Carabid beetle (Coleoptera: Carabidae) seasonal occurrence and species composition in northern Montana cropping systems
by Carin Anne Miller

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Entomology
Montana State University


Abstract:
Carabid beetles (Coleoptera: Carabidae) are important natural enemies in agricultural ecosystems. Species composition and seasonal occurrence of carabid beetles in cropping systems were examined in 1998 and 1999 in experimental plots near Havre, Montana. The experiment was designed to compare two tillage systems, conventional and no-till, and treatments within crop rotations: fallow, CRP (Conservation Reserve Program), spring wheat, pea, sunflower, and yellow mustard. Pitfall traps were used to collect carabid beetles in the field for six 7-day sampling periods in 1998, and five 7-day sampling periods in 1999. Forty-five and thirty eight species were collected in 1998 and 1999, respectively. Data were analyzed using a repeated measures analysis of variance and analysis of variance by date. Analyses of total carabids showed a significant date by crop effect, with greater carabid activity occurring in yellow mustard and sunflower in June through August sample dates. Analyses performed on Harpalus fuscipalpis and Amara littoralis found an association with yellow mustard, suggesting that these species were crop type specialists. Amara thoracica and Harpalus paratus activity were closely associated with sunflower. Other species such as Microlestes linearis, Calosoma lepidum, Harpalus reversus, and Amara obesa. exhibited no strong association with a particular crop. Differences between tillage systems were present in 1999 but not in 1998. Responses of individual carabid species to tillage systems varied; for instance, M. linearis activity was consistently greater in tilled plots.

# CARABID BEETLE (COLEOPTERA: CARABIDAE) SEASONAL OCCURRENCE AND SPECIES COMPOSITION IN NORTHERN MONTANA CROPPING SYSTEMS

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APPROVAL

of a thesis submitted by

Carin Anne Miller

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date 4 December 2000

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TABLE OF CONTENTS

TABLE OF CONTENTS – CONTINUED

# LIST OF TABLES

# LIST OF FIGURES

## ABSTRACT

Carabid beetles (Coleoptera: Carabidae) are important natural enemies in agricultural ecosystems. Species composition and seasonal occurrence of carabid beetles in cropping systems were examined in 1998 and 1999 in experimental plots near Havre, Montana. The experiment was designed to compare two tillage systems, conventional and no-till, and treatments within crop rotations: fallow, CRP (Conservation Reserve Program), spring wheat, pea, sunflower, and yellow mustard. Pitfall traps were used to collect carabid beetles in the field for six 7-day sampling periods in 1998, and five 7-day sampling periods in 1999. Forty-five and thirty eight species were collected in 1998 and 1999, respectively. Data were analyzed using a repeated measures analysis of variance and analysis of variance by date. Analyses of total carabids showed a significant date by crop effect, with greater carabid activity occurring in yellow mustard and sunflower in June through August sample dates. Analyses performed on *Harpalus fuscipalpis* and *Amara littoralis* found an association with yellow mustard, suggesting that these species were crop type specialists. *Amara thoracica* and *Harpalus paratus* activity were closely associated with sunflower. Other species such as *Microlestes linearis*, *Calosoma lepidum*, *Harpalus reversus*, and *Amara obesa*. exhibited no strong association with a particular crop. Differences between tillage systems were present in 1999 but not in 1998. Responses of individual carabid species to tillage systems varied; for instance, *M. linearis* activity was consistently greater in tilled plots.

# CHAPTER 1

# LITERATURE REVIEW

Carabid beetles, also known as ground beetles, form the family Carabidae, the third largest family in the order Coleoptera. They are an extremely diverse group, inhabiting practically all habitat and ecosystem types (Lövei and Sunderland 1996). They have been identified as important natural enemies because they prey on a multitude of pests including insects and weed seeds. For the most part, carabids do not fall in the category of insects suitable for classical biological control due to their generalist predatory habits. However, several studies indicate that increased numbers of carabids and other generalist predators such as spiders can effectively keep pest populations in check (Edwards et al. 1979, Edwards and George 1981, Floate et al. 1990, Lövei and Sunderland 1996). Information will be presented on the life history of carabids, habitat choice, predatory behavior, and effects of tillage and crop type on carabids.

## Life History

In general, carabids develop from egg to adult, reproduce, and then die in less than one year. However, there are exceptions to this rule, with some adults living more than one year. Females lay eggs singly or in small to large batches. Sometimes they are laid in crevices in the soil, or in an excavated chamber prepared by the female, complete with a cache of seeds for the emerging larvae (Ball 1968, Luff 1987, Lövei and Sunderland 1996).

The majority of larvae are free living and campodeiform typically undergoing two to three instars before pupating in a pupal chamber in the soil. In many species, the larvae (second or third instar) undergo diapause, either winter (hibernation) or summer (aestivation).

Some adult carabids have a life span ranging from two-four years (Ball 1968). The longevity of adults depends on environmental conditions and the amount of available food. It is possible for some adults to reproduce more than once during their lifespan.

Many attempts to place carabid beetles into seasonal activity and reproduction categories have been made. Historically, carabids have been separated into two groups: spring breeders or autumn breeders (den Boer and den Boer-Daanje 1990). However, more recent studies have shown that carabid beetles can fall into many different categories, including species with flexible breeding periods and species that require more than one year to develop (Luff 1987, den Boer and den Boer-Daanje 1990, Dülge 1994, Makarov 1994, Fadl and Purvis 1998).

