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Influence of Refuge Habitats on Seasonal Activity-Density of Ground Beetles (Coleoptera:Carabidae) and Northern Field Cricket Gryllus pensylvanicus Burmeister (Orthoptera: Gryllidae) presented by

Dora Mabel Carmona

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INFLUENCE OF REFUGE HABITATS ON SEASONAL ACTIVITY-DENSITY OF GROUND BEETLES (COLEOPTERA: CARABIDAE) AND NORTHERN FIELD CRICKET *GRYLLUS PENSYLVANICUS* BURMEISTER (ORTHOPTERA: GRYLLIDAE)

By

Dora Mabel Carmona

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ABSTRACT

INFLUENCE OF REFUGE HABITATS ON SEASONAL ACTIVITY-DENSITY OF GROUND BEETLES (COLEOPTERA: CARABIDAE) AND NORTHERN FIELD CRICKET *GRYLLUS PENSYLVANICUS* BURMEISTER (ORTHOPTERA: GRYLLIDAE)

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A field study conducted in 1996 and 97 examined the effect of refuge strips and cover crops on carabid beetle population. Refuge strips consisted of perennial flowering plants in a matrix of orchard grass and clovers. Totals of 5,117 and 2,316 carabid beetles were captured in pitfall traps in 1996 and 1997, respectively. In 1996, plots containing a cover crop had higher carabid abundance than non-cover crop plots. Carabid beetle numbers were 2.5 times greater numbers of carabids occurred in refuge strips than in non-refuge strips areas.

A second study examined the northern field cricket, *Gryllus pensylvanicus* Burmeister (Orthoptera:Gryllidae), a potential weed seed predator in annual crops. In 24 hours, female and male of *G. pensylvanicus* consumed an average of 12 and 8 velvetleaf , *Abutilon theoprasti* Medic, 26 and 9 giant foxtail, *Setaria faberi* Herrm, 87 and 69 crabgrass, *Digitaria Sanguinalis* (L.) Scop and, 223 and 90 red root pigweed, *Amaranthus retroflexus* L., seeds respectively. Test of pitfall trap showed that *G. pensylvanicus* is susceptible to this sampling technique. Individuals appeared from August 5, increased and peaked in mid-September and decreased in October.

Dedicated with love to the memory of my parents,
Luisa and Agapito, whose love and life example laid a path
that enabled me to enjoy each moment lived.

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KEY TO SYMBOLS AND ABBREVIATIONS

ANOVA	Analysis of variance
cm	centimeters
df	degrees of freedom
F	Fisher distribution
h	hours
ha	hectares
kg	kilograms
L.	Linnaeus
(L: D)	Light-Dark
m	meters
mg	miligrams
ml	milliliters
^{o}C	degrees centigrade
t	Gossett- student distribution

CHAPTER 1

Introduction to carabid beetles as natural enemies in agroecosystems

There is a growing awareness that agricultural systems must be developed that provide not only what humanity needs today but can continue to be productive for the foreseeable future (Poincelot 1987). Agricultural sustainability is concerned not only with environmental and ecological issues, but also with economic and social sustainability (Edwards 1990). The environmental and ecological principles of sustainable agricultural systems include use of practices that decrease soil erosion, biologically improve soil fertility, maximize utilization of plant and animal residues, improve cultural practices, maintain ecological diversity, and combine crop and animal production. The economic and sociological principles involve adoption of only those practices that are profitable and provide food and other products to satisfy changing human needs (TAC 1988; FAO 1989; Baier 1990; Edwards et al. 1990). Typically, sustainable agricultural systems are defined as those that rely on lower inputs of energy and chemicals to achieve long term productivity and environmental compatibility (Poincelot 1987). One of the important considerations in sustainable agriculture is pest management.

Integrated pest management is defined as the intelligent selection and use of pest control actions (tactics) that will ensure favorable economic, ecological and sociological consequences (Rabb 1972). Long term pest management systems must be developed because intensified production will tend to encourage pest build-up and reduce the effectiveness of pesticides and host-plant resistance (Brady 1990). Integrated pest management is a comprehensive pest technology that uses combined means to reduce the status of pests to tolerable levels while maintaining a quality environment (Pedigo 1996). Under most circumstances, pest managers will need to employ diverse tactics to achieve economic control of all the pests in a cropping system. Tactics used in integrated pest management programs include plant resistance, biological control, chemical control, cultural control, and biorational control (Metcalf & Luckmann 1994; Pedigo 1996).

Biological control is the direct and purposeful manipulation of the natural enemies, pest competitors, or the resources required by these organisms for the reduction of negative pest effect, or pest species' density to levels at or below their economic thresholds (Barbosa & Braxton 1993). The success of biological control agents in maintaining the "balance of nature" relies on suppressing, rather than eliminating, the pest. Because natural enemies depend on the pest for development, a certain population level is necessary to sustain them. This level may need to be high, low or intermediate. Keeping pest population at an acceptable level may be achieved by combining the actions of natural enemies with other means of control (Landis et al. 1993).

There are three approaches in biological control; introduction of exotic species and their establishment in the new environment, augmentation of established species by direct manipulation of their population and conservation of natural enemies through manipulation of their environment, reducing negative influences or/and increasing positive influences (Debach & Rosen 1991). Biological control has clearly been successful against many pests, and the potential exists for an even greater role in pest management systems.

Natural enemies in agroecosystems. Most, if not all, species of insects are preyed upon, or serve as a host for other life forms. As a group, natural enemies may function as parasites, predators, or pathogens and biological control relies on their planned manipulation to reduce the damaging impact of crop pests.

The most important and successful predators in biological control programs have been insects and mites. A classic example is the cottony cushion scale, *Icerya purchasi* Maskell, a pest of California citrus groves, which was successfully controlled by vedalia beetle, *Rodolia cardinalis* (Mulsant). This predator has kept the scale populations below economic levels for more than 100 years. The control of the two-spotted mite, *Tetranichus urticae* Koch, by the predatory mite, *Phytoseiulus persimilis* Athias-Enriot, has also been economically successful (Pedigo 1996; Van Driesche & Bellows 1996).

While nearly every order has important predator species, the order Coleoptera contains a diversity of predaceous species of significance in biological control. Some particularly important groups of predaceous Coleoptera include, the Cincinelidae (tiger beetles), Coccinelidae (ladybird beetles) and the Carabidae (ground beetles) (Pedigo 1996).

Ground beetles (Coleoptera: Carabidae). Ground beetles are an important component of the arthropod community in agricultural systems and have the potential to reduce populations of both weeds and insects (Lindroth 1969; Thiele 1977; Sergeyeva 1991; Cárcamo & Spence 1994). The larvae and adults of most carabid beetles are reported to be predaceous on other insects. Carabid adults feed on a wide variety of pests including black cutworms, *Agrotis ipsilon* Rottemburg; gypsy moth, *Lymantria dispar* (Linné); cabbage maggot, *Delia radicum* (Linné); true armyworm, *Pseudaletia unipuncta* (Haworth); corn rootworms, *Diabrotica* spp.; crickets, *Gryllus* spp.; and slugs, Limacidae spp. The larvae of most species of carabids feed on soft-bodied soil insects (Rivard 1964, 1966; Lindroth 1969; Kirk 1971; Thiele 1977; Best & Beegle 1977; Dindal 1990). Other species of carabids may be phytophagous (Johnson & Cameron 1969; Lindroth 1969; Kirk 1971, 1972; Best & Beegle 1977; Luff 1980; Barney & Pass 1986). More than 150 species are known to use vegetable matter as food in varying degrees, with some species using it almost exclusively (Johnson & Cameron 1969). Members of such genera as *Amara* and *Harpalus* feed more on fruits, seeds and other vegetable matters than on animal prey (Lindroth 1969).

Habitats and distribution in North America. Ground beetles are one of the most diverse and well represented groups of beetles in North America, with over 2,500 known species. They comprise an important component of invertebrate terrestrial communities and occur in nearly every type of habitat including, forests, orchards, crop fields and natural areas (Lindroth 1969; Thiele 1977). Quantitative studies have examined the distribution of carabids in various habitats, including forest stands in the Great Lakes Region: Kulman (1974) on jack pine, oak and maple and on aspen stands with various soil types histories of defoliation; Ostaff & Freitag (1973) on black spruce and aspen; Freitag et al. (1973) on mixed conifers and deciduous forest; and Liebherr & Mohar (1979) on three upland oak sites in different successional stages. Allen & Thompson

(1977) reported on the carabids of bottomland hardwood, upland oak-hickory and loblolly pine stands in Arkansas, while Bell (1971) described the prairie fauna on the Pawnee Grasslands in northeastern Colorado. Purrington et al. (1989) reported 66 ground beetles species in a remnant oak-maple-beech forest and its surroundings in northeastern Ohio. In Alberta, Canada, Spence & Niemelä (1994) captured twelve species of ground beetles in pitfall traps placed in a natural mixed forest composed of trembling aspen, balsam poplar, briches, white spruce and black spruce. Work (1996) determined the impact of gypsy moth, *L. dispar* L., on abundance and species richness of native arthropods in two hardwood ecosystems in Northern lower Michigan. He reported 47 carabid species in sites dominated by northern red oak, *Quercus rubra* L. and white oak, *Quercus alba* L., and 38 species in sites dominated by northern hardwood, sugar maple, *Acer sacharum* Marsh and american baswood, *Tilia americana* L, over a three year period. Riddick & Mills (1995) reported six species of ground beetles in an apple orchard in California. Ground beetles also form a large component of agroecosystems. Probably every field where crops are grown contains carabid beetles. Ground beetles have been reported in soybean (House & All 1981); alfalfa (Barney & Pass 1986); grass and legume combinations (Snodgrass & Stadelbecher 1989); corn fields (Brust 1990; Laub & Luna 1992; Clark et al. 1993) and small grain (Rivard 1966; Dunn 1982; Weiss et al. 1992).

Ground beetles in Midwestern United States agricultural systems. Carabids communities have been studied in all of the major crops produced in the North Central Region of the US. Kirk (1971a) collected 127 species of carabid adults in crop fields, in east central South Dakota, planted continuously to corn, *Zea mays* L.; or corn in rotation with oats, *Avena sativa* L.; wheat, *Triticum* sp.; soybeans, *Glycine max* (L.) Merr; flax or alfalfa, *Medicago sativa* Medic. In northwestern South Dakota, Quinn et al. (1991) found 23 species of carabids on mixed-grass rangeland. Weiss et al. (1990) recorded 14 species of carabids in annual cropping systems in North Dakota. Lund & Turpin (1977) and Weidenman et al. (1992) reported the population density of the three most abundant species of carabids beetles in Indiana cornfields and in his checklist of adult carabid beetles known from Indiana, Schrock (1985) recorded 465 species. Brust et al. (1985) reported the five most abundant species on corn agroecosystems in Ohio. In Michigan, Dunn (1982) collected 26 species in small grain fields; Perfecto et al. (1986) studied the dynamics of two carabid beetles in a system of tomatoes and beans, and Clark et al. (1997) reported 17 species in a combination of plots with annual, perennial and unmanaged native successional systems.

Food preferences of predaceous ground beetles. Carabid beetles may serve as beneficial agents in two ways, by reducing populations of harmful invertebrates or undesirable plants. Among the common carabid species of the midwest crops, *Pterostichus melanarius* Dejean, *Cyclotrachelus sodalis* (Le Conte), *Poecilus lucublandus* (Say) and *Scarites substriatus* F. prefer to feed on invertebrates including green cloverworm, *Plathypena scabra* (F.); field crickets, *Gryllus* spp.; southern corn rootworm, *Diabrotica undecimpuntata* Howardi-Barber; western corn rootworm, *Diabrotica virgifera virgifera* Le Conte; black cutworm, *Agrotis ipsilon* ; terrestrial isopods, *Porcellio* spp. and slugs, Limacidae spp. (Lindroth 1968, 1969; Thiele 1977; Forsythe 1982; Sergeyeve & Gryuntal 1991).

Kirk (1973) observed *Harpalus pensylvanicus* (De Geer) adults capture larvae of the European corn borer, *Ostrinia nubilalis* (Hübner), and western corn rootworms, *Diabrotica virgifera virgifera*. Hughes et al. (1959) concluded that *Bembidion lampros* Herbst and *Poecilus cupreus* L. feed on the cereal aphid, *Rophalusiphum padi* L.. Best and Beegle (1977) tested the food preference of five species of carabids. Three of these species, *Poecilus chalcites* (Say), *Poecilus lucublandus* and *Scarites substriatus* fed upon both live and dead black cutworm; green cloverworm, and crickets. Johnson & Cameron (1969) reported that *Pterostichus melanarius* preferred animal material to grass or grass seed. Baines et al. (1980) reported that *Pterostichus melanarius*, *Pterostichus lucublandus*, *Bembidion quadrimaculatum oppositum* Say, *Clivina fosor* L. and *Anisodactylus santaecrusis* F. were good consumers of fourth instar and pupae of carrot weevil, *Listronotus oregonensis* (Le Conte). Barney & Pass (1986) reported that in alfalfa ecosystems *Cylotrachelus sodalis* and *Scarites* spp. fed on adult alfalfa weevils, *Hypera postica* Gyllenhal. *Harpalus pensylvanicus* fed on adult alfalfa weevils and foliar lepidopteran larvae, *Colias eurytheme* Boisduval and *Plathypena scabra*. *Amara cupreolata* Putzeys fed on alfalfa weevil larvae. Grafius & Warner (1989) found that *Bembidion quadrimaculatum* fed on eggs and first instar of onion maggot, *Delia antiqua* (Meigen).

Food preferences of phytophagous ground beetles. Hughes et al. (1959) reported the genera *Amara* and *Harpalus* are usually considered phytophagous. In experiments by Briggs (1965) larvae of *Harpalus rufipes* (DeGeer) could consume the endosperm of germinating seeds of *Lolium perenne* and seeds of other plants. Luff (1980) reported adults of the same specie fed on seeds of horticultural crops such us strawberries and *Brassica* spp.. Johnson & Cameron (1969), who surveyed the literature on the food relationships of the carabids, emphasized the phytophagous habits of many ground beetles. They carried out feeding experiments that included both animal and vegetable material. They reported that the genera *Amara, Anisodactylus*, *Agonoderus* and *Harpalus* preferred plant material to animal matter in the laboratory.

Field and laboratory studies have examined the food preferences of some phytophagous ground beetles. Kirk (1973) showed evidence that *Harpalus pensylvanicus* adults were common in South Dakota corn fields where the soil was sandy and there were patches of foxtail, *Setaria* spp.. Populations of 18 to 32 beetle adults per m^2 were common in areas of fields where foxtail was abundant. Larval burrows were also common where foxtail was most abundant indicating selective oviposition in these areas. In addition, he reported seed caching by larvae. Other studies indicate that *Harpalus pensylvanicus* is a facultative phytophage readily feeding on certain weeds when available and may function as a selective biological control agent. Seeds of giant foxtail, *Setaria faberi* Herrm; green foxtail, *Setaria viridis* (L.) Beauv; common chickweed, *Stellaria media* (L.) Cyrillo; lambsquarter, *Chenopodium album* L. and redroot pigweed, *Amaranthus retroflexus* L. were fed and damaged by *Harpalus pensylvanicus* (Lund and Turpin 1977). In food preference tests Best & Beegle (1977) found that *Harpalus pensylvanicus* and *Cylotrachelus sodalis* fed on barnyardgrass, *Echinocloa crus-galli* (L.) Beauv, and yellow foxtail seeds, *Setaria lutescens* (Weigel) Hubb. Hagley et al. (1982) reported that *Amara aenea* De G. and *Stenolophus comma* F. showed strong preference for chickweed, *Stelaria media* (L.) and dandelion, *Taraxacum officinale* Weber, seeds. *Harpalus affinis* and *Anisodactylus santaecrusis* fed on crabgrass, *Digitaria spp*. and foxtail grass, *Setaria spp.*

Barney & Pass (1986) reported that in alfalfa ecosystems *Harpalus pensylvanicus* fed on crabgrass, *Digitaria* spp., seeds and *Amara cuproelata* fed on weed seed such as common chickweed, *Stellaria media*. Brust & House (1988) determined weed seed destruction by arthropods and rodents in low- input soybean agroecosystems. Carabid beetles were responsible for more than half of all seeds consumed. Laboratory studies showed that *Harpalus pensylvanicus* consumed ragweed seeds, *Ambrosia* spp. *Harpalus caliginosus* F. preferred sicklepod and wheat seeds as compared with pigweed seeds. Cardina et al. (1996) reported that *Amara cupreolata* and *Amara subfuscus* damaged imbibed seeds of velvetleaf, *Abutilon theophrasti* Medicus.

Life history tactics. Ground beetles are generally univoltine in as much as only one of the series of generations reproduces each year. They overwinter either as larvae or as adults, typically in the soil or beneath plant material. Reproduction can take place at quite different times of the year according to the climate and weather conditions (Lindroth 1969; Thiele 1977; Den Boer & Den Boer-Daanje 1990). Thiele (1977) distinguished 5 different types of annual rhythms in carabid beetles: 1) species which have summer larvae and hibernate as adults; 2) species which have winter larvae and reproduce from summer to autumn but exhibit no adult dormancy; 3) species with winter larvae, the adults of which emerge in spring and undergo aestivation dormancy prior to reproduction; 4) species with flexible reproductive periods, in which spring and autumn reproduction can occur side by side in one and the same population and, what is more important, the larvae, in contrast to those mentioned before, can develop equally well under summer or winter conditions. Reproduction can take place at very different times of the year according to climate and weather, and 5) species that require more than one year to develop.

One common pattern is that in the fall, adult beetles accumulate a reserve of fat and burrow into the soil to overwinter. These overwintered adults emerge from the soil and are active in early spring, eating, mating and laying eggs before dying in the late spring or early summer. These species are called "spring breeders." A second common pattern occurs in species where larvae develop through the summer feeding on prey in the soil and emerge as adults in late summer or early fall. These "autumn breeders" mate and lay eggs in the fall. The subsequent larvae overwinter in the soil. The larvae complete development in the spring and emerge as adults in the late spring or early summer.

