchards under pheromone-based and insecticide-based tortricid management programs (four orchards in 1992, five in 1993)*

	Daleville				Fincastle				Tyro				Spring Valley**	
	1992		1993		1992		1993		1992		1993		1993	
Statistics	Pher	Cont	Pher	Cont	Pher	Cont	Pher	Cont	Pher	Cont	Pher	Cont	Pher	Cont
Total no. individuals	110	14	508	316	254	40	247	190	56	29	112	68	665	543
Total no. species	14	4	27	11	20	16	20	17	9	8	14	13	21	19
Evenness (J')	0.75	0.71	0.72	0.28	0.71	0.90	0.59	0.72	0.72	0.83	0.58	0.73	0.71	0.54
Shannon-Wiener (H')	0.86	0.43	1.03	0.30	0.94	1.08	0.77	0.88	0.69	0.75	0.66	0.82	0.94	0.69
Student's t	10.85		249.32		4.97		17.78		1.82		9.77		111.44	
Degrees of freedom	15		813		42		362		45		112		1197	

* Pher = Pheromone-based management of codling moth and leafrollers; reduced organophosphate/carbamate schedule. Cont = Control, organophosphate/carbamate-based management of codling moth and leafrollers.

** Spring Valley orchard was sampled only during 1993.

pods collected in the pheromone block, 254 were carabid beetles representing 20 species (Table 2). *Anisodactylus nigerrimus*, *Chlaenius emarginatus* Say, *D. elongatus*, *H. longicollis*, *H. pensylvanicus* and *P. coracinus* were the carabid species commonly collected. In the control block, only 40 of the 276 total individuals were carabids, and those represented 16 species.

During 1993, of the 816 individual arthropods collected in the pheromone block, 247 were carabid beetles representing 20 species. The regularly collected species were *H. erythropus*, *H. longicollis* and *H. pensylvanicus*. In the control block, collection totals were higher than in 1992. Of the 601 total individual arthropods, 190 were carabids representing 17 species. *Anisodactylus harrisii* LeConte, *A. nigerrimus*, *H. erythropus*, *H. pensylvanicus* and *P. coracinus* were the most common species collected.

For both years, the control block had significantly greater diversity (H′) than the pheromone block (Table 2). Whereas richness was greater in the pheromone block in both years, as in Daleville, the Fincastle control blocks had a greater evenness component. This probably accounts for the greater H′ values in control block relative to the pheromone block. In 1992, the two blocks had a Horn similarity value of 0.62 whereas the 1993 blocks yielded a similarity of 0.90. The between-year similarity comparison in the pheromone block gave a Horn index value of 0.54, which was higher than the between-year comparison in the control block (0.40).

Tyro orchard. Even though the differences between the blocks were not as pronounced as in the 2 previous orchards, there were still a greater number of individuals and taxa collected for both years in the pheromone block. In 1992, the pheromone block totals were 156 individual arthropods, of which 56 were carabids of 9 species (Table 2). *Harpalus erythropus* and *H. pensylvanicus* were the only readily-collected carabids. In the control block, 29 of the 80 individual arthropods were carabids, representing 8 species. As in the pheromone block, *H. pensylvanicus* was the only common carabid species.

During 1993, almost half of the 244 individual arthropods gathered in the pheromone block were carabid beetles (112), representing 14 species (Table 2). *Galerita bicolor*, *H. longicollis* and *H. pensylvanicus* were the common species. The control block trap captures increased from the 1992 control block totals; of 170 individual arthropods collected, 68 were carabids, representing 13 species. As in the pheromone block, *G. bicolor*, *H. longicollis* and *H. pensylvanicus* were commonly captured.

The control block had a significantly greater H′ in 1993 (Table 2). As in Fincastle, this was apparently due to an elevated evenness component; richness was greater in the pheromone block. H′ did not differ significantly between years in the pheromone block, whereas the control had a significantly greater H′ in 1993 than in 1992. J′ increased in both blocks from 1992-1993. The similarity index was high for the comparison between blocks in both 1992 and 1993. In 1992, the blocks had a Horn Index similarity value of 0.92 whereas in 1993, the blocks had a similarity of 0.93. Similarity for the between-year comparison in the pheromone block comparison was 0.80. The control had a lower between-year Horn Index of 0.74.