The majority of common carabid species found in agricultural fields are nocturnal (Luff 1987). However, the development of time-sorting pitfall traps has enabled researchers to study diurnal versus nocturnal activity (Blumberg and Crossley 1988, Kegel 1990). Kegel (1990) found that daytime activity is positively correlated with soil temperature in diurnal species and negatively in nocturnal species. Nocturnal species seem to have high moisture requirements, conditions that favor activity at night rather than daytime when humidity is typically lower (Thiele 1977). Carabids are able to adapt to a variety of habitats due to their flexibility in life cycle and daily activity.

## Carabid Beetle Impacts on Agroecosystems

Carabid beetles are voracious feeders, consuming up to 3 times their body weight daily. The majority of carabid species are generalist predators, eating both animal and plant material. Some attempts have been made to try and categorize species into carnivores, herbivores, or omnivores, but the majority of species are opportunistic, feeding on whatever is available in abundance in their habitat (Thiele 1977, Luff 1987, Lövei and Sunderland 1996). Some are specialists, such as many species in the genus Calosoma which specialize on lepidoptera larvae (Thiele 1977). Others are morphologically specialized for a certain prey type. For example, members of the tribe Cychrini have a narrow pronotum and specialized mandibles which enable them to eat snails (Thiele 1977). However, the morphology of most species suggests that prey choice is driven by what is available, not by biological specialization (Thiele 1977, Luff 1987, Evans 1994).

Morphological studies are based on an examination of an organism's body plan in order to determine habitat and/or prey specialization. The size and shape of the mandibles and the musculature associated with the mandibles can help determine whether or not the animal crushes or pulverizes its prey, or uses the mandibles to tear and cut (Evans 1994).

The morphology of the digestive tract, particularly the proventriculus, can be used as an indicator of diet (Forsythe 1982). If there is a smooth surface, the organism most likely digests most of its food extra-orally and takes up the resulting liquid. A proventriculus with a grinding surface made up of proventricular teeth, on the other hand, is equipped to handle harder substances such as chitinous body parts of insects and plant material such as hard seed coats (Forsythe 1982).

Most carabid species are nocturnal and rely on a randomized search pattern combined with visual and chemical cues to locate prey (Luff 1987, Lövei and Sunderland 1996). While it has been observed that a few species will climb plants when hunting, most stay on the ground (Forsythe 1982, Luff 1987, Lövei and Sunderland 1996). When a prey item is located, search behavior in that area intensifies for a certain amount of time after consumption before the beetle gives up and resumes the random search behavior (Lövei and Sunderland 1996).

The combination of a voracious appetite, opportunistic feeding behavior, and mobility makes carabid beetles effective and important natural enemies in agroecosystems. In recent years, the role of natural enemies in biological control has become more important, although the carabid species complex is often overlooked. Biological control has focused on classical biological control systems, defined as "the importation and establishment of exotic natural enemies for control of pests (usually exotic)" (DeBach 1964, Bugg and Pickett 1998). Typically, this involves the importation of one specific predator to control one pest. Classical biological control systems are based on knowledge of the population dynamics of the two species and their interactions with the environment. In most systems studied, carabids are represented as a species complex, which makes interpreting interactions between multiple predator species and multiple insect and/or seed prey more complex. Due to their general predatory habits, carabid beetles are more suited to biological control that involves the conservation of existing populations of natural enemies. Conservation may involve habitat modification, use of refugia and/or restricted use of chemicals in order to maintain and protect natural enemy populations (DeBach 1964, Bugg and Pickett 1998).

Many different techniques have been used in order to determine the kind of food that carabid beetles eat. These range from laboratory and field behavioral studies, serological techniques, gut dissections, and morphological analysis. Several literature reviews on carabids and their prey have been done (Thiele 1977, Luff 1987, Allen and Rajotte 1990, Larochelle 1990).

The role of carabids as effective predators of aphids (*Sitobion avenae* Fabricius, *Metopolophium dirhodum* Walker, *Rhopalosiphum padi* L.) has been well documented (Edwards et al. 1979, Edwards and George 1981, Hance 1987, Winder 1990, Bilde and Toft 1999, Kielty et al. 1999). Winder (1990) conducted a study in which he measured the rates at which aphids fell to the ground from the crop canopy and the rates at which they returned to the crop canopy. He manipulated ground predator density (including carabids) with exclusion barriers, and found that aphid climbing rate was highest when predator densities were lowest, suggesting that ground predators reduced the number of aphids that returned to the canopy (Winder 1990). Edwards and George (1981) and Edwards et al. (1979) performed similar experiments where carabid populations were manipulated and found that aphid populations were inversely correlated with numbers of carabids.

