Generalist Predators in Reduced-Tillage Corn: Predation on Armyworm, Habitat Preferences, and a Method to Estimate Absolute Densities

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ABSTRACT

The potential impact of generalist predators on armyworm mortality was evaluated in the field, through a predator removal study, and in the laboratory, through controlled feeding trials. The most common potential armyworm predators removed from the field included ground beetles (Carabidae), rove beetles (Staphylinidae) , ants (Formicidae), and spiders (Araneae). Armyworm damage to corn plants was significantly greater where generalist predator populations were reduced, through the use of pitfall traps and exclusion arenas, than in the control where predator populations were unaltered. The differences in the proportion of damaged plants and the degree of damage between the predator removal treatment and the control were statistically significant. Generalist predator consumption rates of live armyworm larvae in the laboratory were variable, however most predators did feed on the larvae. Large carabid beetles, including *Pterostichus chalcites* Say, *Pterostichus lucublandus* Say, and *Scarites subterraneus* F., exhibited the highest consumption rates.

Generalist predators were sampled in four reduced-tillage corn systems which differed in the degree of soil disturbance and quantity and structure of the surface mulch due to tillage and cover crop management practices. The two sampling methods which were used, pitfall trapping and vacuum sampling, showed similar trends in predator abundance. The treatment with the highest degree of mulch ground cover had the highest overall predator abundance while the treatment which was disked and had no surface mulch had the lowest. Athough several species tended to prefer the system with the least amount of ground cover, most of the common species preferred the treatment with the most groundcover. Pitfall trap catches over a three-day period indicated that predator activity was significantly higher during the day than night in all treatments. However, a laboratory study provided evidence that night activity in the field may have been reduced due to unusually low temperatures. Catch data from pitfall traps, unbaited and baited with live armyworm larvae, indicated that long-distance chemical detection is not an important cue for generalist predators in finding armyworm as prey.

A removal sampling technique was used and evaluated for estimating the absolute densities of ground beetles (Carabidae). Removal sampling is a method of absolute density estimation based on the decline in successive catch numbers as individuals are removed from a population. Field arenas were used to isolate sampling areas in a no-till corn field and barrier pitfall traps were installed within the arenas to remove the carabids. Three three-week sampling trials were conducted in 1991 providing data for estimates on 5 June, 26 June, and 17 July. A single six-week sampling period was conducted in 1992 providing data for estimates on 2 June based on three, four, five, and six weeks of sampling. A linear regression method was used for calculating the estimate from the removal sampling data. The technique's practicality and agreement with the assumptions of removal sampling are discussed.

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Introduction

Recent studies have demonstrated that generalist predator assemblages can be important biological control agents in agroecosystems (Brust et al. 1985, Chiverton 1986, Hance 1986, Grafius & Warner 1989, Riechert & Bishop 1990, Dennis & Wratten 1991). Although they may not exhibit the density-dependent prey tracking typical of specialists, many generalist predators show evidence of flexible functional responses to differing prey densities, thus enabling them to maintain prey below outbreak levels (Best & Beegle 1977b, Kajak 1978). Agricultural practices which conserve generalist predators can increase the level of natural pest control and thus may reduce the need for insecticide applications.

The role of generalist predators in controlling armyworm (*Pseudaletia unipuncta* Haworth) in reduced-tillage corn and the influence of agricultural practices upon them has been studied to some extent, but several questions remained unanswered. First, although many generalist predators have been shown to prey on lepidoperan larvae (Frank 1967, 1971b, Best & Beegle 1977a, b, Lund & Turpin 1977, Lesiewicz et al. 1982, Brust et al. 1985) including armyworm (Brust et al. 1986b), studies have yet to show that an assemblage of generalist predators can have a significant impact on armyworm mortality. Second, the relative importance of different predatory species or groups in preying upon armyworm has not yet been examined. Third, the influence of habitat manipulations on generalist predator populations in reduced-tillage corn needs to be evaluated to determine which practices conserve or enhance their numbers. These questions are addressed in this thesis for the purpose that the information obtained might be used for better management of biological resources, safer production of food, and a more sustainable approach to agriculture.

The objectives of this study are:

1) To evaluate the role of generalist predators in the control of armyworm (*Pseudaletia unipuncta* Haworth) in reduced-tillage corn.

2) To determine the habitat preferences of common generalist predators in reduced-tillage corn.

3) To estimate the absolute densities of carabid beetles in a no-till corn field using a removal sampling method.

Literature Review

Generalist Predators in Corn Agroecosystems

Generalist predators in corn agroecosystems include members of the insect families Carabidae, Staphylinidae, Cicindelidae, Coccinellidae, Histeridae, Formicidae, and various Hemiptera. Other common predatory arthropod groups include Chilopoda, Araneae, Opiliones (Phalangida), and Acari. The composition of generalist predator assemblages varies among locations, over time, and with human manipulation. Brust et al. (1986b) observed predation upon tethered lepidopterous larvae in Ohio corn systems and found Carabidae, Phalangida, Staphylinidae, and Chilopoda to be the most important predatory groups in the early part of the corn season. *Pterostichus chalcites* Say and *Amphasia sericia* Harris were the most important adult carabids at this time while carabid larvae of several genera were also important. Later in the season larger carabids, *Pterostichus tartaricus* Say, *Abacidus permundus* Say, and *Harpalus pennsylvanicus* DeGeer, became the most important predators. Predation rates, which varied with the time of day, were lowest at mid-day and highest near midnight. Few other studies have used visual observation techniques to identify predators in corn systems under field conditions (Kirk 1973). Other studies have used serological techniques (Lund & Turpin 1977, Lesiewicz et al. 1982) and laboratory feeding experiments (Best & Beegle 1977a, b) to identify arthropods which are predacious on particular corn pests. Most of these studies have focused upon carabid species.

Laub & Luna (1992), sampling with pitfall traps, found the most abundant predators in several no-till corn fields in southwestern Virginia to be the carabids, *Pterostichus chalcites, P. lucublandus* Say, *Scarites subterraneus* F., and *S. substriatus* Haldeman, and members of the spider families, Lycosidae and Thomisidae. Harpalini and *Amara* spp. were also commonly collected, however the predatory behavior of these carabids is not well known.

Influence of Habitat Manipulations on Generalist Predators

Habitat manipulations in agroecosystems may have considerable influence on generalist predator populations and species composition within a community. These manipulations may include the use or non-use of pesticides, addition of mulch, manure, or compost, use or non-use of tillage, or altering of the combinations of crops grown either spatially or temporally. The effect on predator populations may be either direct, such as from the use of pesticides (Asteraki et al. 1992), or indirect by influencing microclimate (Honek 1988), prey populations (Chiverton 1984) or habitat structure (Riechert & Bishop 1990).

Some studies have demonstrated that reduced-tillage agroecosystems tend to have higher generalist predator abundances and/or species diversity than those that are conventionally-tilled (House & All 1981, House & Stinner 1983, Blumberg & Crossley 1983, House and Parmelee 1985, House & Alzugaray 1989). This difference may be at least partially due to reduced-tillage systems supporting a detritus-based prey source that is available to predators year-round (Stinner & House 1990). In addition, the crop residues left on the soil surface of reduced-tillage systems may provide a preferred habitat for many generalist predators (Warburton & Klimstra 1984, Honek 1988, Laub & Luna 1992). For example, Brust et al. (1985) observed higher predator abundances and lower black cutworm damage in no-tillage compared to conventional-tillage corn. Other researchers have found generalist predator abundances and diversity to be relatively independent of tillage disturbances although species compositions may be influenced (Ferguson & McPherson 1985, Barney & Pass 1986).

Numerous studies have been conducted to determine the effects of insecticides on generalist predators, and the results have been variable. Although biological control advocates have frequently cited examples where insecticides upset natural prey-predator balances thus causing pest outbreaks (Debach & Rosen 1991), some studies have actually shown increases in certain predator abundances after insecticide applications (Thornhill & Edwards 1985, Inglesfield 1989, Quinn et al. 1991). There are several possible reasons for this phenomenon. First, highly invasive predatory species may move into areas soon after a disturbance by insecticides or second, predators actually may not be more abundant but rather more active. Higher activity, which may be caused by increased searching due to a lack of prey, would be reflected in higher pitfall catches (Chiverton 1984). Many studies, however have shown that insecticides reduce generalist predator abundances. Matcham & Hawkes (1985) found overall generalist predator abundances (including carabids, staphylinids, and spiders) to be 30 percent lower in wheat treated with deltamethrin than in the untreated control. Basedow et al. (1985) found that although carabids were not influenced, staphylinids and linyphiids were severely reduced in winter wheat after the application of deltamethrin. Asteraki et al. (1992) observed that several carabid species in pastures were quite sensitive to chlorpyrifos while others appeared to be unaffected. Rushton et al. (1989) used classification and ordination techniques to determine the influence of various pasture management practices on carabid and spider community structure. They found that the frequency of chlorpyrifos use was a significant factor in determining carabid and spider community composition however they did not present information concerning differences in the effectiveness of the predatory communities in controlling pests or differences in species diversity. Perfecto (1990) showed that chlorpyrifos reduced ant foraging resulting in higher corn leafhopper abundance in a Nicaraguan corn system. Carbofuran had a similar effect on ant foraging and resulted in higher fall armyworm abundances. Mansour (1987) monitored spider population abundances in two sprayed and one unsprayed cotton field in Israel. The pesticides used included chlorinated hydrocarbons, organophosphates, and pyrethroids. The unsprayed field had nearly twice as many spiders per meter of cotton as the sprayed fields. Whiteford et al. (1987) studied the effect on spider families of carbaryl and fenvalerate applications for European corn borer. Only one family, Tetragnathidae, was significantly reduced after an insecticide application and the population appeared to recover within one month. In general, the extent of predator reduction due to insecticides depends upon various factors including the chemical used, the number and timing of applications, the life cycle and sensitivity of the predator species, and the effect on prey populations (Pfrimmer 1964, Brown et al. 1983, Zoebelein 1988, Rushton et al. 1989, Showler & Reagan 1991).

Herbicides have been found to influence generalist predator populations. Most research has indicated that the mechanism is indirect and that the elimination of weeds reduces habitat and herbivorous prey populations thus reducing predators as well (Ahmed et al. 1987, Showler & Reagan 1991). Powell et al. (1985) studied the effect of several herbicide treatments on generalist predators (including Carabidae, Staphylinidae, and Araneae) in winter wheat in England. They found no differences in overall predator numbers among the treatments but did find that certain species preferred particular treatments. Significantly more large carabids were captured in the herbicide-treated plots indicating that their movement may have been restricted by vegetation in the untreated plots. Several carabid and staphylinid species had significantly reduced pitfall catches in the herbicide treatments.

Cover crops used in agroecosystems influence nutrient availability, soil structure, and insect and weed abundances. Research has shown that different methods of cover crop management can have different influences on predator and pest populations. Altieri et al. (1985) reported higher pitfall catches of staphylinids and spiders in a tomato system with a mowed cover crop of clover compared to one which was clean cultivated, however carabid catches did not differ between the two systems. In a study of apple orchards, Altieri & Schmidt (1986) found that an orchard with a clover cover crop tended to have higher spider densities but lower carabid densities than one that was disked. Similarly, Riechert & Bishop (1990) observed significantly higher spider densities and less insect damage in mulched compared to non-mulched garden plots. In addition, 98% of observed predation events were by spiders.

Some studies have compared the influences of different farming systems on generalist predators (Rushton et al. 1989). Hance & Gregoire-Webo (1987) collected carabids in pitfall traps from 16 fields over a 4 year period and analyzed the data using correspondence analysis. The fields varied in crops grown, herbicide and insecticide applications, and manure applications. The authors found that applications of manure tended to increase total abundance and diversity. Overwintering adult carabids were sensitive to fall tillage, whereas those species which overwintered as larvae were not as sensitive. Insecticide usage tended to decrease carabid abundance and diversity. Three studies have compared carabids in organically managed and conventionally managed agroecosystems (Dritschillo and Wanner 1980, Hokkanen & Holopainen 1986, Kromp 1989). Although all three studies found higher abundance and species richness in the organically managed agroecosystems, none of the studies found significant differences in carabid species diversity. Dritschilo & Erwin (1982) reanalyzed data originally published by Dritschillo & Wanner (1980) and suggested that diversity indices are insensitive indicators of changes in carabid communities. Jarosik (1991) argued that long-term catch data are needed when comparing species diversity. Short-term catch data, such as those used by Dritschilo & Erwin (1982), are too variable due to meteorlogical factors and community structure.

Armyworm as a Pest in Corn

The armyworm is a sporadic and unpredictable pest of grass and cereal crops in the eastern half of North America. It occurs most frequently east of the Rocky Mountains but has been found in New Mexico and California (Walton & Packard 1940). It also occurs in South America, England, India, Java, Australia, and New Zealand (Howard 1894, Walton & Packard 1940).

Armyworm larvae have been reported to feed on rye, oats, barley, beets, sorghum, corn, and various grasses (Howard 1894, Davis & Satterthwait 1916, Walton & Packard 1940). Armyworm populations usually do not reach pest levels but can cause extensive crop damage periodically. In the 100-year period from 1860 to 1960, eight widespread outbreaks occurred in North America (Guppy 1961).

No-till corn following a small grain cover crop is at higher risk of armyworm damage than conventional corn because the cover crop provides a preferred oviposition substrate for armyworm females (Breeland 1958). Harrison et al. (1980) found armyworm and black cutworm damage to be consistently higher in no-till compared to conventionally grown sweet corn over a five-year period in Maryland. According to Breeland (1958) the moths lay their eggs in masses in or near fields of young grain or small grasses. Although the number of larval instars varies slightly with climate, there are generally six instars in the mid-Atlantic region. The number of generations per year varies with climate but only the first causes severe damage (Breeland 1958). In Virginia, the first generation can usually be expected in May or June.

According to several authors, armyworm usually overwinters as a partially grown larvae (Howard 1896, Breeland 1958, Pond 1960). Armyworm has also been reported to spend winters in southern United States as an adult, pupa, and rarely as an egg (Howard 1896). The overwintering larvae complete their life cycle in early spring, during which larvae burrow into the soil to pupate. The emergence of adults varies with climate. In Tennessee it usually occurs in mid-April (Breeland 1958).

According to Laub & Luna (1992) the most common parasitoids of armyworm in southwestern Virginia are *Periscepsia laevigata* Wulp (Diptera: Tachinidae) and *Glyptapanteles militaris* Walsh (Hymenoptera: Brachonidae). These authors found parasitism to range from 36 to 45 percent in the armyworm larvae collected from no-till corn fields. Although it has been shown that several predator groups do feed on armyworm, no studies have determined the effect of predatory arthropods on armyworm populations.

Armyworm Damage to Corn

Feeding by first- and second-instar larvae results in skeletonization of the corn leaves, whereas later instars chew holes in the leaves from the edges inward to the mid-rib (Breeland 1958). The sixth instar is responsible for more than 80 percent of the total foliage eaten during the larval stage (Davis & Satterthwait 1916). Yield reduction from armyworm varies with the developmental stage of the corn, climatic conditions, and the larval density and stage. Defoliation of young corn plants may produce comparable or even higher yields than similarly treated but undefoliated corn (Crookston & Hicks 1978). Mulder and Showers (1986) showed that corn in the 7 to 8 leaf growth stage can sustain 20 percent defoliation by armyworm without significant yield loss. These authors also reported that corn artificially infested with as many as 12 fourth- or sixth-instar armyworm per plant produced comparable yields to uninfested corn. They stated that nearly every plant had greater than 50 percent defoliation yet was able to recover.

Evaluating the Role of Predators in Biological Control

Several approaches have been used for evaluation of predation under field conditions. One method of demonstrating the impact of predators is through their removal. Significant differences in a pest abundance between sites with and without predators can strongly indicate the role of the predators in controlling the pest (Luck et al. 1988). Prey can also be added to sites, although Luck et al. (1988) warn against creating unrealistic densities and placing prey in unnatural locations. Barriers or cages can be used to maintain conditions within a site which has been altered either through the removal or enrichment of certain organisms. Such barriers can prevent artificially created conditions from moving towards an equilibrium with the surrounding area; for example, the re-establishment of a removed species, or the attraction of predators or parasites from surrounding areas. Other methods for evaluating predators include the direct observation of predatory events in the field (Brust et al. 1986b, Nyffeler & Benz 1987, Riechert & Bishop 1990) and laboratory techniques including the chemical analyses of gut contents (Frank 1967, 1971b) and controlled feeding studies (Best & Beegle 1977a, b).

Brust et al. (1985) studied predation upon black cutworm in corn with the use of metal enclosures which confined the added prey and either contained or excluded predators. The impact of the predators was evaluated according to the degree of damage to the plants within the enclosures. Brust et al. (1986a, b) used bait stations with tethered prey and visually observed predatory events. In a laboratory study, Best and Beegle (1977a) observed the food preferences of five common carabids of Iowa corn fields and found live and dead smooth-skinned lepidopteran larvae, especially black cutworm, to be favored. Riechert & Bishop (1990) and Nyffeler & Benz (1987) used visual observation techniques in the field to evaluate the role of spiders in vegetable garden and cotton systems, respectively. Lund and Turpin (1977) used serological techniques and found that from 10.2 to 26.5 percent of *P. chalcites* captured in a black cutworm-infested field had consumed black cutworm protein within the previous 24 hours. Although each of the methods mentioned can provide useful information there are also potential biases which should be considered. Therefore a variety of methods should be used when possible.

Generalist Predators as Natural Enemies of Armyworm in Corn

Few studies have investigated the importance of generalist predators in controlling armyworm. Brust et al. (1986b) showed that a variety of generalist predators will feed on tethered armyworm in the field. Although the authors observed no behavioral differences in the armyworm due to the tethering, the larvae were more vulnerable to predation under these conditions because they were prevented from climbing the corn plants. Laub & Luna (1992) found *P. chalcites* and *S. substriatus* to attack and feed on fourth and fifth instar armyworm larvae in the laboratory.

Laub and Luna (1991, 1992) found lower armyworm abundances in no-till corn in which the winter cover crop was mowed compared to that in which it was killed with a contact herbicide. This result could have been due to the direct physical destruction of the larvae by the mower or indirectly, by providing a more favorable habitat for predators, consequently increasing predation. Although the authors showed that mowing resulted in significantly higher numbers of some generalist predators, there was no direct evidence that these predators were responsible for the reduced armyworm numbers.

Sampling and Density Estimation of Adult Carabids

Pitfall traps are commonly used for sampling ground-dwelling arthropods including carabids. They are useful in determining the presence of a species in a habitat but pitfall traps do not necessarily reflect absolute or relative density since they depend on activity. Catches have frequently been termed "activity densities" and "activity abundances" (Thiele 1977). Honek (1988) and Perfecto et al. (1986) found that the density of plant cover can be an important influence on ground predator activity and thus influence pitfall trap catches. Behavioral sensitivity to pitfall traps was suggested by Lesiewicz et al. (1983), who compared pitfall trapping with insecticidal ground sprays followed by visual counts and found the two methods gave different indices of relative abundance. Although the authors felt that the insecticidal ground spray method gave a better representation of true species abundance, the results provided were not sufficient to test this. Thus, researchers should be careful in making conclusions based on pitfall trap data alone.