Biology of common species. During a 9-year period of study Kirk (1971a-b, 1973, 1975a-b), determined the community composition of carabid beetles in South Dakota cropland and described the biology of the most common species.

Poecilus lucublandus has a trans-american distribution and is commonly found in cultivated fields with high moisture. It overwinters as an adult in the soil or beneath surface trash and is most active from May to early July. There was only one generation a year, but the generations overlapped during the summer. Oviposition occurred from May to early September, and one female produced as many as 462 eggs. Young adults were active in fields from August to early October. The mean time for development in the laboratory was 76 days from eggs to adult (Kirk 1971b).

Poecilus chalcites had only one generation per year but adults were found in South Dakota at any time of the year. The beetles overwintered 5-15 cm beneath the soil surface and emerged as early as mid-April if the soil thawed. After the thaw, they are sometimes found beneath surface trash or clods. In the spring, they were easy to find in fall-plowed cornfields. The overwintered beetles were increasingly active from May until about mid-July, activity then decreased until mid-August when there was another period of increased activity through September that included new generation adults. Oviposition occurred from late May until about mid-August. Overwintered females placed their eggs in earthen cells, 1-4 eggs per cell, from 2 to 15 cm beneath the soil surface, either along the sides of cracks and crevices, or to one side of their burrows as they moved through the loose soil. After eclosion the larvae apparently lived in the existing space between soil aggregates or made temporary burrows by pushing their way between loose soil particles. Pupation occurred in earthen cells 2-15 cm deep. Teneral adults became fully colored within one day of eclosion, but the cuticle remained soft for approximately one week during which some of the beetles became active on the soil surface and even flew at night. Laboratory rearing data showed that on average, females produced 351 eggs. The mean egg incubation period lasted 6.8 days, the 1st instar was 9.0, the 2nd instar was 10.4 and the 3rd instar 14.1, the prepupal period was 2.4, and the pupal stage was 7.8 days. Thus, the mean total developmental period was 50.5 days. These data were in close agreement with data obtained in the field (Kirk 1975b).

Harpalus pensylvanicus was the second most common carabid in South Dakota croplands (Kirk 1973). Individuals of *Harpalus pensylvanicus* preferred land that received some cultivation. A few adults were found under stones and logs along streams or in grassy ravines and in pastures or other sod areas, but the numbers were never as great as on land under cultivation. This is the preferred habitat for both larvae and adults, even though a degree of injury and mortality occurs during normal cultural practices (plowing, disking, and cultivating). *Harpalus pensylvanicus* overwintered in soil as 1st to 3rd stage larvae and many adults survived through the second winter (in soil) and were able to oviposit again the following autumn. Adult *Harpalus pensylvanicus* were active in fields during August and September. Males and females accumulated a supply of fat and burrowed several centimeters into the soil to hibernate. Overwintered adults began to emerge from the soil surface about the 1st week in June and were encountered in increasing numbers until after July 12. After that, the new generation of adults from overwintered larvae were also active. Above-ground activity increased greatly and peaked about September 1, then declined steadily. Mating was usually observed in late summer and autumn, generally at night. Oviposition occurred from early August to early October. Overwintered females began oviposition about August 1, a month after the first dispersal flights. Females of the new generation began to oviposit about September 1. Generally the eggs were placed singly 5-15 cm beneath the surface. Also, burrows of *Harpalus erraticus* were used for oviposition by females of *Harpalus pensylvanicus*. In laboratory observations, one group of 13 overwintered females laid a mean of 17.5 eggs/female during a 30-day period. After hatching, the 1st instar larvae constructed a burrow on

September 23. These 1st little burrow were approximately 2 cm diameter, and the 1st instar were about 2 cm the soil surface. By October all 3rd instar were present, and most of the burrows were 15-30 cm deep. Pupa were found in the field as early as June 3 but most larvae pupated in July or early August. A few teneral adults were observed in early July, but they were most abundant from mid-July to mid August. There is only one generation a year, but the generations overlapped during the summer.

Seasonal activity-density. Pitfall trapping has been used extensively in many studies on carabid beetles and other soil surface predators. Although it is generally concluded that the catches provide only data on the degree of activity rather than the actual population density, the result obtained in short-term pitfall trap field studies were often described in terms of abundance (Greenslade 1964, Thiele 1977; Spence & Niemelä 1994). Baars (1979) found that pitfall trap catches gave reliable estimates of the population density of some species only if sampling was done over the whole season. As year-catches are influenced by both abundance and activity, Heydemann (1953), introduced the concept of "activity-density." This term has been generally adopted since the parameters they represent provide a good estimate of the role of a species in an ecosystem, which depends not only on abundance but also mobility.

Kirk (1973) determined the seasonal-activity density of the most abundant species in cropland in South Dakota. The spring breeders species, *Poecilus chalcites*, *Poecilus lucublandus*, *Anisodactylus santaecrusis* and *Stenolophus comma* were found in the field all months of the year, but maximum activity on the soil surface occurred during June and early July and activity was minimal during August and September. By late October and early November , all above-ground activity had ceased. The fall breeder *Harpalus pensylvanicus* was active above-ground in early June, activity increased greatly early in September, then declined steadily and few beetles were caught in pitfall traps during October. Lund 1975 found similar patterns in the activity-density of these species in an Indiana cornfield. In addition, she determined the seasonal activity-density of three more species. The spring breeder *Agonum placidum* was active from mid-May until mid-November, with peak activity observed in mid-August. The fall breeders *Harpalus compar* and *Cylotrachelus sodalis* were active from early June with major peak activity in late August. House & All (1981) in Georgia found *Harpalus pensylvanicus*, *Pterostichus melanarius* and *Scarites substriatus* among the most abundant species of the ground beetle community. Adults of these species made up large proportions of samples in June and early July, and then again in September.

Wiedenmann et al. (1992) established the seasonal activity-density for the three most abundant species, in Indiana. *Poecilus chalcites* dominated the ground beetle community through early August, *Harpalus pensylvanicus* occurred later in the summer, and *Scarites subterraneus* was found primarily in June and September.

Effect of agricultural practices on the population dynamics of ground beetles. In agricultural systems, crop management may influence number and species diversity of ground beetles. House & All (1981), investigated seasonal activity-density and habitat preference of 34 species of carabid beetles in soybean under conventional and conservation tillage systems, in the Piedmont area of the southeastern United States.

Ground beetle density varied in different cropping systems. In general, density increased with conservation-tillage practices. Weiss et al. (1990) determined the influence of tillage management and cropping systems on ground beetles in spring wheat in North Dakota. Treatment combinations included no-tillage, reduced tillage and conventional tillage, combined with continuous cropping, annual cropping, and annual fallow. Generally, lower numbers of individuals of a given species were found in cropping systems associated with conventional tillage. However, the cropping system may have altered communities to a higher degree than the tillage regime. In Virginia, Clark et al. (1993) evaluated habitat preferences of generalist predators comparing their abundance among four reduced-tillage corn systems which differed in the degree of soil disturbance, quantity and structure of the surface mulch due to tillage, and cover crop management practices. The trends observed in overall generalist predator abundance, including ground beetles, showed that predator number increased as a result of the quantity and structure of surface mulch in reduced-tillage corn agroecosystems. In Michigan, Clark et al. (1997) studied the association of common ground beetles and habitat and management characteristics in four annual cropping systems; two perennial crop systems and a native succession habitat. Two of the ground beetle species studied were more abundant in the annual cropping system while two other species were more common in the perennial cropping system. These trends showed that carabid species may respond differentially to habitat management. In Ontario, Canada, Rivard (1966) conducted a three-year study, on the seasonal occurrence of ground beetles in five fields with different crop rotations. A progressive augmentation in beetle activity and population density appeared to coincide with an increase in the humidity of the habitat. Numbers were greatest in pasture grass, followed by forage crop, and then field crops. This indicated that crop type and architecture might influence beetle number. Perfecto et al. (1986) determined the emigration rates of *Cylotrachelus sodalis* and *Harpalus pensylvanicus* in fenced tomato monocultures and in polycultures of tomato and beans, grown at two densities, in southern Michigan. Results showed that the emigration rates were lower in polycultures than in tomato monocultures for both species of carabids, suggesting that the emigration rate may be lower in more diverse agricultural habitats. Other studies have failed to show an effect of cropping systems on carabid beetles. Snodgrass & Stadelbacher (1989) studied the effect of different grass and legume combination on ground beetles in Mississippi. Two species of grasses with six species of clovers were established in plots along a roadside. Each of the grasses was sown without added nitrogen in a mix with one of each of the six species of legumes. There was no difference in the number of ground beetles captured or dominance and species diversity in the various treatments. Cárcamo et al. (1995) determined the effect of agricultural practices on ground beetles. The abundance and species richness of carabids was greater in plots operated under an organic farming regime than in those under a chemical regime, but neither crop type (barley, *Hordeum vulgare* L., faba bean, *Vicia faba* L., barley-pea, *Pisum sativum* L.), intercrop, nor crop rotation had an effect. Reduced tillage did not significantly change overall carabid activity or species richness but species differed in their response to tillage treatments. They reported that effects of agronomic practices on carabid beetles assemblages were complex, reflecting the interaction of biological traits of particular species and the combination of agronomic treatments applied.

Ground beetles are also sensitive to pesticides and their numbers are considerably reduced in intensively cultivated areas and where pesticides are frequently applied (Basedow 1990). Insecticide and herbicide applications may reduce beetle abundance. Brust et al. (1985) determined the joint effect of tillage and soil insecticides on ground beetles and cutworm interaction in Ohio corn agroecosystems. Treatments where soil insecticide was applied with conventional tillage contained significantly more cutworm. *Agrotis ipsilon* (Hufnagel) damaged corn plants and there were fewer predators in areas with insecticides and conventional tillage than areas that were not tilled and had soil insecticide. Quinn et al. (1991) determined the effect of habitat characteristics and perturbation from insecticides on the community structure and dynamics of ground beetles. They concluded that both spatial and temporal changes in the species composition of ground beetles were affected by insecticide treatments and were reduced significantly in the insecticide spray plot.

Brust (1990) tested four herbicides, atrazine, simazine, paraquat and glyphosate for their acute and chronic toxicity as well as repellent effects on five common carabid beetles (*Amara* sp.; *Pterostichus* sp.; *Anisodactylus* sp. and *Harpalus* sp.) in laboratory and green house experiments. He concluded that the four herbicides did not have significant acute or chronic effect on carabid longevity or food consumption during one year after exposure to initial field-rate applications. Laub & Luna (1992) evaluated the effect of spraying the herbicide paraquat, versus mowing the cover crop and they concluded that mowing the cover crop provided a more favorable habitat for predators than cover crop suppression by herbicides.

Conservation of ground beetles. The increase of crop monocultures at the expense of plant diversity has seriously affected abundance, diversity and efficiency of predator ground beetles, which are closely linked to local habitat and plant diversity (Lys et al. 1993). Ground beetles spend most of their life cycle in the cropped field and the cropping system and farm management have a significant impact on their abundance (Booij & Nijs 1992). The use of farming practices that conserve these natural enemies may be one of the most practical alternatives to insecticides to manage pests in sustainable agricultural systems (Cárcamo & Spence 1994; Pedigo, 1996). Agricultural practices may be manipulated to increase the potential of ground beetles as biological control agents. Organic and low-input production systems are associated with greater ground beetle abundance compared with conventional production systems (Dritschillo & Ervin 1982; Kromp 1989; Booij & Norlander 1992). Systems that reduce or eliminate synthetic fertilizer and pesticides and use crop rotation, cover crops, manures, no-tillage and reduced tillage tend to promote greater overall ground beetles abundance (Brust & House 1988; Mainley 1996; Clark 1997). The agricultural landscape can be considered as a mosaic of patches with variable habitat quality for carabid beetles in terms of average reproduction and survival (Booij & Nijs 1992). Ground beetles need more than just suitable host or prey to survive; they often benefit from, or even require, additional food sources, moisture or shelter. The preservation of structures, such as hedges and fields boundaries that provide overwintering sites and food sources for ground beetles may maintain and increase their number. Reductions in field size and an increase in overwintering and refuge sites can be achieved by the introduction of uncropped strips within crop fields (Lys & Netwing 1992; Lys et al. 1994; Zangger et al. 1994). Many studies have investigated the effect of refuge strips on the density and diversity of carabid beetles (Lyz & Nentwig 1992; 1994; Harwood et al. 1994; Lyz et al. 1994; Zangger et al. 1994, Nentwig 1995; Frank 1996). By the introduction of successional strips into large fields, local habitat and vegetation diversity is increased, which leads to higher activity-density and number of species of ground beetles (Lys 1994). There appeared to be a change in carabid community structure through time. Although year to year fluctuations in carabid population can be considerable (den Boer 1986), it is likely that such changes are the result of successional changes from colonization of new habitat rather than just stochastic variation in population structure (Thomas 1990). Many plants provide these resources and may maintain ground beetles in the field (Lys et al. 1994). Thomas et al. 1991, reported that in grass-sown raised earth banks in the center of two fields, the number of Carabidae and other natural enemies increased from the first to the second year of establishment. Lys (1994) observed a remarkable increase in ground beetle activity-density and species diversity over three years of study in a cereal field with five introduced strips of flowering herbs and weed species. He also found a significantly larger number of overwintering ground beetles in the strips than in the cereal areas. Zangger et. al. (1994) determined the accessibility of food and reproduction of *Poecilus cupreus* L. in a winter rye field and in a weed strip during the main reproduction period. She found five times higher activity-density in the weed strips than in the rye field and an increase in the number of eggs produced by *P. cupreus*. She also observed a prolongation of the reproduction period in the refuge strip.

Agricultural areas managed using low inputs, reduced tillage, cover crops and such undisturbed places and adjacent habitats with less disturbance often show higher diversity and abundance of carabid beetles and other predators than areas without these management practices and structures (Welling 1990; Hance et al. 1990).

Given the importance of ground beetles as natural enemies in agroecosystems, a field experiment to study their conservation was conducted. Two years of pitfall trap sampling were completed to determine the seasonal activity-density of carabid beetles in field plots with and without refuge habitats and cover crops. Species richness and relative abundance of the most common species was determined and associated with the different habitat treatments. Seasonal-activity of each species was analyzed and related to their breeding type and feeding behavior.

CHAPTER 2

Influence of refuge habitats and cover crops on seasonal activity-density of ground beetles (Coleoptera: Carabidae) in field crops

Invertebrate species diversity and population density in agroecosystems are related to the type of farmland or other surrounding vegetation (Asteraki 1995). In many instances agricultural landscapes today are characterized by intensive management, which can result in a series of side effects (Netwig 1995). Frequent disturbances such as repeated cultivation, pesticide applications and other management practices are known to be deleterious to natural enemies (Luff and Rushton 1988). Species with long generation times are especially affected, as they are unable to recover quickly after disturbance. Among them are predatory polyphagous arthropods, an important group with respect to prey density regulation and reduction of pest populations (Chiverton, 1986). The colonization of crop fields by predators dispersing from natural and seminatural patches, may be a way to enhance their density on farmland (Kajak & Lukasiewicz 1994).

Ground beetles belong to one of the most important groups of beneficial arthropods in agroecosystems (Lindroth 1969, Thiele 1970). Since these predators are known to be very susceptible to pesticides (Dritschilo & Erwin; Brust et al. 1985; Booij & Noorlander 1988; Brust 1990; Basedou 1990; Quin et al. 1991; Laub & Luna 1992; Reed et al. 1992) and some farming operations (House & Hall 1981; Weiss et al. 1990; Booij & den Nijs 1992; Clark et al. 1993; Cárcamo & Spence 1994; Cárcamo et al. 1995; Pfiffner & Niggli

1996) research promoting their conservation is a logical consequence. The abundance and diversity of ground beetles within fields is closely related to the availability of undisturbed places such as uncultivated field edges (Desender 1982; Sotherston 1985). The importance of field boundaries in providing overwintering sites for many polyphagous arthropods has been well documented (Desender 1982 ; Sotherston 1984, 1985; Kromp & Steinberg 1992; Asteraki et al. 1995). In arable croplands it is known that the undisturbed land surrounding arable fields acts as a reservoir from which ground beetles, spiders and other invertebrates can reinvade the crop (Sotherston 1984, 1985). The lack of such reservoirs may reduce the abundance and rapid spring colonization of these invertebrates, especially the non-flying arthropods, and thus limit the potential value of these insects in reducing pest numbers. High densities of polyphagous predators are especially important in spring, because they are most effective in controlling agricultural pests before the period of rapid population increase (Lys & Nentwig 1994).

Plant diversification in agroecosystems leads generally to a higher animal diversity and can increase natural enemies of pest organisms (Altieri 1982). The introduction of strips of wild flowering herbs into cereal fields has been shown to increase species diversity and activity-density of carabid beetles (Frank 1994; Lys 1994; Lys & Nentwig 1994; Hausammann 1996; Zangger 1994). According to Lys (1994), the abundance of overwintering carabid beetles was found to be significantly higher in the strips than in the cereal crops planted in between the strips. Adults of 14 overwintering species were found within the strips but only two species were found in the cereals. The results of this study showed that the strips offered suitable overwintering sites, providing shelter and a food source for high densities and diversity of carabid beetle species. In their studies using mark-recapture techniques, Lys & Nentwig (1992) found that strip-managed areas were highly attractive as demonstrated by the movements of marked carabid species and/or by their higher activity densities in the strip area of the field. This was thought to be a result of the greater food abundance and structural diversity in strip vegetation. Fluctuations in the number of insects are mainly determined by fluctuations in their carrying capacity (Dempster & Pollard 1981). Food is assumed to be the most important limiting factor for the abundance of carabid beetles especially in respect to the reproduction rate and the survival of larvae (White 1978; Brusting et al. 1986). According to Den Boer (1977, 1981) the strips can also function as refuge, promoting survival and decreasing the risk of extinction.

