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HERBACEOUS FILTER STRIPS IN AGROECOSYSTEMS: IMPLICATIONS FOR GROUND BEETLE (COLEOPTERA: CARABIDAE) CONSERVATION AND INVERTEBRATE WEED SEED PREDATION

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ABSTRACT

A 9.3–ha crop field flanked by two filter strips was selected to: 1) assess carabid beetle activity-density and community composition and 2) assess post-dispersal weed seed predation by invertebrates in these habitats. Overall during 1997 and 1998, 12,937 carabid beetles comprising 58 species were collected. Greater species richness and activity-density was observed in filter strips than in the field. A multivariate ordination revealed that year of capture and habitat were important variables conditioning carabid beetle communities. While two omnivorous species known to eat weed seeds [*Harpalus erraticus* (Say), *Anisodactylus sanctaecrucis* (F.)] dominated the 1997 captures, two carnivorous [*Pterostichus melanarius* (Ill), *Pterostichus permundus* (Say)] were predominant in 1998. Two omnivorous species, *Harpalus pensylvanicus* (DeG) and *H. erraticus*, were primarily captured in filter strips. Weed seed removal was greater in filter strips than in the field. This study shows that habitat management represents a feasible approach to conserve beneficial organisms in farmlands.

Carabid beetles (Coleoptera: Carabidae) are a diverse and important group of polyphagous arthropods occurring in agricultural systems. Numerous field and laboratory experiments have documented the importance of carabid beetles as biological control agents of various pests including arthropods (Lund and Turpin 1977a, Baines et al. 1990), slugs (Asteraki 1993) and weed seeds (Johnson and Cameron 1969, Best and Beegle 1977, Lund and Turpin 1977b, Brust and House 1988, Brust 1994). Despite the potential importance of carabids as beneficial organisms, conventional agricultural management practices such as cultivation, pesticide applications, crop rotation, and harvest act as deleterious disturbances harming carabid populations (Brust 1990, Reed et al. 1992). In contrary, alternative management practices such as cover crops and reduced or no-tillage may boost overall carabid beetle abundance (Brust and House 1988, Cárcamo et al. 1995).

To understand the impact of agricultural management practices on beneficial organisms it is necessary to go beyond the within-field scale of analysis and consider variables measured at the farm and landscape level (Landis

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and Menalled 1998). Providing less disturbed habitats in close spatial association with crop fields represents a logical approach to conserving carabid communities. Refuge habitats can enhance carabid abundance, fecundity, and species diversity by supplying overwintering sites, food, and shelter (Lys and Nentwig 1992, Zangger et al. 1994, Carmona and Landis 1999).

The establishment of filter strips, areas seeded with perennial vegetation along a ditch, stream, pond, or lake reduces surface chemical runoff from agricultural fields (National Research Council 1993, U.S. Department of Agriculture 1997, Schmitt et al. 1999). Properly managed filter strips may provide additional environmental benefits such as wildlife conservation, soil protection and sediment trapping (Henry et al. 1999). Because filter strips represent less disturbed habitats that may provide critical resources for beneficial organisms, they have been proposed as a valuable tool in conservation biological control (Landis et al. 2000). Despite the important role that filter strips may play in invertebrate population dynamics, the impact of such habitats on carabid beetle conservation is largely unknown.

Previous studies conducted in experimental plots or small fields have documented a positive correlation between carabid activity-density in crops and in adjacent boundary vegetation (Coombes and Sotherton 1986, Hawthorne and Hassall 1995). Moreover, declining gradients in beetle abundance with increased distance from refuges is evidence of beetle dispersal from these habitats (Dennis and Fry 1992, Vitanza et al. 1996). Finally, a recent study demonstrated that the presence of herbaceous habitats established in close spatial association with crop fields interacts with insecticide applications in determining within-field carabid beetle activity-density (Lee et al. 2001). Despite the importance of these observations, to our knowledge, no farm-scale research has been done in the Great Lakes region assessing the importance of habitat management on carabid beetle conservation. The objectives of this study were: 1) to compare carabid beetle activity-density and community composition in refuge filter strips and crop habitats in Michigan and 2) assess post-dispersal weed seed predation by invertebrates in these habitats.

MATERIALS AND METHODS

Study Site. This study was conducted in a 9.3–ha field located in the Saginaw Bay watershed, Midland County, Michigan. The field was planted to soybean (*Glycine max*) in 1997 and corn (*Zea mays*) in 1998 and was flanked by two 30 m wide herbaceous filter strips. These filter strips were established in 1994 to reduce soil and chemical deposition into surrounding waterways. One filter strip was composed of switchgrass (*Panicum virgatum*), the other strip was a legume-grass mixture of alfalfa (*Medicago sativa*) and timothy (*Phleum pratense*) (Fig. 1).