Many studies have also shown carabids to be effective predators of Lepidoptera larvae such as cutworms (*Agrotis ipsilon* Hufnagle, *Euxoa ochrogaster* Guenée) armyworms (*Pseudaletia unipuncta* Haworth), and codling moth (*Cydia pomonella* L.) (Frank 1971, Best and Beegle 1977a, Lund and Turpin 1977b, Brust et al. 1985, Brust et al. 1986, Mack and Backman 1990, Laub and Luna 1992, Clark et al. 1994, Riddick and Mills 1994, Suenaga and Hamamura 1998). For example, Frank (1971) found that several species of carabids would feed on redbacked cutworm (*Euxoa ochorgaster*) eggs, larvae, and pupae both in the laboratory and in the field. Best and Beegle (1977a) found several carabid species that would consume various stages of the black cutworm *Agrotis ipsilon* in the laboratory. Clark et al. (1994) found that armyworm (*Pseudaletia unipuncta*) damage to corn (*Zea mays* L.) plants was significantly greater in plots where predators (including carabids, staphylinids, and spiders) were removed using pitfall traps. In addition, carabids have been studied as effective predators of other insect pests such as the wheat midge(*Sitodiplosis mosellana* Géhin) (Floate et al. 1990) and carrot weevils (*Listronotus oregonensis* LeConte) (Baines et al. 1990). Overall, it seems that carabids will take advantage of any potential pest or prey population and that few carabid species specialize on just one species or group of pests.

Historically, carabids have been classified primarily as carnivores, with plant matter considered as a minor part of their diet, eaten only when animal prey was not available. However, in recent decades, spermophagy in carabids has received more attention, and many authors have considered their role in the management of some weed species (Johnson and Cameron 1969, Best and Beegle 1977b, Lund and Turpin 1977a, Barney and Pass 1986a, Brandmayr 1990, Jørgensen and Toft 1997, Menalled et al. 2000). For example, Jørgensen and Toft (1997) studied larval development rates of *Harpalus rufipes* (DeGeer), a common carabid species in Danish cereal fields. They compared development rates of larvae raised on common weed seeds to those raised on a diet of several different insect species and found that developmental time for the first and second instar for those fed the mixed insect diet was about twice as long as the developmental time of those fed the weed seed diet (Jørgensen and Toft 1997). Lund and Turpin (1977a) found that *Harpalus pensylvanicus* (DeGeer) readily ate several different species of weed seeds, including Kentucky bluegrass (*Poa pratensis* L.), redroot pigweed (*Amaranthus retroflexus* L.), and common ragweed (*Ambrosia artemisiifolia* L.). The genera *Harpalus* and *Amara* have primarily been classified as being at least partially, if not primarily, phytophagous (Johnson and Cameron 1969, Thiele 1977, Forsythe 1982, Evans 1994).

## Habitat and Microhabitat

Carabid beetles, like many organisms, are sensitive to the environmental conditions of their habitats. They are an extremely diverse group, with species inhabiting riparian, prairie, forest, and agricultural habitats. Adults are very mobile, and can easily move when local environmental conditions become unfavorable. The soil dwelling larval stage is less mobile with weak chitinization, and is therefore much more sensitive to disturbances and changes in the habitat. Little is known about the larvae of most species, mainly because they live in the soil and are difficult to find in abundance, and must be associated with adults by rearing in the laboratory. Therefore it is difficult to determine how much of a role larvae play in habitat choice, but it is probably very significant.

Several studies have focused on the effects of habitat and microclimate on carabid fauna. Field edges are a type of habitat which are often composed of a diversity of grasses and broadleaf plants including weed species. This may be a more diverse habitat type that is favorable for carabid beetles when compared with a monoculture agricultural field.

Disturbances such as tillage and harvesting practices and chemical applications imposed by agricultural production may result in a habitat that is not favorable for many natural enemies. The lack of plant diversity frequently found in agricultural monocultures results in a subsequent lack of insect diversity that many natural enemies such as carabids depend on for prey (Bugg and Pickett 1998). A weedy field border can provide diversity of both plant and insect species and therefore helps to support a more robust natural enemy population (Shelton and Edwards 1983, Pavuk et al. 1997). Chiverton and Sotherton (1991) compared herbicide treated field edges with non-herbicide treated field edges and found that the non-treated edges supported a greater diversity of prey items and therefore a greater abundance and diversity of carabids than the herbicide treated edges. Field borders can provide a stable overwintering site for ground beetles and other beneficial arthropods, in addition to providing a refuge when the field is disturbed by agricultural practices such as harvesting or tilling (Hance et al. 1990, Lys and Nentwig 1991, Lys et al. 1994).

It seems clear from the literature that weedy field margins help promote and maintain high population levels of natural enemies like carabid beetles. The argument has been made that weedy field borders act as an overwintering site not only for beneficials, but for pests also (Sheehan 1986, Russell 1989). However, a population of prey species is necessary to support the carabid population. One of the reasons that pest species can be so successful in cultivated fields is that monoculture crop fields are low in diversity. Low plant diversity can reduce a pest's search time for a host plant, and once located provide an unlimited supply of food. By maintaining some weedy borders, or perhaps even more extreme; creating them within large fields, the farmer can restore some of the plant diversity to the field. As a result, as natural enemy populations are conserved the potential for a pest outbreak is reduced.

The idea of maintaining or creating a refuge habitat for natural enemies is persistent in the literature on integrated pest management and biological control. The basic idea is to create or maintain an area either surrounding the crop as a field border or as a strip within the crop which will provide an alternate habitat for natural enemies (Tonhasca and Stinner 1991, Lys and Nentwig 1992, Lys 1994, Lys et al. 1994, Zangger 1994, Zangger et al. 1994). Unfortunately, agricultural intensification often results in the removal of hedges and field boundaries (Lys et al. 1994).

