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INTERACTIONS BETWEEN LANDSCAPE STRUCTURE AND LADYBIRD BEETLES (COLEPTERA: COCCINELLIDAE) IN FIELD CROP AGROECOSYSTEMS.

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has been accepted towards fulfillment of the requirements for

PhD ENTOMOLOGY degree in

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INTERACTIONS BETWEEN LANDSCAPE STRUCTURE AND LADYBIRD BEETLES (COLEOPTERA: COCCINELLIDAE) IN FIELD CROP AGROECOSYSTEMS

By

Manuel Colunga-Garcia

A DISSERTATION

Submitted to Michigan State University

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Entomology

1996

ABSTRACT

INTERACTIONS BETWEEN LANDSCAPE STRUCTURE AND LADYBIRD BEETLES (COLEOPTERA: COCCINELLIDAE) IN FIELD CROP AGROECOSYSTEMS

By

Manuel Colunga-Garcia

Management of agroecosystems to enhance natural regulation of insect pests requires an understanding of predator ecology and how predatory insects use the landscape and respond to its structural characteristics. A group of predatory insects, ladybird beetles, were selected to study patterns of habitat utilization in response to vegetation type, management practices, and habitat succession in a complex agricultural landscape.

The field work was conducted at the Long Term Ecological Research (LTER) site at the Kellogg Biological Station (KBS), in southwest Michigan. First, a life systems study of *Coleomegilla maculata lengi* was conducted by sampling wooded habitats to determine beetle aggregation sites in the landscape, and by using stable isotopes to determine paths of energy flow in the beetle-crop system. Secondly, abundance patterns of fourteen species of coccinellids were monitored weekly during the growing season using yellow-sticky traps. The sampled landscape consisted of an array of field crops under different management practices, interspersed with perennial biomass plantations and vegetation in a state of secondary succession. Seven years of weekly abundance records were analyzed using Shannon Wiener and richness indices, Kendall's coefficient of concordance, and principal component analysis. The results of the analysis were used to produce a spatially explicit population model for comparative analysis of landscape-predator interactions.

The main finding of the study were:

a) Habitat Succession. Ladybird beetle species diversity peaked during the second year of secondary succession with a successive decrease in diversity thereafter. In the Poplar plantation, the assemblage of beetle species showed a succession of dominance by three beetle species;

b) Management Practices. Reduced chemical inputs (herbicides and fertilizers) decreased beetle abundance and species diversity in corn fields but these components increased in wheat. In the corn-soybean rotation sequence, *C. m. lengi*, an important native predator, was most abundant when corn vegetation was dominant and least abundant when soybean dominated the landscape; and

c) Habitat type. Adults of *C. m. lengi* used habitats associated with woodlots, hedgerows, and rows of trees to aggregate prior to the onset of winter. Large aggregations occurred near agricultural fields where corn or alfalfa was grown the previous summer. In early spring, flowers constitute important sources of food for beetles before they move to field crops to search for prey. After feeding

on flower pollen, adults beetles move to alfalfa or wheat, and finally to corn in the late summer prior to selecting sites for overwinter.

Within the framework of the KBS LTER theme that ecological knowledge can replace chemical subsidies, this work contributes to the role that management practices can have on beneficial insects and identifies landscape characteristics conducive to maintaining higher numbers of beneficial insect predators within agroecosystems.

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DEDICATION

I dedicate this dissertation primarily to my wife, Maria Guadalupe, for all her understanding, support, and patience that made possible this work. I also dedicate it to my children, Sara Gabriela, Maria Elizabeth, and Miguel Angel, because their presence constantly encouraged me, specially during the difficult moments I had to go through.

ACKNOWLEDGMENTS

I would like to express my sincere thanks to Dr. Stuart. Gage for all his support and direction throughout this study and during my personal development as a scientist. I would like to extend my appreciation to Dr. Mark Whalon, Dr. Edward Grafius, Dr. Peggy Ostrom, and Dr. Douglas Landis for serving on my graduate committee and reviewing this manuscript.

Several individuals helped during the field work and I thank them all.

I would also like to thank my friends, Rosemary Faber, Rod Murphy and Dawn Ciciora for their editorial assistance in the revision of this manuscript.

The Consejo Nacional de Ciencia y Tecnologia, and the Universidad Autonoma Chapingo of Mexico, as well as the Long Term Ecological Research at the Kellogg Biological Station are gratefully acknowledged for their financial support during this study.

Finally, I would like to extend my thanks to the faculty, staff, and graduate students of the Department of Entomology and the Kellogg Biological Station for all their encouragement.

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INTRODUCTION

IMPORTANCE OF LONG TERM ECOLOGICAL RESEARCH

General perspective

Global, international, worldwide... are some of the words used to describe several of the current human activities and their repercussions, particularly when referring to environmental issues (di Castri and Hansen 1992). Our environment is experiencing global change with regard to loss of habitats, earth warming, water and air pollution, soil erosion and salinization (de la Court 1992, Mohrmann 1992, Olson, 1992). Policies in different parts of the world are addressing issues in conservation, restoration, and ecosystem management to achieve a sustainable development. In this context, ecologists are challenged to provide the necessary knowledge to ensure that outcome. Ecological phenomena occur at different scales in time and space, and there is currently a need to obtain ecological information that occur on long time scales (Callahan 1984).

Agriculture

Several environmental problems have originated from agricultural practices (Gilpin et al. 1992, Poincelot 1990). For example, when in the 70's the Green Revolution changed agriculture into a high input activity, an era of prosperity was visualized for humans (Gilpin et al. 1992). For some time, this expectation became reality. However, the long

term environmental impact and repercussions of this high input agriculture counter the economic benefits. Intensive use of chemical products such as fertilizers and pesticides, intensive irrigation, and increase of monoculture cropping, have altered the equilibrium of nature (Altieri 1987, Edwards 1990, Claridge 1991, Pimentel et al. 1992). Ecological management of agriculture, proposed as a counteraction for the excesses mentioned above, is still in the process of development. Pest management for example, needs to evolve toward agroecological management, particularly in relation to scales and strategies (Levins 1986, Barret 1992, Pimbert 1991). Spatial scales should evolve from single farms or small regions defined by one pest toward an agro-geographic regional perspective, while temporal scales will traverse from single season to long-term steady state or oscillatory dynamics (Levins 1986). Design of appropriate agroecosystems should be the main strategy for pest management programs, thus minimizing the need for human interventions (Levins 1986). The transition toward an ecological-managed agriculture will cause, however, an increase in complexity that has yet to be fully addressed in ecological theory.

THE KBS-LTER

To promote research on ecological phenomena that occur at large scales, the Long Term Ecological Research (LTER) network was established as a NSF funded program aimed to conduct and facilitate ecological research of ecological phenomena that occur over long temporal and broad spatial scales (Franklin et al. 1990). The only program within the LTER network which focused on agricultural ecology is located at the Kellogg Biological Station (KBS). The KBS LTER, established in 1987, shares with the other programs a

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commitment to conduct research in five core areas: a) pattern and control of primary production, b) pattern and control of organic matter accumulation in surface layers and sediments, c) patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters, d) patterns and frequency of site disturbances, and e) spatial and temporal distribution of populations selected to represent trophic structure (Callahan 1984).

The general hypothesis of the KBS LTER is that "agronomic management based on ecological concepts can effectively substitute for reliance on chemical subsidies in production-level cropping systems" (Van Cleve and Martin 1991). Several disciplines including entomology, are involved in ecological research toward this end.

COCCINELLIDS AS THE SUBJECT OF THIS STUDY

In 1988, Dr. Stuart H. Gage designed a long term program, within the KBS LTER framework, aimed to monitor the flow of organisms in agricultural landscapes (Gage et al. 1993). Among the species sampled is a complex of coccinellids which receive special attention in the sampling program because:

- a) they represent an important trophic structure in agroecosystems (predatory insects).
- b) their diversity can be an indicator of the integrity of the ecosystem
- c) they are easy to identify in the field
- d) they can be present in most habitats in agroecosystems
- e) they can be monitored at larger scales.

Early publications showed that these expectations were being met (Maredia et al. 1992 a,b,c).

When I joined the LTER program in 1992, I decided to continue the focus on coccinellids. They are part of the complex of natural enemies in several agroecosystems because they prey principally on aphids and scale insects (Hodek 1970). As most beneficial insects, coccinellids are susceptible to agricultural practices (VanderBosch 1982) an therefore they

can be used as ecological indicator to assess the integrity of agroecosystems. Ground beetles have been commonly used as ecological indicators in agroecosystems (Desender et al. 1994, Luff and Woiwod 1995), however they provide insight only at the ground level scale. A more complete view of the system can be obtained if the above-ground dimension is incorporated with the study of plant dwelling predators, such as coccinellids.

GOALS, HYPOTHESIS, AND OBJECTIVES

Goals

My goals in conducting this research were personal and scientific.

My personal interest was to expand the temporal and spatial scope of my knowledge since my entomological background was focused on working at smaller scales. Usually, Ph.D. students are constrained (because of time) to conduct short term studies, and therefore, the future researcher must learn later how to conduct research at larger scales. Working at the KBS LTER was an excellent opportunity to fulfill my desire by gaining expertise during my Ph.D. program in the implementation, analysis, and integration of a long term study in an agroecological context.