Carabid beetles activity-density. Plastic pitfall traps (12 cm in diameter by 16 cm height) were used to compare carabid beetle activity-density between an annual crop field and two herbaceous filter strips. Three replicates of six pitfall traps each were located within the crop field and in each one of the filter strips (Fig. 1). Each replicate was established 60 m from one another; replicates within the crop field were located at least 100 m from any border and replicates within the herbaceous strips were established at 14 m from strip margins. Each replicate consisted of a 2 by 4 m grid with six stations spaced at 2 m intervals. At each grid station, a pitfall trap was established and filled with 50 ml of 10% ethylene glycol as preservative. Every 14 days from 11 June to 1 October 1997 and from 26 May to 30 September 1998

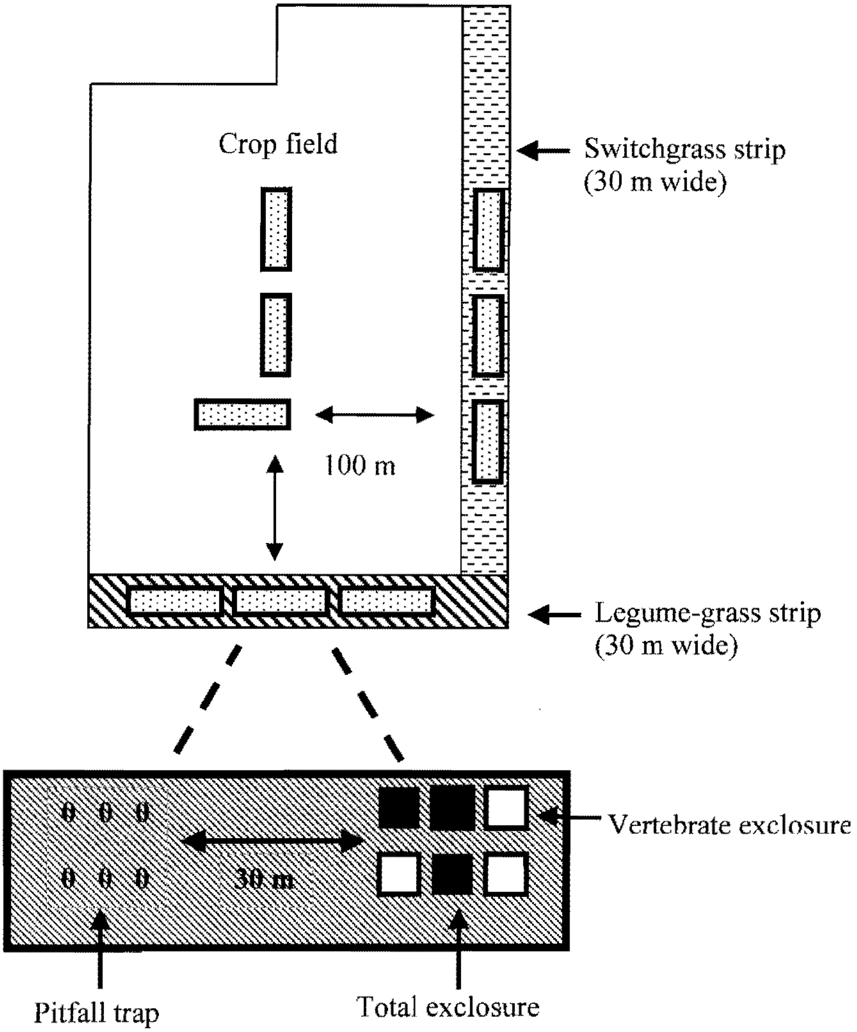

Figure 1. Field design, pitfall trap location, and seed predation cages placement in a 9.3–ha crop field and two adjacent filter strips located in Midland County, Michigan.

the traps were opened for five consecutive days. Pitfall traps were covered with lids between sampling periods. Trap contents were collected in plastic bags and frozen until identified in the laboratory using Lindroth's (1969) key.