Pitfall traps have been used as capture tools for mark-release-recapture (Frank 1967, 1971a, Ericson 1977, Best et al. 1981) and removal trapping (Gist & Crossley 1973) methods for absolute density estimation. Frank (1967) used mark-release-recapture methods within 0.5 m^2 enclosed sampling areas to estimate the densities of 14 of the most abundant carabids in a field in central Alberta, Canada. Best et al. (1981) and Ericson (1977) used mark-release-recapture with pitfall traps arranged in a grid to estimate the densities of several carabids in an Iowa cornfield and in two winter wheat fields in Sweden, respectively. Although mark-release-recapture techniques commonly have been used, these methods are labor intensive and have several drawbacks. Low recapture rates, common in carabid studies (Manga 1972 Ericson 1977 Best et al. 1981), can lead to population estimates with questionable accuracy (Roff 1973, Gilbert 1973). If recapture rates are extremely low, density estimates are impossible to make (Ericson 1977). According to Roff (1973), standard errors of the mean are correlated with the estimate and are therefore insensitive measures of precision.

Removal trapping is a method of absolute density estimation based on the decline in successive catch numbers as individuals are removed from a population. Three assumptions are required (Zippin 1958): (1) the population is closed, (2) each individual has an equal probability of being captured, and (3) the probability of capture remains constant during each sampling period.

Gist and Crossley (1973) used removal sampling to estimate ground-dwelling arthropod densities in a hardwood forest floor. They isolated three sampling areas measuring 25 m^2 with aluminum foil strips coated with a resin and used pitfall traps to remove the organisms. Capture rate (y-axis) was plotted against the cumulative total number captured (x-axis). Linear regression was used to estimate x-intercept which represented the total number of individuals in the sampling area. Although the effectiveness of the barriers could be questioned, the results were similar to those of a hand-sorting method which was used as a comparison.

According to Southwood (1978) use of least-squares linear regression for analysis of removal sampling data is not entirely acceptable. Since the x values are not independent of one another, the independence assumption of least-squares linear regression is violated. He recommended a maximum likelihood procedure for estimating the parameters. However, Zippin (1956) found close agreement between linear regression and maximum likelihood estimates in a simulated sampling experiment. Kleinbaum et al. (1988) state that parameter estimates should be the same for these two methods under the assumption that the samples came from normally distributed populations.

Preuss and Saxena (1977) consider the suitability of removal sampling for absolute density estimation to be due more to a lack of other suitable methods than to the desirability of the qualities characteristic of this method. Isolating sufficient parts of a population in order to prevent migration is frequently impractical or impossible. This difficulty was demonstrated by Menhinnick (1963) who compared removal sampling using a sweep net to mark, release, and recapture and total count methods for estimating densities of foliage-dwelling arthropods in a field of *Lespedeza cuneata*, a perennial woody legume. Although removal sampling was limited, mainly by variation in sweep netting efficiency, it proved more useful than the other two methods in this situation. Similarly, Preuss et al. (1977) found removal sweeping in alfalfa to provide satisfactory density estimates for several foliage-dwelling insects but noted problems due to immigration during sweeping and lack of applicability of sweep netting for sampling certain insects. Although it may be difficult to satisfy all of the requirements of removal sampling for many arthropod populations, mobile ground-dwelling arthropods such as carabids seem to be among the better candidates for use of this method.

Other methods for carabid density estimation include the use of quadrats with visual searching of the ground and surface debris (Brust et al. 1985; House & Stinner 1983; House & Parmelee 1985) and soil core sampling (Dubrovskaya 1970; House & Alzugary 1989). Quadrat sampling may be more time efficient than the methods mentioned above but have some potential drawbacks. Most carabids are highly active and could flee or hide in soil crevices when they sense disturbance, such as an approaching person. In addition, most quadrat sizes are relatively small for sampling organisms with such low population densities. Soil cores may be useful for sampling carabid larvae but have similar problems to quadrats for sampling adults.

References Cited

Ahmed, S. A., A. W. M. Ali, & A. M. Salman. 1987. Effect of weed control on the diversity and abundance of insects in potatoes. Acta Horticulturae 220: 417-424.

Altieri, M. A. & L. L. Schmidt. 1986. Cover crops affect insect and spider populations in apple orchards. Calif. Agric. 40 (1): 15-17.

Altieri, M. A., R. C. Wilson, & L. L. Schmidt. 1985. The effects of living mulches and weed cover on the dynamics of foliage- and soil- arthropod communities in three crop systems. Crop Protect. 4: 201-213.

Asteraki, E. J., C. B. Hankes, & R. O. Clements. 1992. The impact of two insecticides on predatory beetles (Carabidae) in newly-sown grass. Ann. Appl. Biol. 120: 25-39.

Barney, R. J. & B. C. Pass. 1986. Ground beetle (Coleoptera: Carabidae) populations in Kentucky alfalfa and influence of tillage. J. Econ. Entomol. 79: 511-517.

Basedow, T., H. Rzehak, & K. VoB. 1985. Studies on the effect of deltamethrin sprays on the numbers of epigeal predatory arthropods occuring in arable fields. Pestic. Sci. 16: 325-331.

Best, R. L. & C. C. Beegle. 1977a. Food preferences of five species of carabids commonly found in Iowa cornfields. Environ. Entomol. 6: 9-12.

____ 1977b. Consumption of *Agrotis ipsilon* by several species of carabids found in Iowa. Environ. Entomol. 6: 532-34.

Best, R. L., C. C. Beegle, J. C. Owens, & M. Ortiz. 1981. Population density, dispersion, and dispersal estimates for *Scarites substriatus, Pterostichus chalcites*, and *Harpalus pennsylvanicus* (Carabidae) in an Iowa cornfield. Environ. Entomol. 10: 847-56.

Blumberg, A. Y. & D. A. Crossley. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage and old field systems. Agro-Ecosystems 8: 247-253.

Breeland, S. G. 1958. Ecological studies on the armyworm, *Pseudaletia unipuncta* (Haworth) in Tennessee (Lepidoptera: Noctuidae). J. Tenn. Acad. Sci. 33: 263-350.

Brown, K. C., J. H. Lawton, & S. W. Shires. 1983. Effect of insecticides on invertebrate predators and their cereal aphid (Hemiptera: Aphididae) prey: laboratory experiments. Environ. Entomol. 12: 1747-1750.

Brust, G. E., B. R. Stinner, & D. A. McCartney. 1985. Tillage and soil insecticide effects on predator-black cutworm (Lepidoptera: Noctuidae) interactions in corn agroecosystems. J. Econ. Entomol. 78: 1389-92.

_____ 1986a. Predation by soil inhabitaing arthropods in intercropped and monoculture agroecosystems. Agric. Ecosystems Environ. 18: 145-54.

_____ 1986b. Predator activity and predation in corn agroecosystems. Environ. Entomol. 15: 1017-1021.

Chiverton, P. A. 1984. Pitfall-trap catches of the carabid beetle *Pterostichus melanarius,* in relation to gut contents and prey densities, in insecticide treated and untreated spring barley. Entomol exp. appl. 36: 23-30.

_____ 1986. Predator density manipulation and its effects on populations of *Rhopalosiphum padi* (Hom.: Aphididae) in spring barley. Ann. Appl. Biol. 109: 49-60.

Crookston, R. K. & D. R. Hicks. 1978. Early defoliation effects corn grain yields. Crop Sci. 18: 485-489.

Davis, J. J. & Satterthwait. 1916. Life history studies of *Cirphus unipuncta*, the true army worm. J. Agric. Res. 6: 799-812.

Debach, P. & D. Rosen. 1991. Biological control by natural enemies. Cambridge University Press. p. 386.

Dennis, P. & S. D. Wratten. 1991. Field manipulation of populations of individual staphylinid species in cereals and their impact on aphid populations. Ecol. Entomol. 16: 17-24.

Dritschilo, W. & T. L. Erwin. 1982. Responses in abundance and diversity of cornfield carabid communities to differences in farm practices. Ecol. 63: 900-904.

Dritschilo, W. & D. Wanner. 1980. Ground beetle abundance in organic and conventional corn fields. Environ. Entomol. 9: 629-631.

Dubrovskaya, N. A. 1970. Field carabid beetles (Coleoptera: Carabidae) of Byelorussia. Entomol. Rev. 49: 476-83.

Ericson, D. 1977. Estimating population parameters of *Pterostichus cupreus* and *P. melanarius* (Carabidae) in arable fields by means of capture-recapture. Oikos 29: 407-17.

Ferguson, H. J. & R. M. McPherson. 1985. Abundance and diversity of adult Carabidae in four soybean cropping systems in Virginia. J. Entomol. Sci. 20: 163-171.

Frank, J. H. 1967. The insect predators of the pupal stage of the winter moth, *Operophtera brumata* (L.) (Lepidoptera: Hydriomenidae). J. Animal Ecology 36: 375-89.

_____ 1971a. Carabidae (Coleoptera) of an arable field in central Alberta. Quaes. Entomol. 7: 237-52.

_____ 1971b. Carabidae (Coleoptera) as predators of the red-backed cutworm (Lepdoptera: Noctuidae) in Central Alberta. Can. Entomol. 103: 1039-1044.

Gilbert, R. O. 1973. Approximations of the bias in the Jolly-Seber capture-recapture model. Biometrics 29: 501-26.

Gist, C. S. & D. A. Crossley. 1973. A method of quantifying pitfall trapping. Environ. Entomol. 2: 951-52.

Grafius, E. & F. W. Warner. 1989. Predation by *Bembidion quadrimaculatum* (Coleoptera: Carabidae) on *Delia antiqua* (Diptera: Anthomyiidae). Environ. Entomol. 18: 1056-1059.

Guppy, J. C. 1961. Life history and behavior of armyworm, *Pseudaletia unipuncta* (Haw.)(Lepidoptera: Noctuidae) in eastern Ontario. Can. Entomol. 93: 1141-53.

Hance, T. 1986. Predation impact of carabids at different population densities on *Aphis fabae* development in sugar beet. Pedobiologia 30: 251-262.

Hance, T. & C. Gregoire-Wibo. 1987. Effect of agricultural practices on carabid populations. Acta Phytopath. Entomol. Hung. 22: 147-160.

Harrison, F. P., R. A. Bean, & O. J. Qawiyy. 1980. No-till culture of sweet corn in Maryland with reference to insect pests. J. Econ. Entomol. 73: 363-365.

Hokkanen, H. & J. K. Holopainen. 1986. Carabid species and activity densities in biologically and conventionally managed cabbage fields. J. Appl. Entomol. 102: 353-363.

Honek, A. 1988. The effect of crop density and microclimate on pitfall trap catches of Carabidae, Staphylinidae (Coleoptera), and Lycosidae (Araneae) in cereal fields. Pedobiologia 32: 233-242.

House, G. J. & J. N. All. 1981. Carabid beetles in soybean agroecosystems. Environ. Entomol. 10: 194-196.

House, G. J. & M. Del Rosario Alzugaray. 1989. Influence of cover cropping and no-tillage practices on community composition of soil arthropods in a North Carolina agroecosystem. Environ. Entomol. 18: 302-307.

House, G. J. & R. W. Parmelee. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Tillage Res.5: 351-360.

House, G. J. & B. J. Stinner. 1983. Arthropods in no-tillage soybean agroecosystems: community composition and ecosystem interactions. Environ. Mgmt. 7: 23-28.

Howard, L. O. 1894. The armyworm. USDA circular no. 4, second series.

Inglesfield, C. 1989. Pyrethroids and terrestrial non-target organisms. Pestic. Sci. 27: 387-428

Jarosik, V. 1991. Are diversity indices of carabid beetle (Col: Carabidae) communities useful, redundant, or misleading? Acta. Entomol. Bohemoslov 88: 273-279.

Kajak, A. 1978. Analysis of consumption by spiders under laboratory and field conditions. Ekol. Pol. 26: 409-27.

Kirk, V. M. 1973. Biology of a ground beetle, *Harpalus pensylvanicus*. Ann Entomol. Soc. Amer. 66: 513-518.

_____ 1975. Biology of *Pterostichus chalcites*, a ground beetle of cropland. Ann. Entomol. Soc. Amer. 68: 855-858

Kleinbaum, D. G., L. L. Kupper, & K. E. Muller. 1988. Applied regression analysis and other multivariate methods. PWS-KENT Pub. Co., Boston.

Kromp, B. 1989. Carabid beetle communities (Carabidae: Coleoptera) in biologically and conventionally farmed agroecosystems. Agric. Ecosystems Environ. 27: 241-251.

Laub, C. A. & J. M. Luna. 1991. Influence of winter cover crop suppression practices on seasonal abundance of armyworm (Lepidoptera: Noctuidae), cover crop regrowth, and yield in no-till corn. Environ. Entomol. 20: 749-54.

_____ 1992. Winter cover crop suppression practices and natural enemies of armyworm (Lepidoptera: Noctuidae) in no-till corn. Environ. Entomol. 21: 41-49.

Lesiewicz, D. S., J. L. Lesiewicz, J. R. Bradley, & J. W. Van Duyn. 1982. Serological determination of carabid (Coleoptera: Adephaga) predation on corn earworm (Lepidoptera: Noctuidae) in field corn. Environ. Entomol. 11: 1183-1186.

Lesiewicz, D. S., J. W. Van Duyn, & J. R. Bradley Jr. 1983. Determinations on cornfield carabid populations in northeastern North Carolina. Environ. Entomol. 12: 1636-40.

Luck, R. F., B. M. Shepard, & P. E. Kenmore. 1988. Experimental methods for evaluating arthropod natural enemies. Ann. Rev. Entomol. 33: 367-391.

Lund, R. D. & F. T. Turpin. 1977. Serological investigation of black cutworm larval consumption by ground beetles. Ann. Entomol. Soc. Amer. 70: 322-324

Manga, N. 1972. Population metabolism of *Nebria brevicollis* (F.) (Coleoptera: Carabidae). Oecologia 10: 223-42.

Mansour, F. 1987. Spiders in sprayed and unsprayed cotton fields in Israel, their interactions with cotton pests and their importance as predators or the Egyptian cotton leaf worm, *Spodoptera littoralis*. Phytoparasitica 15: 31-41.

Matcham, E. J. & C. Hawkes. 1985. Field assessment of the effects of deltamethrin on polyphagous predators in winter wheat. Pestic. Sci. 16: 317-320.

Menhinick, E. F. 1963. Estimation of insect population density in herbaceous vegetation with emphasis on removal sweeping. Ecol. 44: 617-621.

Mulder, P. P. & W. B. Showers. 1986. Defoliation by armyworm (Lepidoptera: Noctuidae) on field corn in Iowa. J. Econ. Entomol. 79: 368-373.

Murdoch, W. W., J. Chesson, & P. L. Chesson. 1985. Biological control in theory and practice. Am. Nat. 125: 344-366.

Nentwig, W. 1988. Augmentation of beneficial arthropods by strip management. Oecologia 76: 597-606.

Nyffeler, M. & G. Benz. 1987. Spiders in natural pest control: a review. J. Appl. Entomol. 103: 321-39.

Perfecto, I. 1990. Indirect and direct effects in a tropical agroecosystem: the maize-pest-ant system in Nicaragua. Ecology 71: 2125-2134.

Perfecto, I., B. Horwith, J. Vandermeer, B. Schultz, H. McGuinness, & A. Dos Santos. 1986. effects of plant diversity and density on the emigration rate of two ground beetles, *Harpalus pennsylvanicus* and *Evarthrus sodalis* (Coleoptera: Carabidae) in a system of tomatoes and beans. Environ. Entomol. 15: 1028-1031.

Pfrimmer, T. R. 1964. Populations of certain insects and spiders on cotton plants following insecticide applications. J. Econ. Entomol. 57: 640-644.

Pond, D. D. 1960. Life history studies of the armyworm *Pseudaletia unipuncta* (Lepidoptera: Noctuidae) in New Brunswick. Ann. Entomol. Soc. Amer. 53: 661-665.

Powell, W., G. J. Dean, & A. Dewar. 1985. The influence of weeds on polyphagous arthropod predators in winter wheat. Crop Protect. 4: 298-312.

Preuss, K. P. & K. M. Lal Saxena. 1977. Estimation of insect populations by removal sampling. Ag. Exp. Station Rep. 4. Univ. of Nebraska.

Preuss, K. P., K. M. Lal Saxena, & S. Koinzan. 1977. Quantitative estimation of alfalfa insect populations by removal sweeping. Environ. Entomol. 6: 705-708.

Quinn, M. A., R. L. Kepner, D. D. Walgenbach, R. N. Foster, R. A. Bohls, P. D. Pooler, K. C. Reuter, & J. L. Swain. 1991. Effects of habitat characteristics and perturbation from insecticides on the community dynamics of ground beetles (Coleoptera: Carabidae) on mixed grass-rangeland. Environ. Entomol. 20: 1285-1294.

Riechert S. E. & L. Bishop. 1990. Prey control by an assemblage of generalist predators: spiders in garden test systems. Ecology 71: 169-72

Riechert, S. E. & T. Lockley. 1984. Spiders as biological control agents. Ann. Rev. Entomol. 29: 299-320.

Roff, D. A. 1973. On the accuracy of some mark-recapture estimators. Oecologia 12: 15-34.

Rushton, S. P., M. L. Luff, & M. D. Dyre. 1989. Effects of pasture improvement and management on the ground beetle and spider communities of upland grasslands. J. Appl. Ecol. 26: 489-503.

Showler, A. T. & T. E. Reagan. 1991. Effects of sugarcane borer, weed, and nematode control strategies in Louisiana sugarcane. Environ. Entomol. 20: 358-370.

Southwood, T. R. E. 1978. Ecological methods. Chapman and Hall, London.

Stinner, B. R. & G. J. House. 1990. Arthropods and other invertebrates in conservation-tillage agriculture. Annu. Rev. Entomol. 35: 299-318.

Thiele, H. -U. 1977. Carabid beetles in their environments. Springer-Verlag. New York.

Thornhill, W. A. & C. A. Edwards. 1985. The effects of pesticides and crop rotation on the soil-inhabiting fauna of sugar-beet fields. Part I: the crop and macroinvertebrates. Crop Protect. 4: 409-422.

Walton, W. R. & C. M. Packard. 1940. The armyworm and its control. USDA Farm. Bull. No. 1850.

Warburton, D. B. & W. D. Klimstra. 1984. Wildlife use of no-till and conventional tilled corn fields. J. Soil Water Conserv. 39: 327-330.

Whiteford, F., W. B. Showers, & G. B. Edwards. 1987. Insecticide tolerance of ground- and foliage-dwelling spiders (Araneae) in European corn borer action sites. Environ. Entomol. 16: 779-785.

Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. Biometrics 12: 163-189.

_____ 1958. The removal method of population estmation. J. Wildlife Management 22: 82-90.

Zoebelein, G. 1988. Long-term field studies about pesticide effects on ladybird beetles (Coleoptera: Coccinellidae). Entomol. Gener. 13: 175-187.

Chapter 2

Armyworm Predation by Ground-Dwelling Generalist Predators in No-tillage Corn

The importance of generalist predators in regulating herbivorous pests in agroecosystems has been demonstrated (Edwards et al. 1979, Brust et al. 1985, Chiverton 1986, Riechert & Bishop 1990, Perfecto & Sediles 1992). Although generalist predators may not exhibit the density-dependent prey tracking typical of specialists, many generalists have been shown to exhibit flexible functional responses to differing prey densities, thus enabling them to maintain prey below outbreak levels (Best & Beegle 1977, Kajak 1978, Riechert & Lockley 1984, Murdoch et al. 1985, Hance 1987, Dennis & Wratten 1991). Therefore there is a need to evaluate the role of generalist predators when desiging integrated pest management programs for agroecosystems.