Lys et al. (1994) examined the effects of within-field weed strips in a cereal field. They found that the area with weed strips supported greater numbers and greater species diversity of carabids when compared with the control area (no weed strips). The amount of available prey seemed to be the limiting factor in this study. There was a high density and diversity of other arthropod species in the weedy strips, which the authors related to increased carabid numbers and diversity (Lys et al. 1994, Zangger et al. 1994). Hance et al. (1990) also compared the abundance and diversity of carabids in a winter barley field with the adjacent weedy border and also found that the border supported greater diversity and abundance of carabids.

In addition to being opportunistic predators, carabid beetles are extremely sensitive to microclimatic factors (Hance et al. 1990, Lövei and Sunderland 1996). Temperature and humidity extremes are not easily tolerated. In a row crop, there is often a large amount of bare, exposed ground between rows of crops. This often results in a very hot and dry ground surface for the beetles. The weedy field edge usually has a dense, more diverse plant canopy which results in a comparatively more humid and cooler microclimate at the ground surface.

Field borders also often have a greater amount of organic material or leaf litter on the ground surface than cultivated fields. Several studies have shown the positive effects of increased organic material on carabid diversity and abundance (House and All 1981, Weiss et al. 1990, Tonhasca and Stinner 1991, Tonhasca 1993, Burton and Burd 1994). The majority of carabid beetles are nocturnal, and the field edge provides a place for the beetles to avoid unfavorable microclimate conditions and predators by hiding in leaf litter and under rocks during the day. Carabids can then move into the field to hunt at night when temperature and humidity conditions in the field are more favorable

Effects of Tillage on Carabid Beetles

The main differences between conventionally till and no-till systems involve soil structure and the amount of organic matter present (House and Parmalee 1985, House and Brust 1989). In general, the soil in conventional till systems is periodically disturbed by tillage equipment. Different kinds of tillage equipment can vary in the amount of disturbance they cause and may result in variable moisture loss and potential for soil erosion (Young et al. 1994). In addition, organic matter is often reduced in conventional till systems (Young et al. 1994). Most crop residues are buried in the process of tillage and decomposition processes are often accelerated by the increased amount of oxygen introduced by soil mixing (House and All 1981, Stinner et al. 1988).

Long-term no-till systems result in improved soil structure that includes small uniform aggregates, greater infiltration, and increased soil moisture storage capacity and use efficiency (House and Crossley 1987, Stinner et al. 1988). In addition, no-till systems leave crop residues on the soil surface in the field to decompose slowly, resulting in increased soil organic matter (Domitruk et al. 1997). In general, no-till systems tend to support a greater diversity of soil invertebrates.

Several studies have found a clear association between high carabid numbers and diversity in no-till systems when compared to conventional till (House and All 1981, House and Stinner 1983, House and Crossley 1987, Weiss et al. 1990). These authors attribute this trend to availability of prey. Some also hypothesize that increased amount of litter, or crop residues act as a refuge for the beetles, and are therefore associated with higher numbers of carabids. It has also been found that certain species of carabid beetles may be effective weed seed predators, and since weed seeds are usually in greater abundance in no-till systems, this could also be attractive to maintaining higher populations of some carabid species (Lund and Turpin 1977a, House 1989).

Other studies, however, have found that there is no association between no-till and greater carabid abundance. Barney and Pass (1986b) found that carabid species varied in their response to tillage systems, with some species increasing in no-till, while others clearly increased in conventional till. Their overall finding was that carabids as a group were least abundant and least diverse in no-till. Cárcamo (1995) also captured greater numbers of and greater diversity of carabids in conventional till barley fields than in no-till.

Conventional tillage has a consistent deleterious impact on soil arthropod community composition when compared with no-till systems. Tillage reduces arthropod populations in general because it exposes organisms to less favorable microclimate conditions and makes them susceptible to desiccation, mechanical destruction and disrupts their access to food resources (House and Del Rosario Alzugaray 1989). No-till systems, in contrast, maintain more hospitable environmental and soil conditions with less disruption, which results in less moisture loss, and conserves their available prey resources (House and Crossley 1987). The greater retention of residues on the soil surface in no-till systems also helps minimize humidity and temperature fluctuations (Hammond 1987, Tonhasca and Stinner 1991).

In general, predaceous arthropod densities increase with no-till practices due in part to the presence of plant residues as a refuge, lack of disturbances to the system in general, and generally higher populations of potential prey (House and All 1981, Blumberg and Crossley 1983, Clark et al. 1993). As a result, no-till systems often require a more vigilant integrated pest management monitoring program because both pest and natural enemy populations are often enhanced (House and Del Rosario Alzugaray 1989).

## Effect of Crop Type on Carabid Beetles

The diversity and structure of plants can greatly influence habitat suitability and activity of ground beetles and other beneficial arthropods (Norris and Kogan 2000). Rivard (1966) found that different crop types affected the number of beetles captured in pitfall traps. Greater numbers of carabid beetles were found in cereal crops (winter wheat (*Triticum aestivum* L.)and oats (*Avena sativa* L.)) than in forage crops (clover, *Trifolium sp*. and alfalfa, *Medicago sativa* L.) and pastures. He suggested that differences in microclimatic conditions among crops such as increased humidity and ground cover are what caused the crop type effect found in his study. Cárcamo and Spence, (1994) however, found no crop effect on abundance of one species *Pterostichus melanarius* Illiger. Clark et al. (1997) found that carabid species were more abundant in annual crops (wheat, *Triticum aestivum* L., corn, and soybean, *Glycine max* L.) than in perennial crops (alfalfa). Hance and Gregoire-Wibo (1987) found significant differences in species diversity among crop types in their study. In another study, carabid species abundance and diversity were significantly different between sugar beet (*Beta vulgaris* L.), winter wheat, and winter barley (*Hordeum vulgare* L.) crops, but the differences were primarily among winter and spring crops (Hance et al. 1990). They suggested that these differences were most likely correlated with timing of tillage, pesticide applications, and differences in ground cover (Hance et al. 1990).