Post-dispersal weed seed predation. Weed seed removal by invertebrates was assessed using giant foxtail (*Setaria faberii* Herrm.) as a model species. Giant foxtail is an erect annual grass commonly growing as a weed in agricultural fields (Uva et al. 1997). Weed seed removal was evaluated in the crop field and filter strips using two treatments: 1) vertebrate exclosures, which allowed only invertebrates to remove seeds, and 2) total exclosure, which prevented both vertebrates and invertebrates from removing seeds. Total exclosures were used to estimate unknown losses of seeds and evaluate the experimental error inherent in weed seed recovery. Vertebrate exclosures were constructed with cages of 1.25 cm^2 mesh rigid hardware cloth (34 cm long by 34 cm wide by 7 cm high) sunk 3 cm into the soil. Total exclosures consisted of vertebrate exclosure cages enclosing plastic rings (28 cm diameter, 5 cm high) sunk 3 cm into the ground. Rings were painted with Fluon^{TM}, a slick material that prevents invertebrates from climbing the barrier and excludes them from reaching the seeds placed within rings (Mittelbach and Gross 1984, Menalled et al. 1999, Menalled et al. 2000). Each cage was covered with a clear plastic roof to reduce seed losses from rain.

Within each cage, 50 seeds were placed on 11 cm long by 14 cm wide by 0.5 cm high waterproof pads (3–M Metallic Finishing Pad) level with the soil surface. Fifty seeds per pad (3246 seeds m^{-2}) was selected to resemble natural occurring seedbank densities which in Michigan corn, soybean, and wheat fields ranges between 1873 to 5000 seeds m^{-2} (Renner et al. 1998). Pads were used to reduce seed losses from wind and to facilitate recovery of uneaten seeds. Three replicates of the vertebrate and total exclosure cages were established within each habitat with each replicate located at 30 m from the pitfall trap sites used for monitoring carabid beetle activity-density (Fig. 1). The order of the vertebrate and total exclosure cages within replicates was completely randomized in a 2 by 4 m grid with cages 2 m apart.

Seed predation experiments were done twice in late summer of 1997. This period corresponds to the peak abundance of potential invertebrate seed predators and the time of natural weed seed production and dispersal (Carmona and Landis 1999). The first experiment was started on 24 July, and the second on 5 August. Seeds were left in the field for one week, recovered, and the number of seeds remaining on all pads was counted in the laboratory. During these two trials, weather conditions were dry with no heavy rains or winds. Since seed coats were observed on pads, seed removal was assumed to be primarily due to predation.

Data analysis. For each pitfall trap, the number of individuals and species of carabid beetles captured during the five days of each trapping interval was recorded and captures were pooled across years. For each year, differences in total activity-density were analyzed using Proc GLM, SAS software (SAS Institute 1996). For this analysis, we used a two factor (habitat, replicate) nested factorial ANOVA model with replicates nested within habitats. Prior to analysis all data were square root $(x + 0.5)$ transformed to meet the assumptions of ANOVA (Sokal and Rohlf 1995).

The relative importance of habitat and year of study in determining carabid beetle community composition was analyzed by means of a multivariate Principal Component Analysis (PCA). For each species, total capture in the six pitfall traps per replicate was pooled across years and replicates were ordinated using the PC-ORD multivariate analysis software program (McCune and Mefford 1997). To decrease the impact of rare species, the ordination was conducted using only those species that had a relative abundance larger than 2%.

Weed seed removal data were pooled across the two trials and the proportion of seeds removed per day was analyzed using a two factor nested ANOVA model similar to the one employed to assess variations in carabid beetle activity-density. To increase data normality and homoscedasticity, percentage weed seed removal was arcsin transformed prior to analysis (Sokal and Rohlf 1995). Linear regression analysis was employed to assess the relationship between number of weed seed predators captured in pitfall traps between 27 July and 5 August 1997 and weed seed removal rate observed between 24 July and 12 August 12 1997. To meet the assumptions of linear regression, number of seed predators was square-root transformed and percentage weed seed removal was arcsin transformed prior to the analysis.

RESULTS

Carabid beetle assemblages. In total, 12,937 carabid beetles comprising 58 species were collected during 1997 and 1998 (Table 1). The carabid beetles captured ranged in size from 2–3 mm for *Elaphropus anceps* (LeC.) to 17.5–25.5 mm for *Harpalus caliginosus* (F.). The seven most abundant species, *H. pensylvanicus*, *Pterostichus permundus* (Say), *H. erraticus*, *Poecilus chalcites* (Say), *P. melanarius*, *Notibia terminata* (Say), and *Poecilus lucublandus* (Say), comprised 82.1% of total capture. Eleven of the 58 captured species have been reported as omnivores able to consume weed seeds (Johnson and Cameron 1969, Pausch and Pausch 1980, Hagley et al. 1982). However, only two of such omnivores, *H. pensylvanicus* and *H. erraticus*, accounted for > 2% of total specimens (Table 1).