Spring Valley orchard. The Spring Valley orchard was sampled only during 1993. Of 927 arthropods collected in the pheromone block, 665 were carabids; 543 carabids were collected in the corresponding control block, out of 831 arthropods. Nineteen species of carabids were found in the control, compared with 21 species in the pheromone block (Table 2). *Anisodactylus furvus*, *A. harrisi*, *D. elongatus*, *G. bicolor*, *H. erythropus*, *H. longicollis*, *H. pensylvanicus* and *P. lucublandus* were the commonly collected carabids in the pheromone block. In the corresponding control block, *D. elongatus*, *H. erythropus*, *H. pensylvanicus*, and *P. lucublandus* were readily collected. H' and J' were both significantly higher in the pheromone than the control block. Horn's index was calculated to be 0.94 between blocks.

Multivariate analysis. Figure 1 is a dendrogram resulting from the cluster analysis of the carabid data collected in 1992. There are 3 clusters at the 30% similarity level. The longer-term pheromone-treated blocks (Daleville and Fincastle) form a group; there is a trend for conventionally managed orchards to have different carabid communities than pheromone-treated blocks. The exception is that the Tyro pheromone block, under mating disruption for a shorter period, being most similar to the control blocks. Figure 2 is a dendrogram of the carabid data collected in 1993. There are 2 clusters at the 40% similarity level. Pheromone and control blocks within an orchard tend to cluster together, i.e., there was a greater degree of similarity between blocks within orchards. The program by Sall et al. (1991) was used to perform analyses.

Discussion

Carabids were the most common beetles collected. This was reported earlier for apple orchards by Pearsall and Walde (1995). Riddick and Mills (1996b) found *Pterostichus* spp. (including *P. lucublandus*) to constitute 71-83% of the total carabid fauna in unsprayed California apple orchards, and Epstein et al. (2000) reported that beetles of this genus comprised >89% of the carabids collected in Washington and Oregon apple orchards. Most *Pterostichus* spp. are flightless (Lindroth 1966, Kirk 1973) and may need more time than other genera to colonize a newly available site.

Studies have indicated that particular carabid species may be effective predators on fifth-instar codling larvae, apple maggot pupae and on green apple aphids, *Aphis*

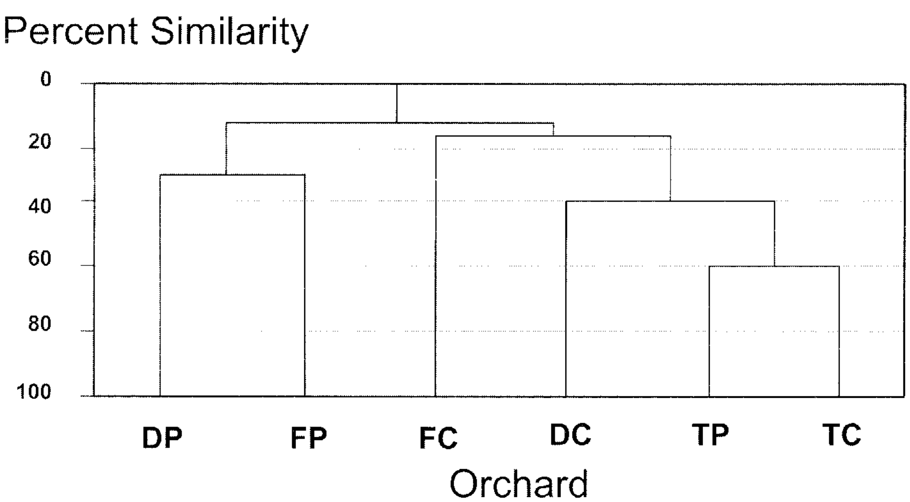

Fig. 1. Cluster analysis dendrogram for carabids collected in mating disruption and conventional apple orchards in 1992. Clustering is by the group-average method. (D = Daleville, F = Fincastle, T = Tyro, P = Pheromone, C = Conventional)