Armyworm (*Pseudaletia unipuncta* Haworth) is a sporadic and unpredictable pest of grass and cereal crops in the eastern half of North America. Although populations usually do not reach pest levels, armyworm has periodically caused extensive crop damage (Breeland 1958, Guppy 1961). No-till corn following small grain cover crops is at higher risk of armyworm damage than conventional-till corn because the cover crop provides a preferred oviposition substrate for armyworm adult females (Harrison et al. 1980, Tonhasca & Stinner 1991). Although the impact of generalist predators on some lepidopterous pests has been documented (Frank 1967, 1971, Lund & Turpin 1977, Lesiewicz et al. 1982, Brust et al. 1985, 1986), there has been little research concerning their predation on armyworm. In a study by Laub & Luna (1992) high numbers of certain carabid beetles and spiders were followed by a decrease in armyworm abundance, suggesting the possible importance of the predators in controlling armyworm.

The objectives of this study were to evaluate the relative consumption rates of armyworm larvae by common ground-dwelling generalist predators under laboratory conditions and to determine the importance of an assemblage of generalist predators in the control of armyworm by evaluating the effect of their removal on corn damage in the field.

Methods and Materials

Laboratory Feeding Study. Pitfall traps were used to collect live predators from April to June 1992 in one no-tillage and two reduced-tillage corn fields in Montgomery County, Virginia: the Virginia Polytechnic Institute & State University (VPI & SU) dairy science farm, the VPI & SU Whitethorne research farm, and the Bishop farm, a commercial dairy farm. Each pitfall trap consisted of a plastic cup (474 ml, 11 cm rim diameter) placed into the ground so that the rim was flush with the soil surface. Predators collected were separated by species, maintained in aquaria on a moist sand substrate (2 cm deep) and provided with live collembola and mites (Acarina) as food. In addition, carabids and staphylinids were given dry dog food (Richfood®).

Fifteen arthropod taxa were entered into armyworm feeding trials. The taxa, representing 5 families (Carabidae, Staphylinidae, Coccinellidae, Lycosidae, Phalangiidae), included the carabids: *Scarites subterraneus* F., *Pterostichus lucublandus* Say, *Pterostichus chalcites* Say, *Agonum cupripennis* Say, *Agonum punctiforme* Say, *Amara cupreolata* Putzeys, *Amara familiaris* Duftschmid, *Anisodactylus carbonarius* Say, and *Anisodactylus harrisi* Leconte, the staphylinids: *Philonthus cognatus* Stephens, *Philonthus lomatus* Erichson, and *Platydracus maculosus* Gravenhorst, the lycosids: *Pardosa milvina* Hentz, *Pardosa saxatilis* Hentz, and *Lycosa helluo* Walckenaer, the coccinellid: *Coccinella septempunctata* L., and the phalandiid: *Phalangium opilio* L.

Armyworm larvae were reared from eggs of a laboratory culture provided by J. M. McNeil (Laval University, Quebec, Canada). Larvae were maintained in 95 x 15 mm petridishes and fed rye foliage (*Secale cereale* L.) which had been stored frozen for at least 48 hours.

Two separate 24-h predator feeding trials were conducted in June 1992; one using second-instar and the other using fourth- instar armyworm as prey. Armyworm instars were determined using head capsule measurements (Breeland 1958). Each predator was placed singly into a 95 x 15 mm petridish containing a 4 x 4 cm piece of moistened paper towel on the bottom, and starved for 24-h before the start of each feeding trial. Petridishes containing predators were kept in an environmental control chamber (14: 10 [L: D]h, 25°C). The number of individual predators of each species entered into a feeding trial depended upon availability from field capture with 15 being the maximum.

Initially two armyworm larvae of the designated instar were placed in each petridish. All petridishes were checked at 8, 16, and 24 h. At 8 h a number of armyworm equal to twice the number preyed upon was added and any remaining live larvae were replaced. Partially consumed larvae were considered to be preyed upon, however the remains were not removed from the petridishes. If neither of the larvae had been preyed upon they were replaced but no additional larvae were provided at that time. At 16 h, only the number of larvae consumed during the previous 8-h period was added. This limited each predator to a maximum of 10 armyworm larvae during a 24-h trial. The results of predators which died during a trial were not considered in the analysis.

Predator Removal Study. The role of ground-dwelling generalist predators in controlling armyworm was evaluated in a no-till corn field in Riner, Virginia (Bishop farm) in 1992. The field, which was a silt loam soil (Berks-Lowell-Rayne complex), had been planted in no-till corn with a winter rye cover crop for two years before this study.

A mixture of alfalfa and orchard grass hay had been grown in the field for the preceding three years. No insecticides had been applied since 1989. Before corn was planted, paraquat (0.23 kg [AI]/ha) was applied to kill the rye cover crop and herbicides (atrazine, 2.2 kg [AI]/ha, simazine, 2.2 kg [AI]/ha) were applied for weed control. Corn (Southern States 728) was planted on 25 May. Liquid dairy manure (7660 l/ha) and liquid urea (78 kg N/ha) were applied to the field at planting.

Six square (2.39 x 2.39 m) predator-removal arenas were installed in randomly-selected locations within a 40 x 40 m study area on 2 June. The arenas were constructed of galvanized steel strips 23 cm high and enclosed an area 5.70 m^2. The bottom edge of an arena was manually driven 3 to 4 cm into the ground. Two barrier pitfall traps (Hilburn 1985) were used to remove predators from the arenas. A trap consisted of an aluminum barrier (flashing strip), 90 cm long and 10.3 cm wide, placed into a 3 cm deep cut in the ground. A pit was installed at each end of the barrier and consisted of two plastic cups (474 ml, 11 cm rim diameter), one inside the other, placed into a hole in the ground so that the rim of the inside cup was flush with the soil surface. This arrangement allowed the inner cup, containing the trapped specimens, to be removed and emptied without damaging the structure of the pit. Diluted ethylene glycol was used as the killing agent and preservative. Plywood raincovers (20 x 20 cm), painted white, were supported above the pits with 7.5 cm long nails. The contents of the traps were removed weekly during the 6-wk period from 2 June to 14 July. This time coincides with the expected seasonal abundance of the first generation of armyworm larvae in southwestern Virginia (Laub & Luna 1991a). Six additional 5.70 m^2 areas were placed randomly as controls.

All plants within the predator-removal arenas and controls were visually examined on 23 and 30 June for armyworm feeding damage on the leaves and whorls and the number of plants with and without damage was recorded. In addition, each plant was rated on a percent-defoliation scale of 1 to 5 with 1 = 0, 2 = 1 to 10, 3 = 11 to 25, 4 = 26 to 50, and 5 = greater than 50 percent defoliation. The proportion of plants with and without damage in the predator removal treatment and control was compared originally using chi-square analysis of a 2 x 12 contingency table. However, due to excessively low expected frequencies, the data were pooled and analyzed in a 2 x 2 contingency table (Zar 1984). Plant damage ratings in the predator-removal arenas and controls were compared with the Wilcoxon two-sample test (SAS Institute 1982).

Results

Laboratory Feeding Study. All of the 16 species studied except two, *Anisodactylus harrisi* Leconte (Carabidae) and *Phalangium opilio* L. (Phalangiidae), attacked and fed upon armyworm larvae in this study (Table 2-1). Most of the species that were entered in both trials consumed more of the second instars than the fourth instars. However, two large carabid species, *Scarites subterraneus* F. and *Pterostichus lucublandus* Say, consumed approximately equal numbers of second- and fourth-instar armyworm. Two other species that consumed relatively large numbers of fourth instars, *Platydracus maculosus* Gravenhorst (Staphylinidae) and *Lycosa helluo* Walckenaer (Lycosidae), were not available for the second-instar trial.

Predator removal study. A total of 367 potential armyworm predators were collected in pitfall traps from the six predator-removal arenas during the first three weeks of the study. Formicidae accounted for 33 percent of the total (Table 2-2); however 81 percent of them were collected from two of the six arenas. Pitfall-trap catches of all other families were relatively similar among the six arenas. By the end of the six-week

Table 2-1. Mean number (± SEM) of second- and fourth-instar armyworm consumed by generalist predators during 24-hour laboratory feeding trials.

Species	Second Instar		Fourth Instar	
	N[a]	Mean (SEM)	N	Mean (SEM)
Scarites subterraneus (Carabidae)	5	8.8 (1.4)	5	10.0 (0.0)
Pterostichus lucublandus (Carabidae)	6	10.0 (0.0)	6	9.2 (0.5)
Platydracus maculosus (Staphylinidae)	-	-	2	8.5 (0.7)
Lycosa helluo (Lycosidae)	-	-	5	7.3 (1.6)
Pterostichus chalcites (Carabidae)	15	9.9 (0.1)	15	5.3 (0.7)
Agonum cupripennis (Carabidae)	14	7.7 (0.6)	13	2.3 (0.4)
Philonthus cognatus (Staphylinidae)	11	5.8 (0.5)	10	2.0 (0.4)
Amara cupreolata (Carabidae)	11	4.8 (0.9)	11	1.4 (0.4)
Amara familiaris (Carabidae)	4	2.5 (1.0)	4	1.0 (0.8)
Anisodactylus carbonarius (Carabidae)	-	-	4	0.8 (0.6)
Coccinella septempunctata (Coccinellidae)	7	3.3 (1.7)	4	0.5 (0.7)
Agonum punctiforme (Carabidae)	5	5.4 (0.8)	5	0.2 (0.2)
Pardosa spp.[b] (Lycosidae)	8	4.1 (0.8)	12	0.0 (0.0)
Anisodactylus harrisi (Carabidae)	-	-	2	0.0 (0.0)
Phalangium opilio (Phalangiidae)	4	0.0 (0.0)	-	-

- : indicates that species or taxa was not entered into feeding trial

[a] Number of predators entered into feeding trial

[b] Includes *P. milvina* and *P. saxatilis*

Table 2-2. Relative cumulative abundances of predatory arthropod families collected in pitfall traps within predator-removal arenas, after three and six weeks, in a no-till corn field, Riner, Virginia, 1992.

	Percentage of the Total Collected	
Family	Three Weeks	Six Weeks
Formicidae	33.0	23.7
Carabidae	14.2	7.6
Lycosidae	11.2	13.1
Staphylinidae	9.3	7.6
Linyphiidae	6.5	29.6
Thomisidae	5.2	3.3
Histeridae	2.1	2.5
Phalangidae	1.4	1.3
staphylinid and carabid larvae	13.9	9.6
other	3.2	1.8

period, 968 predaceous arthropods had been collected with the families Linyphiidae and Formicidae accounting for over 50 percent of the total.

The percentage of corn plants having visible armyworm feeding damage was over two times greater in the predator-removal arenas than in the controls on both sampling dates. According to the chi-square test the differences were highly significant for 23 June ($\chi^2 = 24.1$; df = 1; $P < 0.001$) and 30 June ($\chi^2 = 16.7$; df = 1; $P < 0.001$) (Fig. 2-1). The differences between the mean damage ratings in the predator-removal treatment and control were also highly significant for 23 June ($W = 12314$; m, n = 98, 123; $P = 0.0002$) and 30 June ($W = 12607.5$; m, n = 98, 127; $P = 0.0001$) (Fig. 2-2).

Discussion

The mean number of armyworm larvae attacked and consumed during the 24-hour laboratory feeding trials varied considerably among the different arthropod species. Large carabids in both feeding trials consumed the most larvae. Several species, including *Pterostichus lucublandus*, *P. chalcites*, and *Scarites subterraneus*, apparently could have consumed more than the ten-larvae maximum used in this study. Similarly, Brust et al. (1986) also observed large carabids to consume more tethered lepidoperous larvae than other arthropod predators under field conditions. Although it is probably unlikely that a single predator would encounter this many armyworm larvae in such a short period of time, the data indicate that some of these predators can consume relatively large quantities of prey when they is available.

The ability to consume large numbers of armyworm larvae under laboratory conditions does not necessarily indicate that a predator is effective at controlling armyworm in the field. Predator density, activity, and searching behavior as well as prey density and activity patterns are important factors that influence a predator's efficiency.

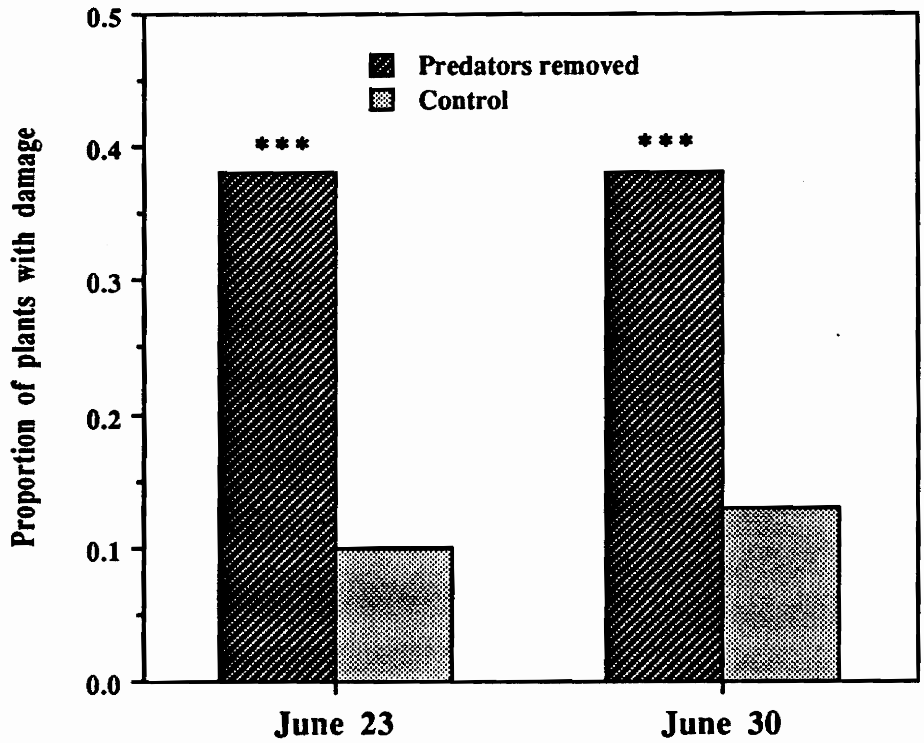

Figure 2-1. Proportion of corn plants with armyworm feeding damage in predator-removal treatment and control. Three asteriks indicate statistical significance ($P < 0.001$, Chi-square test).

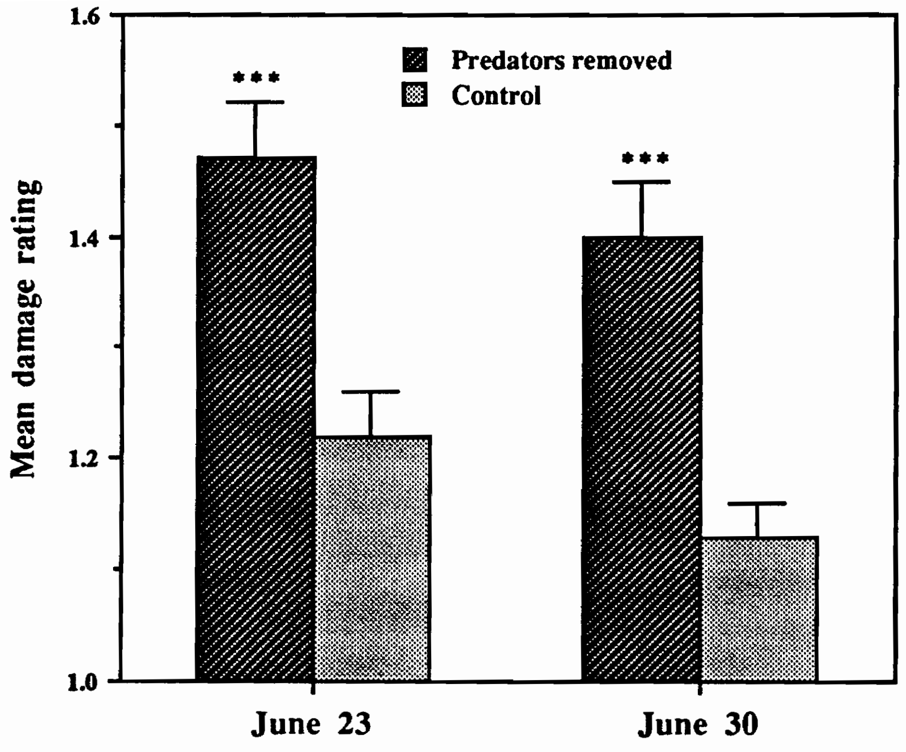

Figure 2-2. Mean damage ratings for corn plants in predator-removal treatment and control. T-bars are SEM. Three asteriks indicate statistical significance (P < 0.001, Wilcoxon two-sample test).

For example, although the small carabid *Amara cupreolata* Putzeys consumed considerably fewer larvae than *P. chalcites, P.lucublandus,* or *S. subterraneus* in this study, Brust et al. (1986) reported that in the field *A. cupreolata* demonstrated a much higher attack rate upon tethered larvae than these three species.

Laub and Luna (1991a) reported armyworm densities as high as 10 per square meter in a Virginia no-till corn field in mid-June. These authors (1991b) also reported that armyworm larvae were most likely found on the ground during the day and on the corn plants feeding at night. Brust et al. (1986) found ground-predator activity in an Ohio corn field to be highest at night with the peak of activity at 0200, the same time Laub & Luna (1991b) found the highest proportion of armyworm larvae on the plants. Thus, it appears that armyworm larvae may partially avoid ground-predator attack by feeding on the plants at night and moving to the ground during the day.

The phalangiid species, *Phalangium opilio* L., did not consume any second-instar armyworm and was therefore not used in the fourth-instar trial. However, in one instance an individual *P. opilio* was observed to consume several first-instar armyworm larvae in a container that was approximately twice as large as that used in the feeding study. This suggests that either the second-instar larvae were too large to serve as prey or that the relatively small space provided in the feeding trial restricted *P. opilio* movement so it could not attack the prey. Similarly, fourth-instar larvae may have been too large a prey for *Anisodactylus harrisi* (Carabidae).

Comparisons of the proportions of damaged plants and plant damage ratings between the predator-removal treatment and control clearly demonstrate that at least some of the arthropods removed were important predators of armyworm. A significantly higher proportion of the plants had been fed upon by armyworm in the predator-removal arenas than in the controls. In addition, the damage rating comparisons indicated that the mean degree of damage per plant was more severe where predators were removed. Brust et al. (1985) obtained similar results in a study of the effects of predator removal on black cutworm damage in which a significantly higher numbers of corn plants were cut where predators were reduced.

Although pitfall traps are usually not used for sampling armyworm larvae, 34 fifth and sixth instars were collected in pitfall traps within the predator-removal arenas over the six-week study. Many of these larvae were probably searching for a pupation site. A peak was observed between 30 June and 7 July (Fig. 2-3). Thus, plant damage inspections conducted on 23 and 30 June appear to be close to the peak in armyworm feeding because it is the sixth-instar (last instar) that is responsible for 80 percent of the total foliage consumed during the larval stage (Davis & Satterthwait 1916).