In 1997, significantly fewer species, individuals, and seed predators were sampled in the crop field (soybean) than in the filter strips (Table 2, Fig. 2). The ANOVA also showed significant differences in the total number of species, individuals, and seed predators among the three replicates nested within each habitat (Table 2). These results reflect high within-field heterogeneity in carabid beetle activity-density and species composition. Inspection of trap captures revealed that, with the exemption of one sample date in early July, the highest number of carabid species was found in the legume-grass strip, followed by the switchgrass strip, and the crop field (Fig. 2 A).

Table 1. Abundance of carabid beetle species sampled in a crop field (soybean in 1997, corn in 1998) and two adjacent herbaceous filter strips in Midland Co., Michigan.

Carabid species	Crop	Legume-grass	Switchgrass
Harpalus pensylvanicus (DeG.) *	148	1046	1333
Pterostichus permundus (Say)	697	854	781
Harpalus erraticus Say *	255	683	791
Poecilus chalcites (Say)	905	249	550
Pterostichus melanarius (Ill.)	503	384	140
Notiobia terminata (Say)	388	168	283
Poecilus lucublandus (Say)	88	273	63
Anisodactylus sanctaecrucis (F.) *	5	99	160
Harpalus herbivagus Say	19	139	88
Agonum cupripenne (Say)	9	39	180
Amara obesa (Say)	24	41	144
Harpalus compar LeC. *	29	59	85
Amara aenea (DeG.) *	5	19	149
Amara rubrica (Hald.)	48	11	86
Other	237	266	414
Total number of species	36	42	50
Total number of individuals	3360	4330	5247
Total number of seed predators	497	1959	2631

*Indicates omnivorous species known to consume weed seeds.

Table 2. Overall nested ANOVA results for number of species, number of individuals and number of seed predators of carabid beetles sampled during 1997 and 1998 in a crop field and two adjacent herbaceous filter strips, in Midland Co., Michigan.

Source of variation	df	Type III MS	Ddf	MS	*F*	*P*
Number of species						
Year. 1997						
Habitat	2	4.09	6	0.23	17.45	0.0032
Replicate(habitat)	6	0.23	45	0.09	2.63	0.0283
Year 1998						
Habitat	2	0.69	6	0.80	0.86	0.4691
Replicate(habitat)	6	0.80	45	0.10	8.04	0.0001
Number of individuals						
Year. 1997						
Habitat	2	219.23	6	22.51	9.74	0.0131
Replicate(habitat)	6	22.51	45	3.58	6.29	0.0001
Year 1998						
Habitat	2	34.84	6	23.19	1.50	0.2959
Replicate(habitat)	6	23.19	45	3.69	6.29	0.0001
Seed predators						
Year. 1997						
Habitat	2	211.65	6	23.44	9.03	0.0155
Replicate(habitat)	6	23.44	45	1.78	13.20	0.0001
Year 1998						
Habitat	2	61.17	6	8.40	7.29	0.0248
Replicate(habitat)	6	8.40	45	1.14	7.36	0.0001

From July through October, more individuals (Fig. 2 B) and seed predators (Fig. 2 C) were trapped in the filter strips than in the center of the soybean field.

In 1998, similar numbers of individuals and species were trapped among the crop field (corn) and two filter strips. Despite these similarities, significantly more seed predators were trapped in the filter strips than in the crop field (Table 2, Fig. 3). Examination of the captures revealed that during the first two sampling periods of 1998, more species and individuals were trapped in the corn-field than in both strips. In contrast, between July and October 1998, more species and individuals were trapped in the filter strips than replicates from the crop field (Fig. 3 A and B). Similarly, in September 1998 more seed predators were trapped in the filter strips compared to the corn-field (Fig. 3 C). As in 1997, high within-field heterogeneity in carabid beetle activity-density and species composition was reflected by significant differences among the three replicates nested within habitats (Table 2).

Multivariate ordination of carabid assemblages indicated that year and habitat were important variables conditioning carabid beetle community composition (Fig. 4). The first component (PC1) contributed 41.7% to the total variation and divided observations gathered in 1997 (negative values) from those obtained in 1998 (positive values). Two omnivorous seed predator species, *H. erraticus* and *Anisodactylus sanctaecrucis* (F.) were negatively associated with PC1 (Eigenvector = –0.43 and –0.38, respectively) with 70.6 and 97.3% of their total capture in 1997. On the other hand, *P. melanarius* and *P. permundus* were positively associated with PC1 (Eigenvector = 0.46