In 1996, strategic planning workshops were held in Montana, Nebraska, and North Dakota to bring together stakeholders to identify agricultural production concerns, including pest management problems and economic issues for dryland wheat production in the Northern Great Plains (Johnson 1999). Many producers expressed interest in the economic and long-term management benefits of alternative non-cereal crops to use in rotation with wheat (Johnson 1999). Along with the benefits that new crops bring, new pest problems can emerge. From the strategic planning workshops, the Sustainable Pest Management (SPM) project was developed. The objectives of the SPM project include investigating the interactions of new crop rotations with both beneficial and pest insects (Johnson 1999). Related to the SPM project, the objective of this study was to examine the effect of tillage and crop type on carabid beetle species activity, diversity, and relative abundance.

# CHAPTER 2

## INTRODUCTION

Carabid beetles, also known as ground beetles, are the third largest family in the order Coleoptera. For the most part, carabid beetles are opportunistic feeders, preying on both live and dead insects, and plant material, particularly seeds. They have been identified as important natural enemies because they prey on a variety of pests including insects and weed seeds. Because of their generalist predatory habits, they are often overlooked regarding their potential role in pest management. However, several studies indicate that increased numbers of carabids and other generalist predators such as spiders can effectively keep pest populations in check (Edwards et al. 1979, Edwards and George 1981, Floate et al. 1990, Lövei and Sunderland 1996).

Carabid beetles are among the most important epigaeic predators in temperate agroecosystems. Several factors drive habitat choice for carabid beetles including presence of prey, plant habitat, and microclimatic conditions such as temperature and humidity. The diversity and structure of plants and their management can greatly influence habitat suitability and activity of ground beetles and other beneficial arthropods (Norris and Kogan 2000). Rivard (1966) found that different crop types affected the number of beetles captured in pitfall traps. Greater numbers of carabid beetles were found in cereal crops (winter wheat and oats) than in forage crops and pastures. He suggested that differences in microclimatic conditions such as increased humidity and ground cover are what caused the crop type effect found in his study. Cárcamo and Spence, (1994) however, found no crop effect on abundance of one species *Pterostichus melanarius*. Clark et al.'s (1997) studies revealed that carabid species were more abundant in annual crops than in perennial crops. Hance and Gregoire-Wibo (1987) found significant differences in species diversity between crop types in their study. In another study, carabid species abundance and diversity were found to be significantly different among sugar beet, winter wheat, and winter barley, but that the differences were primarily between winter and spring crops (Hance et al. 1990). The authors suggested that these differences were most likely correlated with timing of tillage, pesticide applications, and differences in ground cover (Hance et al. 1990).

Tillage systems can also affect carabid beetle populations. Conventional tillage has a consistent deleterious impact on soil arthropod community composition when compared with no-till systems. Tillage reduces arthropod populations in general because it exposes organisms to unfavorable conditions and increases their susceptibility to desiccation and mechanical destruction and disrupts their access to food resources (House and Del Rosario Alzugaray 1989). No-till systems in contrast, maintain hospitable environmental conditions in the absence of mechanical disruption, which results in less moisture loss, conserves available prey resources, and ameliorates temperature extremes (House and Crossley 1987). This is due in part to the fact that these systems result in soils with higher structural diversity because of greater retention of residues on the soil surface (Tonhasca and Stinner 1991).

# CHAPTER 3

# MATERIALS AND METHODS

This project was part of a larger Sustainable Pest Management (SPM) experiment which was established in 1998 to examine the long-term effects of alternative dryland cropping systems in the Northern Great Plains. The site was located approximately 25 miles northeast of Havre, MT (48.775° N, 110.075° W) at the Mark Peterson Grain and Cattle, Inc. farm. The experiment was a randomized complete block design arranged as split-plot with main plots being conventional till or no-till. There were four replications of the experiment. Subplots were crops within 2, 3, and 4 year crop rotations (see Table 1). Every crop in every rotation was represented each year.

## Management of Experimental Plots

This experiment was established on a 50-acre parcel of land that was in the Conservation Reserve Program from 1988-1997. Glyphosate (Monsanto, St. Louis, MO) herbicide was used to terminate the grass/alfalfa CRP planting in the spring of 1997. The conventional till main plot areas of the experiment were tilled prior to planting in the spring of 1998 (Carlson and Lenssen 1999).