The families Formicidae, Carabidae, Staphylinidae, and Lycosidae were the most abundant predator groups collected during the first three weeks of the experiment. This is the time when most armyworm feeding apparently was occurring. Linyphiids, which probably ballooned into the experiment site, did not appear in large numbers until the last three weeks of the experiment. Thus it is not likely that these spiders played an significant role in reducing armyworm abundance in this study.

The results of the predator removal study support other studies which have found assemblages of generalist predators to be important in suppressing pest populations in agroecosystems. The feeding study demonstrated a wide range of consumption rates and the results suggest that a large number of predator species may be preying on armyworm in the field. Further experiments are needed to determine which predator species or groups are most important in controlling armyworm and what types of habitat manipulations could increase predator numbers and efficiency.

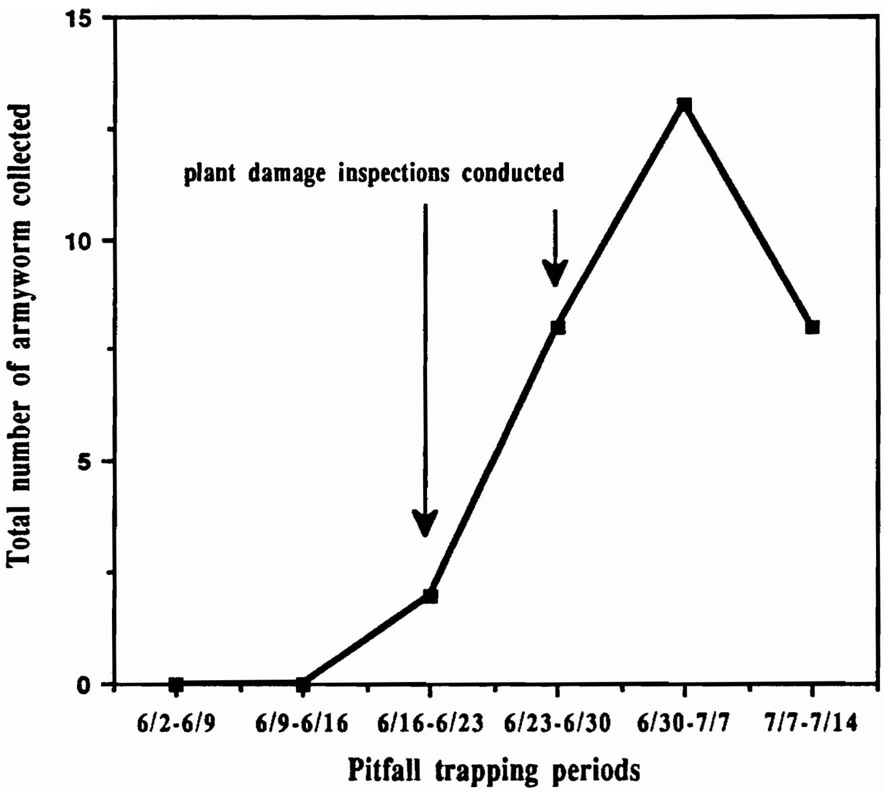

Figure 2-3. Total number of fifth- and sixth-instar armyworm collected in pitfall traps within predator-removal arenas during six consecutive one-week trapping periods at Bishop farm, Riner, Virginia, 1992.

References Cited

Best, R. L. & C. C. Beegle. 1977. Consumption of *Agrotis ipsilon* by several species of carabids found in Iowa. Environ. Entomol. 6: 532-34.

Breeland, S. G. 1958. Ecological studies on the armyworm, *Pseudaletia unipuncta* (Haworth) in Tennessee (Lepidoptera: Noctuidae). J. Tenn. Acad. Sci. 33: 263-350.

Brust, G. E., B. R. Stinner, & D. A. McCartney. 1985. Tillage and soil insecticide effects on predator-black cutworm (Lepidoptera: Noctuidae) interactions in corn agroecosystems. J. Econ. Entomol. 78: 1389-92.

_____ 1986. Predator activity and predation in corn agroecosystems. Environ. Entomol. 15: 1017-1021.

Chiverton, P. A. 1986. Predator density manipulation and its effects on populations of *Rhopalosiphum padi* (Hom.: Aphididae) in spring barley. Ann. Appl. Biol. 109: 49-60.

Davis, J. J. & Satterthwait. 1916. Life history studies of *Cirphus unipuncta*, the true army worm. J. Agric. Res. 6: 799-812.

Dennis, P. & S. D. Wratten. 1991. Field manipulation of populations of individual staphylinid species in cereals and their impact on aphid populations. Ecol. Entomol. 16: 17-24.

Edwards, C. A., K. D. Sutherland, & K. S. George. 1979. Studies on polyphagus predators of cereal aphids. J. Appl. Ecol. 16: 811-823.

Frank, J. H. 1967. The insect predators of the pupal stage of the winter moth, *Operophtera brumata* (L.) (Lepidoptera: Hydriomenidae). J. Animal Ecology 36: 375-89.

_____ 1971. Carabidae (Coleoptera) as predators of the red-backed cutworm (Lepdoptera: Noctuidae) in Central Alberta. Can. Entomol. 103: 1039-1044.

Guppy, J. C. 1961. Life history and behavior of armyworm, *Pseudaletia unipuncta* (Haw.)(Lepidoptera: Noctuidae) in eastern Ontario. Can. Entomol. 93: 1141-53.

Hance, T. 1987. Predation impact of carabids at different population densities on *Aphis fabae* development in sugar beet. Pedobiologia 30: 251-262.

Harrison, F. P., R. A. Bean, & O. J. Qawiyy. 1980. No-till culture of sweet corn in Maryland with reference to insect pests. J. Econ. Entomol. 73: 363-365.

Hilburn, D. J. 1961. Population dynamics of overwintering life stages of the alfalfa weevil, *Hypera postica* (Gyllenhal). Ph.D. dissertation, Virginia Polytechnic Institute & State University, Blacksburg.

Kajak, A. 1978. Analysis of consumption by spiders under laboratory and field conditions. Ekol. Pol. 26: 409-27.

Laub, C. A. & J. M. Luna. 1991a. Influence of winter cover crop suppression practices on seasonal abundance of armyworm (Lepidoptera: Noctuidae), cover crop regrowth, and yield in no-till corn. Environ. Entomol. 20: 749-54.

_____ 1991b. Diurnal abundance and spatial distribution of armyworm (Lepidoptera: Noctuidae) in no-till corn. J. Entomol. Sci. 26: 261-266.

_____ 1992. Winter cover crop suppression practices and natural enemies of armyworm (Lepidoptera: Noctuidae) in no-till corn. Environ. Entomol. 21: 41-49.

Lesiewicz, D. S., J. L. Lesiewicz, J. R. Bradley, & J. W. Van Duyn. 1982. Serological determination of carabid (Coleoptera: Adephaga) predation on corn earworm (Lepidoptera: Noctuidae) in field corn. Environ. Entomol. 11: 1183-1186.

Lund, R. D. & F. T. Turpin. 1977. Serological investigation of black cutworm larval consumption by ground beetles. Ann. Entomol. Soc. Amer. 70: 322-324.

Murdoch, W. W., J. Chesson, & P. L. Chesson. 1985. Biological control in theory and practice. Am. Nat. 125: 344-366.

Perfecto, I.& A. Sediles. 1992. Vegetational diversity, ants (Hymenoptera: Formicidae), and herbivorous pests in a neotropical agroecosystem. Environ. Entomol. 21: 61-67.

Riechert S. E. & L. Bishop. 1990. Prey control by an assemblage of generalist predators: spiders in garden test systems. Ecology 71: 169-72.

Riechert, S. E. & T. Lockley. 1984. Spiders as biological control agents. Ann. Rev. Entomol. 29: 299-320.

Tonhasca, A. & B. R. Stinner. 1991. Effects of srip intercropping and no-tillage on some pests and beneficial invertebrates of corn in Ohio. Environ. Entomol. 20: 1251-1258.

SAS Institute. 1982. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N.J.

Chapter 3

Habitat Preferences, Diurnal Activity, and Prey Detection in Generalist Predators of Reduced-Tillage Corn

Habitat manipulations to agroecosystems can have considerable influence on generalist predator populations. The influence may be either direct, such as in the use of pesticides toxic to predators (Asteraki et al. 1992), or indirect by influencing microclimate (Honek 1988), prey populations (Chiverton 1984), or habitat structure (Riechert & Bishop 1990).

Some research has demonstrated that reduced-tillage agroecosystems tend to have higher generalist predator abundances and/or species diversity than those that are conventionally-tilled (House & All 1981, House & Stinner 1983, Blumberg & Crossley 1983, House & Parmelee 1985, House & Del Rosario Alzugaray 1989,). This may be due at least partially to reduced-tillage systems supporting a detritus-based prey source that is available to predators year-round (Stinner & House 1990). The crop residues left on the soil surface of reduced-tillage systems may also provide a preferred habitat for many generalist predators (Warburton & Klimstra 1984, Honek 1988, Riechert & Bishop 1990, Laub & Luna 1992). Brust et al. (1985) observed higher predator abundances and lower black cutworm damage in no-tillage compared to conventional-tillage corn. Other research has shown generalist predator abundances and diversity to be relatively independent of tillage disturbances although species compositions tend to be influenced (Ferguson & McPherson 1985, Barney & Pass 1986).

Armyworm (*Pseudaletia unipuncta* Haworth) and black cutworm (*Agrotis ipsilon* Hufnagel) are common pests of reduced-tillage corn in the mid-Atlantic region (Harrison et al. 1980, Tonhasca & Stinner 1991). Both of these pests are most destructive during their first generation which occurs in May or June in Virginia. Research has demonstrated that generalist predators can be important in controlling populations of both of these pests (Brust et al. 1985, 1986, Clark 1993). Thus, the use of agricultural practices that conserve or enhance predator populations may reduce the damage caused by these pests.

There were three objectives of this study: (1) to determine the habitat preferences of generalist predators by comparing their abundance in four reduced-tillage corn systems; (2) to determine influence of habitat on the diurnal activity patterns of common ground-dwelling generalist predators; and (3) to evaluate the ability of generalist predators to detect armyworm larvae under field and laboratory conditions.

Methods and Materials

Experimental Site and Treatments. The experimental site was located at the Whitethorne Research Farm near Blacksburg, Virginia, in a field with Hayter loam soil which had been used to grow soybeans during the previous season. On 12 October 1991 the site was disked, limed (8965 kg/ha), and fertilized (18 kg P/ha, 68 kg K/ha). Four treatments, representing reduced-tillage corn cropping systems (Table 3-1), were established in a randomized block design with four replications. The plots were 11 x 15 m and were lined up side by side in a SW to NE orientation. The treatments, which differed in the degree of soil disturbance and ground cover due to fall and spring (prior to corn planting) soil and cover crop management practices, included: (1) fall-planted rye at a seeding rate of 101 kg/ha, which was "rolled down" with a cultipacker (Brillion PMWT124-0) in spring (Rye/Roll); (2) fall-planted rye at a seeding rate of 101 kg/ha, which was killed with paraquat (0.35 kg [AI]/ha) in the spring (Rye/Paraquat); (3) fall-planted rye at a seeding rate of 67 kg/ha, which was mowed and removed in the spring,

Table 3-1. Fall and spring cover crop and soil management operations.

Treatment	Fall Management	Spring Management
Rye/Roll	Rye seed (*Secale cereale*) (101 kg/ha) planted	Cover crop rolled down with cultipacker No herbicides applied
Rye/Paraquat	Rye seed (101 kg/ha) planted	Cover crop killed with paraquat (0.35 kg [AI]/ha) Atrazine and simazine applied (each at 2.2 kg [AI]/ha)
Rye/Remove	Rye seed (67 kg/ha) planted	Cover crop mowed and removed stubble killed with paraquat (0.35 kg [AI]/ha) Atrazine and simazine applied (each at 2.2 kg [AI]/ha)
Fallow/Disk	No cover crop planted	Disked twice before corn planting Atrazine and simazine applied (each at 2.2 kg [AI]/ha)

leaving stubble which was killed with paraquat (0.35 kg [AI]/ha) (Rye/Remove); and (4) winter fallow which was disked in the spring (Fallow/Disk). Fall cover crops were planted on 18 October 1991 with a grain drill (John Deere FB). On 6 May 1992 above-ground plant biomass was sampled in all plots prior to making any cover crop or soil manipulations. Three 0.20 m^2 subsamples consisting of all above-ground vegetation were removed from each plot, dried, and weighed. All spring cover crop manipulations and disking were conducted on 12 May. Corn (Pioneer 3140) was planted on 13 May with a two-row, no-till planter (John Deere 71) modified for high-residue seed beds. The Rye/Paraquat, Rye/Remove, and Fallow/Disk treatments were sprayed with the herbicides atrazine (2.2 kg [AI]/ha) and simazine (2.2 kg [AI]/ha) and all treatments received granular urea fertilizer (15.5 kg N/ha) at corn planting. No herbicides were applied to the Rye/Roll treatment because a study by Luna et al. (1992) indicated that the dense mulch layer provided adequate weed control.

Habitat Preference Study. Two methods were used to sample generalist predators: pitfall trapping and vacuum sampling. The pitfall trapping consisted of five 72-h trapping periods, 10 to 12 days apart, which were conducted between 1 May and 8 July. A single un-baited plastic cup (474 ml, 11 cm rim diameter), arbitrarily placed near the center of each plot, was put into the ground so that the rim of the cup was flush with the soil surface. Diluted ethylene glycol was used as a killing agent and preservative. Plywood raincovers (20 x 20 cm), painted white, were supported above the pits on 7.5 cm long nails. Pits were removed between trapping periods and the contents returned to the laboratory for identification.

Vacuum sampling was conducted once every 15 to 20 days between 30 April and 22 June for a total of four sampling dates. Sampling consisted of isolating a randomly chosen sub-sample with a cylinder, constucted of 20 gauge, galvanized sheet steel and measuring 0.20 m^2 in area and 0.60 m in height. The cylinder was manually driven into the ground to prevent arthropods from moving out of the sampling area. Arthropods were collected using a modified gasoline-powered vacuum (Weed Eater^R GBI 22). The ground surface, vegetation, and debris were vacuumed for 30 seconds for each sub-sample. Three sub-samples were taken and combined for each plot on each sampling date. All samples were taken between 1100 and 1600. Samples were put into 474 ml plastic containers, placed in a cooler, and sorted in the laboratory while the specimens were still alive.

Diurnal Activity and Prey Detection Tests. An additional study was conducted at the same experimental site as the habitat preference study to determine predator diurnal activity patterns and ability to detect the presence of armyworm larvae. In addition to the single unbaited pitfall trap installed for the 21-24 June habitat preference trapping session, a baited pitfall trap of the same dimensions was installed 3 m away in a randomly chosen NW or SE direction within each plot. The bait consisted of a single live third-instar armyworm, placed into a nylon mesh envelope (3 x 3 cm, 0.5 mm mesh width), with several strips of rye foliage (2 cm long) for food. This was attached to the inside of the pit, 2 cm below the rim, with a binder clip. The contents of the traps were emptied and the armyworm larvae and rye foliage strips were replaced, each day at 0800 and 2000 during the three-day period.

A laboratory experiment was conducted to evaluate predator diurnal activity patterns and prey detection ability under more optimal conditions for finding prey. *Pterostichus chalcites* Say (Carabidae) and *Amara cupreolata* Putzeys (Carabidae), were used in this experiment because they are two of the most abundant ground-dwelling predator species present in the field study. Four individuals of each of these species were released into laboratory arenas. Each arena consisted of a circular metal pan (36 cm diameter, 9.5 cm depth) with a 2-cm deep layer of sand on the bottom. In addition, 30 g of cut rye foliage (3-6 cm length) was evenly spread out on the sand surface. This rye had been stored frozen for at least 48 h prior to use. A pitfall trap (6 cm rim diameter, 2 cm depth) was installed in the center of the arena. Prey detection trials were conducted for 2-h periods, under day and night conditions, with and without bait. The bait consisted of three live third-instar armyworm in a nylon mesh envelope (3 x 3 cm, 0.5 mm mesh width), with several strips of rye foliage (2 cm length), placed at the bottom of each pit. Nylon mesh envelopes, containing several strips of rye foliage, but no armyworm, were placed on the bottoms of pits in the unbaited treatment. Each time an individual of either species fell into a pit it was immediately removed and replaced by another individual which was placed arbitrarily along the inside perimeter of the arena. Day conditions were created with sunlight from a window as well as fluorescent lights. Light intensity was 60 to 70 footcandles, temperature was 24 to 27°C, and humidity was 80 to 85%. Under night conditions light intensity was less than 2 footcandles, temperature was 24 to 27°C, and humidity was 88 to 90%. A red light was used for observations under night conditions. A total of ten day and eight night trials for each species were conducted under baited and unbaited pit conditions. Each two-hour trial was considered a replication for statistical purposes.

Analysis. In the habitat preference study all predators comprising one percent or more of the total collected were indentified to species or genus level, except the Linyphiidae, which were not identified below the family level. Habitat preferences of predatory species, families, and total predators were determined by comparing pitfall trap and vacuum sample catches among the four treatments. Only adults were considered for comparisons made at species and family levels. Immature stages (nymphal and larval) were included in comparisons of the total number of predators. All data were subjected to analysis of variance (ANOVA) after the square root transformation $(x + 0.5)^{1/2}$. Duncan's multiple range test (DMRT) (Duncan 1955) was used to separate means when $P < 0.05$. Both the laboratory and field diurnal activity and prey detection tests were treated as 2 x 2 factorial experiments (day and night, bait and no bait). When an effect was insignificant the data were pooled and the remaining effect analyzed with a *t* test for all comparisons except the diurnal activity of *P. chalcites* and *A. cupreolata* in the field for which a Wilcoxon two-sample test was used. All analyses were performed on Statistical Analysis System (SAS Institute 1982).

Results

Cover Crop Biomass. Cover crop biomass yields prior to corn planting were relatively similar among the Rye/Roll, Rye/Paraquat, and Rye/Remove treatments. However, cover crop biomass in the Rye/Roll and Rye/Remove treatments were significantly different from each other due to the lower planting rate in the Rye/Remove treatment (Table 3-2). The biomass yield of the Fallow/Disk treatment was composed primarily of the annual weeds henbit (*Lamium amplexicaule* L.) and common chickweed (*Stellaria media* L.).

Habitat Preference Study. The four most abundant predatory families collected, Carabidae, Staphylinidae, Lycosidae and Linyphiidae, were the same for pitfall trapping and vacuum sampling. The fifth most abundant family was Phalangiidae for pitfall trapping and Coccinellidae for vacuum sampling. These five most abundant families comprised 90 percent and 86 percent of all predators collected by pitfall trapping and vacuum sampling, respectively. Other predatory groups which were collected in small numbers were Histeridae, Chilopoda, and other Araneae including Thomisidae, Gnaphosidae, Araneidae, Oxyopidae, and Tetragnathidae. The total number of generalist

Table 3-2. Cover crop biomass yields prior to spring cover crop and soil management operations.

Treatment	N	Mean Yield (kg/ha) ± SEM
Rye/Roll	4	5134 ± 376a
Rye/Paraquat	4	4801 ± 292ab
Rye/Remove	4	4192 ± 135b
Fallow/Disk	4	208 ± 42c

Means followed by different letters are significantly different ($P < 0.05$, DMRT).

predators collected by pitfall trapping was approximately three times greater than that collected by vacuum sampling.