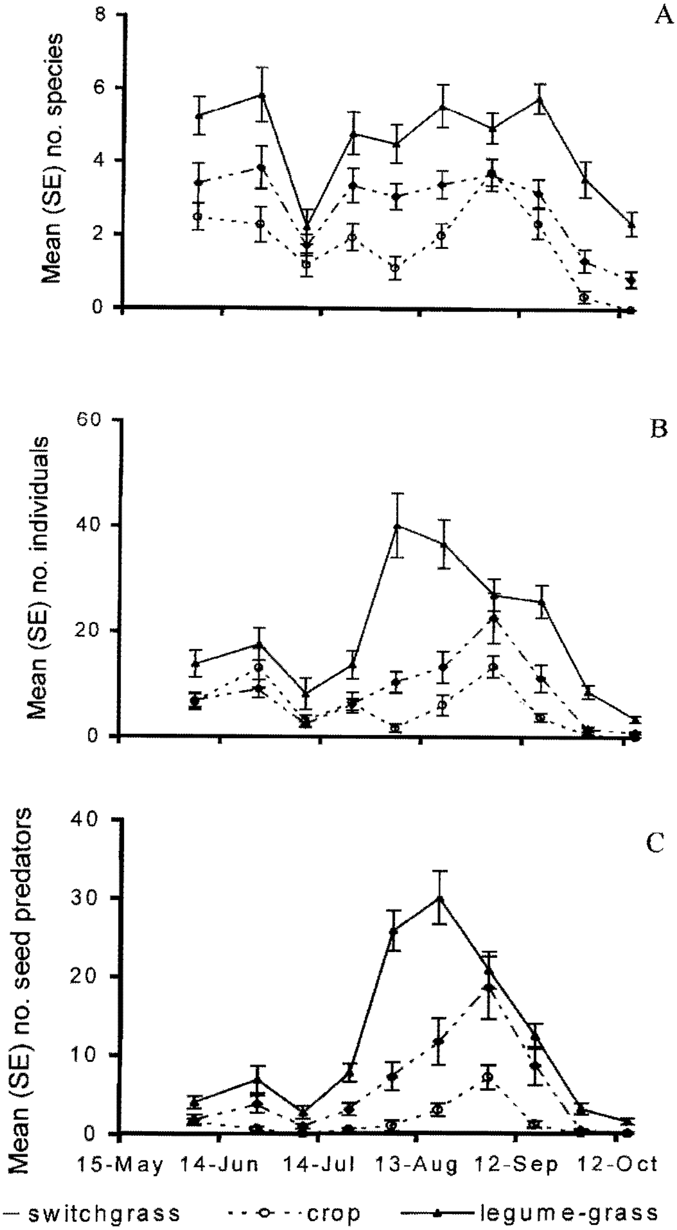

Figure 2. Mean number (± SE) of (A) carabid beetle species, (B) individuals, and (C) seed predators trapped during 1997 in a 9.3–ha soybean field and two adjacent filter strips located in Midland County, Michigan.

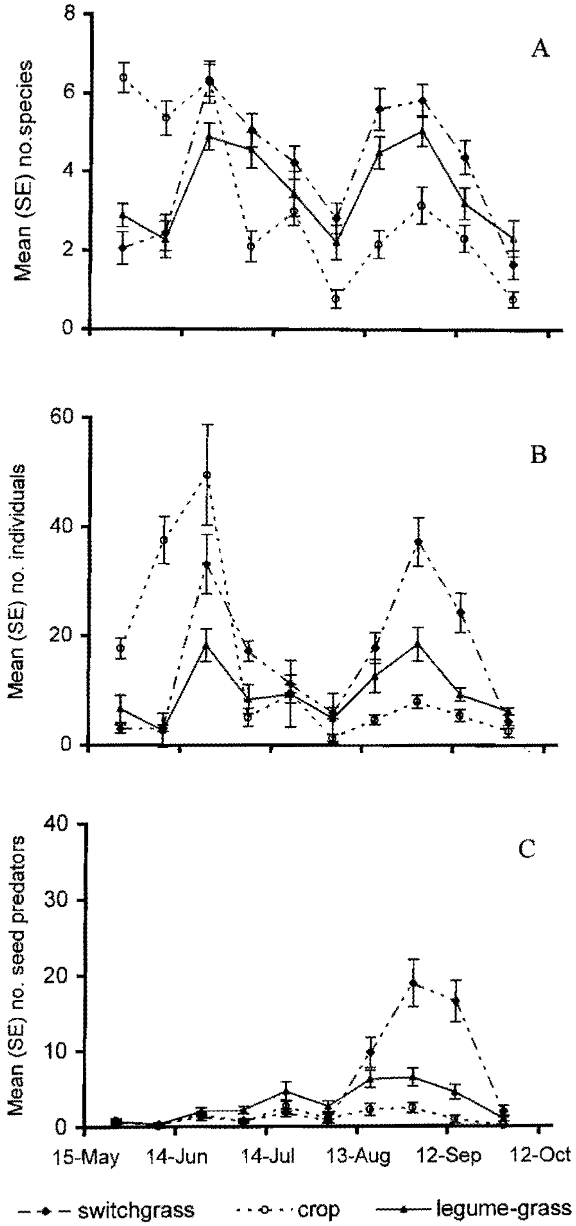

Figure 3. Mean number (± SE) of (A) carabid beetle species, (B) individuals, and (C) seed predators trapped during 1998 in a 9.3–ha corn-field and two adjacent filter strips located in Midland County, Michigan.