Suitable environments for carabid beetles may also be provided by other agricultural practices, such as cover crop management. Various cover-crops which are known to influence arthropod diversity and population density may have potential for use in pest management programs (Manley 1966). Cover crops may play an important role by providing mechanisms to favor increased biotic potential for natural enemies of pest species. Carabid beetles respond positively to cover crop management (Manley 1996). Laub & Luna (1992) stated that the type of cover-crop system appeared to influence activity and number of carabids. An increase in carabid activity was associated with increasing humidity in cover crop. Cover crops, plant residues and lack of disturbances in no-tillage systems were cited as contributing to an increase in carabid densities (Brust et al. 1985).

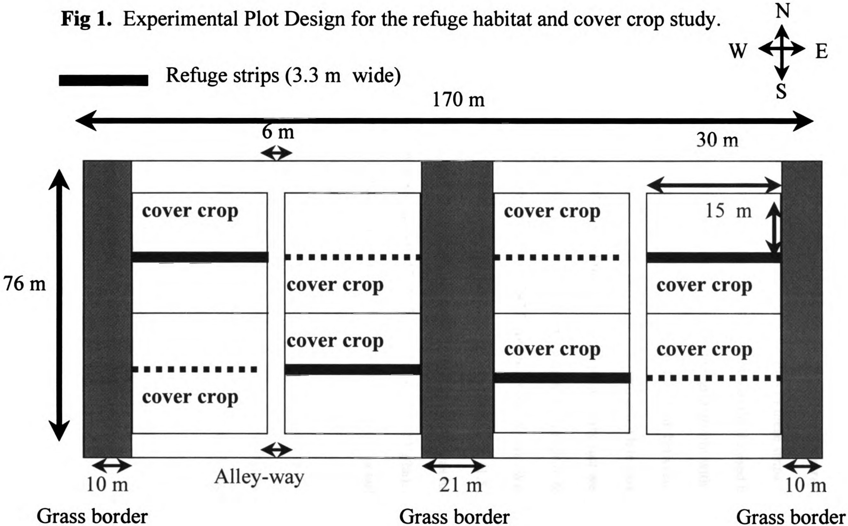
Because of the importance of conservation of carabid beetles in agroecosystems, the following study was performed to assess the activity-density and species diversity of these beneficial insects in habitats with and without the presence of refuge strips and cover crops.

Materials and Methods

Study Site. This study was conducted from May to October, 1996 and 1997 at the Michigan State University Entomology Farm, East Lansing, Michigan. The field was established in autumn of 1994 and arranged in a split-plot design, with four replications. The main plot (66 m x 30 m) was presence or absence of a refuge strip (ca. 3.3 m wide) and the sub-plots were (30 m x 15 m) presence or absence of a cover crop (Fig. 1). Cover crop sub-plots were managed to maximize ground cover throughout the year using agronomic methods shown viable under Michigan conditions. Each main plot was bordered by a 15-m wide grassy headland that was mowed in the late summer each year.

Refuge strips areas were prepared by creating a raised ridge in the center of the strips. The soil was then partial leveled with a field cultivater to produce a slightly raised (approximately 10 cm) central area which gradually tapered to the field level. In the last week of August of 1994 wheat (*Triticum aestivum* L.) was seeded (33 kg/ha) as a cover crop into the cover crop subplots and oats (*Avena sativa* L.) was seeded (74 kg/ha) in conventional tillage plots. The oats naturally winter-killed, and the wheat was killed the first week of May, 1995 with glyphosate at 1.4 L/ha (1.5 qt/A). Two weeks later, three species of perennial flowering plants, *Agastache foeniculun* (Pursh) O. Kuntze *Origanum*

Fig 1. Experimental Plot Design for the refuge habitat and cover crop study.



vulgare L., *Scropularia nodosa* L., were transplanted into the raised bed of the strips. A mixture of orchardgrass, *Dactylis glomerata* L., and clovers, white *Trifolium repens* L. and sweet *Melilotus officinalis* L., was then seeded on the flanks of these strips. A total of 400 plants of the three species were transplanted in the center of the 4 raised beds (100 plants in each one). The three plant species were arranged in a grid pattern with alternative groups of six plants/species placed 24 cm apart and 0.33 cm between plants. A mixture of orchardgrass (6.71 kg/ha), sweet clover (6.71 kg/ha) and white clovers (1.67 kg/ha) was seeded in each side of the central flowering plant strip. In the last week of May non-cover crop sub-plots were field cultivated (conventional tillage) prior to drilling soybean, *Glycine max* L. Merr., into main plots (190,00 pl./ha, 76 cm rows). Weeds were controlled using a preemergence herbicide application of linuron 1.68 kg/ha (1.5 lb/A) and by cultivation of conventional plots in the last week of July. Soybean was harvested at the end of October. Wheat was fertilized (126 kg/ha Urea 46-0-0, 202 kg/ha), and seeded (157 kg/ha); Monoammonium phosphate 10-50-0; and 224 kg/ha of potash 0-0-60) following soybean harvest in all plots.

In March of 1996 cover crop plots were fertilized (N 46-0-0 74 kg/ha) and frost seeded with red clover, *Trifolium pratens* L., (14 kg/ha). Due to excessive winterkill, the wheat was replaced with oats (460 kg/ha) seeded with a no-till planter. Weeds were controlled with two applications of MCPA 4.3 L/ha (3/8 pt/A) in the first week of June. In October of 1996 the field was treated with glyphosate at 5.4 L/ha (2 qt/A), 2,4-D ester 2.24 L/ha (1 qt/A), plus non-ionic surfactant 2.20 L/400 L (2 qt/100gal.) plus Ammonium sulfate 7.70 kg/400 l (17 lb/10 gal.) to kill the clover cover crop and weeds.

Corn was planted (60,000 pl/ha) and fertilized (N 140 kg, P205 54 kg/ ha and K 20kg/ha) in the second week of May of 1997 and was harvested in October. Weeds were controlled with a preemergence application of atrazine 2 L/ha (0.75 qt/A), plus cyanazion 90 DF 1.90 kg/ha (1.7 lb/A) plus alachlor 6.80 L/ha (2.5 qt/A) and two post-emergence (Round up Ultra 2.42 L/ha (1 qt/A) and Ammonium sulfate 7.70 kg/400 L (17 lb/100 gal)) herbicides.

Sampling Method. Sampling was carried out using a total of 120 pitfall traps distributed in the experimental field. Six pitfall traps were placed in each of the treatment subplots, in two rows of three traps each (approximately 9 m between rows and 12 m between traps), leaving a buffer area of about 3 m between traps and the edges. Three pitfall traps were placed in each refuge strip and in the analogous location in plots without refuge strips. In these plots the traps were placed at the interface between cover and no cover crop subplots (Fig 2). In addition, forty-eight pitfall traps were placed in the grassy area around the plot in groups of 12 traps bordering each plot.

Pitfall traps were 12-cm diameter by 16 cm high plastic cups, set into the ground so that the rim was 2 cm below the soil surface. To monitor activity-density of carabids the traps were checked for 5 consecutive days in each month from May 22 to October 29, 1996 and from May 8 to October 20, 1997. In 1997, two samples were taken in May, one prior to and the other following herbicide application. Because pitfall traps were monitored each day and to avoid depletion of the carabid beetles, the pitfall traps were dry empty cups and no killing agent was used. After beetles were counted and identified they were

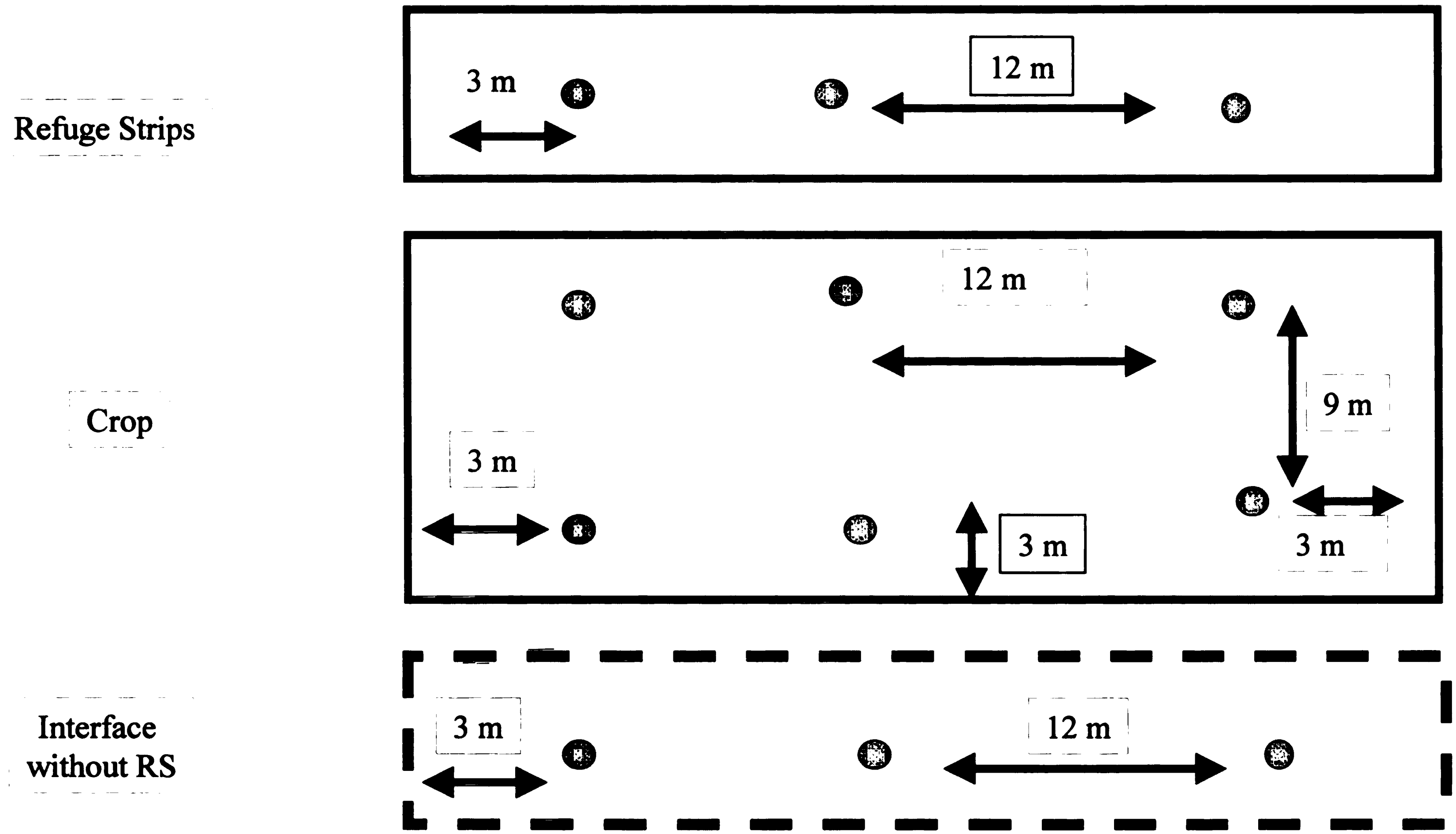


Figure 2. Pitfall trap distribution in the Refuge habitats and cover crop study.

released in the same plot, close to their capture location. Traps were covered with lids between sampling periods. The known species were identified in the field and unknown species were taken to the laboratory and identified using Lindroth's key (1969). All the specimens were verified by Dr. Foster Purrington in the Entomology Department, Ohio State University. The reference collection was deposited in the Insect Ecology and Biological Control Laboratory, Department of Entomology, Michigan State University.

Data analysis. Seasonal activity-density of the carabid community was graphically examined as total number of beetles captured per month, while seasonal-activity per treatment and per species was examined as the average number of beetles captured per trap in each five day sampling period. Activity-density of carabids in treatment subplots, over the entire season and by month, were analyzed using analysis of variance (ANOVA) for split-plot design, following square root (x + 0.5) transformation (Statistical Analysis System Institute, 1996). Statistical differences between the mean number of beetles captured in refuge strips and the non-refuge strip interface were determined by performing a *t-test* (Sokal & Rohlf 1995) on a square root (x + 0.5) transformed data using using proc TTEST, Statistical Analysis System (SAS Institute, 1996). Similarity between habitat treatments and the most common carabid species were examined using cluster analysis (Ludwig & Reynolds 1988). Only those species accounting for more than 5% of the total specimens collected were used in this analysis. The tree algorithms created were based on the Average Linkage Clustering (SAS Institute, 1996). The resulting habitat dendograms for each year were compared visually by examining similarities and differences in the branching patterns produced according to community composition of beetles. In the same way, the resulting species cluster for each year were compared visually by examining similarities and differences in the branching pattern, produced according to the occurrence of different species in different habitats. Habitat and species clusters were combined graphically and related with the proportion of carabid species recorded to determine which species were present in the different habitats (Nimis et al. 1989, 1994; Menalled & Adamoli 1995). Homogeneity within the clusters, was verified by performing a *Chi*-square test (Sokal & Rohlf 1995, SAS Institute, 1996).

Results

Species richness and relative abundance. Totals of 5,117 carabid beetles in 1996 and 2,114 specimens in 1997 were captured in pitfall traps, comprising 14 and 20, species respectively. There was a higher number of spring breeding than autumn breeding species captured in both years (Tables 1 & 2). The four most abundant species were *Pterostichus melanarius, Poecilus lucublandus*, *Poecilus chalcites* and *Pterostichus permundus*. These four species made up 74% of the total capture in 1996 and 66% in 1997. In addition, only six species in 1996 and five in 1997 accounted for more than 5% of the total capture. The remaining 5% in each year were made up by relatively uncommon species, in some cases represented by only few specimens (Tables 1 & 2). Most of the species captured prefer animal prey to vegetable material. However, four species, *Harpalus pensylvanicus*, *Harpalus herbivagous*, *Anisodactylus santaecrusis* and *Amara aenea* prefer vegetable material and made up 15% in 1996 and 8% in 1997 of the total number of beetles (Tables 1 & 2).

Table 1. Carabid beetles captured in pitfall traps in a field including plots with and without refuge strips and, with and without a cover crop. May-October 1996. Michigan State University, Entomology Farm, East Lansing, MI.

Species	Number of beetles	%	Reproductive type	Food Preferences
Pterostichus melanarius (Illiger)	1702	33	A	*
Poecilus lucublandus (Say)	1047	20	S	*
Poecilus chalcites (Say)	629	12	S	*
Pterostichus permundus (Say)	468	10	A	*
Harpalus pensylvanicus(De Geer)	388	8	A	**
Harpalus herbivagus Say	275	6	S	**
Agonum cupripenne (Say)	244	<5	S	*
Cyclotrachelus sodalis (Le Conte)	111	2	A	*
Amara aenea (De Geer)	86	<2	S	**

Anisodactylus sanctaecrucis (Fabricius)	81	<2	S	**
Scarites quadriceps Chaudoir	67	<2	S	*
Chlaenius impunctifrons Say	50	<1	A	*
Chlaenius tricolor Dejean	16	<1	A	*
Agonum placidum (Say)	13	<1	S	*
Total = 5,117				
Number of species (S) = 14				

S, Spring breeding species; A, Autumn breeding species

* Mainly carnivorous, feed on other insects and slugs

** Mainly phytophagous, weed seed predators

Table 2. Carabid beetles captured in pitfall traps in a field including plots with and without refuge strips and, with and without a cover crop. Michigan State University, Entomology Farm, East Lansing, MI. May-October 1997

Species	Number of beetles	%	Reproductive type	Food preferences
Pterostichus melanarius (Ill)	529	23	A	*
Pterostichus permundus (Say)	505	22	A	*
Poecilus lucublandus (Say)	305	13	S	*
Poecilus chalcites (Say)	188	8	S	*
Agonum cupripenne (Say)	187	8	S	*
Cyclotrachelus sodalis (Le C.)	98	5	A	*
Anisodactylus santaecrusis (F.)	97	4	S	**
Scarites quadriceps Chd.	72	3	S	*
Harpalus herbivagous Say	69	2	S	**

Amara aenea (De G.)	57	2	S	**
Clivina bipustulata (F.)	34	2	S	*
Bembidium nitidum (Kby)	31	1	S	*
Harpalus pensylvanicus (De G.)	30	1	A	**
Anisodactylus rustis (Say)	28	1	A	*
Stenolophus comma (F.)	25	1	A	*
Bembidium quadrimaculatum L.	24	1	S	*
Clivina impressefrons Lec.	19	0.8	S	*
Elaphorus anceps (Lec.)	12	0.5	S	*
Patrobus longicornis (Say)	3	0.2	S	*
Agonum placidum (Say)	3	0.1	S	*

Total number = 2,316

Number of species (S) = 20

S, Spring breeders; A, Autumn breeders

* Predaceous, feed on other insects and slugs

** Mainly phytophagous, weed seed predators

Influence of refuge strips and cover crop on seasonal activity-density of beetles. Overall activity-density of carabids reached peak between June and August of each year with larger numbers of specimens captured in 1996 versus 1997 (Figure 3).

In 1996, the presence or absence of a refuge strip did not affect the activity-density of beetles in the surrounding plot area (F = 0.45, P = 0.55) and there was no interaction of refuge strip by cover crop effect (F = 0.26, P = 0.63). However, the presence of cover crop did marginally increase the number of beetles captured in the cover crop subplots (F = 4.52, P = 0.07) (Table 3). From May through August, pitfall trap captures were consistently higher in cover crop subplot than in subplots without a cover crop (Fig. 4). This effect was significant in June (F = 13.22, P = 0.010) and August (F = 9.27, P = 0.022) (Table 4).

During May-July, the highest activity-density of carabid beetles occurred in the refuge strips themselves (Fig. 5). On average, carabid beetles numbers were 2.5 times greater in the refuge strips than in the area plot interface without a refuge strip. This effect was significant through the season (Table 5) but varied from month to month (Table 6). In June- July, significantly more beetles occurred in refuge strips, however, in September- significantly more beetles were captured in plot interface without refuge strips (Figure 6).