The scientific goal of this research was to analyze patterns of seven years of habitat utilization by a complex of coccinellids in all the different habitats and management practices that occur in the KBS LTER main site and synthesize that information in a landscape-coccinellids model.

Hypothesis

This work was conducted with the hypothesis that assemblages of coccinellid predators with high mobility and a wide range of habitat utilization can be affected by changes in the temporal and spatial diversity of the landscape.

Objectives

To pursue the scientific goal of my research four specific objectives were proposed:

- a) gain insight into the life system of coccinellids using Coleomegilla maculata lengi
 Timberlake as a case study
- b) determine an adequate scale for the analysis of interaction patterns between coccinellids and agricultural landscapes.
- c) analyze the effect of temporal diversity and management practices in the assemblage of coccinellids species
- d) integrate results in a computer simulation model

METHODS

This thesis was organized into five chapters (Figure 1) and a detailed explanation of the methodology used is provided within each chapter.

Chapter 1 describes a study of the life system of coccinellids in the landscape using C.m.lengi case studies. The first case deals with the use of wooded habitats in agricultural landscapes by overwintering adults, and the second case characterizes patterns of habitat utilization in field crop agroecosystems during the Summer (May - August).

Chapter 2 is an analysis of the issue of scale to provide a framework for ecological studies in agroecosystems. It includes the assessment of the use of sticky traps as a sampling tool for long term studies of coccinellid patterns as well as the analysis of long term patterns of coccinellids in different habitats in the landscape.

Chapter 3 is an analysis of temporal diversity in the assemblage of coccinellid species which include two case studies: a) the effect of habitat maturation in alfalfa, poplar, and secondary plant succession, and b) the effect of a corn-soybean rotation.

Chapter 4 is an assessment of the effect of agricultural management in the assemblage of coccinellids, and Chapter 5 is the development of a model of interactions between the landscape and coccinellids to assess the effect of spatial diversity on the assemblages of coccinellids.



Figure 1 Phases in the development of the coccinellid-landscape model.

CHAPTER 1: LIFE SYSTEM OF PREDATORY COCCINELLIDAE (COLEOPTERA) ON AGROECOSYSTEMS: CASE STUDIES ON

Coleomegilla maculata lengi Timberlake

Coleomegilla maculata lengi Timberlake, is a native species of America distributed east of the Rocky Mountains (Gordon 1985). In Michigan, it is one of the most abundant native species of coccinellids in agricultural crops (Maredia et al. 1992a).

BIOLOGICAL CYCLE

C.m. lengi, as well as all other species of coccinellids, is a holometabolous insect with larvae as the active immature stage which have similar habits as the adults. Adults, as predators, spend most of their active time searching for food and sites for reproduction, and if a habitat is suitable, oviposition will occur. The subsequent larval stage will search for food until the completion of its development (Ferran and Dixon 1993), and after a pupal stage, a new adult emerges (Hodek 1973, Frazer 1987) (Figure 2).

SEASONAL HABITAT UTILIZATION

The life system of C.m. lengi is mostly defined by the interaction of the adult with the landscape since the dynamics of the immature stages are constrained by the habitat selected by the adult for reproduction.



Figure 2. Biological cycle of predatory coccinellids and the role of each biological stage.

From the adult perspective, the life system consists of a cycle that involves the presence of aggregation sites during the winter and sites for feeding and reproduction during the summer, with temporal patterns of movement and dispersion among the different habitats (Figure 3). From the classification of movement by Wratten and Thomas (1990), three types of movement can be used to characterize *C.m. lengi*. First is the colonization of crops from aggregation sites in the spring, and returning to them during the fall (Hodek et al. 1993), a phenomena regulated primarily by photoperiod and temperature (Hagen 1962). Second is the movement among habitats (mainly crops) during the growing season, in which searching for food is normally the driving factor (Frazer 1987). *C.m. lengi*, for

instance, has a difficult time searching for prey in polyculture corn (Andow 1991). In polyculture situation, *C.m. lengi* adults move rapidly and remain in this habitat less time than in monoculture corn (Wetzler and Risch 1984). The third type of movement is the aggregative numerical response to habitats when high prey density occur (Wright and Laing 1980, Evans and Youssef 1992).



Figure 3. Life system of predatory coccinellids in agricultural landscapes.

The following is a description of two case studies designed to gain more understanding of C.m. lengi habitat utilization in agricultural landscapes.

CASE STUDY I. Toward the Characterization of Landscape Use by Overwintering Aggregates of *Coleomegilla maculata lengi* Timberlake (Coleoptera: Coccinellidae) in Field Crop Ecosystems in Relation to Wooded Habitats.

Introduction

C.m. lengi adults aggregate during the winter in or adjacent to wooded areas either far from or near to crop fields (Roach and Thomas 1991). Specific sites for overwintering include litter, stones, fallen trees, or grass clumps (Hodek 1973). Early in the spring, adults become active and start feeding on nearby flowers and begin their dispersal to agricultural habitats (Benton and Crump 1981). During the fall adults start to aggregate again in overwintering sites (Benton and Crump 1979). Discovery of overwintering aggregates of *C.m. lengi* in woodlots of an MSU experimental area in 1994, provided an opportunity to observe their dynamics prior to dispersion and to better understand the landscape features used by these organisms to select aggregation sites.

General methodology.

Study area. I conducted this work at the MSU research farms (East Lansing, MI) in spring of 1994 and later at the MSU Kellogg Biological Station (Hickory Corners, MI) during spring of 1995.

Spring 1994 Aggregation sites at the MSU experimental station were located in two major woodlots: Elsesser and Box. The first site was surrounded by alfalfa and wheat

fields, and the second was 10m adjacent to a corn field. In the north-western corner of the Box woodlot there was a small woodlot, Box II, in which I also observed aggregates of beetles. Each day, woodlots were observed to document when beetles leave aggregation sites. Spring flowers which were frequented by the adults for pollen feeding were collected for identification.

When dandelion flowers (*Taraxacum officinale*) were abundant in the landscape and adult beetles were feeding on them (early May), I measured the number of adults per flower to estimate relative abundance. This sampling method was used because: a) there were enough flowers at the edges of the woodlots to assess the preference of *C.m. lengi* adults for specific locations, and b) the color of the beetles contrasted with the yellow flowers which make easy to count them.

To conduct this sampling, I established a transect parallel to the southern side of each woodlot. The length of the transects was 105m in the Elsesser and 80m in the Box II. I did not sample the Box woodlot because most dandelion plants were destroyed during the plowing of the field adjacent to the woodlot. I sampled once in each woodlot recording the numbers of beetles on flowers and the number of flowers every 1m² quadrat along transects. Beetles were "focused" on their activity in the dandelion flowers and slow movement of the observer seldom disturbed them.

After sampling MSU woodlots and assessing the association of *C.m. lengi* and dandelion flowers when beetles were near aggregation sites, I went to KBS to find aggregates of beetles in woodlots. Searching dandelion flowers concentrations I found a beetle aggregation in a woodlot located in the north-western corner of the LTER main site. There, I sampled beetles using the same protocol as above.

During that spring I also measured the spatial distribution of *C.m. lengi* in the surrounding area in a woodlot that had an aggregation site. I selected the Elsesser woodlot for this set of observations because it was surrounded by alfalfa which facilitated the use of the sweep net sampling method. I used a sweep net (25 sweeps per sample) in transects parallel to the edges of the woodlot. I made a total of 85 samples in a ratio of 100 m² to the woodlot using wooden stakes as visual cues to determine the location of sampling points. The interval between sampling points was 25-30 m. I assigned each sample location to a (X,Y) coordinate. Using the coordinate and the numbers of beetles captured at each sampling location, I produced a surface map of the spatial distribution of *C.m. lengi* using the Kriging method provided in the program SURFER 4 (Golden Software 1990).

Spring 1995. With the expectation that I could use *C.m. lengi* adults on dandelion flowers as indicators of the presence of aggregation sites near woodlots, I designed a sampling method to determine the distribution of beetle aggregation patches in agricultural landscapes. I selected KBS for this study because the abundance of tree related habitats interspersed with agricultural fields allowed me to see patterns of habitat discrimination by *C.m. lengi*.

To conduct the sampling, I divided the KBS landscape in 1 km² quadrats using an aerial photo and physical features of the landscape as references. I systematically visited dandelion patches along woodlot edges and those that occurred at the base of individual trees present in each quadrat. In some parts of KBS the dominant flower was garlic mustard (*Alliaria officinalis*), and after observing that beetles in aggregate sites used this

flower as source of food, I included the beetle-garlic mustard association in addition to dandelion as an indicator of potential aggregates. Once I found associations of beetles on flowers, I searched the area more thoroughly to find evidence of an aggregation site (beetles under leaves, branches, or in crevices at the base of trees, or adults crawling in the vegetation near the selected location in the case of woodlots). When I confirmed the existence of an aggregate, I recorded the location and the type of crop (if any) present in the vicinity during the previous season. Later in the summer I identified the main species of trees present in aggregation sites. Due to the limited time available for sampling, (I could sample only when dandelion was flowering and when days were warm so flowers were open) no attempt was made to estimate abundance of beetles in the aggregation sites to enable me to focus on searching for beetle aggregates in the landscape. The beetle/flower ratio method I used during 1994 was useful only as an indicator of the presence of aggregation sites. I could not use it to estimate relative abundance during the season because: a) there were two kind of flowers (dandelion and garlic mustard) with different plant architecture and b) the number of dandelion flowers at the base of individual trees was very low compared to woodlot areas.