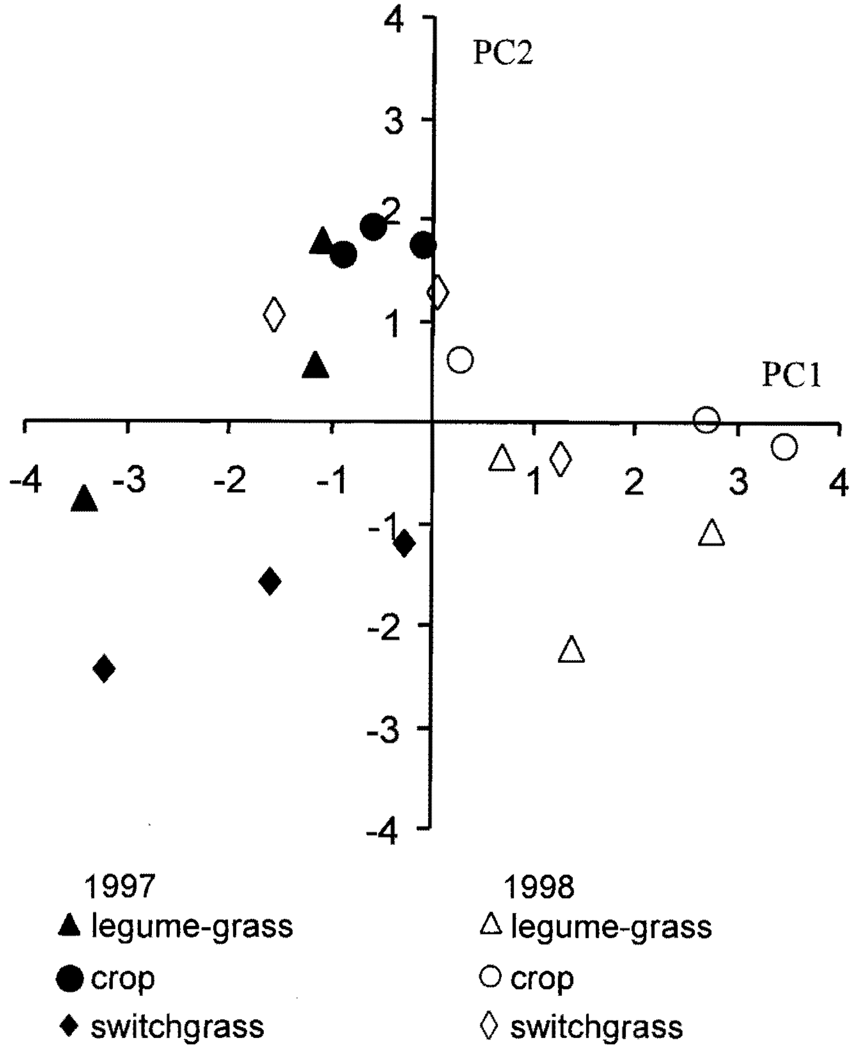

Figure 4. Principal component analysis of sample sites based on carabid beetle captures. Data were collected in 1997 and 1998 in a 9.3–ha crop field and two adjacent filter strips located in Midland County, Michigan.

and 0.48, respectively) with 85.5 and 85.7% of their capture in 1998. The second component (PC2) accounted for 20.9% of the total variation and was associated with habitat differentiation. While the majority of crop replications were located in the positive values of PC2, switchgrass and legume-grass captures were mostly found in its negative values. *Harpalus pensylvanicus* and *H. erraticus*, were negatively correlated with PC2 (Eigenvector = –0.67