The taxa which represented one percent or more of the total number of predators collected, excluding the linyphiids, comprised 64.6 percent and 56.6 percent of all predators collected by pitfall trapping and vacuum sampling, respectively (Table 3-3). However, only four taxa, *Philonthus cognatus* Stephens (Staphylinidae), *Pardosa* spp. (Lycosidae), *Phalangium opilio* L. (Phalangiidae), and *Amara familiaris* Duftschmid (Carabidae) were common to both lists.

Pitfall trap catches showed significant differences between treatments for staphylinids only ($F = 7.35$; df = 3,9; $P = 0.008$), whereas vacuum sampling results showed significant differences for the staphylinids ($F = 6.32$; df = 3,9; $P = 0.01$), lycosids ($F = 6.21$; df = 3,9; $P = 0.01$), and linyphiids ($F = 4.40$; df = 3,9; $P = 0.04$) (Fig. 3-1). The staphylinids and lycosids showed preferences for the three treatments which had winter cover crops over the Fallow/Disk treatment. The linyphiids showed a preference for the Rye/Roll treatment over all others (Fig. 3-1)

The staphylinid, *P. cognatus*, represented over 50% of all staphylinids and 22.6% of all predators collected by pitfall trapping. Pitfall trap catches indicated that this species preferred the three treatments with surface residues over the Fallow/Disk treatment ($F = 10.78$; df = 3,9; $P = 0.003$) (Fig 3-2). The carabid, *Pterostichus lucublandus* Say, showed a similar trend ($F = 7.74$; df = 3,9; $P = 0.007$) but was not collected in the Rye/Remove treatment. The staphylinid, *Platydracus maculosus* Gravenhorst ($F = 6.37$; df = 3,9; $P = 0.01$), and the carabid, *P. chalcites* ($F = 7.35$; df = 3,9; $P = 0.009$), showed a distinct preference for the Rye/Roll treatment (Fig 3-2). Two carabids, *A. cupreolata* and *Scarites subterraneus* F., and the phalangiid, *P. opilio*, showed opposite trends with the highest numbers being collected from the Fallow/Disk

Table 3-3. The taxa (excluding Linyphiidae) representing one percent or more of the total predators collected by pitfall trapping and vacuum sampling, in the four corn systems, Whitethorne, Virginia, 1992.

Pitfall trapping		Vacuum sampling	
Species (Family)	% of total	Species (Family)	% of total
Philonthus cognatus Stephens (Staphylinidae)	22.6	*Pardosa* spp.[a] (Lycosidae)	16.2
Pardosa spp.[a] (Lycosidae)	12.9	*Stenus flavicornis* Erichson (Staphylinidae)	15.7
Phalangium opilio L. (Phalangiidae)	9.8	*Amara familiaris* Duftschmid (Carabidae)	7.4
Pterostichus chalcites Say (Carabidae)	5.2	*Coleomegilla maculata* DeGeer (Coccinellidae)	5.9
Amara cupreolata Putzeys (Carabidae)	3.9	*Pseudaptinus* sp. (Carabidae)	3.9
Philonthus lomatus Erichson (Staphylinidae)	2.2	*Schizocosa avida* Walckenaer (Lycosidae)	2.5
Pterostichus lucublandus Say (Carabidae)	2.2	*Coccinella septempunctata* L. (Coccinellidae)	1.5
Scarites subterraneus F. (Carabidae)	1.9	*Colliuris pensylvanica* Linne (Carabidae)	1.5
Agonum punctiforme Say (Carabidae)	1.7	*Philonthus cognatus* Stephens (Staphylinidae)	1.0
Amara familiaris Duftschmid (Carabidae)	1.2	*Phalangium opilio* L. (Phalangiidae)	1.0
Platydracus maculosus Gravenhorst (Staphylinidae)	1.0		
Total	64.6	Total	56.6

[a] Includes *P. milvina* Hentz amd *P. saxatilis* Hentz.

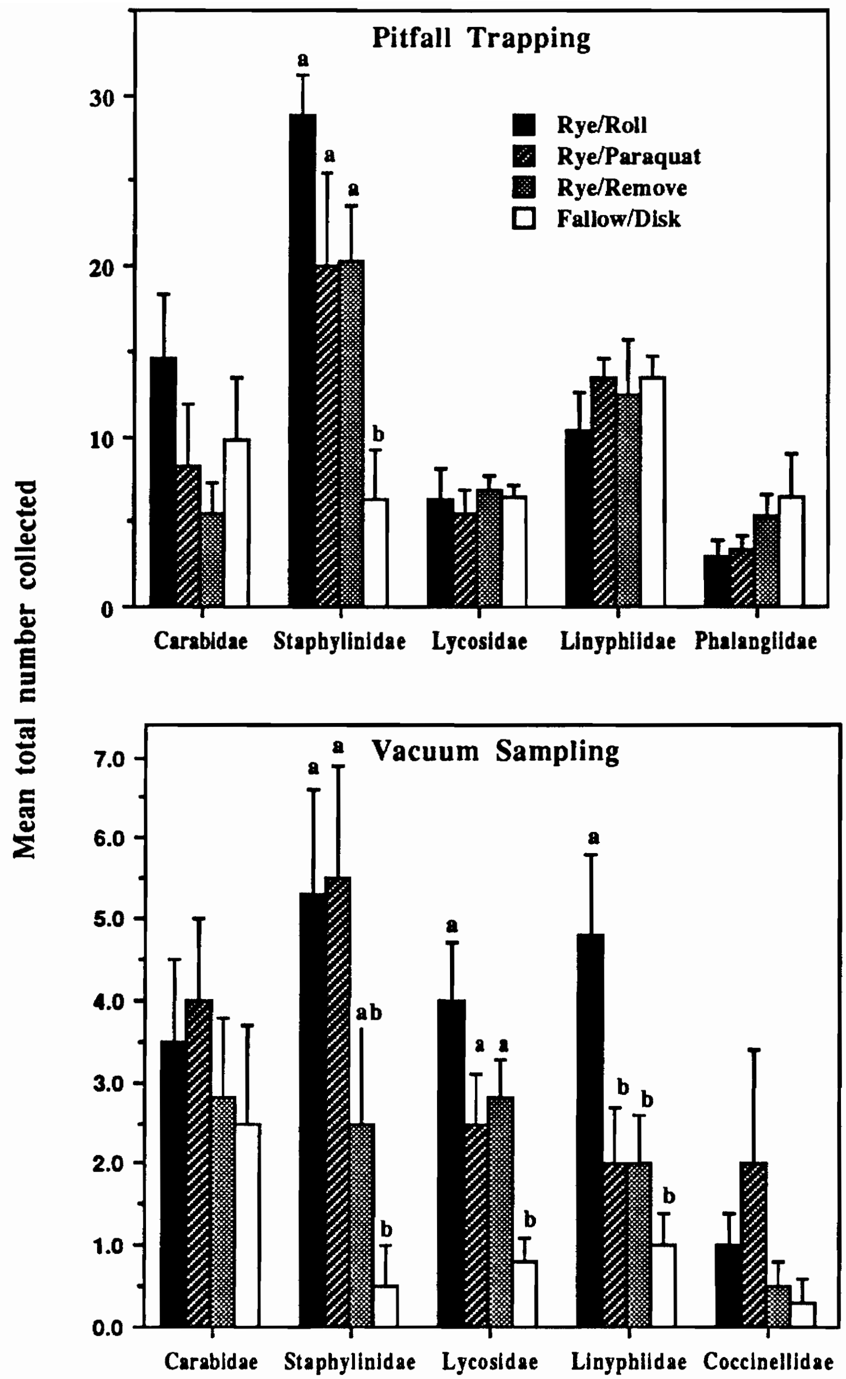

Figure 3-1. Mean total number of the five most abundant generalist predator families collected by pitfall trapping and vacuum sampling. T-bars are SEM. Means with different letters are significantly different (DMRT, $P < 0.05$).

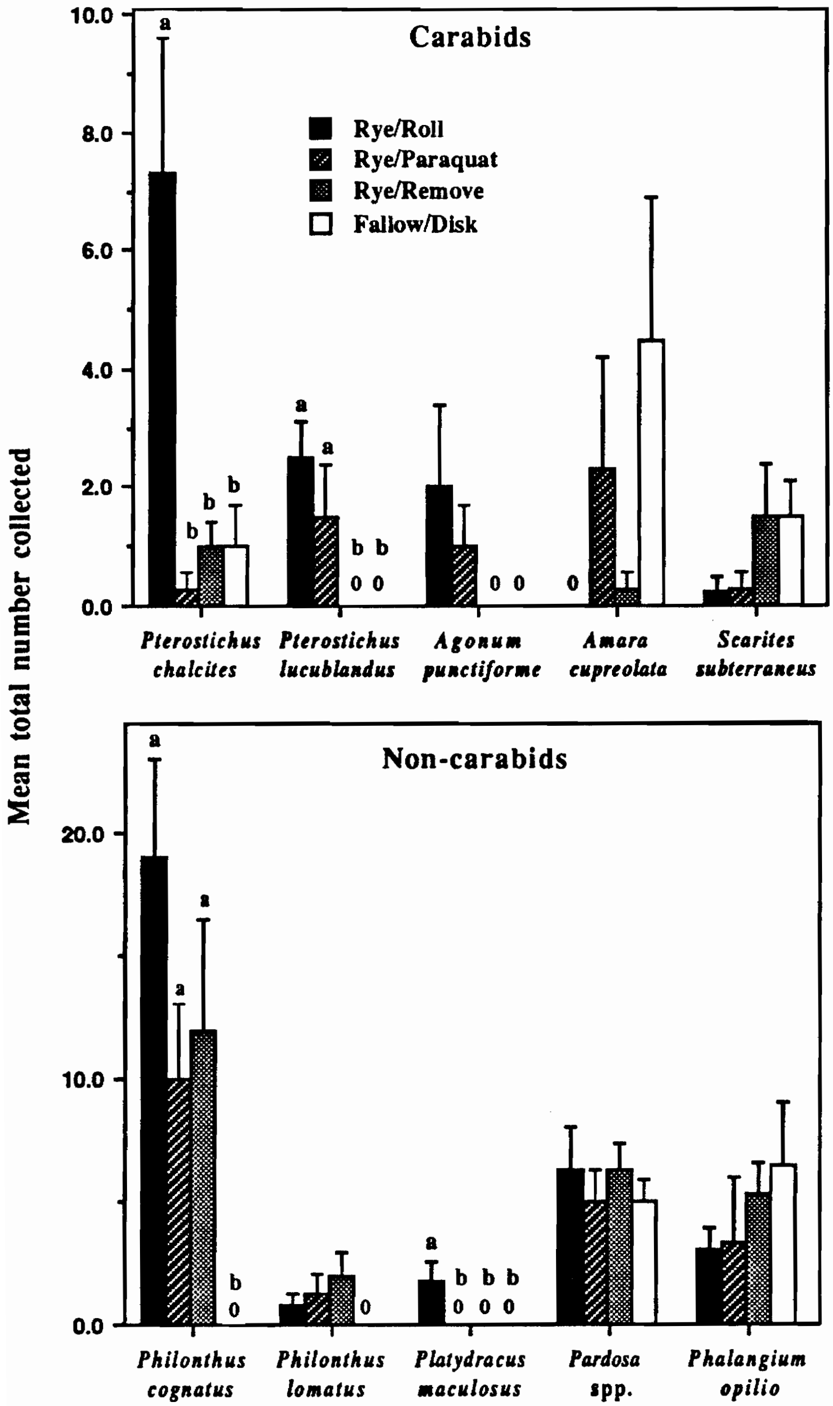

Figure 3-2. Mean total numbers of the five most abundant carabid and non-carabid predators (excluding Linyphiidae) collected in pitfall traps. T-bars are SEM. Means with different letters are significantly different (DMRT, $P < 0.05$).

treatment and the lowest numbers from the Rye/Roll treatment. However, these trends were not statistically significant (Fig 3-2).

Three of the five most abundant predator taxa (excluding Linyphiidae) collected by vacuum sampling exhibited preferences for the three treatments with surface residues over the Fallow/Disk treatment (Fig. 3-3). These taxa were *Pardosa* spp. (Lycosidae) ($F = 7.96$; df = 3,9; $P = 0.007$), *Stenus flavicornis* Erichson (Staphylinidae) ($F = 6.03$; df = 3,9; $P = 0.02$), and *Pseudaptinus* sp. (Carabidae) ($F = 5.02$, df = 3,9, $P = 0.03$). The coccinellid, *Coleomegilla maculata* DeGeer, showed a similar trend, however the model did not meet the statistical criteria for using DMRT ($F = 3.59$; df = 3,9; $P = 0.06$). The carabid, *Amara familiaris* Duftschmid, showed the opposite trend with the highest numbers collected from the Fallow/Disk treatment and the lowest from the Rye/Roll and Rye/Paraquat treatments (Fig 3-3). However, this trend was not statistically significant.

Both pitfall trapping and vacuum sampling showed similar overall trends in mean total predator abundance with the Rye/Roll treatment having the greatest number, followed by the Rye/Paraquat, Rye/Remove, and Fallow/Disk treatments, respectively (Fig. 3-4). However, differences were statistically significant only for vacuum sampling (F = 11.14; df = 3,9; P = 0.002). Significant differences in predator abundance were not detected at the same times with the two sampling methods (Fig 3-5). Pitfall trapping data indicated that all three cover crop treatments had significantly higher predator abundances than the Fallow/Disk treatment prior to the tillage and cover crop management operations ($F = 4.09$; df = 3,9; $P = 0.04$). However, no differences were observed following the farming operations. Vacuum sampling data showed significant differences following the farming operations, on 3 June ($F = 7.30$; df = 3,9; $P = 0.009$) and 22 June ($F = 4.10$; df = 3,9; $P = 0.04$) (Fig 3-5).

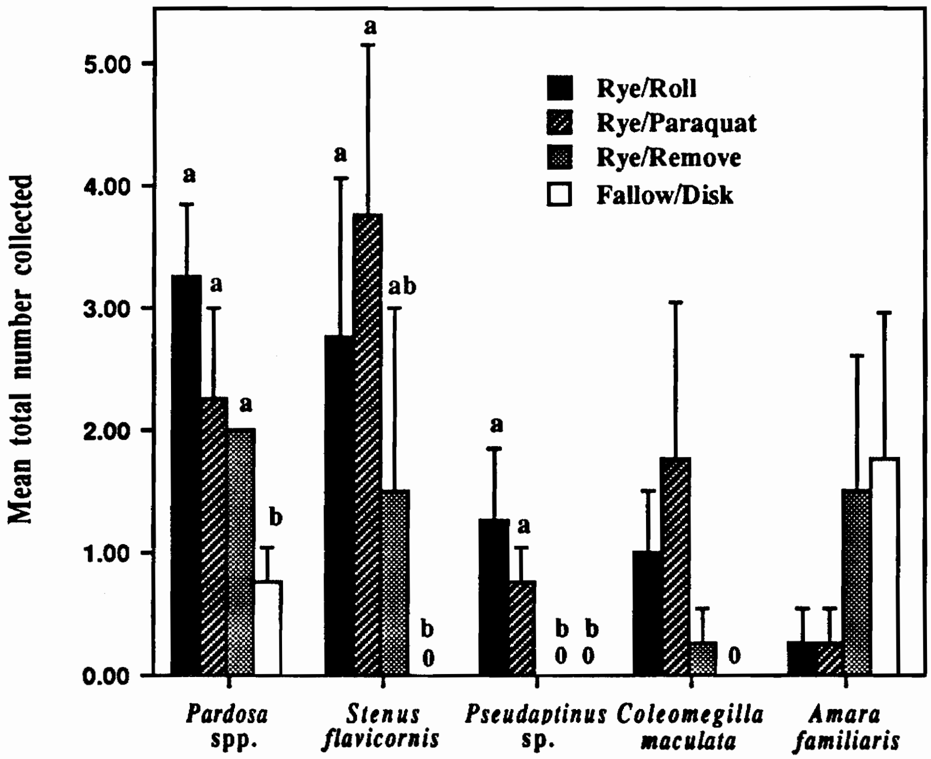

Figure 3-3. Mean total numbers of the five most abundant predators (excluding Linyphiidae) collected by vacuum sampling in the four treatments. T-bars are SEM. Means with different letters are significantly different (DMRT, P < 0.05).

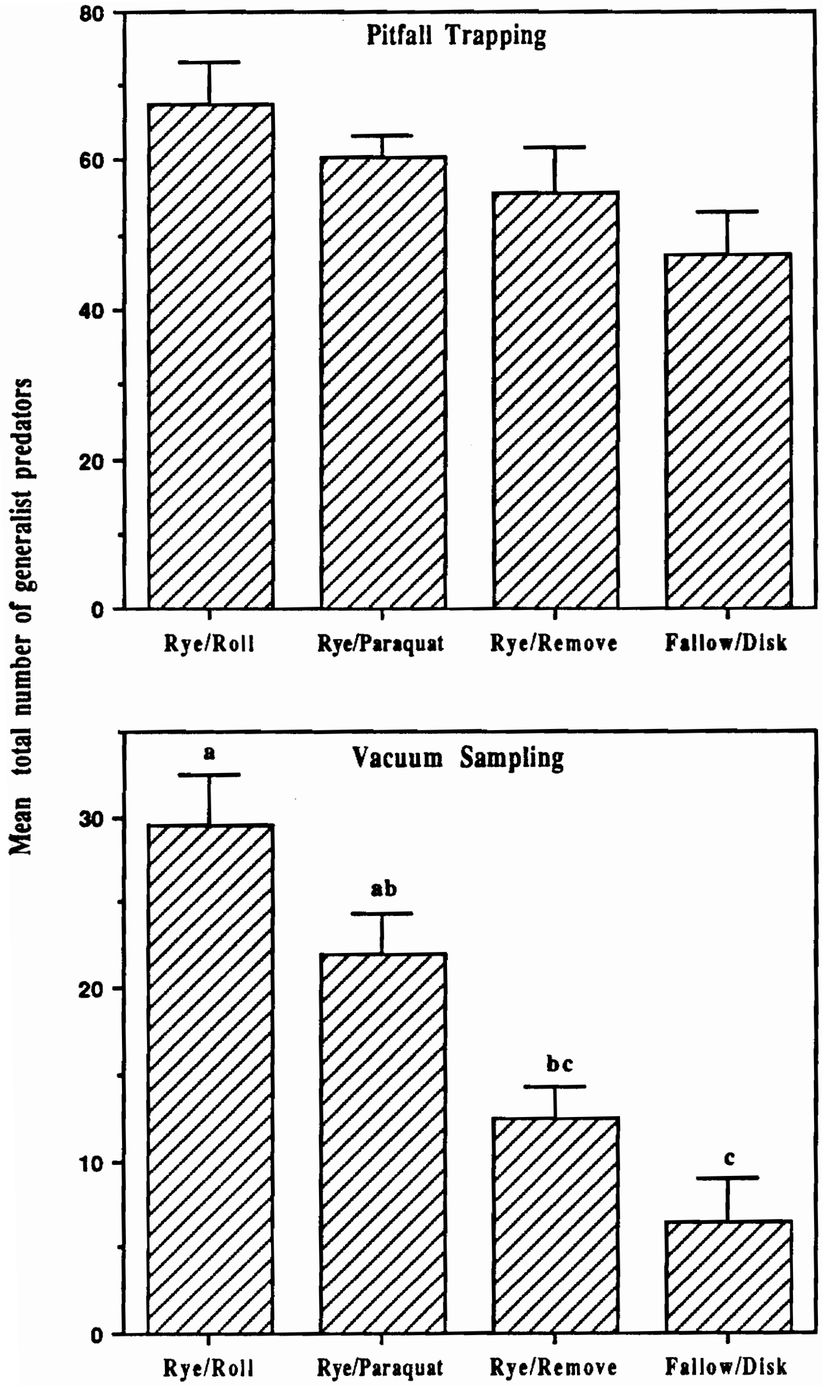

Figure 3-4. Mean total number of generalist predators collected in each treatment by pitfall trapping and vacuum sampling. T-bars are SEM. Means with different letters are significantly different (DMRT, $P < 0.05$).