To characterize the use of tree-related habitats in the landscape by overwintering beetles, I used the following classification: a) row, b) cluster, c) hedgerow, and d) woodlot (Figure 4).



Figure 4. Classification of tree-related habitats for C.m. lengi aggregates in the landscape.

Rows were normally associated with field margins and roads, and hedgerows were field boundaries. Clusters had the same constitution as hedgerows but they were isolated patches (2-3 trees).

Results

Spring 1994.

The conditions of the two major woodlots at the MSU experimental station, Elsesser and Box were different. In Elsesser (Figure 5a) there was a variety of spring flowers on which beetle adults fed: wood anemonae *Anemone quinquefolia*, spring beauty *Claytonia virginica*, and dandelion *Taraxacum officinale* (Figure 5, c). This woodlot was surrounded by alfalfa, and adult beetles were hidden under litter.



Figure 5. a) South side of the Elsesser woodlot, MSU campus, East Lansing, MI. b) Coleomegilla maculata lengi adults feeding on "spring beauty" in the Elsesser woodlot, c) C.m. lengi feeding on dandelion flowers at the edges of the Box woodlot, MSU campus, and d) C.m. lengi adults hidden under leaves from the previous corn crop at the edges of the Box woodlot.

In the Box wooodlot, the only spring flower present was the dandelion. The field across this woodlot was a field in which corn was planted the previous year. Along the south edge of this woodlot there were leaves from the previous corn crop and adult beetles were hidden under them (Figure 5, d).

I observed that *C.m. lengi* displayed major activity when dandelions flowered in the landscape. Despite the fact that dandelions were almost everywhere in the landscape, beetle adults concentrated on those flowers that were near aggregation sites. This behavior, mentioned by Benton and Crump (1981) was confirmed after measuring the beetles-flowers ratio. In the Box II woodlot, adults concentrated on dandelion flowers nearby the hibernation spots with a gradient of diffusion thereafter (See the peaks in Figure 6).



Figure 6. Relative abundance of C. maculata lengi (measured as adults per flower) and dandelion flowers in one m² quadrats along a transect on the south edge of the Box II woodlot. MSU, East Lansing MI. 1994.
When the woodlot ended (after 60 m), there was an open field with plenty of dandelion flowers, but there were almost no adults found on dandelion. In the Elsesser woodlot a major aggregation site was found at the southwestern corner. In addition, several aggregations were observed along the woodlot edge as confirmed by the distribution of beetles on dandelion flowers (Figure 7).



Figure 7. Relative abundance of C. maculata lengi (measured as adults per flower) and dandelion flowers in one m² quadrats along a transect on the south edge of the Elsesser woodlot, MSU, East Lansing MI. 1994.

In the KBS LTER woodlot the distribution of adults on dandelion flowers coincided with the presence of beetle aggregates in the woodlot (peaks in the Figure 8). An interesting observation related to this woodlot was that corn was planted in the fields near the woodlot (corn is an important habitat for C.m. lengi) the previous season and the number of overwintering beetles in 1994 was high. From

50 to 80 m there were 23 quadrats with one to 60 adults and the average beetleflower ratio was 0.21 ± 0.04 (Figure 4). During the summer of 1994 soybeans were the crop in the landscape next to the woodlot. The following spring (1995) only three quadrats contained beetles and the average was 0.02 ± 0.01 (approximately only a 10% of that observed the previous year).



Figure 8. Relative abundance of *C. maculata lengi* (measured as adults per flower) and dandelion flowers in one m² quadrats along a transect on the south edge of the KBS woodlot, , Hickory Corners, MI. 1994.

The spatial distribution map around the Elsesser woodlot showed three areas of concentration of *C.m. lengi* at the southwest and southeast corners of the woodlot (Figure 9). Besides those concentrations of beetles next to aggregation sites, the other concentration was observed near wheat. Although I can assume that beetles in

wheat may have come from the aggregation in the woodlots, the lack of previous sampling made the assumption difficult. Three days later I could not find any adults in the aggregation sites.



Figure 9. Spatial distribution of *C. maculata lengi* overwintering adults on a 100 m perimeters around the Elsesser woodlot. MSU, East Lansing MI. 1994.

Spring 1995.

Aggregation sites of *C.m. lengi* were very dispersed across the KBS landscape (Figure 10), and results showed that any tree-related habitat in the landscape can be a potential aggregation site if it has a southern exposed to sun light, is located near agricultural fields, and is not subject to human disturbance (Table 1).



Figure 10. Distribution of aggregation sites (black squares) of C. maculata lengi in the Kellogg Biological Station landscape. Large polygon is the actual area observed. S= single tree, H= hedgerow, C = cluster of trees, R = row of trees, and W = woodlot.

The observation that I did not find aggregation sites near trees on private property which have a clear base (no weeds nor litter) indicated that human disturbance was an important factor. However for obvious reasons, I could only sample a small portion of those trees (mostly trees close to the road) so further confirmation of this is necessary. I also observed that rows of trees (which are normally close to a road, were subject to removal of weeds and debris. In early spring weeds were primarily composed of dandelions which provide early food for the beetles. Therefore, human management of the landscape played an important role in the dynamics of C.m. lengi at this time of the season.

Туре	Number	Orientation	Dominant tree (Genus)	Neighboring crops
Row	5(8)	4(4) EW	Carya, Querqus, and	Mostly corn,
		1(3) NS	Prunus	alfalfa and soybean
Cluster	4(4)	South side	Rhus, Morus, and	corn, soybean
			Prunus	
Hedgerow	4(5)	3(3) EW	Prunus, Morus, and	corn, alfalfa,
		1(2) NS	Juglans	soybean
Woodlot	0(3) conifer		Picea, Pinus	
	2(4) deciduous	South side	Prunus, Morus, Juglans,	corn, soybean
			Ulmus, and Robinia	

Table 1. Characteristics of tree-related aggregation sites of *C. maculata lengi* in the Kellogg Biological Station Landscape 1995.

Numbers inside parenthesis represent the number of similar elements present in the observed area.

Although no determination of relative abundance was made, my visual assessment indicated that woodlots and clusters of trees (such as hedgerows) have more beetles per aggregation than individual trees in a row. Four important concentrations of adult beetles associated with individual trees were found in what I called rows (Figure 4). Of all the trees in one row, approximately fifty percent of them were used as aggregation sites by *C.m. lengi* (Table 2). No special preference for any tree species was observed. The dominant species seemed to provide more aggregate sites.

Sampling site	Measurement	Quercus	Tree Genus Carya	Prunus
Site 1	All trees	14	28	11
	Trees with beetles	7	16	5
Site 2	All trees	13	13	8
	Trees with beetles	3	4	4
Site 3	All trees	2	4	
	Trees with beetles	1	2	
Site 4	All trees	3	4	1
	Trees with beetles	3	3	0

Table 2. Number of trees with and without C. maculata lengi aggregations on four selected rows of trees at the Kellogg Biological Station, Hickory Corners MI. 1994.

Discussion

Tree-related habitats are an important place for C.m. lengi aggregates in the agricultural landscape. Hedgerows and woodlots seemed to harbor the major aggregates if neighboring fields were corn or alfalfa rather than soybeans. The

smallest aggregates were in areas where soybean was the crop the summer before. An interesting study to conduct in the future would be to investigate the life system of C.m. lengi in the landscape under conditions of a corn-soybean rotation (a common practice in Michigan) near aggregation sites. I recommend sampling beetles during November to March before the activity of beetles starts, because at that time flowers or grasses are not grown and beetles are not mobile.

The use of spring flowers that are very abundant in the landscape was useful to localize tree-related aggregates of *C.m.lengi* in agricultural landscapes. This method takes advantage of the beetle's behavior to feed on those flowers while it remains close to aggregates during the early spring. Although this method has the disadvantage of localizing aggregation sites after they have been used for overwintering, the habit of coccinellids to use the same location for overwintering for several years (Benton and Crump 1979) may overcome the problem.

This study also allowed me to see the importance of understanding the life system of beneficial insects in the landscape and the impact that agricultural management may have on them. In several tree-related habitats near agricultural fields or roads, dandelions were mowed at a time when beetles were feeding on them, a practice which could cause adult mortality and can also reduce primary food sources for adults before dispersion. The objective of eliminate dandelions at field edges is to reduce the population of these flowers that become weeds within agricultural fields. However, as I showed in this work, only those flowers near aggregation sites are used for the beetles. Preserving localized patches of flowers associated with aggregation sites may enhance the population of beneficial coccinellids.

CASE STUDY II. Habitat Use Patterns of Coleomegilla maculata lengi Timberlake During Summer in Field Crop Agroecosystems.