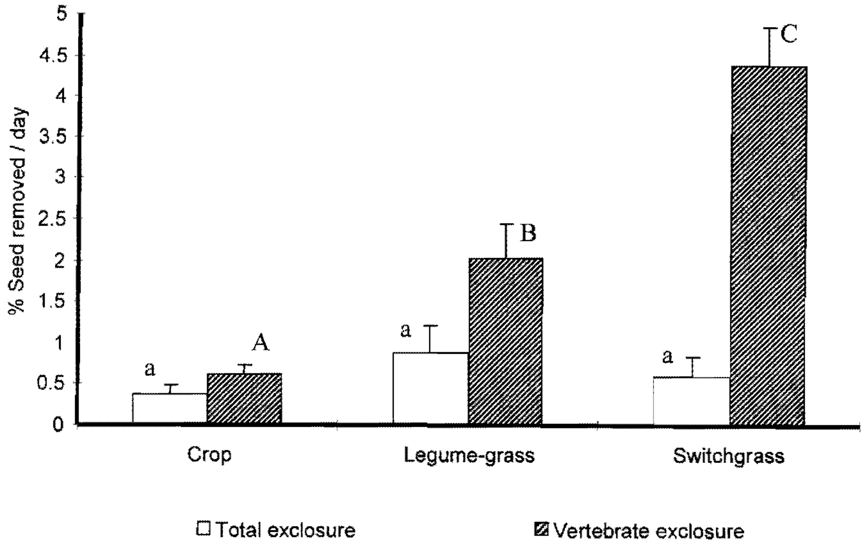

Figure 5. Percentage weed seed removed per day (mean ± SE) per exclosure treatment and habitat type. For each treatment (total exclosure, vertebrate exclosure) columns with the same letter indicate no significant differences between habitats (nested ANOVA, $P < 0.05$). Lower case letters compare seed removal from total exclosures and capital letters compare removal from vertebrate exclosures.

and –0.38, respectively) and were mostly captured in filter strips (Table 1). No clear pattern could be detected for the third component (13.0% contribution to total variation).

Seed predation experiments. The overall number of weed seeds removed from total exclosure cages was significantly lower than the amount removed from vertebrate exclosure cages (Fig. 5) (df = 1, 36, F = 45.74, P = 0.0001). Also, the percentage of weed seeds removed differed among habitats (df = 2, 2, F = 15.60, P = 0.0042). Despite the heterogeneity observed in carabid activity-density and species richness among replications nested within habitats, no significant difference was observed in the number of weed seeds removed among replications (df = 1, 36, F = 0.89, P = 0.5134). A multiple comparison revealed that whereas the number of weed seeds removed from total exclosure cages did not differ among habitats; weed seed removal from vertebrate exclosure cages was highest in the switchgrass strip, intermediate in the legume-grass strip, and lowest in the crop field (Fig. 5). A linear regression analysis showed that percentage of weed seed removal increased as a function of weed seed predator activity-density (Fig. 6).

DISCUSSION

From an ecological point of view, conventionally managed annual crops can be characterized as ephemeral habitats in which pest-natural enemy interactions are restricted by intensive and frequent disturbances such as cul-

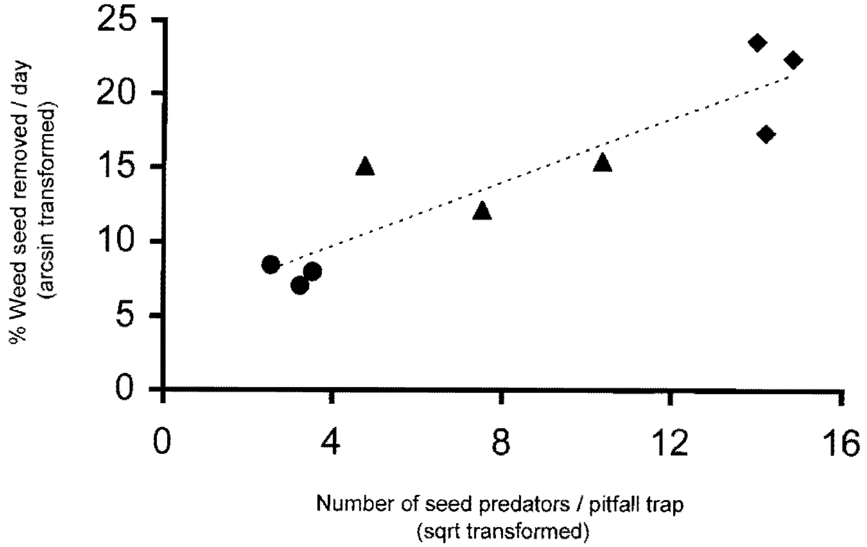

Figure 6. Relationship between percentage of weed seed removed and number of weed seed predators collected in pitfall traps located in the corn-field (●), legume-grass strip (▲), and switchgrass strip (◆) ($y = 1.089x + 5.3488$, $r^2 = 0.8272$, $P < 0.001$).

tivation, crop rotation, pesticide application, and harvest (Wiedenmann and Smith 1997, Landis and Menalled 1998). Because filter strips have not been widely adopted in Michigan, we could not spatially replicate this experiment at additional sites and our conclusions are limited to the role of vegetative buffers at the studied site alone. Despite this limitation, this farm-scale study supports the postulate that conservation biological control through habitat management represents a suitable approach to mitigate the impact of agricultural practices and enhance the survival, fecundity, and longevity of natural enemies (Landis et al. 2000). Future work should explore the extent to which these observations represent generalizations of row-crop systems.