Table 1. Summary of all crops and rotations included in the Sustainable Pest Management Project, Havre 1998 and 1999. Crops sampled for carabid beetles are in bold.

| *Rotation Description* | *1998 Crops* | *1999 Crops* |
|---|---|---|
| Baseline | **Conservation Reserve Program (CRP)** | **Conservation Reserve Program (CRP)** |
| | **Continuous spring wheat** | **Continuous spring wheat** |
| Two year | **Fallow** – Spring Wheat | Fallow – Spring Wheat |
| | Lentil – Spring Wheat | Lentil – Spring Wheat |
| Three year | Fallow – Spring Wheat – Spring Wheat | Fallow – Spring Wheat – Spring Wheat |
| | Fallow – **Yellow Mustard** – Spring Wheat | **Fallow** – **Yellow Mustard** – Spring Wheat |
| | Fallow – Spring Wheat – Safflower | Fallow – Spring Wheat – Safflower |
| | Fallow – **Pea** – Spring Wheat | Fallow – Spring Wheat – **Pea***|
| | Fallow – Spring Wheat - Chickpea | Fallow – Chickpea – Spring Wheat |
| | | **Pea** – Spring Wheat - **Sunflower** |
| Four year | Fallow – Lentil – Spring Wheat - **Sunflower** | |

* Traps were moved to these pea plots after 1 July 1999, when the pea-spring wheat-sunflower rotation was terminated.

A standard cultivator with overlapping sweeps was used for conservation tillage and the final seedbed was prepared with a Triple-K cultivator. The conventional till fallow plots were cultivated 3 times during each season using sweeps for weed control (see Table 2 for exact dates). All plots were seeded and fertilized with a 12 ft. (3.66 m) wide ConservaPak (ConservaPak Ltd., Indian Head, SK) air seeder. Table 3 summarizes information on crop cultivars, seeding dates, rates, and depths, and fertilizer applications (Carlson and Lenssen 1999).

Table 2. Dates of tillage in 1999 for weed control in conventional till fallow plots. Dates unavailable for 1998.

| Tillage Event | 1999 |
|---|---|
| Tillage 1 | 26 May |
| Tillage 2 | 16 June |
| Tillage 3 | 16 August |

## Carabid Beetle Study

The objective of this project was to examine the effect of tillage and crop type on carabid beetle species activity, diversity, and relative abundance. Six treatments were selected from the rotations described in Table 1: Conservation Reserve Program (CRP), fallow, continuous spring wheat, yellow mustard, pea, and sunflower (see Table 1 for the cropping sequence for these treatments). Conservation Reserve Program plots were

Table 3. Crop cultivars, seeding dates, rates, depths, fertilizer applications, and harvest dates, 1999. Summarized from Carlson and Lenssen 1999.

| Crop | Cultivar | Seeding date | Seeding rate (kg/ha) | Seeding depth (cm) | Urea (kg/ha) | MAP (kg/ha) | Nitrogen (kg/ha) | $P_2O_5$ (kg/ha) | Harvest/ Termination date |
|---|---|---|---|---|---|---|---|---|---|
| spring wheat | McNeal | 20 April | 70.6 | 5.1 | 156.9 | 53.3 | 78.5 | 27.7 | 9 August |
| pea | Alfetta | 20 April | 257.8 | 6.4 | 0 | 53.3 | 5.4 | 27.7 | 2 July/ 29 July |
| yellow mustard | AC Pennant | 20 April | 12.3 | 1.3 | 82.9 | 53.3 | 5.4 | 27.7 | 1 August |
| sunflower | Cenex 803 | 20 April | 5.2 | 3.8 | 104.3 | 53.3 | 53.7 | 27.7 | 2 July |

seeded equally with alfalfa (*Medicago sativa* L.), western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Love), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), and green needlegrass (*Nassella viridula* (Trin.) Barkworth). However, after these plants became established, alfalfa accounted for 95% of the cover in these plots. Individual plots measured 14.63 meters by 30.48 meters. Although crops occurred within different crop rotations (see Table 1), crop type and tillage system were the main factors investigated in this study.

Carabid beetles were sampled using pitfall traps. Traps were constructed using plastic 2-liter soda bottles which had the top of the bottle cut off just above the top of the label so that it was approximately 20 cm tall. The neck of the top half of the bottle was cut away, leaving an opening with a diameter of 4-5 cm. The top half was then inverted into the bottom half to create a funnel. A removable plastic 16 oz. drinking cup was placed inside the soda bottle and insects were directed into this cup by the funnel. About 60 ml of undiluted propylene glycol was poured into the bottom of the cup as a killing agent and preservative. Three pitfall traps were placed in the eastern half of each plot. Traps were placed lengthwise approximately 3.7 m from the eastern edge of the plot, with approximately 7.6 m from the northern and southern edges of the plots and between traps. Traps were placed between crop rows so as to minimize disturbance to the crop.

When samples were collected, the funnel was removed, and the drinking cup with preserved insects was removed. The insects in the cup were then separated from the propylene glycol by filtering them through a square of cotton fabric. The dead insects on the fabric were then placed in sample bags and returned to the lab for identification.

Samples were kept in cold storage (4-5° C) until they could be sorted. Carabid beetles were sorted from the rest of the insects and identified to species using Lindroth's (1961-69) keys. Species names were updated using Bousquet and Larochelle's (1993) catalog (see Appendix A for names that have changed since Lindroth's keys). Voucher specimens were deposited in the Montana Entomology Collection at Montana State University, Bozeman, MT.