Forage legumes, small grains, and corn constitute very important habitats for several species of coccinellids including C.m. lengi (Hodek 1973, Honek 1982, Kieckhefer and Elliot 1990, Maredia et al. 1992b). C.m. lengi use aphids as a main source of food (Gordon 1985), and can also feed on eggs and larvae of many coleopterans and lepidopterans (Conrad 1959, Warren and Tadic 1967, Groden et al. 1990). Adults also feed on pollen from several sources including corn (Hodek 1973). In field crop agroecosystems, winter wheat (planted during previous fall) and alfalfa (a perennial crop) are habitats available early in the growing season. Corn and soybean (planted during the spring) become available later on. When several of those habitat are present in the landscape, patterns of habitat utilization by a polyphagous species like C.m. lengi may become very complex. Continuous sampling in different habitats during the growing season can provide information on the number of individuals of this species at different times. By comparing population densities in different habitats we can infer a pattern of habitat utilization by C.m. lengi. This inference could be strengthened if we were able to analyze the feeding history of C.m. lengi at different times of the season. An approximation to this approach can be done with the use of stable isotope analysis. The method of stable isotopes has been used for food web studies (Wada et al. 1991) and it is based on the observation that the carbon and nitrogen isotope composition ($\delta 13C$ and $\delta 15N$, respectively) of organic material of a consumer is similar to or deviates by a consistent amount to its diets (Boutton et al. 1983, Ostrom and Fry 1993). The nitrogen isotope value of an organisms deviates by approximately 3‰ from its diet. Consequently, it may be possible to determine the trophic position of any organism within a food chain (Wada et al. 1991). It is also possible to determine the relative importance of food sources that have unique isotope ratios (Fry and Sherr 1984, Harrigan et al.1989). The relative contribution of different food sources to the consumer is given by:

$$\delta_{consumer} = \sum_{i}^{n} F_{i} \delta_{i}$$

where F_i and δ_i are respectively the fractional contribution and isotopic composition of C or N from an individual source, *i* (Harrigan et al. 1989). Stable isotope analysis thus enables researchers to determine pathways of energy flow through food webs. This information is essential if researchers want to know not only where organisms were present (determined by counting methods) but also which food source contributed to their diet.

This work was designed to determine habitat use patterns of C.m. lengi in field crop agroecosystems, by combining analysis from temporal and spatial distribution of C.m. lengi adults with the analysis of pathways of energy flow in which this species is involved.

Methodology

Study area. This work was conducted at the Kellogg Biological Station during the Summer of 1992. The experimental design, consisted of four plots each containing a different field crop: alfalfa, corn, rye, and wheat is shown in the Figure 11.

Sampling method. Six double-sided, yellow cardboard sticky traps (22.5 x 14.0 cm) suspended 1.2 m above the ground from a metal rod (as described by Maredia et al. 1992b) were placed in each crop (Figure 11).



Figure 11. Experimental design to study habitat utilization patterns by *C.m lengi* at the Kellogg Biological Station, MI.

Yellow cardboards were replaced every second week. Each trap was placed at a permanent geopositioned location, and the experimental area was gridded using X,Y coordinates measured in meters where the initial point (x=0, y=0) was located at the south-western corner.

Sampling was conducted from May to September. C.m. lengi adults on traps were counted, recorded, detached from traps and frozen. Along with the beetles, plants were sampled in the different habitats at each of the trap locations and samples were frozen. Using the XY coordinates from each trap surface maps were calculated to obtain the spatial distribution of *C.m. lengi* based on sticky trap captures using the Kriging method provided in Surfer 4 (Golden Software 1990).

The isotopic composition of *C.m. lengi* was determined at the Environmental Geochemestry Laboratory in the Department of Geological Sciences at MSU. Beetle adults and plant samples were dried at 40°C, ground to homogeneous fine powder, and stored in a freezer. A 20 mg aliquot of plant tissue or a whole insect was combusted in a sealed quartz tubes in the presence of excess copper and copper oxide (Macko et al. 1987). Carbon and nitrogen gases were obtained by cryogenic gas separation. The isotopic determination was performed using a PRISM stable isotope ratio mass spectrometer (VG ISOTECH).

Results and Discussion

The temporal dynamics of *C.m. lengi* showed that alfalfa, wheat, and corn were used sequentially (Figure 12). The peak catch of this ladybird beetle species in wheat was observed the week after the alfalfa was cut, and the peak catch in corn coincided with the beginning of pollination in this crop.



Figure 12. Mean trap captures (± S.E.) of C. maculata lengi in three habitats, as measured by sticky traps, at the Kellogg Biological Station, MI. 1992.

The spatial distribution maps of beetle catch are shown for May and August (Figure 13). These show that the abundance of C.m. lengi is highest in alfalfa and corn during May and August respectively.

In May (Figure 13) I observed a trend of C.m. lengi dispersal coming from the northern part of the fields. At the north edge of the fields the row of trees (Figure 11) could have been the source of overwintering beetles that dispersed into the alfalfa in May. In August, beetles in corn were observed to be dispersing from western and southern edges (Figure 13) which were adjacent to other corn fields (Figure 11).

The results of the stable isotopes analysis corresponded with the field observations. *C.m. lengi* beetles captured in alfalfa during May revealed a 68% contribution of a corn-based diet and 32% alfalfa (Ostrom et al. in press). The conclusion was that beetles captured in May were overwintering adults which fed on a corn-based diet prior to dispersion to overwintering sites. This situation was very likely because corn is the preferred habitat for *C.m. lengi* at the end of the season (Figure 12).

For *C.m. lengi* adults captured in corn during August, the isotopic analysis showed a balanced contribution from alfalfa (52%) and corn (42%), even though large numbers were captured in wheat after the alfalfa was cut. No apparent explanation was found for this situation, and it helps to illustrate the complexity of the habitat-insect interactions that are occurring in the field.



Figure 13. Surface maps of the spatial distribution of *C. maculata lengi* as measured by sticky traps in four field crops during two times of the season: May and August. 1992.

This research was able to characterize some elements of the life cycle of *C.m. lengi* by including a field crop habitats (alfalfa, wheat, and corn) used by the beetles for feeding and reproduction as well as tree-related habitats potentially used by the beetles to make aggregations during the winter. Having field crop habitats near overwintering sites minimized the probability of "isotopic contamination" during the early season, which could have occur if beetles coming from distant areas had already fed in habitats outside the experimental design.

This work showed the importance of stable isotopes to record the feeding history of predatory beetles in field crop ecosystems, and thus to delineate pathways of material transfer between agricultural crops and insects.

CHAPTER 2: THE ISSUE OF SCALE IN STUDIES OF PREDATORY COCCINELLIDAE (COLEOPTERA) IN AGRICULTURAL LANDSCAPES

Since I was involved in a long term monitoring of a complex of organisms I consider it necessary to address the issue of scale and its implications on my work. In any ecological study there must be a correspondence between space and time scales. Either extreme - long term study in a small spatial scale, or short term study in a large spatial scale- can produce misleading results (Wiens 1989). A detailed discussion on the subject of scale can be found in Levin (1992) and Allen and Hoekstra (1992). In this chapter I will focus on the main considerations of scale I had to weigh with respect to my work: a) establishing a framework of scale, b) measurement of coccinellid dynamics at larger scales, and c) establishing an analytical approach for field measurements of coccinellids.

FRAMEWORK OF SCALE

Importance

Allen and Hoekstra (1992), discussing differences among ecological levels of organization, defined scale as "the grain and extent that are required to see the entities that characterize the level (of organization)". <u>Grain can be defined as "the size of the individual units of observation, the quadrats of a field ecologist or the sample unit of a statistician", while extent is "the overall area encompassed by a study" (Wiens 1989).Determination of the scale for an ecological phenomena can be highly influenced by the subjectivity of the observer (Allen and Hoekstra 1992). Therefore it is important to define a framework of scale that a researcher can use as a reference to assess the scope of</u>

an ecological study and as a means to increase the predictability of ecological phenomena.

Coccinellids and scales of biodiversity

One aspect that readily emerges from the literature with regard to coccinellids is the issue of diversity of habitats and food sources that these organisms can use in agricultural systems (Hodek 1973). Biodiversity is a rather complex concept describing different features that vary in time and space (Altieri 1994). In referring to arthropods, biodiversity research has focused on vegetational diversity and the effect it has on arthropod populations (Sheehan 1986, Andow 1991). Literature dealing with biodiversity concerning arthropods, and in particular coccinellids, is vast and can become too complex unless an attempt is made to classify the different expressions of diversity. These include plant architecture (Kareiva and Perry 1989, Grevstad and Klepetka 1992), plant phenology (Ferran et al. 1989, 1991), intercropping (Andow and Rish 1985, Coderre et al. 1989, Trujillo-Arriaga and Altieri 1990), cover crops (Bugg and Dutcher 1993), and multiple habitats (Honek 1985a), Galecka 1992, Maredia et al. 1992b). Crop rotation (Altieri 1994) and plant succession (Price 1991) are also expressions of diversity that may affect coccinellids.