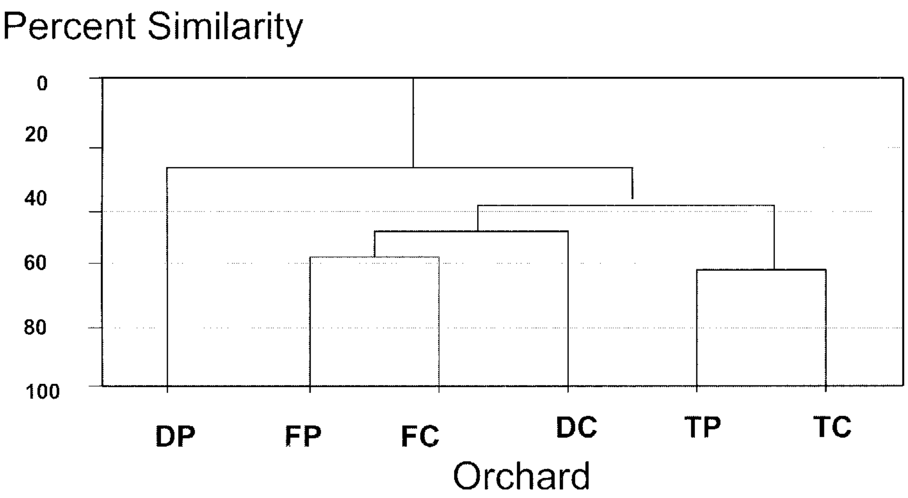

Fig. 2. Cluster analysis dendrogram for carabids collected in mating disruption and conventional apple orchards in 1993. Clustering is by the group-average method. (D = Daleville, F = Fincastle, T = Tyro, P = Pheromone, C = Conventional)

pomi DeGeer (Hagley et al. 1982, Hagley and Allen 1988, 1990, Allen and Hagley 1990, Riddick and Mills 1994). Riddick and Mills (1994) reported that carabids consumed up to 60% of tethered codling moth larvae per night, and they indicated that carabids might become more important as a mortality agent with increased use of smooth-barked dwarf trees. Causse (1976) also reported higher predation on codling moth on modern, smooth-barked trees relative to older, rough-barked orchards.

Harpalus species are polyphagous and may feed on seeds as well as insects (Kirk 1973). Because *H. pensylvanicus* feeds on seeds and other plant matter in addition to insects, cessation of insecticides with concomitant differences in potential prey may play less of a role in affecting this species. Another important factor influencing *H. pensylvanicus* populations and other species may be the dramatic change in weather from 1992 and 1993. Kirk (1971) reported that *P. lucublandus* are voracious feeders, and Shough (1940) noted that they readily attack lepidopteran larvae 2-3 times their size. Allen and Hagley (1990) stated that *P. lucublandus* can be predators on apple maggot, whereas Riddick and Mills (1994) reported that *Pterostichus* species appeared to be important early-season predators of codling moth. Tomlin (1975) also suggested that the larvae of *Pterostichus* species may be important in pest control. Another carabid species, *Amara littoralis* Mannerheim, may feed on early instars of codling moth (Hagley et al. 1982). No research has been conducted on the ability of *A. nigerrimus* to feed upon apple orchard pests; it is predominately a seed feeder (Blatchley 1910). However, other species of *Anisodactylus* have been known to feed on young codling moth larvae and apple maggot pupae (Hagley et al. 1982), thus indicating a potential for species in this genus to prey on apple pests. *Amphasia interstitialus* has similar feeding habits as other *Anisodactylus* species. *Galerita bicolor* is predacious on various caterpillars (Forbes 1883) and is, therefore, likely to feed on apple pests. Lindroth (1969a) and Bell (1990) relate that *D. elongatus* is primarily a snail feeder and as a result is unlikely to feed upon apple pests.

There were always more carabid beetles collected in pheromone blocks (1.2-7.9 times more) than in conventional blocks. There were more carabid species as well (1.1-3.5 times as many). Diversity of the carabid species did not show the same pattern between treatments, apparently because of the contribution of evenness to the diversity concept; sometimes H′ was increased because low populations artificially inflated the evenness component of diversity. It was apparent that a single index did not adequately describe diversity. Riddick and Mills (1995) reported that even some environmentally more benign pest management programs differ in their impacts on carabid populations. Carabids may sometimes be more active under organic orchard management, but numbers may not differ (Riddick and Mills 1996a). If orchard blocks are totally unmanaged, carabid abundance may actually decline (Pearsall and Walde 1995).

It is important to note that the overall collections of carabids were much higher in both the pheromone and control blocks in 1993 than in 1992. One influencing factor for this dramatic change in numbers was that greater rainfall totals were observed in the period between 1 May and 16 October 1992 (70.7 cm) relative to 1993 (approx. 51 cm) (Gronning 1994). It is possible that higher rainfall in 1992 enhanced reproduction or larval survival, resulting in greater abundance of adults in 1993, or simply increased adult activity on the soil surface. Baars (1979) noted that weather can play an important role when collecting individuals with pitfall sampling.

Of the orchards studied, the Daleville pheromone block had consistently the greatest difference not only from its corresponding control block but also from the other blocks as seen in cluster analyses. The diversity indices indicated that the block's carabid community was quite diverse, whereas the similarity indices showed that the block was also similar between years, despite climatological differences. The greatest number of carabid species was found in this block, whereas over 80% of all carabids collected in the Daleville control were *H. pensylvanicus*. *Harpalus erythropus* was also quite common.