In 1997 the presence or absence of refuge strips did not influence the number of beetles in the sourrounding plot area (F = 1.3; P = 0.38) (Table 7). In 1997 there was no established cover crop in corn and the marginal effect of cover crop observed in 1996 did not occur in 1997 (F= 0.19, P = 0.67) (Table 7). Again, there was no refuge strip by cover crop interaction effect (F= 0.08, P = 0.78) (Table 7). Trends in beetle captures in the refuge

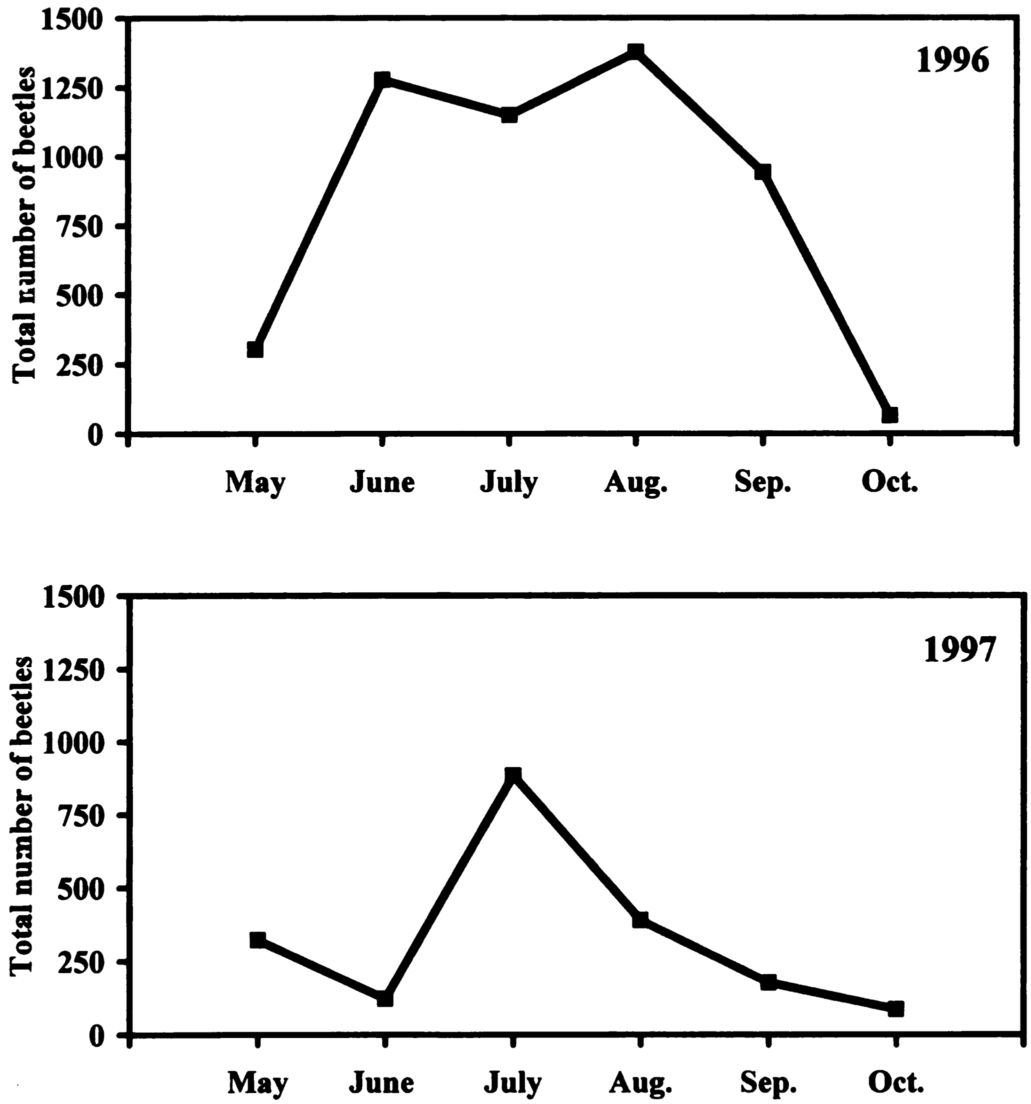


Figure 3. Seasonal activity-density of carabid beetles captured in pitfall traps. May-October, 1996-1997.

Table 3. Split-plot design ANOVA of beetle abundance through the whole season, 1996.

Source	**df**	**MS**	**F**	**P**
Refuge	1	0.44	0.45	0.55
Cover	1	28.22	4.52	0.077
Refuge x cover	1	1.60	0.26	0.63

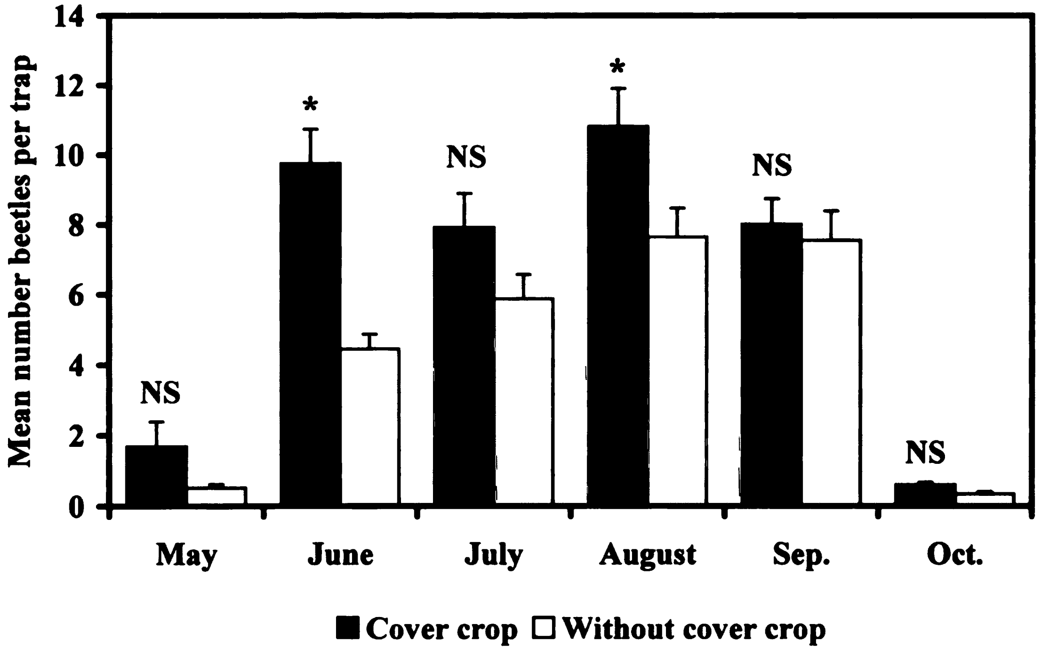


Figure 4. Mean number (+ SE) of beetles captured in subplots with presence and absence of cover crop. May-October, 1996.

Table 4. Main and subplot factor effect ANOVA for carabid beetles abundance. May- October, 1996.

May 1996.

Source	**df**	**F**	**P**
Refuge	1	3.38	0.163
Cover	1	3.49	0.111
Refuge x Cover	1	0.01	0.910

June 1996

Source	**df**	**F**	**P**
Refuge	1	0.01	0.93
Cover	1	13.22	0.010
Refuge x Cover	1	0.37	0.56

July 1996

Source	**df**	**F**	**P**
Refuge	1	2.33	0.224
Cover	1	0.93	0.3709
Refuge x Cover	1	3.18	0.124

August 1996

Source	df	F	P
Refuge	1	0.90	0.41
Cover	1	9.27	0.022
Refuge x Cover	1	0.36	0.567

September 1996

Source	df	F	P
Refuge	1	3.84	0.144
Cover	1	0.09	0.777
Refuge x Cover	1	0.02	0.883

October 1996

Source	df	F	P
Refuge	1	0.00	0.98
Cover	1	1.65	0.245
Refuge x cover	1	2.08	0.199

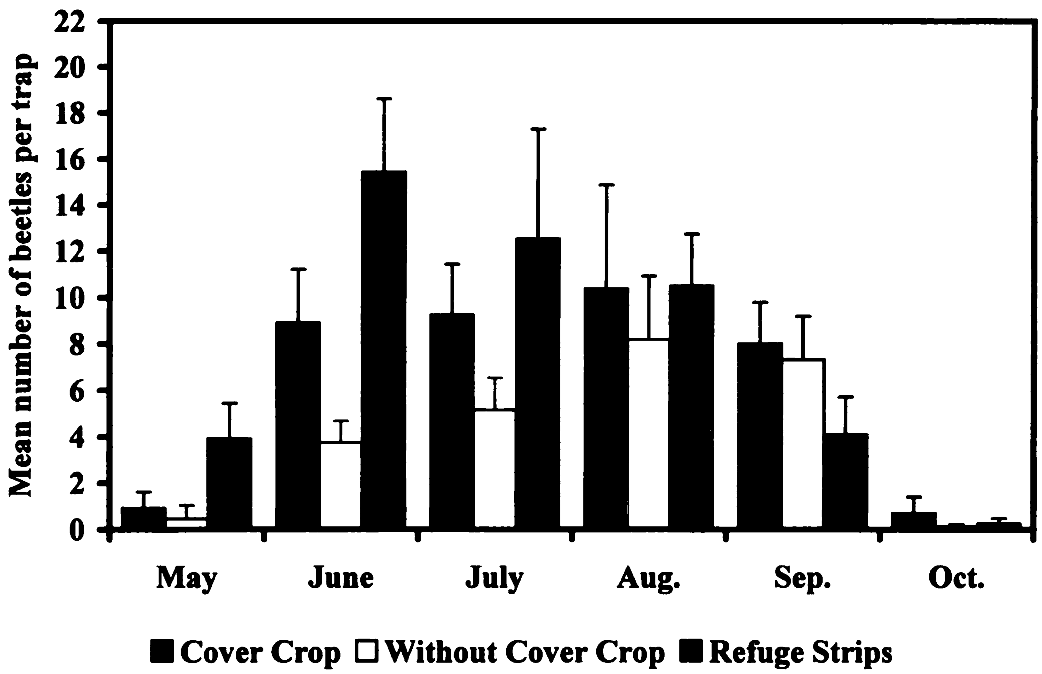


Figure 5. Seasonal activity-density of carabid beetles in subplots with and without the presence of a refuge strips and cover crop. May-October, 1996.

Table 5. Mean (± SE) number of carabid beetles captured in refuge strips and without refuge strips interface through whole season, 1996.

	Refuge strips	**Without Refuge Strips Interface**	
1996	Mean (± SE)	Mean (± SE)	P
	7.05±0.76	2.57±0.13	0.036

Table 6. Mean (± SE) number of carabid beetles captured in refuge strips and without refuge rtrips interface. May-October, 1996.

Month	**Refuge strips** Mean (± SE)	**Without Refuge Strips Interface** Mean (± SE)	P
May	4 ± 1.53	1.5 ± 1.42	0.08
June	15.5 ± 3.20	7 ± 2.13	0.03
July	12.5 ± 4.79	5.7 ± 2.49	0.002
August	10.5 ± 2.23	9 ± 2.45	0.12
September	4 ± 1.64	7.1 ± 1.50	0.01
October	0.2 ± 0.23	0.7 ± 0.64	0.27

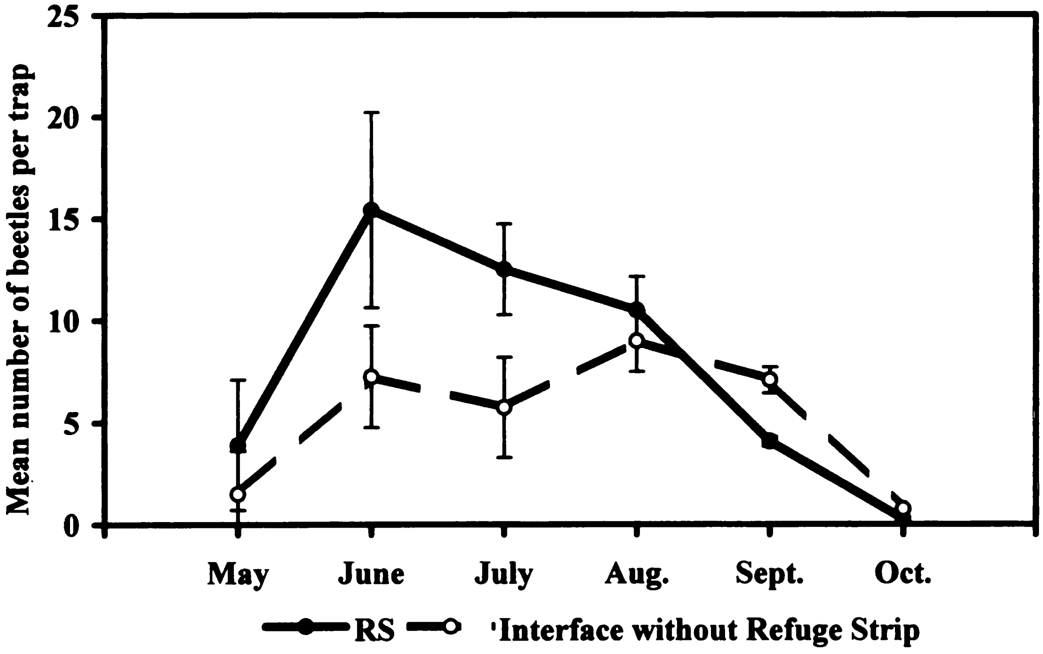


Fig. 6. Mean number (± SE) of beetles captured in refuge strips and without refuge strips interface. May-October, 1996.

Table 7. Split-plot design ANOVA of beetle abundance through the whole season, 1997.

Source	df	MS	F	P
Refuge	1	0.57	1.03	0.38
Cover (1996)	1	0.17	0.19	0.67
Refuge x cover	1	0.07	0.08	0.78

species. *Poecilus lucublandus* and *Poecilus chalcites* and *Harpalus herbivagous* clustered together but the linkage distance were not uniform in average distance, and *Pterostichus permundus* and *Harpalus pensylvanicus* were linked at the same habitats ((Fig. 12).

The graphical combination of habitat and species clusters and relative proportion of carabid species showed that the 51% of *Pterostichus melanarius* occurred in refuge strip habitats; 35% in cover crop and only13% in without cover crop (Fig. 13). The *P. lucublandus*, *P. chalcites* and *H. herbivagous* cluster occurred in higher proportion in refuge strips (38 %), while *Pterostichus permundus* and *Harpalus pensylvanicus* occurred in the same proportion in cover and non-cover crop habitats but slightly at a lower proportion in the refuge strips (30%) (Fig 13).

In 1997 when there was no actively growing cover crop, there were only two distinct habitat grouping based on the carabid communities (Fig. 11). Plots with and without refuge strips and the non-refuge strip interface clustered together irrespective of if they contained a cover crop in the previous year. On the other hand, the carabid community in the refuge strips themselves was again distinct (Fig. 11). Carabid species dendograms showed two major cluster and one outlier (Fig. 12). *P. melanarius* occurred in habitats with *P. lucublandus*. *P. chalcites*, *C. sodalis*, *A. santaecrusis* were present in the same habitats and *A. santaecrusis* was apart, but sharing the same branch. *P. permundus* occurred isolated by itself (Fig. 12). The graphical combination of clusters showed that *P. permundus,* and the *P. melanarius* and *P. lucublandus* group occurred in higher proportion in the refuge strips (62% and 56% respectively). Conversely, the *P. chalcites*,

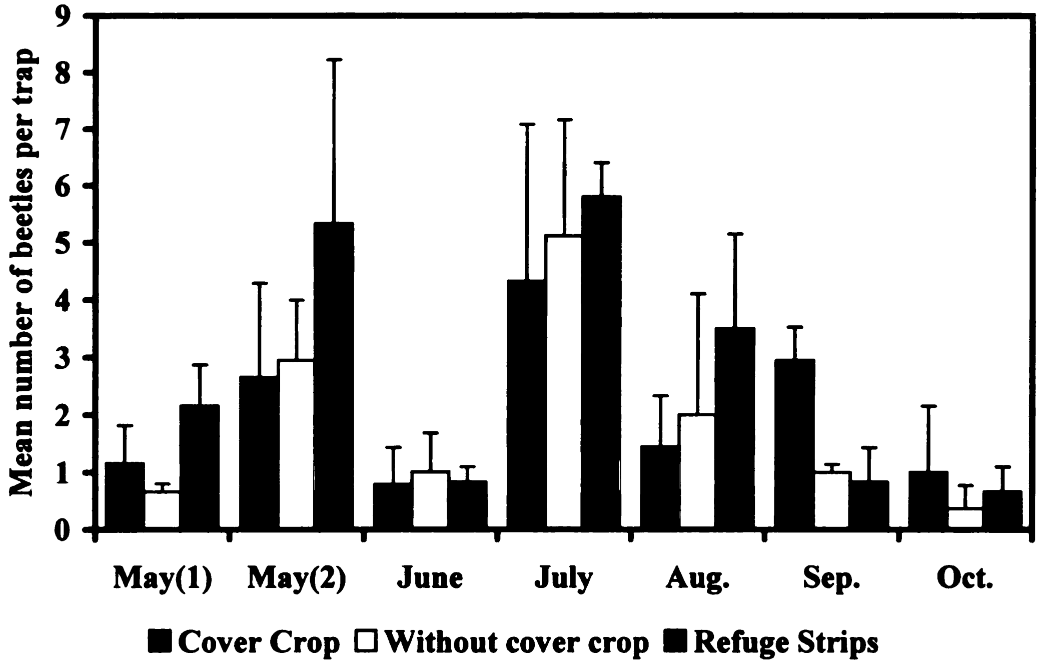


Fig. 7. Seasonal activity-density of carabid beetles in subplots with presence and absence of cover crops and refuge strips. May-October, 1997.

Table 8. Main and subplot factor effect ANOVA for carabid beetle abundance. May- October, 1997.