Since there was no hierarchical classification of diversity in the literature, I developed a classification system by grouping the most common expressions of diversity in agroecosystems based on their spatial (individual plant, field, landscape) and temporal (daily, seasonal, two or more years) dimensions (Figure 14).

In this diagram I made a correspondence between temporal and spatial scales (i.e plantdaily, field-season, landscape-2 or more years). The importance of considering both type of scales in long term studies has been previously mentioned and is exemplified by the results obtained by Elliot and Kiechhefer (1990). They sampled a complex of coccinellid species during 17 years in small grains. After that time, they were able to explain temporal population trends within single seasons, but not across growing seasons. They concluded that it is important to consider other habitats in the surrounding landscape to have a better understanding of long term patterns of coccinellid dynamics.



Diversity in Agroecosystems

Figure 14. Expressions and dimensions of diversity at different scales on time and space in agroecosystems.

LONG TERM MEASUREMENTS OF ARTHROPOD POPULATIONS

Hierarchy theory and the concept of sampling

Hierarchy theory has become an important paradigm to address the issues of scale in ecology (Urban et al. 1987). It recognizes the existence of hierarchical scales of organizations (systems) which are constrained in their behavior by intrinsic limitations (the potential manifestation of its elements) and by the activity of higher levels in the hierarchy (Allen and Starr 1982). Interactions among different systems are possible due to the presence of "signals" that transmit back and forth between different levels of organization in the hierarchy (Allen and Starr 1984). The lower the level, the faster and more intense is the transmission of signals; the higher the level, the slower the speed of the transmission. Long term changes in climate, for example, may have an impact on the population dynamics of specific herbivores in agricultural crops. However, such an impact may be in the form of gradual change taking several decades to occur. On the other hand, a pest outbreak in the herbivore subsystems will cause an immediate response from the management subsystem (the farmer), which in turn will affect the herbivore subsystem (with a pesticide application). Such response will also have an impact on the beneficial organisms subsystem (increasing mortality), all of this occurring in the time span of a few days. The objective of sampling in this hierarchical framework is to intercept the signals among subsystems or levels of organization of interest at the appropriate scale so that through an analysis we can interpret the system's function.

Characteristics of long term sampling

Sampling is one of the crucial activities in any ecological study. Southwood (1978) summarized the main principles and techniques of this issue. Long term sampling, however, requires special considerations that have not been emphasized properly in the literature. Most of such studies are descriptive by nature since the goal is to discover temporal and spatial patterns that short term scale studies are unable to address (NSF 1978). Since it is very difficult in these kind of studies to set the appropriate scale of measurements *a priori*, researchers tend to increase, as much as they can, the extent of the information obtained, the frequency of the observations, and the duration of the sampling (Allen and Starr 1982). This way, researchers try to minimize the possibilities of missing important information during the sampling process. From studies of this nature with arthropods, the following considerations can be distinguished for a long term sampling:

- a) The use of standard methodology that allow the comparison of information obtained at different sampling points in time and space (NSF 1978, Gage and Russell 1987).
- b) Establishment of fixed sampling locations. Randomized sampling in long term studies mixes temporal and spatial variances. By spatially fixing sampling points, we can analyze separately temporal and spatial changes among sampling points (Taylor 1986, Gage et al. 1990).
- c) Use of a trapping method with low maintenance, that can be placed in different habitats, and that is constantly sampling organisms. Examples of such devices for long term studies are: light traps (Taylor 1986, Nowinszky and Ekk 1988, Szentkiralyi 1992, Kadar and Loevei 1992), suction traps (Taylor 1986, Quinn et al. 1991),

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pheromone traps (Nasr et al. 1984, Gage et al. 1990, Srivastava et al. 1990), pitfall traps (Burel 1989), and malaise traps (NSF 1978).

 d) Regular time estimates to be able to detect patterns of temporal changes (Gage and Russell 1987).

Sticky traps as sampling tools for coccinellids

Different techniques have been used to sample coccinellids in agricultural fields: the use of a sweep-net, "D-VAC" suction sampling, collection via light and sticky traps, and counting predators observed within a certain time period (Lapchin et al. 1987). Several of these techniques have been the subject of studies to evaluate their efficiency in measuring coccinellid population densities in wheat (Lapchin et al. 1987, Iperti et al. 1988, Elliot et al. 1991), lentil (Schotzko and O'Keeffe 1989), and strawberry (Frazer and Raworth 1985).

Sticky traps have been used for sampling coccinellids in several studies (Ewert and Chiang 1966; Mack and Smilowitz 1979, Ives 1981, Dean 1982, Neuenschwander 1982, Ricci 1986, Sirota 1990, Maredia et al. 1992b). The color of the traps was usually white or yellow as these colors have been found to be attractive for coccinellids (Dowell and Cherry 1981, Benton and Crump 1981, Maredia et al. 1992a). However, it was not until the KBS-LTER project (Gage et al. 1993), that sticky traps were used intensively and extensively as the main sampling tool in a long term study (Maredia et al. 1992b,c). The reason Gage began using this sampling method was that sticky traps were suitably installed at permanent locations in a variety of habitats and were attractive to coccinellids.

This system was easily maintained and allowed for continuous sampling process during the entire growing season.

Comparison of two sampling methods: sweep-net sampling and sticky trap in wheat at different time intervals.

Trap devices successfully used for long term sampling have had an attractive component (pheromone or light traps) or have been simple passive (pitfall or suction) traps (Southwood 1978). Sticky traps are a combination of both type of traps because they are stationary in the landscape intercepting flying insects and also they have an attractive component (the color). Sticky traps depend on insect activity, which complicates the interpretation of the meaning of trap captures. In particular I was interested in determining to what extent I would be able to use sticky traps catches as a measure of relative abundance of coccinellids. To that end I designed a two year study to conduct a comparison between using sticky trap catch and catch using sweep-net sampling. Wheat was selected because this crop is highly preferred by coccinellids (Honek 1985a), the number of coccinellids captured using sticky traps is high (Maredia 1992c) and it was reasonable to expect to have significant numbers of coccinellids via sweep-net sampling. I used the sweep-net as the method of comparison because it has been evaluated and used as a measure of relative abundance of coccinellids in wheat (Elliot and Kieckhefer 1990, Elliot et al. 1991).

Methodology.

Study area. I conducted this study during 1993 -1994, using three and four wheat fields respectively each year. I used spring wheat in 1993, and winter wheat in 1994.

<u>Sampling</u>. In each field I placed six double-sided, yellow cardboard sticky trap (22.5 x 14.0 cm) suspended 1.2 m above the ground from a metal pole (as described by Maredia et al. 1992a). These traps were designated upper traps. A second yellow cardboard was attached to the pole at the height of the crop canopy and moved weekly as the crop grew. Sampling was started in the first week of May and was continued until the crop was harvested. Coccinellid adults caught on traps were counted, recorded, and removed every week Traps were replaced every second week.

For sweep sampling a sweep-net of 37.5cm of diameter was used. Sampling was conducted following an imaginary diagonal path in each field. In 1993 I made 25 sweeps per sampling period while in 1994 I made two samples of 50 sweeps per sampling period in each field. Insect captures in both years were converted to number of adults per sweep.

<u>Normality assessment and Taylor's power law</u>. I assessed the normality of the data from the two sampling methods using the Sapiro-Wilks test (SPSS 1993). Then I used Taylor's power law to assess the need for a transformation to normalize the data. I first divided the whole sampling period in each year into intervals of 100 degree days (50F). Second, I estimated mean and variance for each 100 degree day interval in each year per each field. Third I used the following equation:

$$log (variance) = log a + b log (mean)$$

in which log a and b were respectively the Y intercept and the slope in the general equation for a straight line Y=a + bX.

Dara were transformed by solving the equation:

 $z = x^p$

where z is the transformed value, x is the original (raw) number, and p is equal to 1-b/2 (Southwood 1978).

Due to the low numbers of coccinellids obtained using the sweep sampling method in 1993, I pooled all the coccinellid species together to work with coccinellids as a complex. Correlation of sampling methods. I conducted a test for correlation between the different sampling methods using the Pearson product-moment correlation (SPSS 1993). Correlation was performed at three different time scales: 100, 400, and 800 degree day interval. Fields from the two years were used together as replicates for correlation analysis.

Results.

Insect dynamics. Sticky traps at both levels had similar temporal patterns during both years with more adult beetles captured on the canopy traps than on the 1.2m traps (Figure 15 and Figure 16). In 1993, peak catches on sticky traps occurred after the peak observed using sweep-net captures. A similar lag in response was observed in 1994 when peak abundance of beetles caught using sticky traps occurred after a peak observed using sweep-net sampling around 400 degree days. However, in this year the highest number of coccinellid caught using sweep-net sampling occurred toward the maturation of the crop.

This increase in the population of beetles was detected in the sticky traps although the difference in numbers of beetles between the two sampling methods was not proportional to differences observed at other times of the season.