The Fincastle pheromone block did not exhibit the pronounced differences seen in the Daleville orchard. The 1993 control had higher Shannon diversity and evenness than the pheromone block. The 1992 and 1993 pheromone block produced a greater number of carabid species and individuals than the control. Shannon diversity incorporates not only species richness but also evenness (Brower et al. 1990). The low numbers collected in the control artificially inflate evenness which, in turn, inflates Shannon diversity to artificially high levels. Whereas the pheromone block had a greater number of individuals for each carabid species, this was not reflected in the indices. Similarity is calculated in the same manner. Although the pheromone block yielded greater overall numbers, the ratio of the number of individuals collected for a particular species is the same between the blocks. As a result, similarity was high. Therefore, it is important not to rely solely upon a single index in determining the ecological balance of the orchard. Examining the cluster analyses may better determine how the Fincastle pheromone and control blocks interrelate with the other orchard blocks. In the 1992 dendrograms (Fig. 1), the Fincastle pheromone block clusters with the Daleville pheromone block, the other long-term pheromone block. This, however, was not seen in 1993 (Fig. 2). A possible reason for this is the relatively high proportion of *H. pensylvanicus* collected in both the control and pheromone blocks. Therefore, when the blocks are compared with each other, the presence of this species will draw the similarity of the pheromone block closer to the control rather than the Daleville pheromone, which has a lower population and different ratio of *H. pensylvanicus* to the other carabids. *Chlaenius emarginatus* was one of the prevalent species in the Fincastle pheromone and control blocks. Riddick and Mills (1994) found that, whereas *Chlaenius* spp. could successfully kill fifth-instar codling moth larvae, they were less so than *Pterostichus* spp., and were more easily deterred by alternative food sources.

The Tyro blocks adjoin each other and, therefore, would likely provide the best insight on how a reduced insecticide plus mating disruption program may affect the apple orchard arthropod community. However, the pheromone block had undergone only 2 yrs of a reduced insecticide plus mating disruption program by the end of the 1993 field season. The surrounding habitat (mainly hay fields) is probably a poor source of immigration, especially given the limited mobility of some species, e.g., *P. lucublandus*. *P. lucublandus*, as well as most *Pterostichus* species, are flightless (Kirk 1971); they were poorly represented in Tyro, whereas *H. pensylvanicus*, which can fly (Kirk 1973), was common. Therefore, it is not surprising to find that the 2 blocks had a high level of similarity. Dendrogram analysis indicated the similarity of the 2 Tyro blocks, even after 2 yrs of mating disruption. This is probably not enough time for the populations of beneficial arthropods to increase. Also of importance is that the pheromone block yielded more individuals and species during both years. One of the commonly collected species in the 1993 pheromone block (Table 1), *Cicindela punctulata* Olivier, is highly predaceous. The dramatic change in numbers collected from 1992-1993 is likely due to the weather (Gronning 1994).

The Spring Valley orchard was undergoing its third year of disruption during its single year of study. While this orchard was expected to show differences between the management programs, none were apparent. The diversity indices, as discussed above, indicated that pheromone block contained a more diverse fauna than the control (Table 2). Similarity of the two blocks was also high (0.94). This suggests that both blocks were diverse independent of the management program.

Carabid beetles were more numerous and diverse in apple orchard blocks under low-spray mating disruption tortricid management programs, relative to blocks under conventional, insecticide-based management. It appears that *H. pensylvanicus* is a dominant species in apple orchards, independent of orchard location (i.e. east or west of the Blue Ridge mountain chain) and insect control tactics; this species comprised 38.2% of the carabids collected and was actually more common in control blocks. Among the species more common in mating disruption blocks were *P. lucublandus*, *P. coracinus*, *D. elongatus*, *A. furvus*, *A. nigerrimus* and *H. erythropus*.

Epstein et al. (2000) also reported higher populations of carabids among other epigeal arthropods in orchard blocks with no neuroactive insecticides, relative to conventionally managed orchard blocks. The impact on carabid populations appears to be less pronounced in blueberry, where only 1 species increased with reduced pesticide input (O'Neal et al. 2005). Carabids in wheat plantings were reported to increase with reduced insecticide load (Navntoft et al. 2006).

Several areas of research are suggested to expand understanding of this system. One is the role of carabids in actual predation of fruit pests that spend part of their life cycles on the soil surface. This is especially important given the planting of dwarf fruit trees with smooth bark that may force species that overwinter under loose bark onto the ground for overwintering. In particular, the predatory potential of the most common species in Virginia orchards (*P. lucublandus*, *P. coracinus*, *D. elongatus*, *A. furvus*, *A. nigerrimus* and *H. erythropus*) should be determined.

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