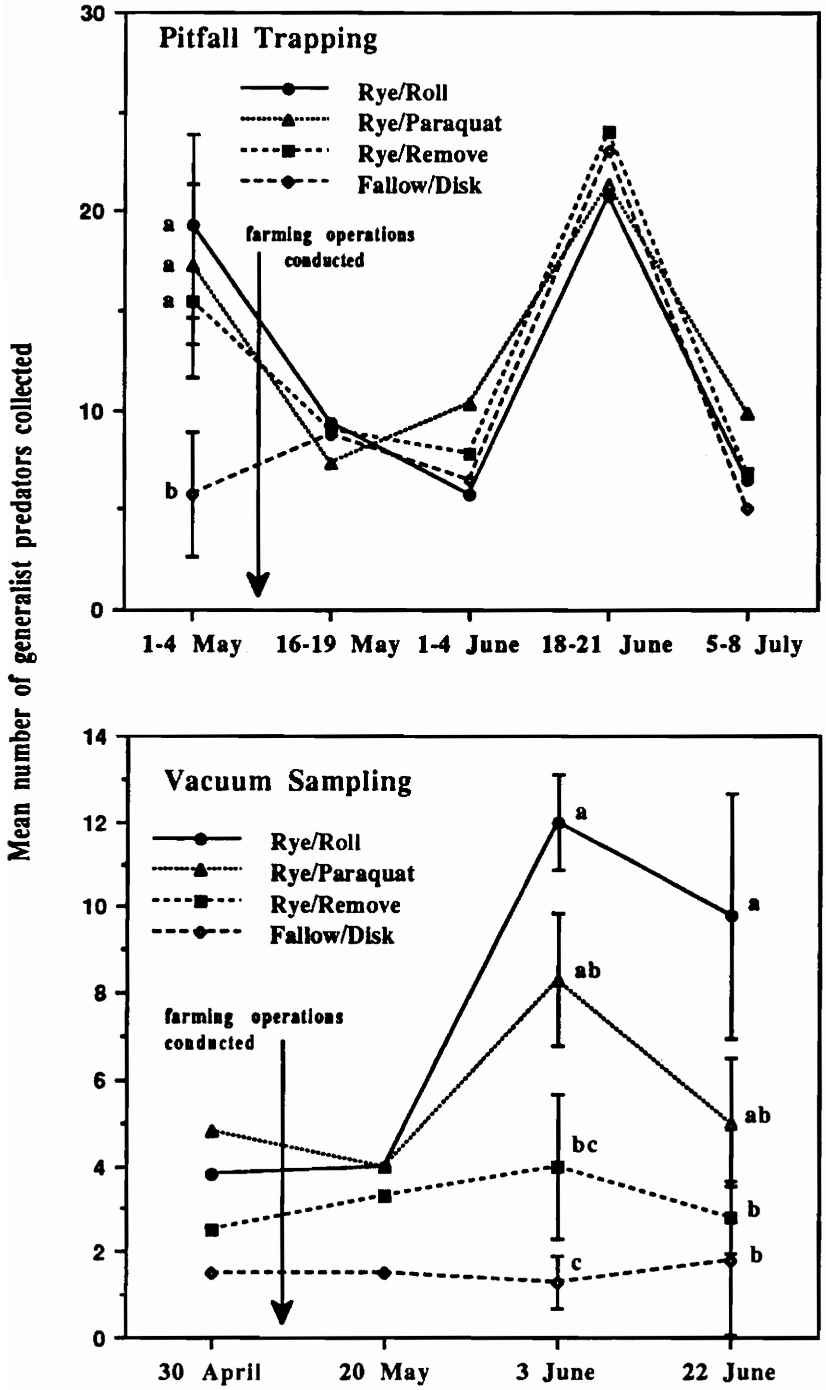

Figure 3-5. Mean number of generalist predators collected per treatment by pitfall trapping and vacuum sampling. Standard error bars and different letters are presented where significant differences were observed (DMRT, $P < 0.05$).

Diurnal Activity and Prey Detection Tests. Analysis of variance indicated that the addition of bait to pitfall traps was an insignificant factor in determining pitfall catches in both the field and laboratory experiments. Therefore data were pooled for more power in detecting patterns in diurnal activity. Pitfall trap catches indicated that overall predator activity was significantly higher during the day than the night for the Rye/Roll (t = 2.76; df = 5; P = 0.04), Rye/Remove (t = 2.41; df = 5.9; P = 0.05), and Fallow/Disk (t = 3.83; df = 5.8; P = 0.009) treatments (Fig 3-6). The difference in diurnal activity for the Rye/Paraquat treatment followed a similar tend, however was not statistically significant (t = 2.0; df = 6; P = 0.09). Day catches were significantly higher than night catches for the four most abundant predator families, Carabidae (t = 3.50; df = 51.6; P = 0.001), Staphylinidae (t = 4.43; df = 54; P = 0.0001), Lycosidae (t = 5.34; df = 44.6; P = 0.0001), and Linyphiidae (t = 3.20; df = 62; P = 0.002). Phalangiidae, the fifth most abundant family, was collected in significantly greater numbers at night (t = 3.82; df = 48.9; P = 0.0004) (Fig. 3-7).

Significantly higher numbers of *P. chalcites* (W = 1168; m, n = 32, 32; P = 0.003) and *A. cupreolata* (W = 1120; m, n = 32, 32; P = 0.02) were collected during day than night conditions in the field (Table 3-4). This trend was reversed in the laboratory study; however, catch differences were statistically significant only for *P. chalcites* (t = 2.28; df = 34; P = 0.03) (Table 3-5).

Discussion

Habitat Preference Study. Both sampling methods used in this study, pitfall trapping and vacuum sampling, showed similar overall trends in generalist predator abundances among the four treatments. In addition, the same four dominant arthropod families, Carabidae, Staphylinidae, Lycosidae, and Linyphiidae, were collected in relatively similar proportions. However, the species composition of the samples differed

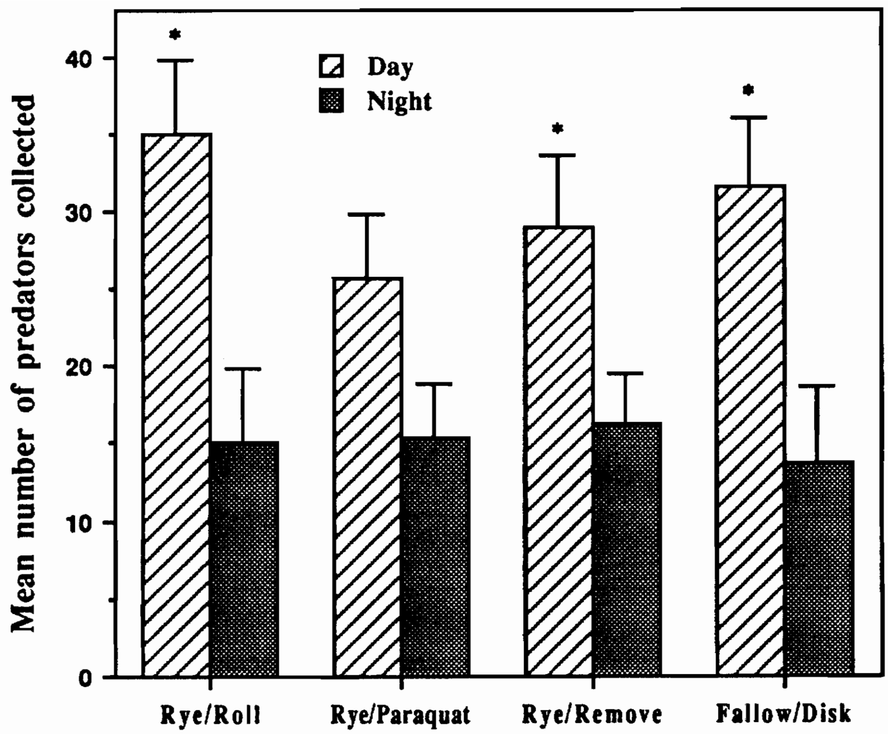

Figure 3-6. Mean number of generalist predators collected in pitfall traps during the day and night, over a 72-h period (18-21 June), in the four treatments. T-bars are SEM (4 replicates). Asterisks indicate significant differences (t test, $P < 0.05$).

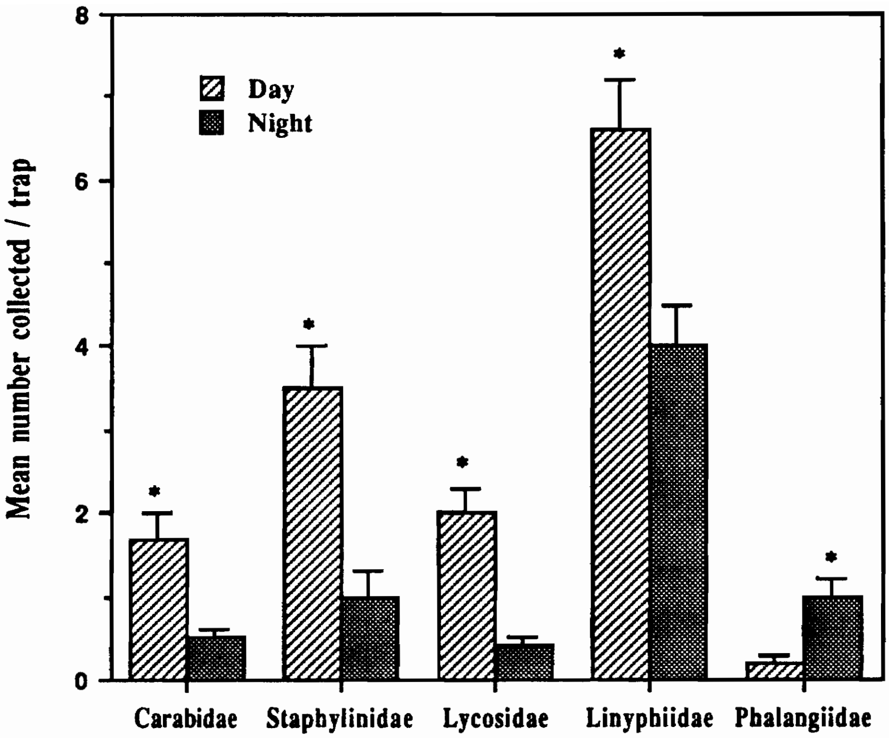

Figure 3-7. Mean number of the most abundant predator families collected per pitfall trap during day and night over the 72-h period from 18 to 21 June. T-bars are SEM (32 replicates). Asterisks indicate significant differences (t-test, $P < 0.05$).

Table 3-4. Mean number of *P. chalcites* and *A. cupreolata* collected in the field during a 72-h period by pitfall trapping during day and night conditions.

Species	Condition	N	Mean Collected	SEM
Pterostichus chalcites	day	32	0.5 *	0.2
	night	32	0.0	0.0
Amara cupreolata	day	32	0.2 *	0.1
	night	32	0.0	0.0

* Means significantly different ($P < 0.05$, Wilcoxon two-sample test).

Table 3-5. Mean number of *P. chalcites* and *A. cupreolata* collected by pitfall trapping in two-hour laboratory trials under day and night conditions.

Species	Condition	N	Mean Collected	SEM
Pterostichus chalcites	day	20	1.5 *	0.3
	night	16	2.8	0.6
Amara cupreolata	day	20	0.5	0.2
	night	16	0.9	0.3

* Means significantly different ($P < 0.05$, *t* test).

between the two methods. Pitfall trapping tended to collect more large species, whereas vacuum sampling collected smaller ones.

There are several possible explanations for the difference in species composition. First, larger species may have been too heavy to be sucked into the vacuum sampler, especially when clinging to or hiding under debris or vegetation. However, larger species, such as *P. chalcites* and *Lycosa helluo* Walckenaer (Lycosidae), were occasionally collected by vacuum sampling. There is also evidence that larger species are more susceptible to pitfall trapping than smaller ones (Luff 1975). Thus, it is likely that smaller species were underrepresented in pitfall catches relative to larger species. Secondly, vacuum sampling was conducted only under mid-day hours while pitfall trapping periods extended equally over the entire day. Some arthropods, including certain carabids and staphylinids, may have been inactive and in underground refuges during mid-day hours when vacuum sampling was conducted. Finally, pitfall trap catches are dependent not only on arthropod density but also on activity (Honek 1988) and behavior (Halsall & Wratten 1988). Thus, species with similar population densities may have very different capture rates in pitfall traps.

Honek (1988) found crop density to be an important influence on pitfall trap catches of carabids, staphylinids, and lycosids in cereal fields. The numbers of carabids and lycosids collected in rows without crops were generally much higher than those in dense cereal stands. The author suggested that this was probably due to microclimatic factors which possibly increased both density and activity. Researchers who have compared pitfall trapping to other sampling methods including visual searching within quadrats (Greenslade 1964) and insecticidal ground sprays followed by visual searches (Lesiewicz et al. 1983) have found that pitfall trap catches are poor indicators of both relative and absolute densities.

In this study it is likely that vacuum sampling gave a better indication of predator relative densities than pitfall trapping because the samples were collected from well-defined, isolated areas. However, estimates may have been biased downward due to inefficiencies in the method. Pitfall trapping provided useful information as well because activity is also an important component in determining the roles of predators in agroecosystems.

Diurnal Activity and Search Tests. The field and laboratory prey detection tests indicated that long-distance chemical detection of prey was not an important cue for predators in finding armyworm larvae. This supports the observations of other researchers who have identified random searching, primarliy driven by hunger and frequency of prey encounter, as the strategy used by hunting generalists (Chiverton 1984, 1988, Jeffords & Case 1987, Grafius & Warner 1989). However, individuals of *P. chalcites*, in laboratory aquariums, appeared to be attracted to areas where other individuals of the same species were either feeding upon recently killed larvae or struggling to overtake a live larvae. This suggests the possibility of an olfactory cue from wounded larvae.

The results of the field-diurnal activity test contradict those of Brust et al. (1986) who observed predator activity to be highest at 0200 and lowest during mid-day in corn agroecosystems in Ohio. There are several possible explanations for this discrepancy. First, in this study pitfall traps were used for sampling, whereas Brust et al. (1986) used visual observations of predators feeding upon bait. Inherent biases in either of the methods may be partially responsible for the apparent contradiction. Second, the data collected by Brust et al. (1986) extended much later into the growing season than the data in this experiment which were collected over a single three-day period from 21 to 24 June. The species composition of predators within corn agroecosystems changes considerably over the season (Lesiewicz et al. 1983, Best et al. 1981, Kirk 1971), thus the diurnal activity patterns may also change. Finally, the weather was unusually cool during the sampling period in this study and may have reduced night activity. This is supported by the results of the laboratory study in which *P. chalcites* and *A. cupreolata*, collected only during the day in the field, tended to be more or at least equally active under night conditions as under day conditions. The lowest temperature under laboratory night conditions was 24°C while that in the field was 4.5°C.

In summary, the results of the habitat preference study indicate that the quantity and structure of surface mulch in reduced-tillage corn agroecosystems can significantly influence generalist predator abundance and activity. In this study, greater ground cover was accompanied by increased generalist predator abundance, although certain species showed a preference for less ground cover. The similarity in predator diurnal activity patterns among the four corn system treatments indicates that the different surface habitats did not substantially influence predator diurnal activity. However, the diurnal activity patterns observed in this experiment should not be considered conclusive. Instead, these results suggest the need for research to determine the factors which influence diurnal activity patterns. Finally, the prey detection test indicates that olfactory cues are generally not important to predators, particularly *P. chalcites* and *A. cupreolata*, in finding armyworm as prey. This finding supports other studies which have observed generalist predator hunting strategies to be primarily random searching.

References Cited

Asteraki, E. J., C. B. Hankes, & R. O. Clements. 1992. The impact of two insecticides on predatory beetles (Carabidae) in newly-sown grass. Ann. Appl. Biol. 120: 25-39.

Barney, R. J. & B. C. Pass. 1986. Ground beetle (Coleoptera: Carabidae) populations in Kentucky alfalfa and influence of tillage. J. Econ. Entomol. 79: 511-517.

Best, R. L., C. C. Beegle, J. C. Owens, & M. Ortiz. 1981. Population density, dispersion, and dispersal estimates for *Scarites substriatus, Pterostichus chalcites*, and *Harpalus pennsylvanicus* (Carabidae) in an Iowa cornfield. Environ. Entomol. 10: 847-56.

Blumberg, A. Y. & D. A. Crossley. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage and old field systems. Agro-Ecosystems 8: 247-253.

Brust, G. E., B. R. Stinner, & D. A. McCartney. 1985. Tillage and soil insecticide effects on predator-black cutworm (Lepidoptera: Noctuidae) interactions in corn agroecosystems. J. Econ. Entomol. 78: 1389-92.

_____ 1986. Predator activity and predation in corn agroecosystems. Environ. Entomol. 15: 1017-1021.

Chiverton, P. A. 1984. Pitfall-trap catches of the carabid beetle *Pterostichus melanarius,* in relation to gut contents and prey densities, in insecticide treated and untreated spring barley. Entomol exp. appl. 36: 23-30.

_____ 1988. Searching behavior and cereal aphid consumption by *Bembidion lampros* and *Pterostichus cupreus*, in relation to temperature and prey density. Entomol. exp. Appl. 47: 173-182.

Clark, M. S. 1993. Generalist Predators in reduced-tillage corn: predation on armyworm, habitat preferences, and a method to estimate absolute densities. M.S. thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Duncan, D. B. 1955. Multiple range and multiple *F* tests. Biometrics 11: 1-42.

Ferguson, H. J. & R. M. McPherson. 1985. Abundance and diversity of adult Carabidae in four soybean cropping systems in Virginia. J. Entomol. Sci. 20: 163-171.

Grafius, E. & F. W. Warner. 1989. Predation by *Bembidion quadrimaculatum* (Coleoptera: Carabidae) on *Delia antiqua* (Diptera: Anthomyiidae). Environ. Entomol. 18: 1056-1059.

Greenslade, P. J. M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). J. Animal Ecol. 33: 301-310.

Halsall, N. B. & S. D. Wratten. 1988. The efficiency of pitfall trapping for polyphagus predatory Carabidae. Ecol. Entomol. 13: 293-299.

Harrison, F. P., R. A. Bean, & O. J. Qawiyy. 1980. No-till culture of sweet corn in Maryland with reference to insect pests. J. Econ. Entomol. 73: 363-365.

Honek, A. 1988. The effect of crop density and microclimate on pitfall trap catches of Carabidae, Staphylinidae (Coleoptera), and Lycosidae (Araneae) in cereal fields. Pedobiologia 32: 233-242.

House, G. J. & J. N. All. 1981. Carabid beetles in soybean agroecosystems. Environ. Entomol. 10: 194-196.