May, 1997

Source	df	F	P
Refuge	1	0.00	0.985
Cover	1	2.68	0.152
Refuge x Cover	1	2.11	0.196

June, 1997

Source	**df**	**F**	**P**
Refuge	1	0.30	0.622
Cover	1	1.68	0.242
Refuge x Cover	1	0.43	0.535

July,1997

Source	**df**	**F**	**P**
Refuge	1	0.26	0.642
Cover	1	2.43	0.170
Refuge x Cover	1	4.55	0.076

August, 1997

Source	**df**	**F**	**P**
Refuge	1	0.57	0.503
Cover	1	0.71	0.431
Refuge x Cover	1	0.49	0.511

September, 1997

Source	df	F	P
Refuge	1	1.89	0.263
Cover	1	1.51	0.265
Refuge x Cover	1	7.78	0.031

October, 1997

Source	df	F	P
Refuge	1	0.15	0.721
Cover	1	1.43	0.277
Refuge x cover	1	0.12	0.736

Table 9. Mean (± SE) number of carabid beetles captured in refuge strips and without refuge strip interface through whole season, 1997.

Refuge strips	Without Refuge Strip Interface	
Mean (± SE)	Mean (± SE)	P
3.16 ± 0.46	1.69 ± 0.24	0.015

Table 10. Mean (± SE) number of carabid beetles captured in refuge strips and without refuge strip interface. May-October, 1997.

Month	**Refuge strips**	**Without Refuge Strip Interface**	
	Mean (± SE)	Mean (± SE)	P
May (1)	2 ± 0.69	1.5 ± 0.57	0.161
May (2)	5.33 ± 1.41	7 ± 1.1	0.191
June	0.9 ± 0.28	0.5 ± 0.08	0.184
July	5.8 ± 1.26	2.75 ± 0.003	0.003
August	3.5 ± 0.06	2.41 ± 0.199	0.199
September	0.83 ±0.40	0.41 ± 0. 35	0.28
October	0.66 ± 0.00	0.58 ± 0.00	0.27

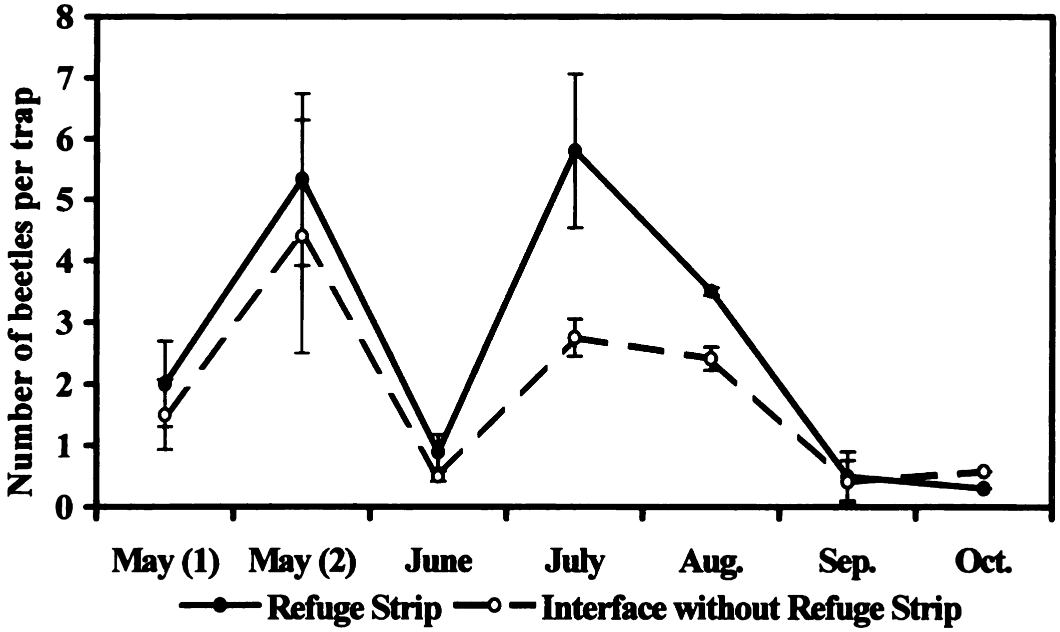


Figure 8. Mean number (± SE) of beetles captured in refuge strips and without refuge strips interface. May-October, 1997.

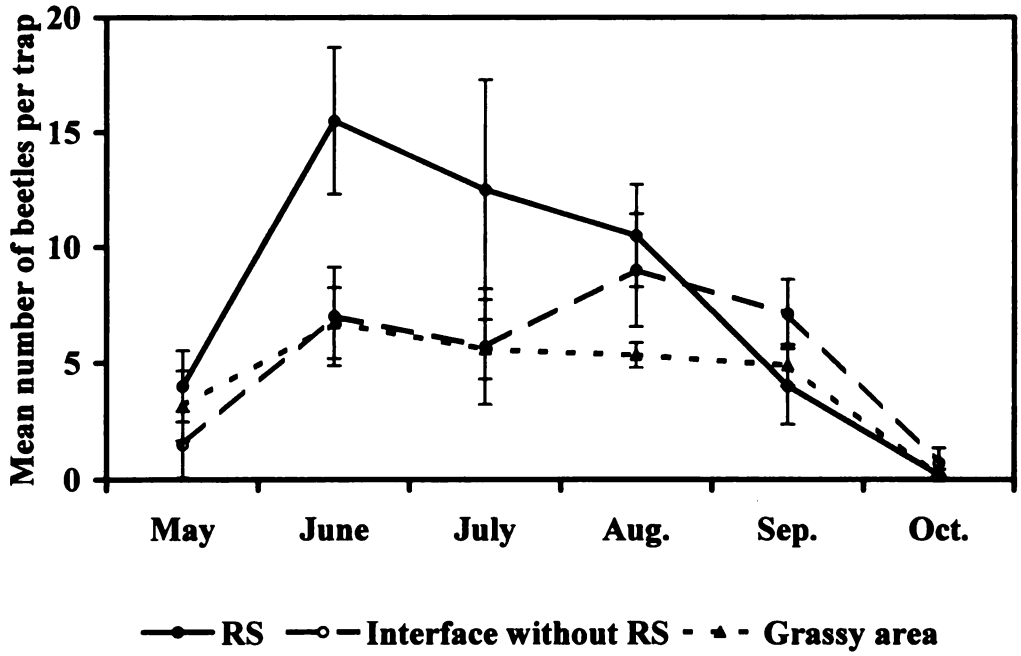


Figure 9. Mean number (± SE) of beetles captured in refuge strips, without refuge strip interface and grassy area. May-October, 1996.

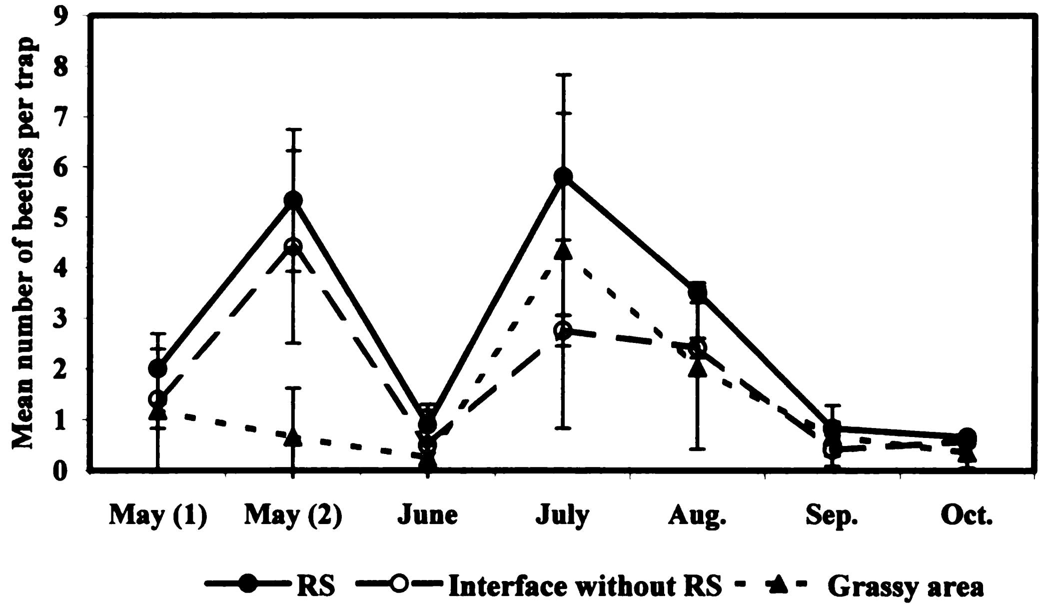


Figure 10. Mean number (± SE) of beetles captured in refuge strips, without refuge strip interface and grassy area. May-October, 1997.

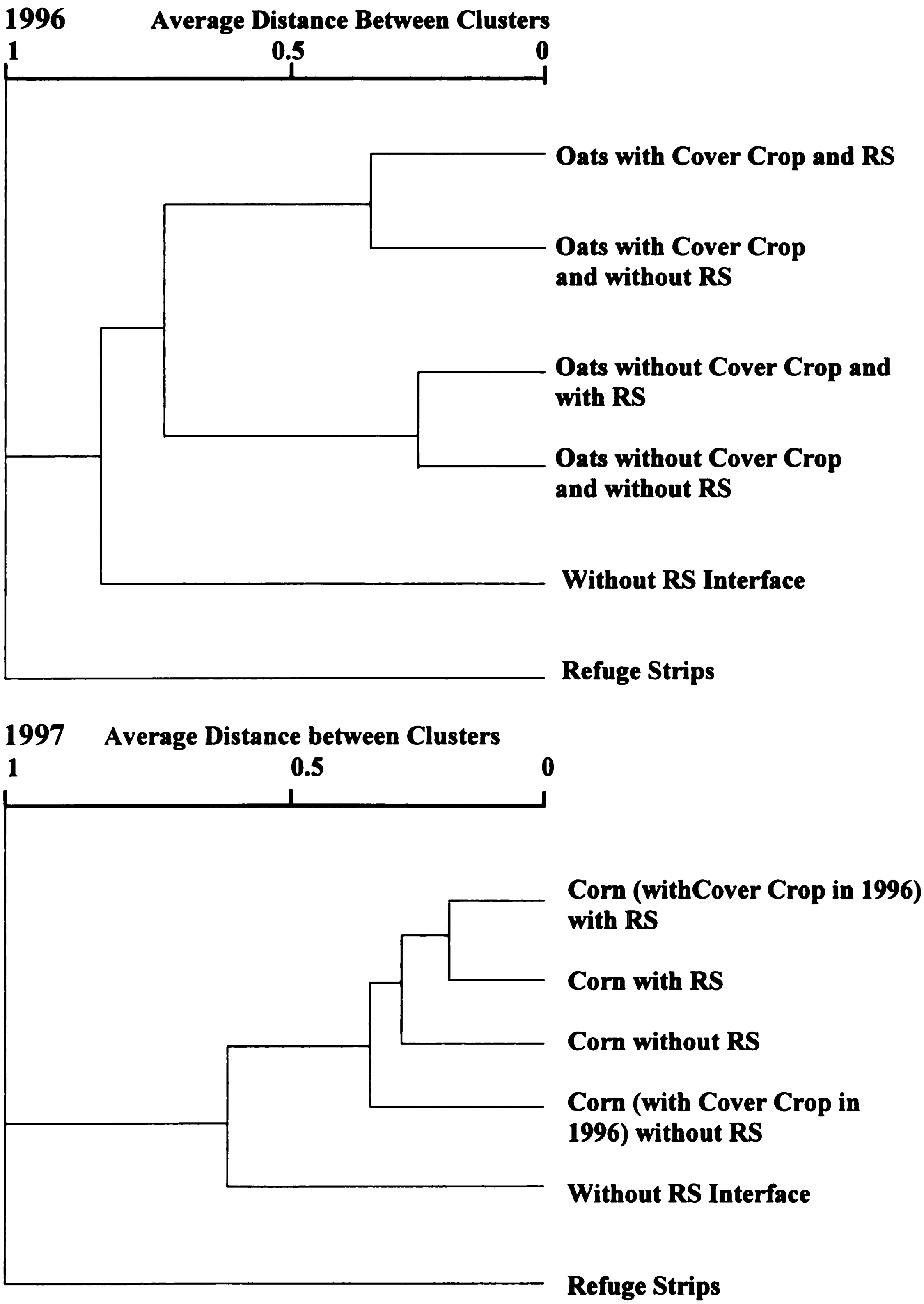


Figure 11. Hierarchical clusters created using average linkeage of similarity in carabid beetle community composition of the different habitats.

species. *Poecilus lucublandus* and *Poecilus chalcites* and *Harpalus herbivagous* clustered together but the linkage distance were not uniform in average distance, and *Pterostichus permundus* and *Harpalus pensylvanicus* were linked at the same habitats ((Fig. 12).

The graphical combination of habitat and species clusters and relative proportion of carabid species showed that the 51% of *Pterostichus melanarius* occurred in refuge strip habitats; 35% in cover crop and only13% in without cover crop (Fig. 13). The *P. lucublandus*, *P. chalcites* and *H. herbivagous* cluster occurred in higher proportion in refuge strips (38 %), while *Pterostichus permundus* and *Harpalus pensylvanicus* occurred in the same proportion in cover and non-cover crop habitats but slightly at a lower proportion in the refuge strips (30%) (Fig 13).

In 1997 when there was no actively growing cover crop, there were only two distinct habitat grouping based on the carabid communities (Fig. 11). Plots with and without refuge strips and the non-refuge strip interface clustered together irrespective of if they contained a cover crop in the previous year. On the other hand, the carabid community in the refuge strips themselves was again distinct (Fig. 11). Carabid species dendograms showed two major cluster and one outlier (Fig. 12). *P. melanarius* occurred in habitats with *P. lucublandus*. *P. chalcites*, *C. sodalis*, *A. santaecrusis* were present in the same habitats and *A. santaecrusis* was apart, but sharing the same branch. *P. permundus* occurred isolated by itself (Fig. 12). The graphical combination of clusters showed that *P. permundus,* and the *P. melanarius* and *P. lucublandus* group occurred in higher proportion in the refuge strips (62% and 56% respectively). Conversely, the *P. chalcites*,

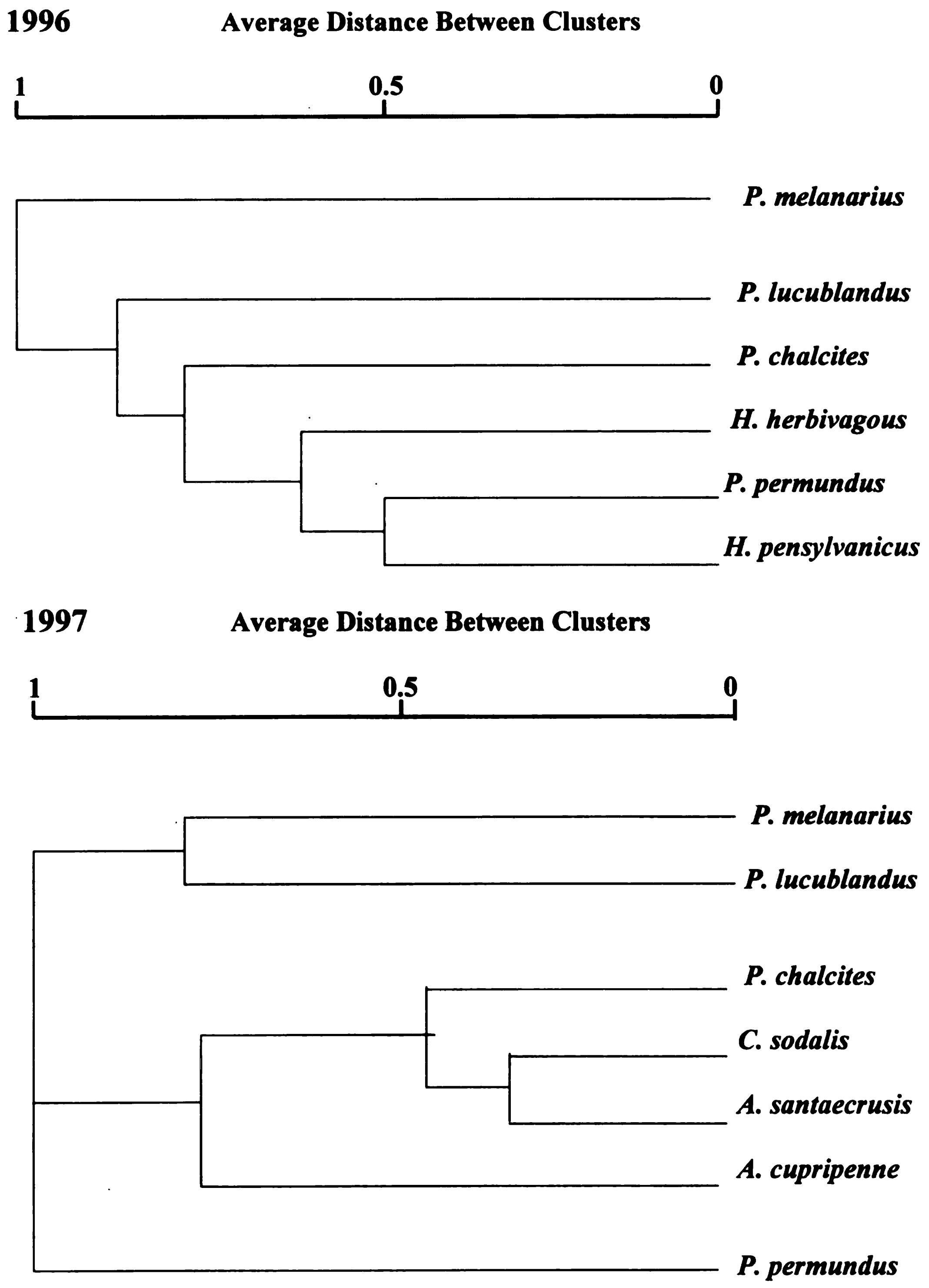


Figure 12. Hierarchical clusters created using average linkage of similarity, in their occurrence at different habitats, of the carabid species.