Previous studies documented that refuge habitats are highly used by adult spring breeding carabids during the winter (Desender 1982, Sotherton 1985) and by both autumn and spring breeders during the winter and summer (Lys and Nentwig 1994, Carmona and Landis 1999). Despite these observations and in accordance with previous studies (Quinn et al. 1991, Asteraki 1995), the multivariate ordination analysis revealed that carabid beetle community composition was influenced by year of study and habitat characteristics. While two omnivorous spring breeder species (*H. erraticus*, and *A. sanctaecrucis*) were trapped mostly in filter strips during 1997, two autumn breeder and carnivorous species (*P. melanarius* and *P. permundus*) were captured during 1998 in the corn-field and filter strips. *H. pensylvanicus*, an autumn breeder known to consume large amount of weed seeds, was mostly captured in filter strips in 1997 and 1998.

Understanding the dispersal capabilities of carabids from filter strips into crop fields represents an important step to determine the distance at which strips should be established within the agricultural landscape. Although this study was not designed to specifically test the extent to which the presence of filter strips enhances within-field carabid beetle activity-density, it suggests that any potential influence of filter strips fades by 100 m within the crop field. In accordance, when modeling how the spatial scale would affect the enhancement of natural enemies by a central vegetational strip, Corbett and Plant (1993) determined that strips could augment natural enemies in the field to an extent of 20 to 40 m. Moreover, Zangger et al. (1994) observed that the beneficial effects of herbaceous strips on *Poecilus cupreus* L. abundance decreased significantly at 50 m within a crop field.

Due to the higher number of seed predators found in filter strips, we anticipated a clear difference in seed predation between the crop field and the filter strip habitats. As predicted, weed seed removal from invertebrate exclosure cages located within filter strips was significantly greater than from cages located at the center of the crop field. Since most seed predators are nocturnal, a direct observation of invertebrates responsible for removal of weed seeds is difficult to determine (Lys 1995, Cardina et al. 1996). To overcome this problem, and with some limitations, previous studies used laboratory-feeding trials to assess the potential importance of invertebrates as biological control agents (Clark et al. 1994, Menalled et al. 1999). The significant and positive linear relationship between seed predators activity-density and weed seed removal suggests that carabid beetles have the potential to consume large amount of weeds seeds in row-crop systems. Thus, habitat management approaches aimed to enhance carabid beetle survivorship represents a viable tool in the design of weed management program that integrate a wide variety of tactics aimed to maintain weed abundance below an acceptable threshold level (Liebman and Gallandt 1997). Other beneficial organisms that might have removed weed seeds include crickets, gastropods, millipedes and annelids (Cardina et al. 1996, Carmona et al. 1999).

Although previous studies have documented seed predation in crop fields (Best and Beegle 1977, Lund and Turpin 1977b, Brust and House 1988, Cardina et al. 1996, Cromar et al. 1999, Menalled et al. 2000), the degree to which seed predators might influence weed population dynamics is almost unknown. In a series of greenhouse experiments, Brust (1994) demonstrated that seed predation by invertebrates differentially affects broadleaf weed growth and competitive ability. In field experiments, White et al. (2000) showed that vertebrate and invertebrate weed seed predation reduces velvetleaf (*Abutilon theophrasti* Medicus) and giant foxtail seedling emergence. A simulation analysis of crop rotation effects on weed seed banks determined that winter survivorship in the upper-seed bank (0– to 10–cm) was the most influential parameter on green foxtail (*Setaria viridis* (L.) Beauv.) and velvetleaf population dynamics (Jordan et al. 1995).

In conclusion, our results suggested that the establishment of herbaceous filter strips represents a viable option to increase the abundance and diversity of beneficial organisms within agricultural landscapes. Despite the clear correlation between the abundance of omnivorous carabid beetles and weed seed removal, a long-term study assessing the joint variation in carabid beetle and weed communities is lacking. Hopefully, our results will stimulate future farm-scale research aimed to develop an integrated weed management program that increases beneficial organism abundance, reduce seedbank density, and diminish weed seed germination.

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