House, G. J. & M. Del Rosario Alzugaray. 1989. Influence of cover cropping and no-tillage practices on community composition of soil arthropods in a North Carolina agroecosystem. Environ. Entomol. 18: 302-307.

House, G. J. & R. W. Parmelee. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Tillage Res. 5: 351-360.

House, G. J. & B. J. Stinner. 1983. Arthropods in no-tillage soybean agroecosystems: community composition and ecosystem interactions. Environ. Mgmt. 7: 23-28.

Jeffords, M. R. & L. J. Case. 1987. Effect of prey density on diurnal activity and ovarian development in *Calosoma calidum* (Coleoptera: Carabidae): implications for biological control of the gypsy moth, *Lymantria dispar* (Lepidoptera: Lymantriidae) in the midwest. Great Lakes Entomol. vol. 20: 93-97.

Kirk, V. M. 1971. Ground beetles in cropland in South Dakota. Ann. Entomol. Soc. Amer. 64: 238-241.

Laub, C. A. & J. M. Luna. 1992. Winter cover crop suppression practices and natural enemies of armyworm (Lepidoptera: Noctuidae) in no-till corn. Environ. Entomol. 21: 41-49.

Lesiewicz, D. S., J. W. Van Duyn, & J. R. Bradley Jr. 1983. Determinations on cornfield carabid populations in northeastern North Carolina. Environ. Entomol. 12: 1636-40.

Luff, M. L. 1975. Some features influencing the efficiency of pitfall traps. Oecologia 19: 345-357.

Luna, J., V. Allen, J. Fontenot, L. Daniels, D. Taylor, D. Vaughan, S. Hagood, C. Laub, D. Ess, S. Clark, L. VanLieshout, K. Horn. 1992. Low-input crop and livestock systems for the southeastern United States, 1990-1991 progress report. Virginia Polytechnic Institute and State University, Blacksburg. 22pp.

Riechert S. E. & L. Bishop. 1990. Prey control by an assemblage of generalist predators: spiders in garden test systems. Ecology 71: 169-72

Stinner, B. R. & G. J. House. 1990. Arthropods and other invertebrates in conservation-tillage agriculture. Annu. Rev. Entomol. 35: 299-318.

Tonhasca, A. & B. R. Stinner. 1991. Effects of strip intercropping and no-tillage in some pests and beneficial invertebrates of corn in Ohio. Environ. Entomol. 20: 1251-1258.

Warburton, D. B. & W. D. Klimstra. 1984. Wildlife use of no-till and conventional tilled corn fields. J. Soil Water Conserv. 39: 327-330

Chapter 4

Evaluation of Removal Sampling for Estimating Absolute Densities of Adult Carabids

Research has shown that carabid beetles can be important biocontrol agents in agroecosystems (Edwards et al. 1979, Best & Beegle 1977, Brust et al. 1985, 1986, Chiverton 1986, Hance 1987) and that agricultural practices can have considerable influences on their species composition, abundance, and activity (Blumberg & Crossley 1983, House & Stinner 1983, Brust et al. 1985, 1986, House & Parmelee 1985, Perfecto et al. 1986, Honek 1988, House & Del Rosario Alzugaray 1989, Kromp 1989, Quinn et al. 1991). Although there have been numerous studies on carabid ecology, there has been relatively little research done to estimate their absolute densities in agroecosystems.

Pitfall traps have been used as sampling tools for mark-release-recapture (Frank 1967, 1971, Ericson 1977, Best et al 1981) and removal sampling (Gist & Crossley 1973) methods for absolute density estimation. Frank (1971) used mark-release-recapture within $0.5m^2$ enclosed sampling areas to estimate the densities of 14 of the most abundant carabids in a field in central Alberta, Canada. Best et al. (1981) and Ericson (1977) used mark-release-recapture with pitfall traps arranged in a grid to estimate the densities of several carabids in a corn field in Iowa and two winter wheat fields in Sweden, respectively. Although mark-release-recapture methods can provide information on density, dispersion, and dispersal, they are labor intensive and have several problems. For example, low recapture rates, common in carabid studies (Manga 1972, Ericson 1977, Best et al. 1981), can lead to unreliable population estimates (Roff 1973, Gilbert 1973) and if recapture rates are extremely low, density estimates are impossible to make (Ericson 1977). In addition, there is the potential for bias due to handling and marking the beetles.

Other methods for carabid density estimation include the use of quadrats with visual searching of the ground and surface debris (Brust et al. 1985, House & Stinner 1983, House & Parmelee 1985), insecticidal ground sprays followed by visual searching (Lesiewicz et al. 1983), and soil core sampling (Dubrovskaya 1970, House & Del Rosario Alzugary 1989). Quadrat sampling may be more time efficient than the mark-release-recapture or removal trapping methods but has some potential drawbacks. Most carabids are highly active and possibly could flee or hide in soil crevices when they sense disturbance, such as an approaching person. In addition, most quadrat sizes are relatively small for sampling organisms with low population densities, such as many carabid species. Soil cores may be very useful for sampling carabid larvae but have problems similar to those of quadrats for sampling adults.

Removal sampling is a method of absolute density estimation based on the decline in successive catch numbers as individuals are removed from a population. Three assumptions are required (Zippin 1958): (1) the population is closed, (2) each individual has an equal probability of being captured, and (3) the probability of capture remains constant during each sampling period. Gist and Crossley (1973) used removal sampling to estimate ground-dwelling arthropod densities on a hardwood forest floor. They isolated sampling areas with aluminum foil strips coated with resin and used pitfall traps to remove the organisms. The results were similar to those obtained by a hand-sorting method which was used as a comparison.

In this study a removal trapping technique was used to estimate adult carabid absolute densities in a no-till corn field in southwestern Virginia. The technique was evaluated according to its agreement with the assumptions.

Materials and Methods

Removal trapping procedures were carried out in 1991 and 1992 in a 40 m x 40 m field site within a no-till corn field in Riner, Virginia (Bishop farm). The field site, which was a silt loam soil (Berks-Lowell-Rayne complex), had been planted in no-till corn with a winter cover crop of rye since 1990. Orchardgrass-alfalfa hay was grown in this field for the preceding three years. No insecticides had been applied since 1989. In 1991 and 1992 paraquat (0.23 kg [AI]/ha) was used to kill the cover crop before corn planting. The residual herbicides atrazine (2.2 kg [AI]/ha) and simazine (2.2 kg [AI]/ha) were applied for weed control. Manure (7660 l/ha) and liquid urea (78 kg N/ha) were applied at corn planting. In 1991 corn (Pioneer 3352) was planted on 15 May and in 1992 corn (Southern States 728) was planted on 25 May.

Six square arenas, constructed of galvanized steel strips, were driven into the ground to isolate randomly chosen trapping areas within the field site. The arenas measured 23 cm in height and 2.39 m in length for each side. This created a sampling area of 5.70 m^2 for each arena. Two barrier pitfall traps (Hilburn 1985) were installed within each arena. A trap consisted of an aluminum flashing strip (90 cm long x10.3 cm wide) placed into a 3 cm deep slice in the ground which functioned as the barrier. A pit was installed at each end of the barrier and consisted of two plastic cups (474 ml, 11 cm rim diameter), one inside of the other, placed in a hole in the ground so that the rim of the inside cup was flush with the soil surface. This allowed the inner cup, which contained the trapped specimens, to be taken out without damaging the structure of the pit. The inner cup contained diluted ethylene glycol as a killing agent and preservative. Plywood rain covers (20 x 20 cm) were suspended above the pits by inserting 7.5-cm-long nails through the four corners of each cover, to serve as supports.

In 1991 three, three-week trapping periods were conducted between 5 June and 8 August providing density estimates for the trap initiation dates: 5 June, 26 June, and 17 July. During the first trapping period five samples were removed at two- to six-day intervals. During the second and third sampling periods three samples were removed at seven- or eight-day intervals. After a trapping period was completed, arenas were moved to new randomly selected positions within the field site and barrier pitfall traps installed as described. In 1992 a single six-week trapping period was conducted, with samples removed weekly between 1 June and 14 July. Absolute density estimates were made after three, four, five, and six weeks of trapping.

Samples were sorted in the laboratory and carabid specimens identified to species or genus level. Absolute density estimates were made for individual species when possible and for the carabid community as a whole using a linear regression technique (Zippin 1956, 1958, Seber & Le Cren 1967). The number of individuals captured per sample (y-axis) was regressed against the previous total number captured (x-axis). Theoretically, if the number captured per sample were to reach zero, all individuals in the sampling area would have been collected. Thus, if the assumptions were valid, the resulting x-intercept of the regression line would represent the total number of organisms in the sampling area (Figure 4-1).

Due to low trap catches from individual arenas the data from the six arenas were pooled and considered a single sample for data analysis. Although this prevented the use of the arenas as replicates, it increased sample sizes and allowed regressions to be conducted for more species while maintaining a constant sampling area. A criterion was used in which intercepts were calculated only if six individuals of a species had been collected during a trapping period (mean = one per arena). Therefore density estimates were not calculated for many of the rare species for which random variation may have

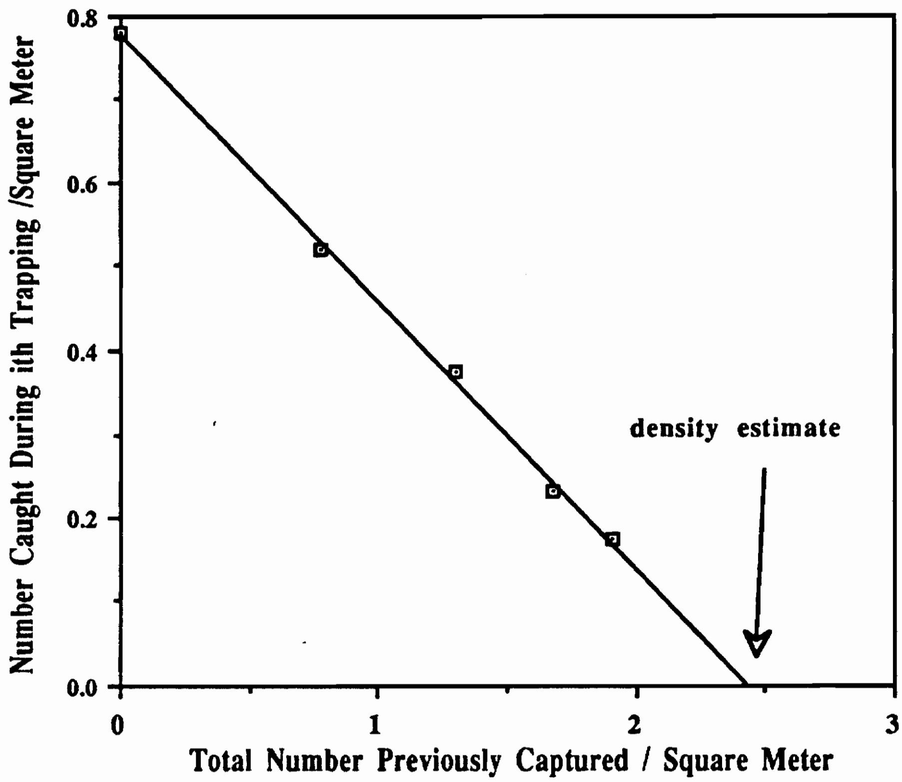

Figure 4-1. Calculation of an absolute density estimate using the linear regression method with removal sampling data.

substantially influenced estimates of the x-intercept. All regressions were conducted using the GLM procedure on Statistical Analysis System (SAS Institute 1982).

Results and Discussion

More than 20 species were collected during the sampling periods in 1991 and 1992 (Table 4-1). Six taxa met the criterion of having six or more individuals collected during a sampling period and appeared to satisfy the assumptions of the removal trapping method to use the linear regression technique for density estimation in at least one trapping period: *Anisodactylus sancaecrucis* F., *Pterostichus chalcites* Say, *Pterostichus lucublandus* Say, *Harpalus herbavigus* Say, *Agonum punctiforme* Say, and *Amara* spp. (primarily *A. cupreolata* Pultzeys) (Fig. 4-2).

In 1991, density estimates were calculated for five taxa. Although the number of *Harpalus pensylvanicus* DeGeer captured per square meter was relatively large (1.10, 2.03, and 0.95 for the three sampling periods, respectively), the many teneral adults present during the last week of the 5 June sampling period until the first week of the 17 July sampling period was an indication that the assumption of a closed population was violated. This made it impossible to use the linear regression technique for this species and it substantially altered the population estimates for total carabids. Thus, regressions were conducted and density estimates calculated for total carabids with and without *H. pensylvanicus* (Fig. 4-3, Table 4-2).

In the 1992 trapping period the number of carabid species and total carabid abundance was considerably less than that for the same time period in 1991 (Table 4-1). Three taxa, *Amara* spp., *A. punctiforme*, and *P. lucublandus*, were collected in adequate numbers and met the criterion for density estimation by the removal sampling technique.

Table 4-1. Carabid species and the total number collected during three three-week trapping periods in 1991 and one six-week trapping period in 1992.

	Total Number Collected			
	1991			1992
Carabid species	6/5	6/26	7/17	6/2
Harpalus pensylvanicus DeGeer	37	70	34	0
Anisodactylus sanctaecrucis F.	71	53	50	3
Pterostichus chalcites Say	3	6	9	5
Amara spp.	42	21	3	24
Harpalus herbavigus Say	14	3	1	5
Pterostichus lucublandus Say	5	4	11	6
Anisodactylus rusticus Say	5	-	-	-
Anisodactylus carbonarius Say	3	3	2	-
Clivina impressifrons Leconte	1	2	1	4
Anisodactylus harrisi Leconte	2	2	2	-
Agonum cupripennis Say	2	2	-	2
Agonum punctiforme Say	5	1	-	9
Colliuris pennsylvanica Linné	1	-	-	-
Harpalus fulgens Csiki	1	-	-	-
Lebia analis Dejean	2	-	-	-
Stenolophus unicolor Dejean	1	-	-	-
Chlaenius tricolor Dejean	1	-	-	-
Agonum octopunctatum F.	-	-	-	-
Scarites subterraneus F.	-	1	1	6
other	2	-	-	8
total carabids	198	168	114	75

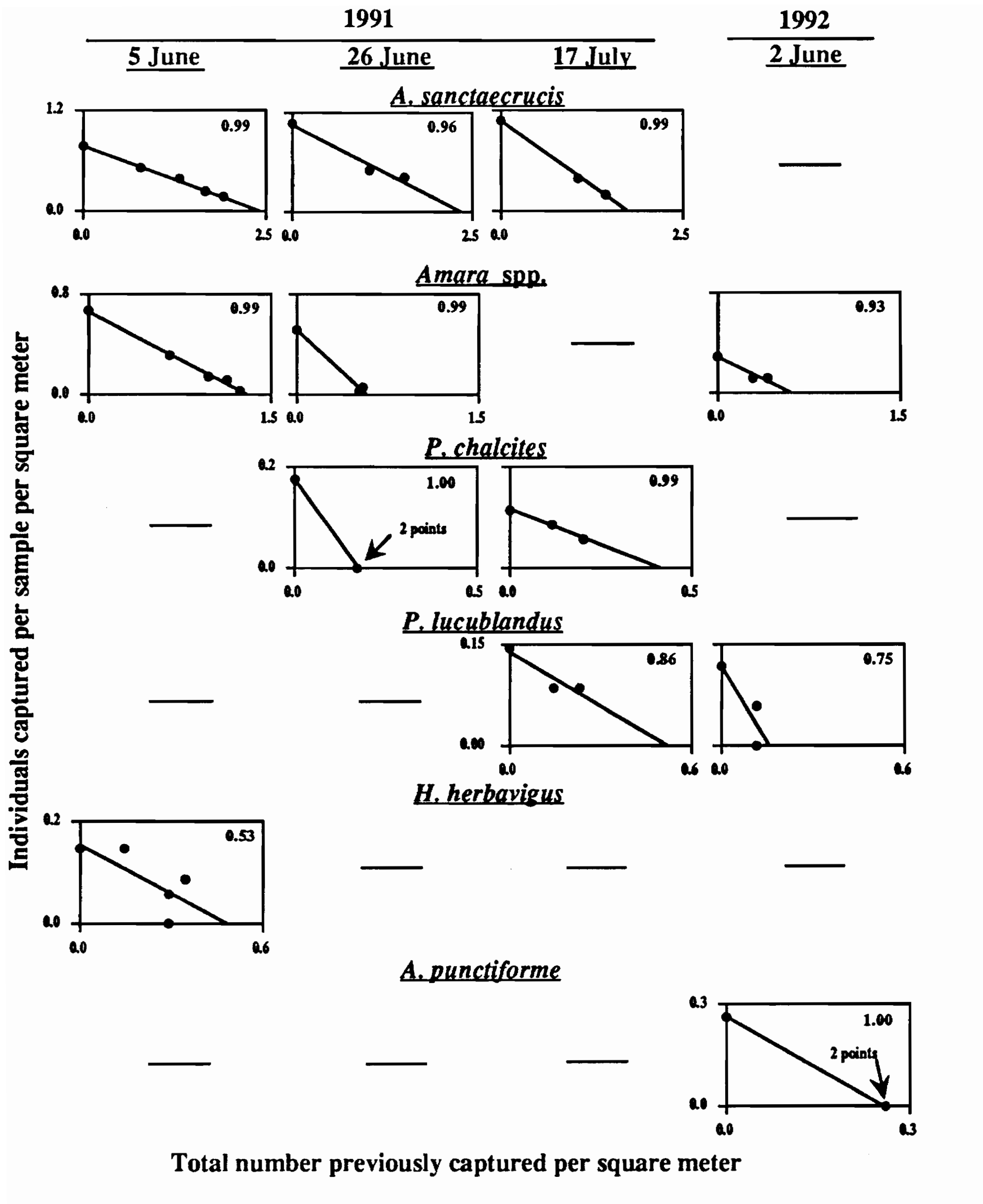

Figure 4-2. Regressions from removal sampling data for carabids based on three-week sampling periods in 1991 and 1992. Columns are trap-initiation dates and rows are species. Dashes indicate that the criterion for conducting a regression was not met. The r-square values are presented in the upper right corners of each graph.

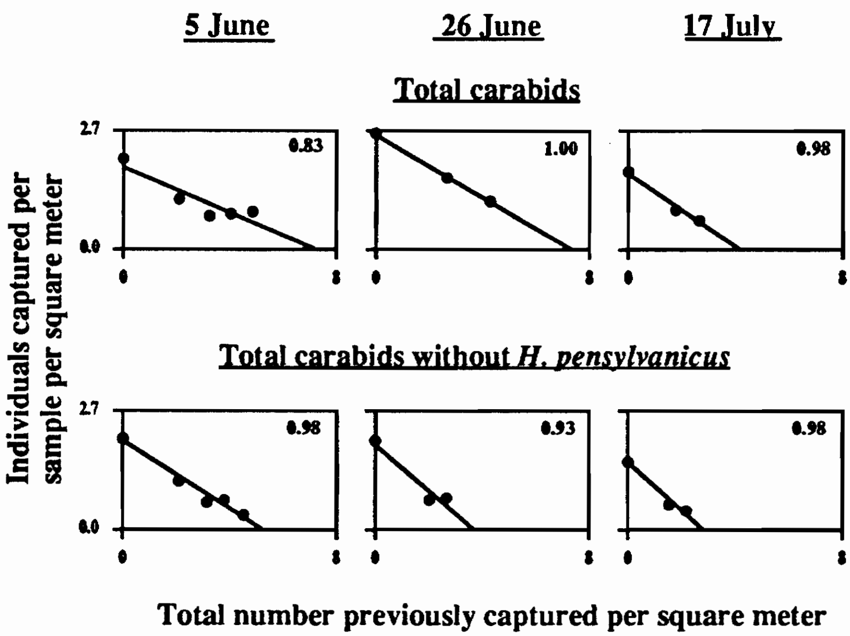

Figure 4-3. Regressions from removal sampling data for total carabids and total carabids without *Harpalus pensylvanicus* for three, three-week sampling periods in 1991. The r-square values are presented in the upper right corner of each graph.