Pitfall traps were initially set during the third week of May (14 May 1998, 19 May 1999), approximately 3 to 4 weeks post-planting. Carabid beetles were sampled from May through September in 1998 and May through August in 1999. Actual sampling dates in 1998 were 14-20 May, 9-23 June, 1-8 July, 22-28 July, 19-26 August, and 4-12 September. Actual sampling dates in 1999 were 19-26 May, 15-22 June, 1-7 July, 22-28 July, and 16-24 August. Traps were set on day one and then collected on day seven. The traps were then covered and allowed to "rest" for approximately 14 days before they were set again. The purpose of this rest period was to avoid sampling continuously, minimizing the impact of sampling on carabid beetle populations during the season. Each sampling period lasted approximately seven days, dependent on weather conditions. Trap catches from sampling periods that were greater than seven days were corrected for a seven day period.

On 1 July 1999, the pea – spring wheat – sunflower rotation was terminated due to overpopulation of weeds. After these plots were destroyed, traps were shifted into other pea plots associated with the fallow – spring wheat – pea rotation. There were no other options for sunflower, therefore no data were collected in sunflower plots after July 1, 1999.

In 1999 only, a HOBO® data logger (Onset Computer Corporation, Pocasset, MA) was placed in each crop type and tillage treatment to measure temperature and relative humidity. We placed these data loggers in the crops to determine if the different crop canopies or tillage practices had a significant effect on temperature and relative humidity at the ground level. The data loggers were mounted on wooden stakes that were pounded into the ground so that the data loggers were approximately 9 cm above the ground.

HOBO data loggers collected data from 1 June – 30 June 1999. A base temperature of 5°C for carabid activity threshold was used (Jones 1979). Hourly temperature data were collected and used to calculate degree hours that were summed for each 24 hour period to determine degree days. Degree days were summed over time to get cumulative degree days. Relative humidity was also collected hourly and averaged over 24 hour periods. Data in both tilled and untilled fallow plots were used as a baseline, and relative humidity values from each crop were plotted as the difference from fallow.

## Statistical Analysis

Analysis of variance with sampling date as the repeated measure was performed for each year. (PROC GLM. SAS Institute, Inc. 1998). In addition, an analysis of variance for each sampling date was performed.

# CHAPTER 4

# RESULTS

A total of 9525 and 9188 carabid beetles were collected in 1998 and 1999, respectively. Forty-five and thirty-eight species were represented for 1998 and 1999 respectively (Table 4). In 1998 the five most abundant species (in decreasing order) were *Harpalus fuscipalpis* Sturm, *Amara obesa* (Say), *Amara thoracica* Hayward, *Harpalus paratus* Casey, and *Microlestes linearis* (LeConte). In 1999 the five most abundant species (in decreasing order) were *Harpalus fuscipalpis*, *Microlestes linearis*, *Harpalus reversus* Casey, *Calosoma lepidum* LeConte, and *Amara littoralis* Mannerheim. Total number of each carabid species is summarized in Table 4.

The mean number of each beetle species collected per trap per seven day sampling period is shown for each crop and tillage type in Figures 1-12. Although carabid species composition was similar between no-till and till treatments for most crops, activity levels between tillage systems for some species differed by tillage system in some cases. For example, *Amara obesa* activity was greater in till compared with no-till treatments in spring wheat, pea, fallow, and yellow mustard in 1998 (Figures 2,3,5, and 6). *Harpalus fuscipalpis* activity was greater in no-till plots in pea in 1998 (Figure 3) and yellow mustard and CRP plots in 1999 (Figures 7 and 12), although its activity was greater in till compared with no-till plots in CRP in 1998 (Figure 1). In 1999, *Microlestes*

Table 4. Total number of specimens collected for each carabid species in Northern Montana crop and tillage treatments, 1998 and 1999.

| **Species** | **1998** | **1999** |
|---|---|---|
| *Harpalus fuscipalpus* Sturm | 3820 | 4850 |
| *Microlestes linearis* (LeConte) | 425 | 1354 |
| *Amara obesa* (Say) | 901 | 262 |
| *Amara thoracica* Hayward | 807 | 146 |
| *Harpalus paratus* Casey | 759 | 5 |
| *Harpalus reversus* Casey | 301 | 354 |
| *Pasimachus elongatus* LeConte | 359 | 269 |
| *Calosoma lepidum* LeConte | 299 | 322 |
| *Amara littoralis* Mannerheim | 323 | 278 |
| *Bembidion nitidum* (Kirby) | 153 | 132 |
| *Harpalus amputatus* Say | 122 | 141 |
| *Bembidion versicolor* (LeConte) | 130 | 113 |
| *Dyschirius globulosus* (Say) | 113 | 99 |
| *Calosoma obsoletum* Say | 172 | 35 |
| *Piosoma setosum* LeConte | 42 | 154 |
| *Harpalus ventralis* LeConte | 82 | 112 |
| *Agonum placidum* (Say) | 92 | 95 |
| *Poecilus scitulus* LeConte | 56 | 92 |
| *Agonum cupreum* Dejean | 72 | 31 |
| *Bembidion rapidum* (LeConte) | 90 | 11 |
| *Poecilus lucublandus* (Say) | 51 | 44 |
| *Amara quenseli* (Schonherr) | 90 | 4 |
| *Bembidion quadrimaculatum dubitans* (LeConte) | 18 | 56 |
| *Calosoma luxatum* Say | 27 | 47 |
| *Bradycellus congener* (LeConte) | 9 | 56 |
| *Cratacanthus dubius* (Palisot de Beauvois) | 12 | 52 |
| *Harpalus desertus* LeConte | 21 | 29 |
| *Cymindis planipennis* LeConte | 34 | 2 |
| *Amara apricaria* (Paykull) | 30 | 5 |
| *Harpalus compar* LeConte | 31 | 0 |
| *Harpalus opacipennis* (Haldeman) | 9 | 17 |
| *Bembidion obscurellum* (Motschulsky) | 18 | 8 |
| *Cicindela punctulata punctulata* Olivier | 20 | 1 |
| *Cicindela purpurea audubonii* LeConte | 16 | 0 |
| *Poecilus corvus* (LeConte) | 6 | 5 |
| *Chlaenius sericeus sericeus* (Forster) | 2 | 2 |
| *Stenolophus comma* (Fabricius) | 2 | 2 |
| *Calleida caerulea* (Casey) | 3 | 1 |
| *Cymindis borealis* LeConte | 1 | 1 |
| *Lebia solea* Hentz | 1 | 1 |
| *Cicindela limbalis* Klug | 2 | 0 |
| *Anisodactylus sanctaecrucis* (Fabricius) | 1 | 0 |
| *Bembidion nudipenne* Lindroth | 1 | 0 |
| *Harpalus somnulentus* Dejean | 1 | 0 |
| *Lebia atriceps* LeConte | 1 | 0 |
| **TOTAL** | 9525 | 9188 |