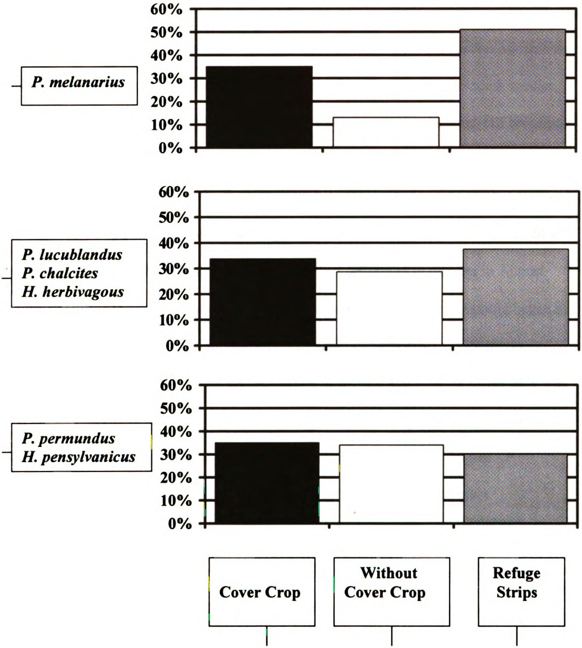


Figure 13. Percentage of each group of carabid beetle species represented in each cluster of habitats. May-October, 1996.

C. sodalis, *A. santaecrusis* and *A. cupripenne* occurred in higher proportion in cover and non-cover crop habitats (76 %) (Fig. 14).

Seasonal activity-density of carabid species. In 1996 there were six species of carabids which comprised more than 5% of the total trap capture. Three spring breeding species, *Poecilus lucublandus, P. chalcites* and *Harpalus herbivagous*; one summer-fall breeding, *Pterostichus melanarius*, and two fall breeding, *P. permundus*, and *H. pensylvanicus* species were represented. Overall, *P. melanarius* was the most abundant carabid species. Its seasonal activity pattern showed that it appear in May and the population increased in June with a marked peak in July. The population then decreased in number in August-September (Fig. 15). *P. lucublandus* was present in low numbers when trapping began in mid-May. Its population peaked in mid-June and again in September. *P. chalcites* appeared in mid-May and showed a spring peak in mid–June and July. A lower peak was observed in September and with individuals caught until early October. *H. pensylvanicus* and *H. herbivagous* both appear in June and showed a marked peak in August. *P. permundus* appeared in August and showed a marked peak in mid-September.

In 1997 five species comprised more than 5 % of the total carabid capture. The same four species most abundant in 1996 were again dominat in 1997. They included *Poecilus lucublandus, P. chalcites, P. melanarius* and *P. permundus* along with another spring breeding species *Agonum cupripenne*. The activity pattern of the common species changed slightly, respective to 1996 (Fig. 16). *P. melanarius*, appeared in June (a month later than 1996) with peaks in July, and decreased noticeably in August-September.

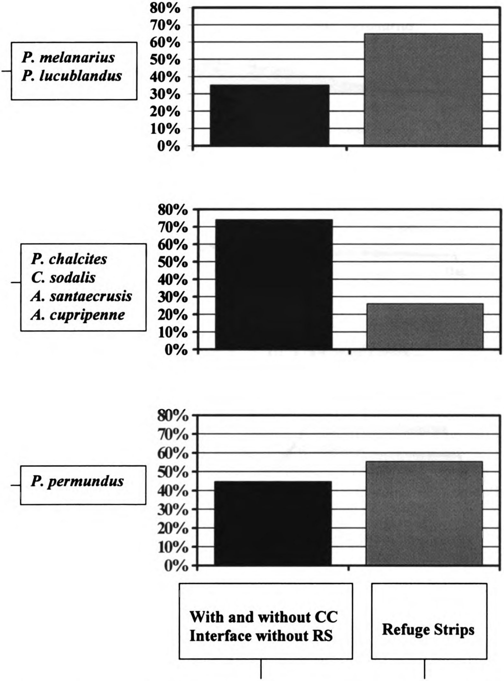


Figure 14. Percentage of each group of carabid beetle species represented in each cluster of habitats. May-October, 1997.

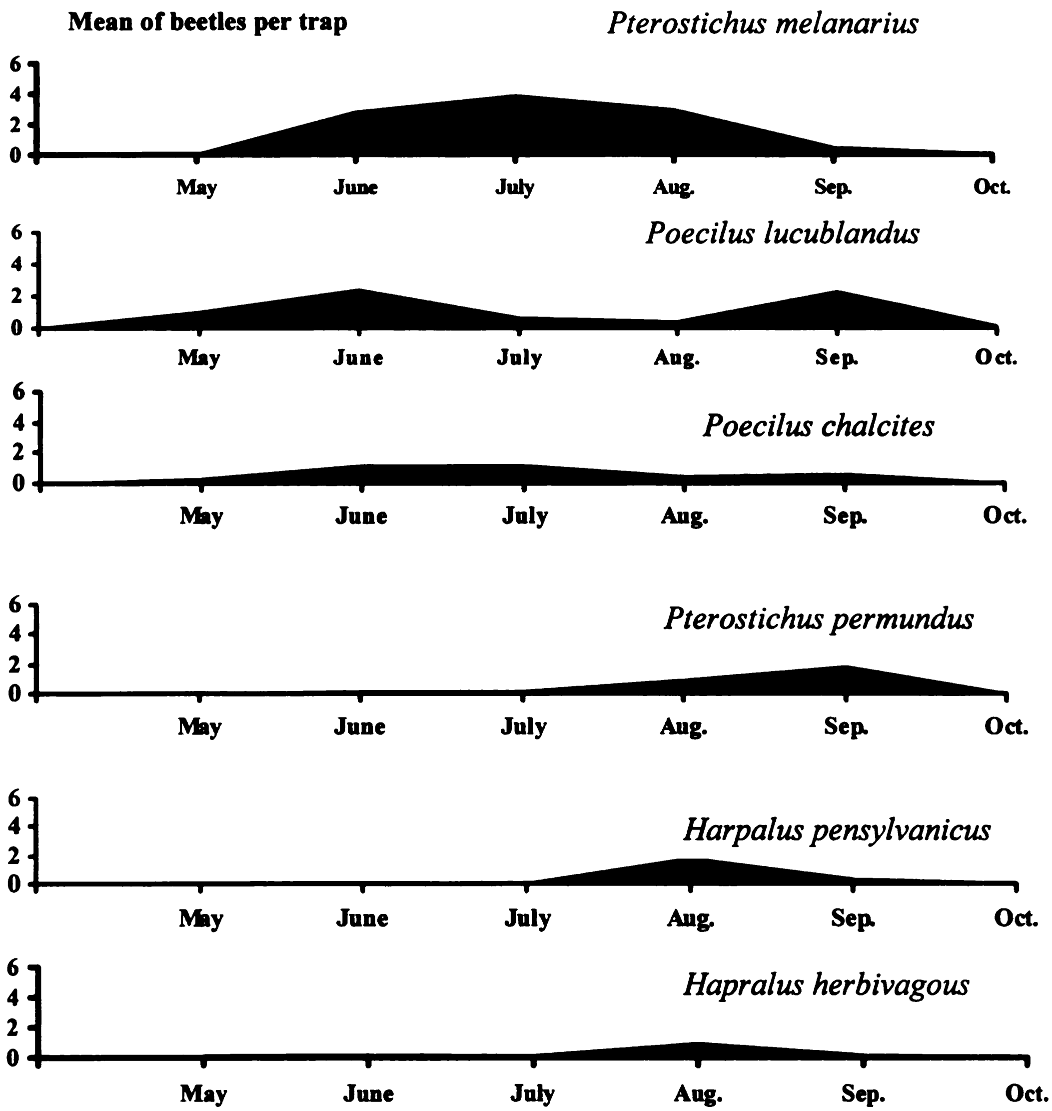


Figure 15. Seasonal activity density of carabid species that represent more than 5% of the total capture. May-October, 1996.

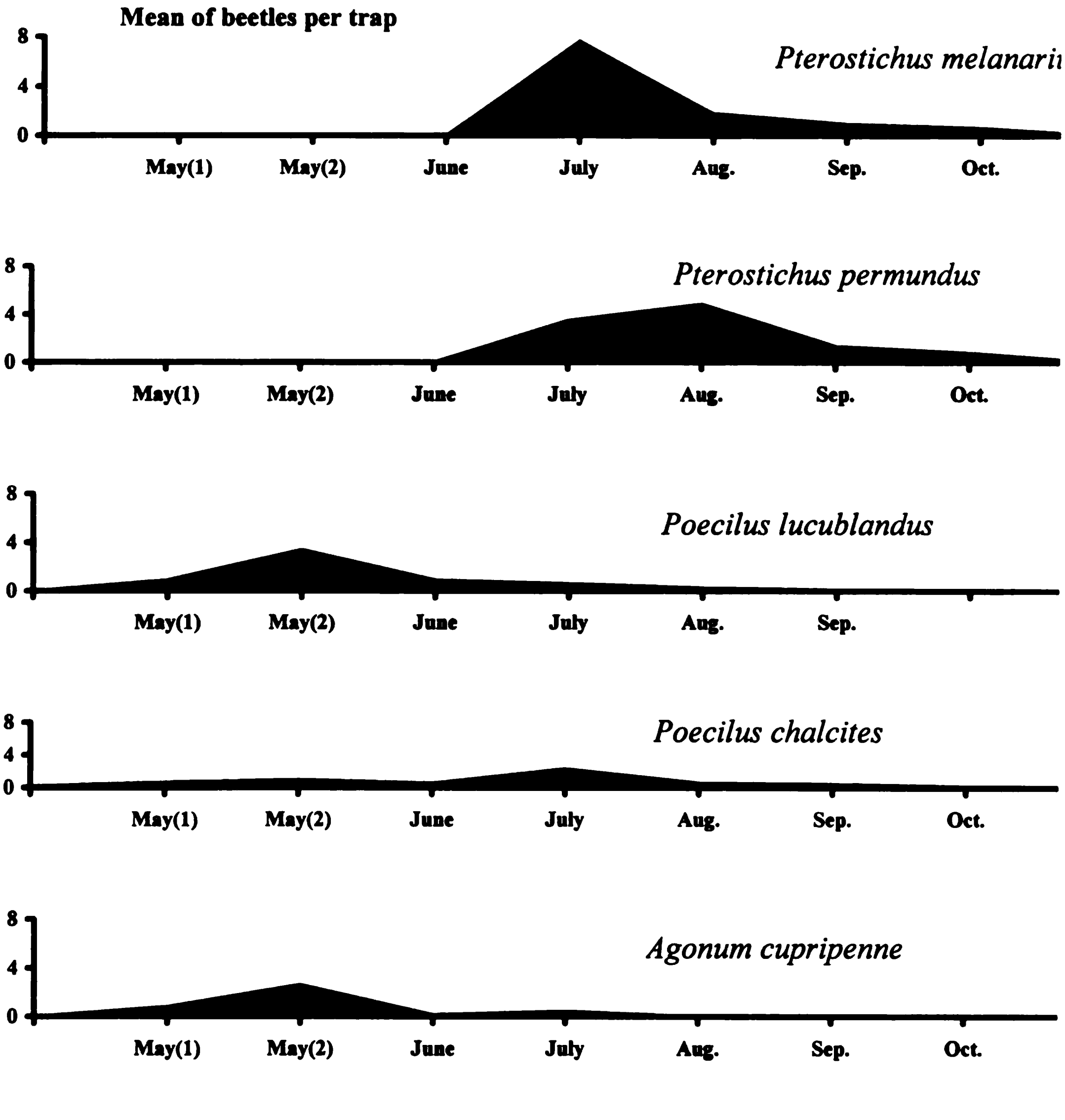


Figure 16. Seasonal activity-density of carabid species that represent more than 5% of the total capture. May-October, 1997.

P. lucublandus occurred only during the spring peak with few individuals during the summer and fall. *P. chalcites* presented more short and concentrated peak in July, and *P. permundus* appeared earlier and the population peaked in August. *Agonum cupripenne* occurred only during the spring peak with few individuals during the summer and fall.

Discussion

The twenty carabid species captured during two years of these studies are part of a complex of species common in North America agricultural landscapes (Lindroth 1969; Johnson & Cameron 1969; Kirk 1970). The most abundant species each year were *Pterostichus melanarius*, *Poecilus chalcites*, *Poecilus lucublandus* and *Pterostichus permundus*, while the relative abundance of the remaining species varied each year. These four most abundant large carabid beetles have been found in various annual cropping systems in the Midwestern US (Kirk 1970; Wiedenmann et al. 1992; Dunn 1982). Seasonally captures showed that the number of carabid beetle species increased from 14 in 1996 to 20 in 1997, but the total number of beetles captured decreased in 1997. Seasonal activity-density showed that carabids were most numerous/active in June to August of each year with lower number/activity in May, September, and October. Because of the life histories (spring, summer-fall, and fall breeding) of the different carabid species, their seasonal activity-density showed overlapping presence and population peaks in different months. In general, carabid numbers increased from early spring to mid-summer and then decreased to a low in late-fall. The overlapping generations of different carabid species accounted for a number of these natural enemies in the field throughout most of the season.

In 1997 beetles populations declined noticeably in June. A prolonged rainy period (approximately 18 days) contributed to the lower than expected trap catch during this period. It is unclear why overall trap captures were lower in 1997 than in 1996.

In both years of this study, the presence of refuge strips did not significantly affect the number of beetles in the sourrounding plot areas. However, in both seasons, trap captures tended to be greatest in the refuge strips indicating that these refuges were a preferred habitat for carabid activity. In their studies Lys (1994); Lys et al. (1994); Lys & Netwing (1994); Zangger (1994); Frank (1996) found a positive influence of strips ("strip management") on ground beetle populations in cereal fields. Their results showed greater numbers of carabid beetles in the strip managed areas than in control areas without refuge strips. Furthermore, Lys (1994) found three time the number of beetles in the refuge strips than in the cereal field between strips. The results of my study suggest that beetles were captured in the refuge strips in greater numbers than in plot interfaces without refuge strips. In addition, refuge strip captures were greater than in grassy areas surrounding the plot. This pattern may be due two two factors. First, it is possible that refuge strips are so attractive that beetles do not tend to disperse from them into surrounding areas; or alternatively, it may be that the size of the experimental plot was too small relative to the dispersal capabilities of the predominant large beetle species to show an effect of refuge strips. Increased vegetational diversity is hypothesized to augment natural enemies (primarily through providing shelter and food sources) and to nfluence their movements (den Boer 1981; Lys 1994; Lys et al. 1994). Although diversifying agroecosystems using refuge habitats within fields could enhance carabid beetle density and diversity, highly attractive strips may have a negative effect on the dispersion of beetles. It is not clear whether vegetation which provides abundant resources will act as a "source" or as a "sink" of natural enemies in agroecosystems (Corbett & Plant 1993). Given the abundance of resources in refuge habitats, carabid beetles may not have been inclined to move to the surrounding plot areas. On the other hand, studies of dispersal in large carabid beetle species (Thiele 1977, Best et al. 1981; Wallin & Ekbon 1988), have shown that they can move from 2 m to 10 m/day average (depending on the species, dispersal mechanism and food source available) to a maximun of 90 m/day (i.e. *Poecilus chalcites*). Taking this into account, it is likely that due to the size of my experimental plots (30 x 30 m), carabids could easily move between plots. As a consequence the effect of refuge strips on number of beetles in the immediate surrounding plot areas may have been to transient to observe.

In 1996, the presence of a cover crop marginally increased the number of beetles in these plots throughout the season. Reduced tillage systems in combination with cover crops enhanced the number of soil arthropod natural enemies (Brust 1985). Particularly, it has been shown that activity of large carabids increases with increasing humidity and food sources (Brust 1985, Clark 1993, 1995, Manley 1996).

In spring of 1997, the cover crop was killed with herbicide, and no additional cover crop was interseeded into the corn plot. During the summer of 1997 there was no effect of the previous cover crop on the number of beetles in the cover crop subplots. Environmental disturbance such as herbicide applications can affect carabid beetles both directly and indirectly (Messermith and Adkins 1995). I did not observe any obvious direct negative effect of herbicide application on carabid population. The sample that I took after herbicide application indicated a larger beetle population than the sample prior to herbicide application. According to Boac and Pospisil (1985) the application of herbicides does not directly influence the activity of ground beetles. They state that changes in the activity of carabids due to herbicides is more related to the elimination of ground cover. Carabids apparently respond to the destruction of plant material that can result in a less favorable habitat (Brust 1990). Laub and Luna (1992) found that there were higher numbes of *Pterostichus* spp and *Scarites* spp in mowed cover crop treatment compared with herbicide killed cover crop treatments. Mowed plots showed a subsequent reduction in larval densities of armyworm, *Pseudaletia unipuncta*, within the same summer season.

Unlike the pattern for abundance, species richness of carabid beetles increased from 1996 to 1997. Carabids species vary in response to tillage (Clark et al. 1993) and even the same species may respond differently to the same tillage treatment in different sites (Weiss et al. 1990). In addition, crop type and rotation may affect the number and type of the carabid species that occur in an area (Cárcamo & Spence 1994). In studies by Boac and Pospisil (1985), carabid species diversity was lower in corn than in wheat fields. In their opinion, moisture content is higher in wheat due to a dense plant cover compared with corn. However, in my study the number of species increased from 1996 (oats) to 1997 (corn). Although the corn has a more open structure and conversely, less humidity than oats, I recorded six more species, *Clivina* spp, *Bembidium* spp., *Elaphorus anceps* and *Sthenolophus comma.* In this crop these small carabids (<1cm) are reported adapted to open and dry areas and *Stenolophus comma* and *Clivina impressifrons* Le Conte are known to feed on germinated seed when animal food is not available (Lindroth 1969, Pausch & Pausch 1980). In addition, in open areas the small beetles may have easy dispersal capabilities due to the less restrictive ground cover in open habitats such as corn. This would in turn, increase the chance for those species to be captured in pitfall traps (Hawthorne 1995).