Table 4-2. Absolute density estimates (number / m^2) of carabids based on a removal sampling technique conducted over four three-week trapping periods in 1991 and 1992.

	Number / m^2			
	1991			1992
Carabid species	6/5	6/26	7/17	6/2
Anisodactylus sanctaecrucis F.	2.44	2.30	1.74	+
Pterostichus chalcites Say	0.09	0.17	0.41	+
Amara spp.	1.31	0.58	+	0.58
Harpalus herbavigus Say	0.36	0.07	+	0.10
Pterostichus lucublandus Say	0.13	+	0.47	0.14
Agonum punctiforme Say	+	+	-	0.26
Total Carabids[a]	5.13	3.36	2.77	1.45
Total Carabids[b]	6.49	7.40	4.11	1.45

+: species collected but did not meet criterion for estimating absolute density
-: species not collected
[a] Not including *Harpalus pensylvanicus* DeGeer
[b] Including *Harpalus pensylvanicus* DeGeer

Absolute density estimates, calculated for three-, four-, five-, and six-week sampling periods, increased slightly as the length of the trapping period increased for all taxa except *A. punctiforme*, which only was collected during the first week (Fig. 4-4,Table 4-3). The estimate increase after six weeks was 17, 14, and 28 percent greater than the three-week estimate for *Amara* spp., *P. lucublandus*, and total carabids, respectively. This indicates that at least one of the assumptions of the method was violated to some degree. A violation in the assumption that all individual carabids had equal probability of capture was indicated in the r^2 value of the total carabid estimate for the six-week trapping period (Fig 4-4). This violation was possibly due to different species having different susceptibilities to capture in pitfall traps (Luff 1975, Halsall & Wratten 1988). In addition, the probability of capture for single species may not have remained constant over the entire trapping period either, because pitfall trap catches depend upon activity. Therefore, any factor which influenced activity, such as microclimate or prey availability, could have influenced the probability of capture.

The arenas used in this experiment were designed to prevent ground surface movement by carabids in or out of the trapping area. Thus, a violation in the assumption of a closed population due to migration was not likely. However, some leakage may have occured, especially after heavy rains when small gaps were created around the bases of the arenas due to erosion. In addition, some individuals may have burrowed under the arenas during the course of the experiment. The violation in the assumption of a closed population for *H. pensylvanicus*, in 1991, appeared to be due to pupae which were under the soil surface, within the arenas, and emerged during the experiment. Flight migration by newly-emerged adults of *H. pensylvanicus* was also possible (Kirk 1973). Although

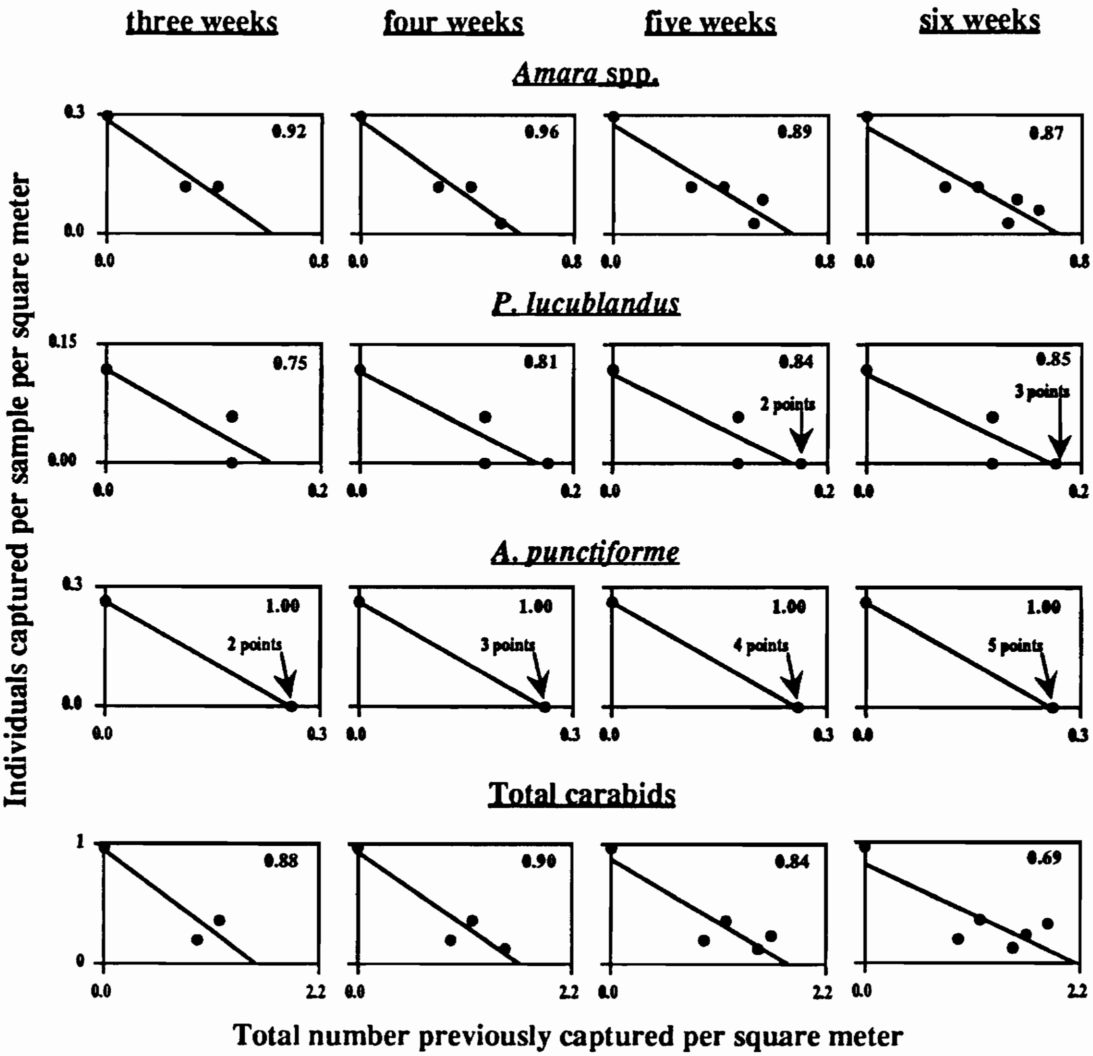

Figure 4-4. Regressions from removal sampling data for three carabid species and total carabids over three-, four-, five-, and six-week trapping periods in 1992. The r-square values are presented in the upper right corner of each graph.

Table 4-3. Absolute density estimates (number / m^2) of carabids based on a removal sampling technique conducted over a three-, four-, five-, and six-week trapping period in 1992.

	Number / m^2			
Carabid species	three-week	four-week	five-week	six-week
Amara spp.	0.58	0.58	0.63	0.68
Pterostichus lucublandus Say	0.14	0.15	0.16	0.16
Agonum punctiforme Say	0.26	0.26	0.26	0.26
total carabids	1.45	1.58	1.71	1.86

many carabid species have demonstrated the ability to fly, flight in carabids is generally considered to be rare (Thiele 1977). Some species are polymorphic or dimorphic, meaning that within a species or even a population some individuals may be capable of flying while others are not. Some species fly only at certain life-stages. Cages, placed over the arenas, could be used to prevent carabids from flying in or out of the arenas and possibly improve the accuracy of the density estimates. The use of cages might also make it possible to estimate the densities of other arthropods, such as hunting spiders, which in this study were capable of moving over the tops of the arenas.

Other possible improvements to this removal sampling technique include increasing the size of the trapping area, which could be accomplished by installing additional arenas. This would increase the number of species for which absolute density estimates could be made since most of the species were not collected in adequate numbers to make estimates. In addition, more traps within each arena could decrease the length of the trapping periods and reduce error caused by natality and mortality.

The density estimates made in this study are relatively similar to estimates which have been made using mark-release-recapture techniques. For example, Best et al. (1981) reported that *P. chalcites* had a mean density of 0.08 m^{-2} from June to August and peak density of 0.20 m^{-2} in early June, in a conventional-till corn field in Iowa. Frank (1971) determined that the mean density of *P. lucublandus* was 0.7 m^{-2} from May to July, in a barley field in Alberta, Canada. However, the estimates for *A. sanctaecrucis*, *P. chalcites*, and *Amara* spp., are considerably higher than those determined by Lesiewicz et al. (1983), who used an insecticidal ground spray technique in a conventional-till corn field in North Carolina. Possible explanations for the differences include the effects of conventional-tillage compared to no-tillage on carabid populations (House & Parmelee 1985, Brust et al. 1986, House & Del Rosario Alzugaray 1989), climatic differences between the study sites, or biases in either of the methods. Lesiewicz et al. (1983) stated that their estimates may have been low due to the abnormally dry conditions during the study.

According to Southwood (1978) use of least-squares linear regression for analysis of removal sampling data may not be acceptable because the data are autocorrelated; thus violating one of the assumptions of the regression method. He recommends another procedure for estimating the parameters which is based upon maximum likelihood. However, Zippin (1956) found close agreement between mean estimates calculated with least-squares regression and maximum likelihood in a simulated sampling experiment. In addition he showed that the estimates calculated with both of these methods were reasonably close to the true mean. Thus, although the assumption of independence is violated, least-squares regression appears to be an acceptable method for fitting lines to removal sampling data. The influence of this assumption violation on variance estimates of the x-intercept has not been investigated.

In addition to the autocorrelated data, the least-squares assumption of homogeneity of variance is also violated to some degree. Means and variances tend to increase together; thus the variances of samples taken at the beginning of a sampling period will be larger than those of estimates taken later in the sampling period because the population size decreases with the removal of each sample. The influence of this assumption violation on mean and variance estimates needs to be evaluated.

Preuss and Saxena (1977) consider the suitability of removal sampling for absolute density estimation to be more due to a lack of other suitable methods than to the desirability of the qualities characteristic of this method. Isolating sufficient parts of a population in order to prevent migration is frequently impractical or impossible for a researcher. This difficulty was demonstrated by Menhinnick (1963) who compared removal sampling, using a sweep net, to mark-release-recapture and total count methods for estimating densities of foliage-dwelling arthropods in *Lespedeza cuneata* (Dumont) G. Don, a perennial woody legume. Removal sampling was limited, mainly by variation in sweep netting efficiency, but proved to be more useful than the other two methods in this situation. Similarly, Preuss et al. (1977) found removal sweeping in alfalfa to provide satisfactory density estimates for several foliage-dwelling insects but noted problems due to immigration during sweeping and lack of applicability of sweep netting for sampling certain insects. Although it may be difficult to completely satisfy the assumptions of removal sampling for many arthropod populations, mobile ground-dwelling arthropods such as carabids seem to be among the better candidates for use of this method.

References Cited

Best, R. L. & C. C. Beegle. 1977. Consumption of *Agrotis ipsilon* by several species of carabids found in Iowa. Environ. Entomol. 6: 532-34.

Best, R. L., C. C. Beegle, J. C. Owens, & M. Ortiz. 1981. Population density, dispersion, and dispersal estimates for *Scarites substriatus, Pterostichus chalcites*, and *Harpalus pennsylvanicus* (Carabidae) in an Iowa cornfield. Environ. Entomol. 10: 847-56.

Blumberg, A. Y. & D. A. Crossley. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage and old field systems. Agro-Ecosystems 8: 247-253.

Brust, G. E., B. R. Stinner, & D. A. McCartney. 1985. Tillage and soil insecticide effects on predator-black cutworm (Lepidoptera: Noctuidae) interactions in corn agroecosystems. J. Econ. Entomol. 78: 1389-92.

_____ 1986. Predation by soil inhabitaing arthropods in intercropped and monoculture agroecosystems. Agric. Ecosystems Environ. 18: 145-54.

Chiverton, P. A. 1986. Predator density manipulation and its effects on populations of *Rhopalosiphum padi* (Hom.: Aphididae) in spring barley. Ann. Appl. Biol. 109: 49-60.

Dubrovskaya, N. A. 1970. Field carabid beetles (Coleoptera: Carabidae) of Byelorussia. Entomol. Rev. 49: 476-83.

Edwards, C. A., K. D. Sutherland, & K. S. George. 1979. Studies on polyphagus predators of cereal aphids. J. Hance, T. 1987. Predation impact of carabids at different population densities on *Aphis fabae* development in sugar beet. Pedobiologia 30: 251-62.

Ericson, D. 1977. Estimating population parameters of Pterostichus cupreus and P. melanarius (Carabidae) in arable fields by means of capture-recapture. Oikos 29: 407-17.

Frank, J. H. 1967. The insect predators of the pupal stage of the winter moth, *Operophtera brumata* (L.) (Lepidoptera: Hydriomenidae). J. Animal Ecology 36: 375-89.

_____ 1971. Carabidae (Coleoptera) of an arable field in central Alberta. Quaes. Entomol. 7: 237-52.

Gilbert, R. O. 1973. Approximations of the bias in the Jolly-Seber capture-recapture model. Biometrics 29: 501-26.

Gist, C. S. & D. A. Crossley. 1973. A method of quantifying pitfall trapping. Environ. Entomol. 2: 951-52.

Halsall, N. B. & S. D. Wratten. 1988. The efficiency of pitfall trapping for polyphagus predatory Carabidae. Ecol. Entomol. 13: 293-299.

Hance, T. 1987. Predation impact of carabids at different population densities on *Aphis fabae* development in sugar beet. Pedobiologia 30: 251-262.

Hilburn, D. J. 1985. Population dynamics of overwintering life stages of the alfalfa wevil, *Hypera postica* (Gyllenhal). Ph.D. dissertation, Virginia Polytechnic Institute & State University, Blacksburg.

House, G. J. & M. Del Rosario Alzugaray. 1989. Influence of cover cropping and no-tillage practices on community composition of soil arthropods in a North Carolina agroecosystem. Environ. Entomol. 18: 302-307.

House, G. J. & R. W. Parmelee. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Tillage Res.5: 351-360.

House, G. J. & B. J. Stinner. 1983. Arthropods in no-tillage soybean agroecosystems: community composition and ecosystem interactions. Environ. Mgmt. 7: 23-28.

Kirk, V. M. 1973. Biology of a ground beetle, *Harpalus pensylvanicus*. Ann. Entomol. Soc. Amer. 66: 513-518.

Kleinbaum, D. G., L. L. Kupper, & K. E. Muller. 1988. Applied regression analysis and other multivariate methods. PWS-KENT Pub. Co., Boston.

Kromp, B. 1989. Carabid beetle communities (Carabidae: Coleoptera) in biologically and conventionally farmed agroecosystems. Agric. Ecosystems Environ. 27: 241-251.

Lesiewicz, D. S., J. W. Van Duyn, & J. R. Bradley Jr. 1983. Determinations on cornfield carabid populations in northeastern North Carolina. Environ. Entomol. 12: 1636-40.

Luff, M. L. 1975. Some features influencing the efficiency of pitfall traps. Oecologia 19: 345-357.

Manga, N. 1972. Population metabolism of *Nebria brevicollis* (F.) (Coleoptera: Carabidae). Oecologia 10: 223-42.

Menhinick, E. F. 1963. Estimation of insect population density in herbaceous vegetation with emphasis on removal sweeping. Ecology 44: 617-621.

Perfecto, I., B. Horwith, J. Vandermeer, B. Schultz, H. McGuinness, & A. Dos Santos. 1986. effects of plant diversity and density on the emigration rate of two ground beetles, *Harpalus pennsylvanicus* and *Evarthrus sodalis* (Coleoptera: Carabidae) in a system of tomatoes and beans. Environ. Entomol. 15: 1028-1031.

Preuss, K. P., & K. M. Lal Saxena. 1977. Estimation of insect populations by removal sampling. Ag. Exp. Station Rep. 4. University of Nebraska.

Preuss, K. P., K. M. Lal Saxena, & S. Koinzan. 1977. Quantitative estimation of alfalfa insect populations by removal sweeping. Environ. Entomol. 6: 705-708.

Quinn, M. A., R. L. Kepner, D. D. Walgenbach, R. N. Foster, R. A. Bohls, P. D. Pooler, K. C. Reuter, & J. L. Swain. 1991. Effects of habitat characteristics and perturbation from insecticides on the community dynamics of ground beetles (Coleoptera: Carabidae) on mixed grass-rangeland. Environ. Entomol. 20: 1285-1294.

Roff, D. A. 1973. On the accuracy of some mark-recapture estimators. Oecologia 12: 15-34.

SAS Institute. 1982. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Seber, G. A. F. & E. D. Le Cren. 1967. Estimating population parameters from catches large relative to the population. J. Animal Ecology 36: 631-643.

Southwood, T. R. E. 1978. Ecological methods. Chapman & Hall, London.

Thiele, H. -U. 1977. Carabid beetles in their environments. Springer-Verlag. New York.

Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. Biometrics 12: 163-189.

_____ 1958. The removal method of population estimation. J. Wildlife Management 22: 82-90.

Summary & Conclusions

The predator-removal study (Chapter 2) indicated that generalist predator assemblages can be important in controlling armyworm populations in reduced-tillage corn. Both the proportion of plants with feeding damage and the degree of damage were greater within arenas where predator populations were reduced. Laboratory feeding trials provided information on the relative consumption rates of common generalist predators and suggested that a large number of species may be feeding on armyworm in the field.

The habitat preference study (Chapter 3) showed that the quantity and structure of surface mulch can influence generalist predator populations in reduced-tillage corn agroecosystems. In general, higher predator abundances were associated with greater degrees of ground cover, although a few species appeared to prefer treatments with less mulch. According to pitfall trapping results, the different habtitat treatments did not influence predator diurnal activity patterns; however, research is needed to determine what factors do influence these patterns. Field and laboratory prey detection tests, using live armyworm larvae as bait, indicated that olfactory cues are probably not important for predators in finding armyworm prey.

A removal sampling technique was used to estimate the absolute densities of common carabids in a no-till corn field (Chapter 4). Although there appeared to be some violations in the assumptions of the method, the estimates are similar to other estimates obtained in other studies using mark-release-recapture methods. Possible improvements to the technique and further testing of the effects of the assumption violations on the parameter estimates are suggested.

VITA

I was born in Baltimore, Maryland on 27 July 1967 and spent my first 18 years in Harford County, Maryland. I have spent most of the last 7 years in Blacksburg, a place I enjoy immensely. During this time I received a B.S. degree in Biology from Virginia Tech in 1989, interned for the Virginia Student Environmmental Health Project for several months, worked in the Agronomy Department at Virginia Tech for about a year, was married to a girl named Stephanie, and got a son named Niles. In August 1990, I began work on a M.S. degree in Entomology. I have concentrated my studies in agroecology and plan to continue with this focus, as well as with a few others, on my trek in pursuit of knowledge.