Figure 1. Mean number of carabid beetles per trap per sampling period in CRP, tillage systems combined, 1998.

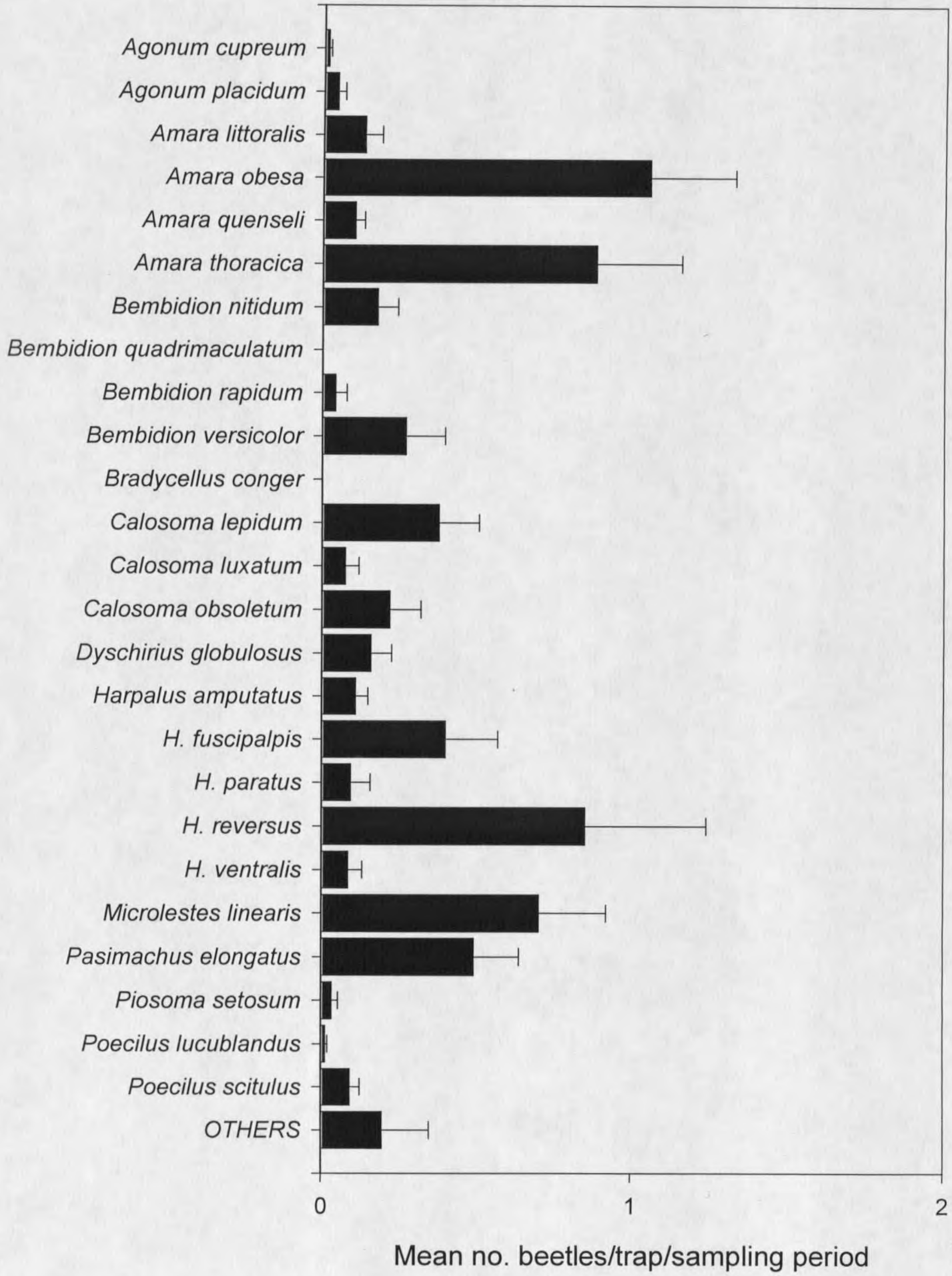

Figure 2. Mean number of carabid beetles per trap per sampling period in till and no-till fallow, 1998.