In 1996 when the cover crop was present there were distinct communities of beetles in the three different habitats. Refuge strips were dominated by *Pterostichus melanarius* and to a lesser extenct *Poecilus lucublandus*, *Poecilus chalcites* and *Harpalus herbivagous*. On the other hand *Pterostichus permundus* and *Harpalus pensylvanicus* occured in higher proportions in crop habitats than in refuge strips. According to Wallin (1986), the summer-fall breeder *Pterostichus melanarius* is known to prefer habitats with denser vegetation (forest versus cultivated land). Càrcamo and Spence (1994) captured higher numbers of *Pterostichus melanarius* in intercrops of peas, *Pisum sativum* L., and barley, *Hordeum vulgare* L., with denser plant structure than in monocultures of the same species and fescue, *Festuca rubra* L. Studies of the surface activity of carabids in cereal fields have shown that activity-density of *Pterostichus melanarius* is greatly disturbed by changes in the field. However, Rivard (1964) reported *P. melanarius* as one of the most abundant species in cereal fields. In addition, Clark (1997) found relatively lower numbers of *Pterostichus melanarius* in *Populus* and native succession habitats than in disturbed annual systems. My results showed that *Pterostichus melanarius* occurred in highest proportion in refuge strips in both years, followed by the cover crop and non-cover crop plots in 1996.

The spring breeders *Poecilus lucublandus, Poecilus chalcites*, and *Harpalus herbivagous* were active at almost at the same proportion in refuge strips and cover crops. These species were reported by Rivard (1964) to occur in open areas with moderate vegetation. Esau & Peters (1975) did not find any preference by *Poecilus lucublandus* for corn field compared with prairie habitats. However, they found that *Poecilus chalcites* definitely preferred corn fields versus prairies.

The autumn breeders *Harpalus pensylvanicus* and *Pterostichus permundus* were most abundant in crop areas. The phytophagous *Harpalus pensylvanicus* has been reported to be adapted to open ground (Rivard 1964; Lindroth 1969; Kirk 1970, 1973) or prairies where grasses seeds are present (Esau & Peters1975). These species occurred in a slightly higher proportion in the refuge habitats.

In 1997 the most abundant species group; *Pterostichus melanarius* and *Pterostichus lucublandus* preferred the refuge strips. *Pterostichus permundus* also occurred in greater proportion in the refuge strips.

The results of this study show that many species of carabid beetles were found in the refuge area. Although, refuge strips likely improved living conditions offering more food, overwintering sites and a wide range of niches (Zanger 1992; Lys et al. 1994), it is not clear if this influenced the dispersion and dispersal of carabids to adjacent crop plots.

The general hypothesis is that refuge habitats within crop fields offer overwintering sites for carabids and they will move to the fields during the crop season and control pests. However, numerous factors are known to affect community structure, abundance and number of carabid species (Thiele 1977, den Boer 1986). Tillage, crop type and crop rotation, pesticide management and climatic condition can affect the number and species composition in each field situation. Refuge strips within fields provide stable habitats for carabid beetles to compensate the environmental disturbance in crop systems. However, information about size and number of these refuges and distance between them related with their influence in the dispersal and dispersion of beetles is necessary to understand how best to manage this strategy. In addition, knowledge of the interaction between ground beetles and pests in such systems should be considered in further studies. Finally, given the fluctuation in abundance, and species diversity of these generalist natural enemies, attention should be given to long-term conservation studies that utilize larger experimental sites.

CHAPTER 3

Weed seed predation by *Gryllus pensylvanicus* Burmeister (Orthoptera: Gryllidae)

Introduction

The northern field cricket, *Gryllus pensylvanicus* Burmeister, is the most abundant and widely distributed field cricket in the northeastern United States, occurring in various grassy habitats, such as fields, pastures, weedy areas, roadsides, and lawns (Alexander 1957). This medium size cricket is typically black with light brown wings and produces a chirping song. *G. pensylvanicus* overwinters as an egg or nymph. They resume development in June and July and by the first week of August adults emerge and remain active into September-October (Alexander 1957). This field cricket is partially nocturnal preferring to hide from the sun's rays during hot days. In first stage it is much more apt to walk than jump. With the approach of cold weather the adults make cone-shaped cavities an inch or two across the top and about as deep, beneath decaying logs and debris. Sometimes the margins of the burrows are surrounded by fragments of grass stems and pieces of decaying leaves (Blatchley 1920). *Gryllus pensylvanicus* is omnivorous, consuming both dead and living insects, broadleaf plants, as well as grasses and seeds (Criddle 1925).

Because of their abundance, and the damage they occasionally cause, *Gryllus pensylvanicus* has been considered an economic pest for many years. Recently, the northern field cricket was recognized as a pest in the establishment of no-till alfalfa

(Grant et al. 1982; Byers & Bierlein 1984; Rogers et al. 1985) where it feeds on emerging seedlings. Studies by Byers & Barratt (1991) found that alfalfa was damaged by both *G. pensylvanicus* and the slug, *Derocerus reticulatum* (Müller), and their combined feeding damage increased seedling mortality.

However, there is also evidence that *Gryllus pensylvanicus* can be a beneficial insect, feeding on both insect pests and weeds. Criddle (1925) and Smith (1959) reported that this cricket dug up and devoured grasshopper eggs. In studies of crickets as predators of the apple maggot, *Rhagoletis pomonella* (Walsh), Monteith (1971) found that *G. pensylvanicus* was well adapted to prey on this pest. He reported that this cricket tended to aggregate around fallen apples where adults of apple maggot were attracted to oviposit. In the fall when the crickets population is highest, they may be the most important predator of *R. pomonella* pupae. The role of the cricket as a predator was emphasized by the fact that very few individuals of any other potential predator of the pupae were found. Barney et al. (1979) found that the carabids *Harpalus pensylvanicus* (De Geer), *Abacidus permundus* (Say), *Evarthrus sodalis* Le Conte and the field cricket *G. pensylvanicus* were the most abundant potential predators of the alfalfa weevil, *Hypera postica* (Gyllenhal), and clover root curculio *Sitona* spp., in alfalfa fields. In laboratory feeding studies Barney et al. (1979) observed that these four species do indeed prey upon the two weevil alfalfa pests. Bechinski et al. (1983) evaluated predators of green cloverworm, *Plathypena scabra* (F.) pupae and determined that *G. pensylvanicus* along with three large carabid beetle species, were primarily responsible for contributing to overall predation. Burges & Hinks (1987) recorded a high incidence of predation on adults of the crucifer flea beetle, *Phyllotreta cruciferae* (Goeze), by *G. pensylvanicus* in a laboratory test. However, they reported that only a small percentage of crickets had eaten flea beetles in a mustard, *Brassica juncea* (L.) field plot. They stated that the difference in predation levels between the laboratory and field probably resulted from the absence of alternate food sources and increased ease of prey capture in the laboratory.

Field crickets have been also recognized as weed seed predators in crop fields. In studies of weed seed destruction by arthropods in low-input soybean agroecosystems, Brust & House (1988) found that two carabid beetles, *Harpalus pensylvanicus* and *Harpalus caliginosus,* and field crickets, *Gryllus* spp., removed a substantial portion of the small-seeded weed seeds especially common ragweed, *Ambrosia artemisiifolia* L. and red root pigweed, *Amaranthus retroflexus* L. In his studies of post dispersal weed seed removal by carabid beetles in Michigan agroecosystems, Menalled (personal communication) observed the presence of crickets feeding on the weed seeds placed in the field as experimental treatments. These studies and field observations indicate that weed seed-feeding carabid beetles and *G. pensylvanicus* may occur at the same site and at the same time, coincident with the seed drop of many common weeds, and together contribute to weed seed loss. To quantify the contribution of arthropods to weed seed predation, it is necessary to asses their potential weed seed consumption rates in laboratory studies, to determine how to sample them in the field and finally, to determine their seasonal abundance in various crops habitats. The previous chapters of this thesis have shown that there is ample evidence for carabid beetles contributing to weed seeds loss, however, a literature review of *G. pensylvanicus* as a weed seed predator indicated that information is limited. Given this lack of information, laboratory and field studies were carried out to determine the potential role of *G. pensylvanicus* in the biological control of common agricultural weeds. The following three objectives were proposed:

1) Determine acceptability and rate of consumption of four common weed seeds, giant foxtail, *Setaria faberi* Herrm, large crabgrass, *Digitaria sanguinalis* L., velvetleaf, *Abutilon theophrasti* Medic and redroot pigweed, *Amaranthus retroflexus* L. by the northern field cricket, *G. pensylvanicus*.
2) Test pitfall traps as sampling method for *G. pensylvanicus*.
3) Determine seasonal abundance and activity of adult *G. pensylvanicus* in selected field trials.

Materials and Methods

The crickets used in the following studies were identified by the author as *Gryllus pensylvanicus* Burmeister using Alexander's Key (1957) and verified by Dr. Richard Alexander, in the Department of Entomology, University of Michigan, Ann Arbor. A reference collection was deposited in the Insect Ecology and Biological Control Laboratory, Department of Entomology, Michigan State University.

Weed seed predation test. Acceptability and rate of consumption of weed seeds by the northern field cricket, *G. pensylvanicus,* was determined using adult specimens of male and female crickets collected in the field. The mean seed weight of each test species was determined by carefully counting out lots of 100 seeds and weighing them on an electronic balance. The procedure was repeated 5 times and the average weight of 100 seeds is reported (Table 11). Two grasses, giant foxtail, *Setaria faberi*, and large crabgrass *Digitaria sanguinalis*, and two broadleaf weeds, velvetleaf, *Abutilon theophrasti*, and redroot pigweed *Amaranthus retroflexus* were used in the test. Adult crickets were collected by placing boards on top of low vegetation near the interface of an old field and mown lawn. Crickets were captured by hand by lifting the board each evening and removing any adult which had sought shelter there. Individuals were maintained in the laboratory in two gallon buckets containing 10 cm of field soil covered with dead timothy, *Pheum pratense* L., residue. Adults were acclimatized to laboratory conditions for two days, and 24 h before the experiment the vegetable residue was removed from the buckets and the individuals maintained only with soil to starvation. Ten replications of each sex with each different weed seed specie were conducted. Individual crickets were placed in a circular plastic arena (ca. 18 cm of diameter x 8 cm high) containing 300 gm of steam-sterilized sandy-mix field soil (88.5% sand, 7.5% silt, 4.0% clay and 2.3% organic matter) with approximately 9% soil moisture. Treatments consisted of either 40 foxtail seeds, 40 velvetleaf seeds, 100 crabgrass seeds or 500 pigweed seeds, placed on the soil surface. Arenas containing weed seeds of each species but without crickets added were used as controls. Arenas were placed in a growth chamber at 24 $^{\circ}$ C and approximately 60% relative humidity and exposed to alternating 16:8 (L: D). After 24 h the crickets were removed from the boxes and the number of undamaged and damaged seed on the soil surface was recorded. In addition, the soil was sifted to recover the remaining seed using a 0.85 mm opening

Table 11. Mean weight (± SE) of 100 seeds of weed species used in laboratory feeding trial.

Seed species	**Weight (mg) (± SE)/100 seeds**
Giant foxtail	40 ± 3.83
Large crabgrass	44 ± 2.10
Velvetleaf	850 ± 6.46
Redroot pigweed	37 ± 1.44

screen sieve. The mean number of seeds and biomass consumed by each sex were compared by *t* test following square root transformation (x + 0.5) of the data. All analysis were conducted using Statistical Analysis System (SAS Institute).

Pitfall trap sampling test. Capture of *G. pensylvanicus* adults in pitfall traps was tested in a model system that consisted of two plastic arenas 1.5 m diam. by 1 m high designed to simulate field conditions. Each arena was filled with 5 cm of field soil covered by 110 g of wheat straw (Fig. 17). Two circular ceramic pot bottoms (15 cm diameter) and two rectangular wood pieces (25 x 12 cm) were placed on the soil surface to provide uniform refuges for crickets to hide during the day. One edge of each refuge was elevated 1.5 cm off of the soil surface to allow crickets access. One pitfall trap (12 cm diameter and 16 cm high) was placed in the center of each with the surface flush with the soil arena and filled with 50 ml of ethylene glycol as a preservative.

Four male and four female *G. pensylvanicus*, collected by hand in the field, and after a three days period of acclimatization-starvation in laboratory, were released into each arena at 4 p.m. each day. Pitfall traps were opened at 8 p.m. each evening, and checked at 8 am the following day. Pitfalls were covered with lids between sampling hours. The number of individual crickets of each sex which were recaptured in pitfalls was recorded. If the total number of crickets released were not recaptured in pitfall traps, the spaces under refuges and the arenas' surface were carefully inspected. The location of any cricket thus located was recorded and the cricket

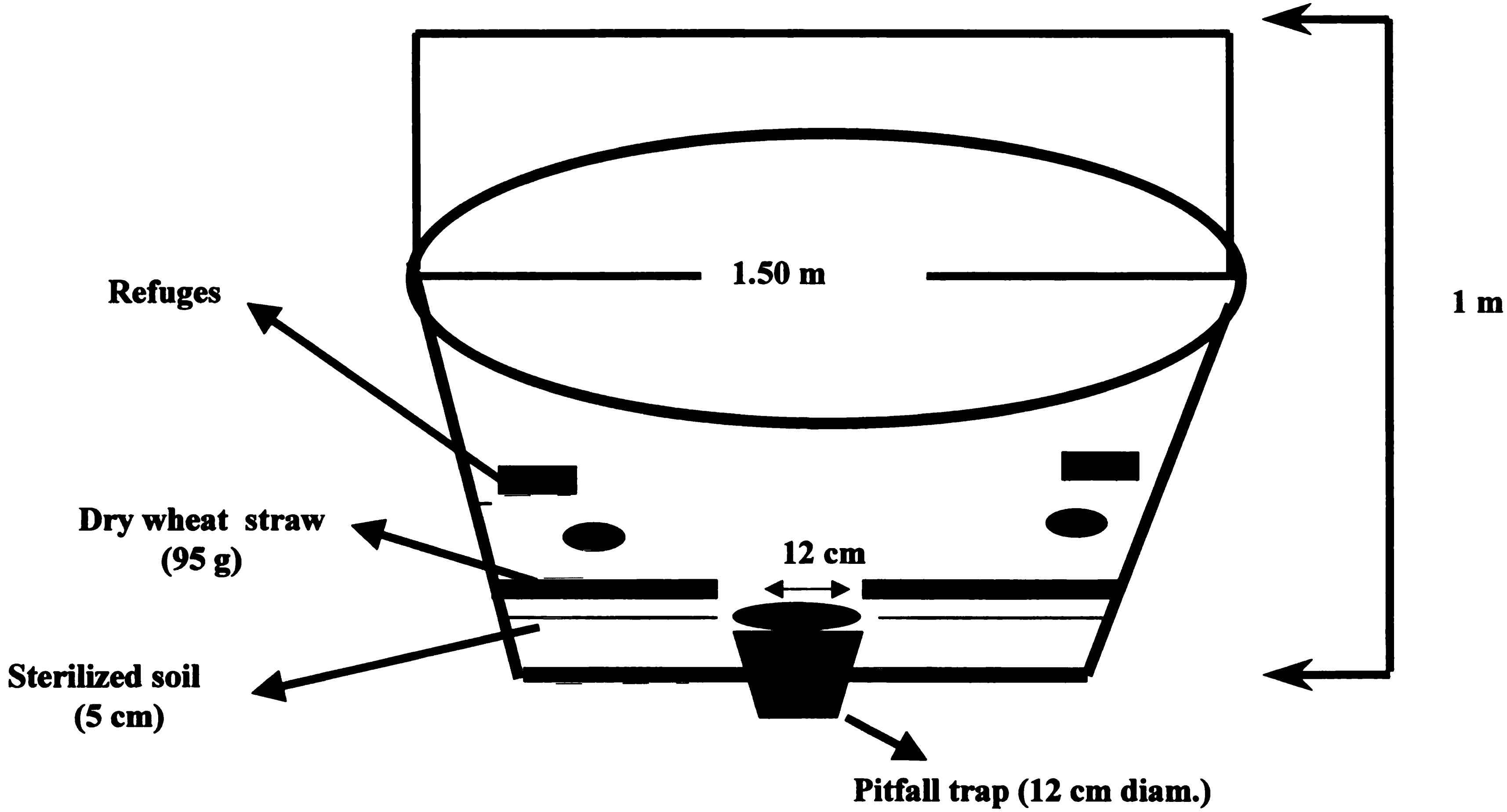


Figure 17. Pitfall trap artificial arena.

was removed. Crickets were marked with "liquid paper" paint (Gillete Co.) of different colors for each day of the experiment such that data was recorded only for crickets captured in the 16 h following release. The experiment was run for ten consecutive days. A total of 40 males and 40 females were tested in this manner. Data are expressed as the total proportion of each sex recaptured at each site.

Seasonal abundance of *G. pensylvanicus*. Pitfall trap sampling was carried out from August 5 to October 15 in a field located in Midland Co., Michigan. One 9.3 ha soybean (*Glycine max* L. Merr.) field and two adjacent conservation filter strips were selected for this study (Fig. 18). Each filter strip was 30 m wide, one composed of switchgrass, *Panicum virgatum* L., and the other an alfalfa, *Medicago sativa* L., and timothy, *Pheum pratense* L., mixture. The crop field and each one of the strips were subdivided into three sections. Each section was 60 m long and 60 m from the next section. Six pitfall traps were established at 2 m intervals within each section. Within the soybean field the traps were placed at least 100 m from any border and these were 15 m from the middle line between pitfall traps to the border in the buffer strips.