Normalization of data. Data from all sampling methods had a significant departure from normality (P < 0.01) at 100 degree day intervals. The Taylor's power law assessment suggested the following powers (p) to normalize data: upper traps p=0.5, canopy traps p=0.3, sweep-net p=0.8. Based on these results I selected the square root transformation $(\sqrt{x+.001})$ for the three methods. The only significant departure from a normal distribution after data transformation (P <0.01) was observed in the canopy trap sampling when using data from time intervals of 100 degree days

<u>Sampling methods correlation</u>. Significant correlation (r) was found between captures from both levels of sticky traps: upper and canopy at all intervals (r >0.76, P < 0.001). The correlation between sticky trap sampling and sweep-net was non significant (r = 0.29, d.f.=40, P > 0.58) at 100 degree day intervals to significant correlation at 400 degree day intervals (r = 0.8, d.f.=11, P < 0.001) and at 800 degree days (r > 0.9, d.f.=5, P < 0.005).



Figure 15. Temporal dynamics of coccinellid adults in spring wheat measured by sticky traps (upper 1.2 m and canopy level) and sweep-net sampling, Kellogg Biological Station. 1993.



Figure 16. Temporal dynamics of coccinellid adults in winter wheat measured by sticky traps (upper 1.2 m and canopy level) and sweep-net sampling. Kellogg Biological Station. 1994.

An analysis of the high correlation observed at the whole year scale interval (800 degree days) showed the existence of two clusters of data: one of low numbers of insects in 1993 and one of high numbers of insects in 1994 (Figure 17). T tests showed that means $(\bar{x} \pm SE)$ in 1994 for sweep-net (0.08 \pm 0.02), upper sticky trap (1.14 \pm 0.44) and canopy sticky trap (3.25 \pm 0.64) were significantly higher (P \leq 0.001) than the respective means obtained in 1993 for the same methods: sweep-net (0.02 \pm 0.008), upper sticky trap (0.09 \pm 0.33) and canopy sticky trap (0.34 \pm 0.005). A correlation analysis conducted at the same scale (800 degree days), but separately for each year, showed no significant correlation between sweep sampling and sticky traps (P > 0.56).

Discussion.

The results of this analysis of sampling methods allowed me to interpret sticky trap catch as a sampling method for coccinellids in a long term study. Sticky traps catches, for example, have been used as a measure of the spatial distribution of the corn rootworm adults (Midgarden et al. 1993). The Taylor's power law for corn rootworms indicated an aggregated distribution ($p\sim 0.25$), which is similar to what I obtained in this study for coccinellids on sticky traps at the canopy level (p=0.3). The level of aggregation for coccinellids was less in the upper sticky trap estimates (p=0.5), and in sweep-net sampling (p=0.75). Changes in the level of aggregation registered by each of the sticky trap levels could be the result of the ratio of influence of each trap level. Canopy traps may have captured beetles near the vicinity of the traps and therefore may be highly influenced by the local spatial distribution of the coccinellids; while the upper traps may have been visible by beetles from several meters away from the traps and thus reducing the aggregational influence. This hypothesis was supported by the results of the sweep-net sampling, since the transect attempts to cover most of the field, which made samples less susceptible to changes in the spatial distribution of coccinellids within a field. These are important considerations if a sampling program based on sticky traps is conducted to determine spatial distribution of coccinellids within a field.



Figure 17. Correlation between sticky trap sampling at two levels (upper=1.2m, and canopy) and sweep-net sampling considering whole season captures of coccinellid adults in wheat.

Another key consideration before discussing the correlation of sampling methods at different time intervals is the fact that sweep sampling is an instantaneous measure of relative abundance, while sticky traps are an accumulative measure over time which may include insects arriving, leaving, and remaining in the field. Other changes due to daily weather conditions are averaged by the constant exposure of the traps (Tollefson and Calvin 1994). This may have played a role in the lack of correlation between sweep-net and sticky trap sampling methods at narrow intervals (100 degree days). However, as time intervals became broader, trap captures tended to better represent the relative abundance of coccinellids. This observation was also made for pitfall traps (Baars 1979), in which vear-round catches are more linked to insect abundance while narrow intervals become measures of a mixture of density-activity (Nentwig 1988, Lester and Morrill 1989). The fact that sticky traps and sweep-net samples are sensitive to changes in relative abundance within the same habitat (wheat) was demonstrated by the differences observed by the two methods when comparing captures between two different years. However subtle differences like those that occurred among wheat fields in the same year showed no correlation between methods even at whole season intervals. These results have important implications for the analysis of sticky trap captures in this thesis. First, it is beyond question that total counts methods are the best way to determine abundance of coccinellids in field studies. However, as the scope of the field studies increases in complexity (more habitats, long term, large extent), total counts techniques become cumbersome (in time and personnel), making them no longer feasible for such studies. Second, other sampling techniques commonly used for coccinellids such as sweep-net sampling cannot be implemented in all kind of habitats and capture low number of coccinellids. Third, sampling techniques that rely on trapping systems are the best options currently available for large scale sampling despite their sensitivity to different factors that affect the interpretation of insect captures (Spence and Niemela 1994). Fourth, the

influence of factors that affect the interpretation of trap captures is sensitive to the time scale used in both: the sampling interval and the analysis. Environmental factors can be averaged for large exposures of traps in the field, and year-round counts tend to average for activity effects and relate more to abundance accounts.

As a final note I want to suggest a potential hypothesis regarding the attractiveness of the color yellow by coccinellids. Observations in wheat showed that mature (and overmature) wheat can be a suitable habitat for coccinellid reproduction (I observed an increase in the number of eggs and larva of coccinellids and lacewings). This activity and the abundance of coccinellids are barely detected by the sticky traps, despite the fact that sweep sampling showed an important increase in the relative abundance of the coccinellid population (Figure 16). Although there could be several explanations for this observation, my hypothesis concerns the lack of attractiveness of the yellow color at this phenological state of the crop. As was mentioned previously the color yellow is generally attractive for coccinellids. Why it is attractive has not been a matter of discussion. One explanation could be that the yellow color reflects the condition of the crop when there is an attack of sap sucking insects. In this case, when wheat is maturing and changing its color, the yellow color may have lost its attractiveness for the coccinellid adults. If this hypothesis is true, then sticky traps may become a passive sampling devices without the power to attract nearby insects.

Temporal patterns of coccinellids at the KBS LTER main site

An additional asset of the sticky trap sampling method was that insect captures reflected temporal patterns exhibited by the populations of the different species of ladybird beetles. For example, an analysis conducted on data obtained from seven years (1989-1995) in six habitats showed that the dominance of *C. septempunctata* in the landscape reached its maximum between 400-600 degree days (Figure 18). Peak populations of subdominant and rare species on the other hand occurred either before or after the one of *C. Septempunctata*. In other example, an annual time series showed the existence of patterns that suggest the influence of special factors on the abundance of ladybird beetle species (Figure 19). For instance, *C. septempunctata* had the maximum peak in 1989, while *C. munda* and *A. bipunctata*, had theirs in 1990. *C.m. lengi*, which had normally two peaks in the season (Figure 18) had the first one gradually increasing from 1989 to 1992, with decreases thereafter. *B. ursina*, was not present from 1989-1992, and then started to increase its population.

Conclusions on the use of sticky traps as a sampling tool for coccinellids

a) Sticky traps are the best tool currently available to conduct long term sampling of a complex of coccinellids in multiple habitats.

b) There is evidence that sticky trap captures have a strong abundance component when averages are scaled up to a year-round basis.

c) Annual time series showed temporal patterns that suggested the possibilities of diversity effect on coccinellids.

d) Year-round captures from the perspective of diversity in agroecosystems set my the scale of my thesis study at the higher temporal (2 to more years) and spatial (landscape) dimensions (Figure 14).



Figure 18. Patterns of coccinellid captures during a season measured as frequency of sticky trap catches in 100 degree days intervals using data collected from 1989 to 1995. Habitats included were corn, wheat, alfalfa, soybean, poplar and secondary succession.



Figure 19. Patterns of coccinellid captures during the year measured as frequency of sticky trap catches in 200 degree days intervals from 1989-1995. Habitats included are corn, wheat, alfalfa, soybean, poplar and secondary succession.

CHAPTER 3: ASSEMBLAGE OF PREDATORY COCCINELLIDAE (COLEOPTERA) IN RESPONSE TO TEMPORAL DIVERSITY WITHIN AN AGROECOSYSTEM

Ecological management of agricultural systems relies heavily on the potential for beneficial organisms to regulate pest populations (Vandermeer 1995). An increase in the vegetational diversity has been considered as a necessary step to enhance natural regulation of pests (Pimentel 1960). Diversity, mentioned in the previous chapter, had several expressions depending on time and space (Figure 14). The effect of increasing diversity in agroecosystems is explained in terms of two hypotheses: a) the difficulty of herbivores to find their food, and b) the enhancement of the action of beneficial natural enemies (Risch et al. 1983, Sheehan 1986). The rationale behind the second hypothesis, in regard to spatial diversity, is that beneficial organisms will have alternate sources of food and shelter necessary to maintain their presence in the landscape (Dover 1989, vanEmden 1990). Adult parasitoids, for example, that depend on the availability of nectar sources, will be greatly benefited by the presence of flowers near agricultural fields (Idris and Grafius 1995). Predators, often seek wooded habitats near agricultural fields to spend the winter (Roach and Thomas 1991).

While spatial diversity can be seen in terms of landscape heterogeneity, temporal diversity relates more to landscape change. In agricultural landscapes, most changes are the result of man-made disturbances (Forman and Godron 1986).

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Agricultural fields, for example, are chronic disturbance patches in which a crop is planted every year, raised and eliminated (harvested) in the landscape. If the same crop is grown every year in the same place, the chain of disturbances associated with such crop become predictable. When a disturbance is predictable, organisms adapt to it (Resh et al. 1988). Crop rotation could be seen as a way to maintain the change in the landscape. From a pest management perspective, crop rotation would be an effort to delay the adaptability of certain species (pest) to periodical disturbances associated with always raising the same crop in the same place.

When a previously disturbed patch is left undisturbed (to promote, for example, uncultivated areas in agroecosystems), then it becomes a "regenerated patch" (Forman and Godron 1986). In these patches, temporal changes faced by the arthropod community are now due to successional changes in species composition and changing plant architecture (Southwood et al. 1979).

Since the KBS LTER main site represent an excellent scenario to evaluate the response of coccinellid assemblages to temporal diversity, I focused part of my analysis on two main sources of temporal diversity: plant succession and crop rotation.

CASE 1: HABITAT MATURATION IN ALFALFA, POPLAR, AND SECONDARY SUCCESSION

Price (1991) using parasitoids as an example of secondary consumers, synthesized the importance of plant succession dynamics in determining communities of beneficial organisms. Southwood et al. (1979) showed that insect diversity is correlated with plant diversity during the early stages of secondary succession, but later the correlation of insect diversity switches to the increasing complexity of plant architecture.

One of the treatments in the KBS LTER was an early secondary succession which represented a habitat with heterogeneous and changing plant composition subject to zero management disturbances. A second treatment was a poplar plantation, which represented a wooded perennial habitat with uniform plant composition but with a changing plant architecture due to plant growth from small cuttings to full grown trees on a six year period. A third habitat used in this study as a control, was alfalfa. This was a herbaceous perennial habitat with uniform plant composition subject to periodical agricultural disturbances.

My specific objective was to study the effect of consecutive years of growth and maturation in alfalfa, poplar plantation and secondary succession, on the assemblages of predatory coccinellids species.
METHODS

Study area. This study was conducted at the Long Term Ecological Research (LTER) site at the Kellogg Biological Station (KBS), MI from 1989-1995. The experimental design was established in 1989 consisting of seven treatments: four wheat-corn-soybean rotations, two perennial biomass plantations: (alfalfa and poplar) and a secondary succession. All treatments were replicated six times using one hectare plots as experimental units (Figure 20). Alfalfa *Medicago sativa* L was first planted in 1989, and after a five-year cycle, a new stand of alfalfa was planted in 1994. Due to severe attack by the potato leaf hopper *Empoasca fabae* (Harris) pesticide applications (one spray) were used in alfalfa during 1990, 1991, and 1994. Alfalfa was harvested four times each year. Poplar (*Populus x euramericana*) tree cuttings (15 cm) were planted in Spring of 1989, with a cover crop (red fescue *Festuca rubra* L.) seeded in 1990. Secondary succession plots were tillage in 1989, with no more agricultural management conducted during the rest of the study.

Sampling method. In each plot, five double-sided, yellow cardboard sticky trap (22.5 x 14.0 cm) suspended 1.2 m above the ground from a metal trap (as described by Maredia et al 1992b), were placed at permanent geopositioned locations. Yellow cardboards were replaced every second week. Coccinellid adults caught on traps were counted, recorded, and removed every week. The duration of the sampling was from May to August of each year.



Figure 20. Experimental design of the Long Term Ecological Research site Kellogg Biological Station showing the spatial distribution of treatments and replicates. Hickory Corners, MI.

Data analysis.

To conduct inter-year comparisons with selected treatments, I selected a data subset with a similar scale. Since temperature is an important factor in the development of insects used degree days as a criteria to determine the rank to use for data analysis. For each year I selected the data that were included within 300 to 1000 degree days. Yearly mean trap captures per species in each sampling plot were calculated by averaging each plot trap capture for each sampling week and then averaging all sampling weeks to obtain the yearly mean.

Three analytical techniques were used to analyze and compare coccinellid species assemblages: a) multiple comparisons of relative abundance, species richness, and species diversity (H'), b) the Kendall rank correlation test, and c) principal component analysis. This analytical approach has been effective in detecting responses of assemblages of coccinellids to habitat utilization in the landscape (Colunga-Garcia et al. In press)

Multiple comparisons

<u>Relative abundance</u> is the yearly mean of the number of adult beetles captured per trap in each treatment. This was estimated for individual species as well as for the complex of coccinellids (i.e. by summing all individuals regardless of species). <u>Species richness</u> is the yearly mean of the number of species captured per trap in each treatment.

Species diversity (H') was estimated using the Shannon Wiener equation

$$H = -\Sigma [pi][log_{10}(pi)]$$

where pi is the proportion of the species i in the sample (Magurran 1988).

Data were normalized prior to statistical analysis using a $\sqrt{x + 0.001}$ transformation. Analysis of variance (ANOVA) and the Tukey-HSD test were used

to test for statistically significant differences among treatments or years (SPSS 1993).

Kendall rank correlation

Kendall's coefficient (τ) was used as a measure of similarity between species ranking of different treatments (or years) (Southwood 1978). I estimated ' τ ' based on the mean trap captures per treatment (or years) using the Kendall's rank correlation test (Kendall 1955, SPSS 1993). For this analysis, rare species were eliminated (Bullock 1971).

Principal component analysis

Multivariate methods are a set of tools applied to ecology that allow researchers to describe or test differences in community structure (Green 1980). Of these techniques, principal component analysis (PCA) facilitates the reduction in dimensions of the original variables to produce a small number of variables (components) ordered by the amount of variance they explain (James and McCulloch 1985). Since the PCA procedure recognizes only linear combination of the original variable (James and McCulloch 1990) I log (x+0.001) transformed the data before analysis (SPSS 1993). Prior to PCA the data were arranged on a matrix in which treatments were the headings of the columns and species were the headings for the rows. Each intersection row (r)-column (c) had a value that represented the yearly mean of the species "r" in the treatment "c". Interpretation of

components is conducted by constructing plots using component values as graphical coordinates (Randerson 1993). For each PCA, two plots were produced. The first plot used the components for coccinellid species (also known as eigenvalues), and the second plot used the components for treatments (or years) (also known as scores). Visual interpretation of components is greatly reinforced with the use of both plots together (Randerson 1993).

RESULTS

The fourteen species of coccinellids sampled in this study were, Coccinella septempunctata (L.), Coleomegilla maculata lengi Timberlake, Cycloneda munda (Say), Adalia bipunctata (L.), Hippodamia parenthesis (Say), Brachiacantha ursina (Fab.), Hippodamia convergens Guerin-Meneville, Chilocorus stigma (Say), Coccinella trifasciata perplexa Mulsant, Hippodamia tredecimpunctata tibialis (Say), Hyperaspis undulata (Say), Anatis labiculata (Say) Hippodamia glacialis glacialis (F.), and Harmonia axyridis (Pallas). H. axyridis (an exotic species) was first captured in 1994.

Alfalfa

The dominant species of coccinellids in this habitat during the seven years of study was *C. septempunctata*. The changes in relative abundance, species diversity, and richness observed in this habitat (Figure 21), were mostly driven by the changes in relative abundance observed by this species (**Error! Reference source not found.**). The lowest species diversity was observed in 1989 and in 1994, which were years in which alfalfa was newly planted. The relative abundance of coccinellids was very high during the first year of study (mostly *C. septempunctata*). Thereafter the numbers of coccinellids remained relatively stable with no significant differences (Figure 21). Species richness also showed no significant differences except for the third (1991) and last (1995) year of the study in which were observed respectively the lowest and highest number of species (Figure 21). Three species that were never captured in this habitat were: *H. g. glacialis*, *H. t. tibialis* and *A. labiculata*.

Table 3 Yearly mean trap captures (x 100) \pm S.E. of adults of fourteen species of coccinellids sampled in alfalfa using yellow sticky traps from 1989 to 1995. Long Term Ecological Research- Kellogg Biological Station, Hickory Corners, MI.