Pitfall traps (12 cm diameter and 16 cm high plastic cups) were filled with 50 ml of ethylene glycol as preservative. Every fifteen days the traps were opened and checked after five consecutive days capture. Trap contents were collected in plastic ziploc bags and maintained in a freezer until identification in the laboratory.
Pitfall traps were covered with lids between sampling periods. Specimens were identified and the number captured by sex in each system recorded.

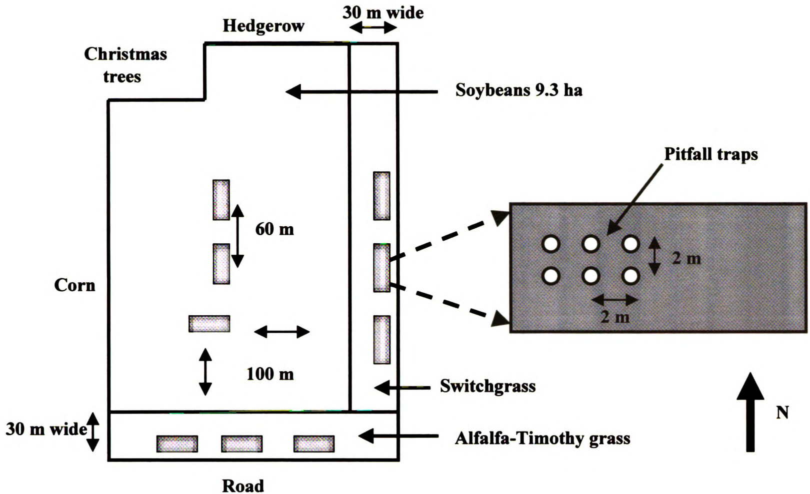


Figure 18. Pitfall traps distribution in the different habitats of the field site study. Midland Co. MI. 1997.

Abundance of *Gryllus pensylvanicus* in different systems over the season and by sex were analyzed using analysis of variance (ANOVA) for nested factorial design following square root (x + 0.5) transformation (SAS Institute 1996).

Results and Discussion

Weed seed predation. *G. pensylvanicus* actively searched the soil surface in the plastic arenas, located seed, and feeding (personal observation). In general, *Gryllus pensylvanicus* readily fed on each of the four species of weed seeds, however, feeding behavior, the number of seeds and amount of biomass consumed varied by sex and by weed species. Male and female of *G. pensylvanicus* did not appear to have great difficulty handling any of the four species tested, but feeding behavior was different for each weed species. Both sexes consumed the endosperm of velvetleaf and redroot pigweed while the pericarp was chewed and smashed. Foxtail and crabgrass endosperm was consumed leaving the pericarp almost intact.

Mean seed consumption ranged from a low of 9 giant foxtail seeds /24 h by males to a maximum of 223 seeds of redroot pigweed /24 h by females that represent 36 and 83 g of biomass (Table 12). One female *G. pensylvanicus* was observed to damage a total of 340 reedroot pigweed seeds or 126 g of biomass in 24 h.

Male and females showed different consumption rates for each of the three of the weed species tested. Females consumed higher numbers of giant foxtail (P = 0.0005), crabgrass (P = 0.003), and pigweed (P = 0.0009) seed than males. There was no difference in the number of velvetleaf seed consumed by both sexes (Table 12). The difference in consumption rate between sexes may be due to different physiological

Table 2. Mean number and biomass of weed seed species consumed by adult *Gryllus pensylvanicus* in a 24 h period

	FEMALE		MALE		
	Number of seeds	**Biomass**	**Number of seeds**	**Biomass**	
Species	**Mean (± SE)**	**Mean**	**Mean (± SE)**	**Mean**	
Giant foxtail	26 ± 2.9	36	9 ± 1.6	12	**
Crabgrass	87 ± 8.1	38	69 ± 7.7	30	**
Velvetleaf	12 ± 1.5	102	8.2 ± 0.9	70	
Redroot Pigweed	223 ± 28.8	83	90.7 ± 8.2	34	**

requirements. For most insect species, given the series of functions (i.e. mating, reproduction) inherent to them, females require more energy than males. *G. pensylvanicus* females used in the test were very active and, in most cases, only one minute after they were placed in the plastic boxes, they found the weed seeds very easily and started eating them. When I sieved the soil to evaluate the number of damaged seeds I found eggs in most replications containing females. In the case of males, they commonly walked randomly for a few minutes until they touched the seeds, and then began foraging more actively and feeding. Evidently, there was a difference between males and females in searching behavior, physiological requirements, and as a consequence, in consumption rate.

Direct observation in the laboratory showed that the size and shape of the seed might affect the ease with which the cricket could handle and open the seed. The size of the seeds tested might influence the number of seeds damaged in two ways. Larger seeds such as velvetleaf would provide more food material per seed and therefore require fewer seeds to satiate the insect. Foxtail and crabgrass, both smaller seeds, were consumed in higher number and in the case of redroot pigweed, the smallest seeds tested, were consumed by crickets in very large numbers (Table 12). Coincident with my results, Brust & House (1988) found that, in the field *Gryllus* spp. removed a higher proportion of redroot pigweed than large weed seed species such as sicklepod, *Cassia obtusifolia* L. and jimsonweed, *Datura stramonium* L.

The large size of velvetleaf seeds may explain the lower number consumed among the seed species tested. This is the only case in which males and females consumed almost the same number of seeds. Comparing the amount of biomass consumed by *G. pensylvanicus* (Table 12), male and female consume 70 and 102 g eating a maximum of 8 and 12 of seeds respectively, versus 34 and 83 g of biomass eaten a maximum of 90 and 223 redroot pigweed seeds respectively. There was higher biomass of velvetleaf with only 12 seed versus 223 pigweed seed consumed. Velvetleaf has a hard pericarp that is not easy to penetrate. Crickets appeared to spend more time trying to crack it than other seeds but, because of the seeds' biomass, the energy return/handling time ratio is still favorable to *G. pensylvanicus*. In both sexes, after consuming some velvetleaf seeds, crickets started walking in the small arena with large numbers of intact veltvetleaf seeds remaining. In this case the number of seeds consumed was related to satiation level rather than feeding behavior/preferences of the crickets.

On the other hand, comparing the seed size of the three smaller species, giant foxtail seed is the bigger one, being crabgrass smaller and redroot pigweed the smallest (Table 11). Male and female of *G. pensylvanicus* consumed lower number of giant foxtail seeds (9 and 26 respectively) than crabgrass (69 and 87 respectively) and redroot pigweed (90 and 223 respectively). Looking at the amount of biomass consumed per weed species by females it is clear that, irrespective of the number of seed consumed, there was not difference of biomass consumed between the two grass species (36 g of giant foxtail and 38 g in crabgrass).

Although redroot pigweed was the smallest seed, along with the higher number of seeds I recorded the highest amount of biomass consumed, that almost the amount of grass biomass (83 g) (Table 12). Conversely to velvetleaf, in this case the rate of consumption was related to feeding behavior/preferences rather than satiation level of the crickets. Given these results and from the biological control point of the view, *G. pensylvanicus* may have greater impact in pigweed plant population than in the other weed species tested. In the lab experiment *G. pensylvanicus* female ate an average of 223 pigweed seeds that means 223 "missing" future plants versus only 12 velvetleaf seeds or 12 "missing" future plants.

Pitfall sampling test. In arenas simulating field conditions *G. pensylvanicus* were easily captured using pitfall traps (Table 13). Eighty percent of males and 85% of females were recovered during the first night, in the 12 h period in which traps were open. Most of the crickets released were recovered in pitfall traps (Table 13). The remaining crickets were easily found under the refuges or in the first cm of soil under the straw. Both males and females were active at night, and there was no difference in the number of individuals of each sex recaptured. Based on this data it appears that *G. pensylvanicus* is susceptible to being captured in pitfall traps. These results are in contrast to Barney et al. (1979), who reported that the number of *G. pensylvanicus* evident in the field by visual observation constituted a much greater density than that demonstrated by pitfall captures. They concluded that adult field crickets did not appear to be susceptible to pitfall trapping. In my experiment *G. pensylvanicus* were readily recaptured in pitfall traps. Given this result, pitfall traps placed in the field to determine carabid beetle activity-density were checked also for field cricket abundance. The result of the field sampling confirmed the artificial arena results, showing not only that pitfall traps are effective in cricket captures

Table 13. Percentage of males and females of *Gryllus pensylvanicus* recaptured in 10 days experimental period in different sites in arenas

Site of recapture	Male		Female	
	n	%	n	%
Pitfall traps	32	80	34	85
Wood refuges	4	10	6	15
Ceramic refuges	1	4	0	0
Soil-straw surface	3	6	0	0
Total	**40**	**100**	**40**	**100**

but also that, given that carabid weed seed feeders and *Gryllus pensylvanicus* occur in the field at the same time in the season, the same pitfall traps can be used for captured both groups of insects.

Seasonal abundance of *G. pensylvanicus*. Seasonal pitfall captures showed that adult crickets were active from August 19 to October 15, and reached a peak in September 17 (Fig. 19 A). According to Alexander (1957), the northern field cricket is a fall brood, active from August to the end of October early-November depending on the weather conditions. Particularly in Michigan, *G. pensylvanicus* is active as an adult after August 5 (Alexander, personal communication). Throughout the sampling period, switchgrass had a higher number of crickets than the legume-grass mixture and soybean (F = 6.09; *P* = 0.03) (Fig. 19 B). Switchgrass is a less disturbed system compared with soybean. According to Smith (1959) *G. pensylvanicus* was observed in large numbers along roadsides with a bare or sparsely covered slope on the field side of the ditch. The bottom of the ditch and the other slope up to the roadway were usually covered with a moderate to heavy growth of weeds and grass. In their studies of predation of green cloverworm, *Plathypena scabra* (F.), in soybean fields Bechinski et al. (1983) found that, among other predators, *G. pensylvanicus* occurred in higher numbers at the fencerow, where the predominant vegetation was smooth bromegrass, *Bromus inermis* Leysser, compared with soybean. These results show that less disturbed habitats containing grasses appear suitable for *G. pensylvanicus*.

Although the seasonal activity pattern was similar for both sexes, males reached peak on

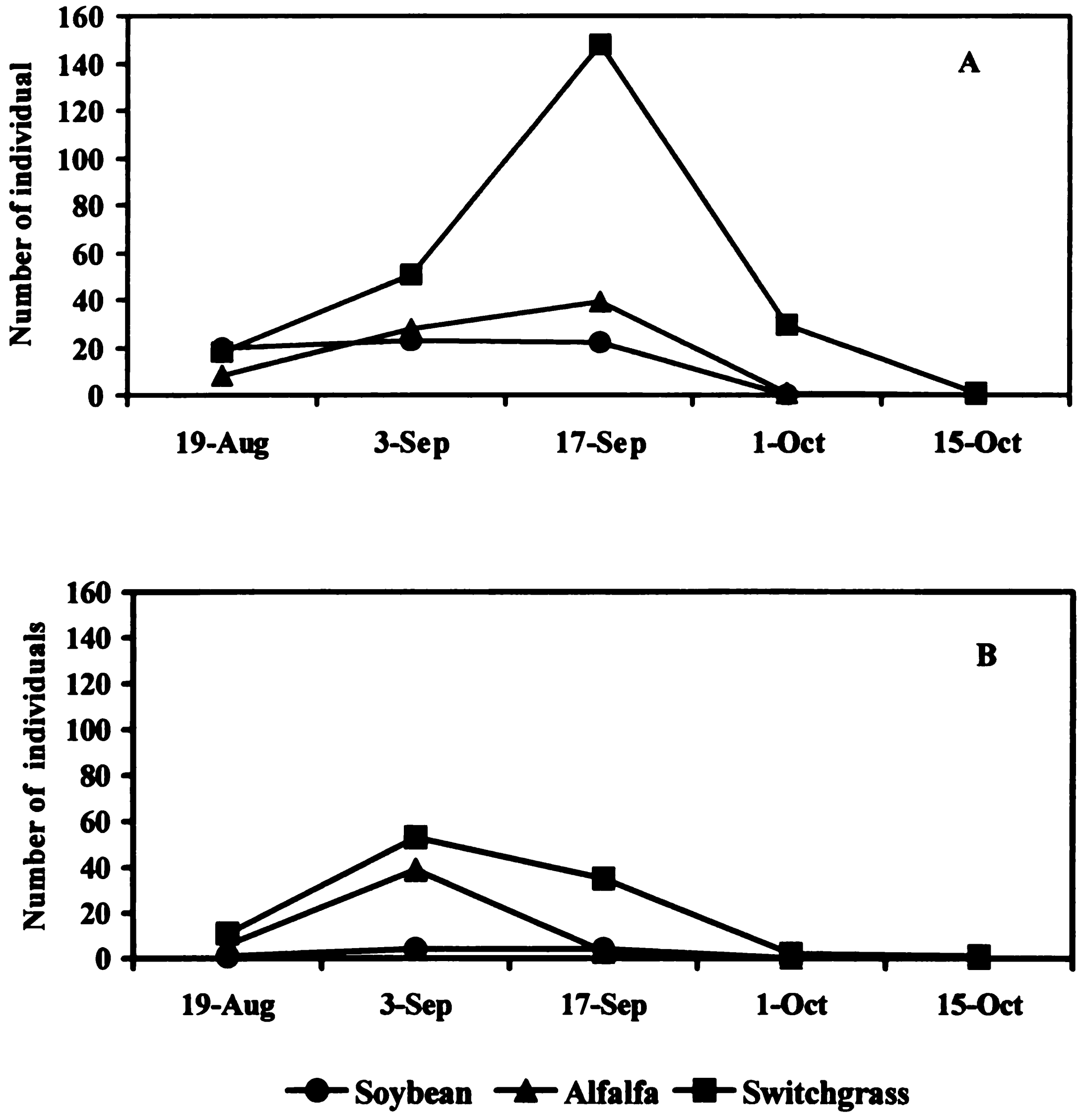


Figure 19. Seasonal bundance of *Gryllus pensylvanicus* in the three different systems. A.- Female. B.- Male

September 3, 14 days before females. The occurrence of both males and females in different habitats followed the same pattern (Fig. 14 A &B), with a higher number of individuals in switchgrass than in alfalfa-timothy grass or soybean (Table 14). The sex ratio of individuals captured was very heterogeneous between different habitats and trapping sites and throughout the season (Table 14).

The results of this study showed that *G. pensylvanicus* is susceptible to pitfall trapping under controlled conditions and that pitfall traps can be used in the field to detect presence of *G pensylvanicus* in different habitats. The relative efficiency of capture in different habitats would need to be researched prior to using pitfall as a quantitative measure of cricket abundance /activity.

G. pensylvanicus was present in stable habitats surrounding fields (filter strips) and in lower numbers in the field itself in the late summer and fall, coincident with seed rain of common agricultural weeds.

Coup'ed with the observation that *G. pensylvanicus* can consume large numbers of weed seeds in the laboratory, it appears that may be this specie may be contributing to seed predation in the field.

Finally, further studies are necessary to determine food preferences of *Gryllus pensylvanicus* (animal versus vegetable material; seeds versus other plant parts) in laboratory and in the field; habitat preference (to oviposition and overwinter eggs and nymphs), and the sex ratio in different habitats and during the season. Although, some aspects about this field cricket are still unknown, *Gryllus pensylvanicus* should be considered, along with some carabid beetle species, as potentially important groups of natural enemies in weed management programs. Conservation of these natural enemies in agricultural systems should be considered as part of an integrated weed management program.

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APPENDIX

APPENDIX 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 1998-05

Title of thesis or dissertation (or other research projects):

Influence of Refuge Habitats on Seasonal Activity-Density of Ground Beetles (Coleoptera: Carabidae) and Northern Field Cricket (*Gryllus pensylvanicus* Burmeister)

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name (s) (typed)

Dora Mabel Carmona

Date 6 August 1998

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America. Bull. Entomol. Soc. Amer. 24:141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Included as Appendix 1 in copies of thesis or dissertation. Museum(s) files. Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

APPENDIX 1.1

Voucher Specimen Data

Page 1 of 3 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
COLEOPTERA: CARABIDAE									
Agonum cupripenne (Say)	USA, MI Ingham Co. East Lansing Entomology Farm MSU, June 1997					10			
Agonum placidum (Say)						10			
Amara aenea (De G.)						10			
Anisodactylus rusticus (Say)						10			
Anisodactylus sanctaecrucis (F.)						10			
Bembidion nitidum (Kby.)						5			
Bembidion quadrimaculatum L.						5			
Chlaenius impunctifrons Say						10			
Chlaenius tricolor Dej.						10			

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Dora Mabel Carmona

Date 6 August 1998

Voucher No. 1998-05

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date 6 Aug 1998

APPENDIX 1.1

Voucher Specimen Data

Page 2 of 3 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Clivina impressefrons Le C.	USA, MI Ingham Co. East Lansing Entomology Farm MSU, July 1997					5			
Clivina bipustulata (F.)						3			
Cyclotrachelus sodalis (Le C.)						10			
Elaphropus anceps (Le C.)						4			
Harpalus herbivagus Say						10			
Harpalus pensylvanicus (De G.)						10			
Patrobus longicornis (Say)						3			
Poecilus chalcites (Say)						10			
Poecilus lucublandus (Say)						10			

(Use additional sheets if necessary)

Investigator's Name(s) (typed)
Dora Mabel Carmona

Date 6 August 1998

Voucher No. 1998-05
Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date 6 Aug 1998

APPENDIX 1.1

Voucher Specimen Data

Page 3 of 3 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Pterostichus melanarius (Ill.)	USA, MI Ingham Co. East Lansing Entomology Farm MSU, July 1997					10			
Pterostichus permundus (Say)						10			
Scarites quadriceps Chd.						10			
Stenolophus comma (F.)						10			
ORTHOPTERA: GRYLLIDAE									
Gryllus pensylvanicus Burm.	USA, MI Mason Old field-around house Landis Family October 1997					5	5		

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Dora Mabel Carmona

Date 6 August 1998

Voucher No. 1998-05

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Curator Date 6 Aug 1998