Species Name							Year							
	198	6	199(6	1661		1992		1993		1994		1995	
C. septempunctata	1185 ±	86 c	502 ±	82 ab	346 ±	135 a	381 ±	56 ab	455 ±	52 ab	723 ±	80 bc	237 ±	24 a
C.m. lengi	13 ±	5 abc	32 ±	6 bc	14 ±	10 ab	65 ±	25 с	2 ±	2 a	++ ∞	4 ab	14 ±	4 abc
H. parenthesis	7 ±	5 a	∓ 0	0 a	∓ 0	0 a	38 ±	21 b	1	4 ab	∓ 0	0 a	∓ 0	0 a
C. munda	4 +	ß	2 ±	2	∓ 0	0	2 ±	2	∓ 0	0	∓ 0	0	7 ±	S
C. stigma	2 ±	2	73 ±	73	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0
A. bipunctata	4 +	3 a	29 ±	5 b	∓ 0	0 a	2 ±	2 a	∓ 0	0 a	7 ₹	4 a	7 ±	5 a
B. ursina	∓ 0	0 a	∓ 0	0 a	∓ 0	0 a	∓ 0	0 a	4 +	3 ab	3 ±	3 ab	14 ±	5 b
C.t. perplexa	∓ 0	0	∓ 0	0	∓	0	+ 0	0	4 +	°	∓ 0	0	∓ 0	0
H. axyridis	∓ 0	0 a	∓ 0	0 a	∓ 0	0 a	∓ 0	0 a	∓ 0	0 a	∓ 0	0 a	58 ±	18 b
A. labiculata	∓ 0	0	∓ 0	0	∓	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0
H.t.tibialis	∓ 0	0	∓ 0	0	∓	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0
H. undulata	∓ 0	0	∓ 0	0	∓ 0	0	+ 0	0	2 ±	5	3 	e.	2 ±	2
H. glacialis	+ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0
H. convergens	∓ 0	0	∓ 0	0	∓ 0	0	2 ±	2	∓ 0	0	∓ 0	0	3 ±	e

Means (± S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).



Means (\pm S.E.) within a habitat which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).

Figure 21 Relative abundance, species diversity, and richness of a complex of predatory coccinellids in alfalfa, poplar and secondary succession during seven years of habitat growth at the Long Term Ecological Research site at the Kellogg Biological Station. Hickory Corners, MI.

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Significant changes (P > 0.05) in species concordance in this habitat were observed in 1989-1990, 1992-1993, and 1993-1994 (Table 4).

Table 1. Kendall's coefficients for coccinellid species concordance(species = 9) between consecutive years in poplar, alfalfa, andsecondary succession. Long Term Ecological Research- KelloggBiological Station, Hickory Corners, MI.

Interval (years)	Poplar	Alfalfa	Secondary succession
1989-1990	0.23 *	0.55	• 0.68
1990-1991	0.77	0.61	0.51 *
1991-1992	0.89	0.71	0.78
1992-1993	0.24 *	0.50 *	0.56
1993-1994	0.84	0.46 *	0.79
1994-1995	0.57	0.57	0.49 *

Coefficients with an asterisks (*) indicate no concordance in species ranking (P > 0.05) (Kendall's rank correlation test).

Poplar

The most important event observed in this habitat was the "succession" of dominance by three species of coccinellids: *C. septempunctata*, *C.m. lengi*, and *B. ursina*. In 1989, when poplar reached a height of 1.5 meters, *C. septempunctata* was the dominant species in the habitat. From 1990 to 1992, *C. m. lengi* was

captured in high numbers with a peak in 1991. Starting in 1993, *B. ursina* became the dominant species in the habitat (Figure 22).



Figure 22 Temporal distribution of three dominant coccinellid species in poplar during the seven years of habitat growth at the Long Term Ecological Research site at the Kellogg Biological Station. Hickory Corners, MI.

Species richness was similar (P > 0.05) during the seven years of study (Figure 21). Two species, *H. t. tibialis* and *A. labiculata* were not observed in this habitat during the seven years. Species diversity was significantly lower during 1989, 1991, and 1995 (the peak years of abundance for the three dominant coccinellids mentioned above). The relative abundance of the complex of coccinellids was significantly higher in 1991 and 1995 influenced by the high relative abundance of C. m. lengi and B. ursina respectively for each year (Table 5).

The Kendall's coefficient showed that species concordance changed significantly (P > 0.05) from 1989 to 1990, and from 1992 to 1993 which represents the transition years of the dominant species (Table 4).

Secondary succession

The most significant trend observed in this habitat was the temporal change in species diversity which was low during the first year, reached a peak the following year, and showed a gradual decline thereafter. Finally in 1995 species diversity reached a maximum (Figure 21). Changes in relative abundance were driven mostly by the abundance of *C. septempunctata* (the dominant species in this habitat) (Table 6) which followed a cycle that peaked in 1989 and 1994. Richness was higher the second and last years of study while it was lowest during the third and fifth years (Figure 21). *H. axyridis*, was first detected in this habitat in 1994. By 1995 this species ranked second in relative abundance behind *C. septempunctata*.

Table 5 Yearly mean trap captures (x 100) \pm S.E. of adults of fourteen species of coccinellids sampled in *Populus* using yellow sticky traps from 1989 to 1995. Long Term Ecological Research- Kellogg Biological Station, Hickory Corners, MI.

Species Name					Year							
	1989	1990	1661		1992		1993		1994		1995	
C. septempunctata	566 ± 46 c	71 ± 20 b	17 ±	8 ab 1	7 7	3 ab	6 ± 3	a 2	5 ± 23	3 a	∓ 0	0 a
C.m. lengi	8 ± 5 a	467 ± 93 c	1155 ± 12	1 d 5	1 ± 2	0 b	6 ± 3 8	a 2	+ +	9 ab	10 ±	3 a
H. parenthesis	8 ± 5	0 = 0	2 #	5	2 +	2	4 + 3		4 +	4	∓ 0	0
C. munda	8 ± 5 a	75 ± 30 ab	221 ± 7	6 b 4	1 = 1	5 ab	146 ± 51 1	b 13	8 ± 5]	1 b	188 ±	40 b
C. stigma	5 ± 5 a	0 ± 0 a	+ 0	0 a	3 1+	2 a	8 ± 61	b 1	++ 33	5 b	5 ±	5 a
A. bipunctata	17 ± 7 ab	70 ± 13 b	62 ± 3	3 ab 2	2 ± 1	6 ab	2 ± 2	e) + 0	0 a	∓ 0	0а
B. ursina	0 ± 0 a	2 ± 2 a	+ 0	0 a	+ 0	0 a	246 ± 73	b 33	7 8 ∓ 0	4 b 1	665 ± 3	243 c
C.t. perplexa	0 7 0	2 ± 2	3 ⊭	m	∓ 0	0	0 7 0) + 0	0	∓ 0	0
H. œyridis	0 = 0	0 = 0	+ 0	0	∓ 0	0	0 = 0		+ 0	0	7 ±	S
A. labiculata	0 = 0	0 ∓ 0	+ 0	0	∓ 0	0	0 7 0) + 0	0	∓ 0	0
H.t.tibialis	0 7 0	0 7 0	∓ 0	0	∓ 0	0	0 = 0) ∓ 0	0	∓ 0	0
H. undulata	0 = 0	$0 \neq 0$	∓ 0	0	3 H	5	0 7 0		+ 5	5	∓ 0	0
H. glacialis	$0 \neq 0$	$0 \neq 0$	∓ 0	0	∓ 0	0	0 = 0) + 0	0	2 ±	7
H. convergens	17 ± 10 b	0 ± 0 a	∓ 0	0 a	∓ 0	0 a	0 7 0	e) + 0	0 a	∓ 0	0 a

Means (± S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).

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Table 6	Yearly m	iean ti	rap cé	aptures	(x 10	0) ± 5	6.E. of	f adult	s of	fourte	en spe	ecies c	of coccin	ellids	sampled	in earl	y secondar
	success	ion us	sing 1	yellow	sticky	/ traps	from	1989	t	1995.	Long	Term	Ecologi	cal R	esearch-	Kellog	g Biologica
	Station,	Hick	ory C	orners,	MI.												

Species Name				Year				
·	1989	1990	1661	1992	1993	1994	1995	
C. septempunctata	566 ± 46 c	71 ± 20 b	17 ± 8 a	ab 12 ± 3	ab 6±3a	t 25 ± 23 a	∓ 0	0 a
C.m. lengi	8 ± 5 a	467 ± 93 c	1155 ± 121 6	i 97 ± 20	b 6±3a	$1 23 \pm 9 ab$	10 ±	3 а
H. parenthesis	8 ± 5	0 7 0	2 ± 2	2 ± 2	4 ± 3	4 ± 4	∓ 0	0
C. munda	8 ± 5 a	75 ± 30 ab	221 ± 76 t	o 40 ± 15	ab 146 ± 51 t	$138 \pm 51 b$	188 ±	40 b
C. stigma	5 ± 5 a	0±0a	0 = 0	1 3 ± 2	a 8±6t	0 13 ± 5 b	5 ±	5 a
A. bipunctata	17 ± 7 ab	70 ± 13 b	62 ± 33 ^₅	ab 22 ± 16	ab 2±2a	t 0 ± 0 a	∓ 0	0 a
B. ursina	0 ± 0 a	2 ± 2a	0 7 0 5	a 0 ± 0	a 246 ± 73 t	$330 \pm 84 \mathbf{b}$	1665 ± 3	243 c
C.t. perplexa	0 = 0	2 ± 2	3 ± 3	0 7 0	0 + 0	0 + 0	∓ 0	0
H. axyridis	0 = 0	0 ∓ 0	0 = 0	0 7 0	0 = 0	0 = 0	7 ±	S
A. labiculata	0 7 0	0 ∓ 0	0 = 0	0 7 0	0 = 0	0 = 0	∓ 0	0
H.t.tibialis	0 = 0	$0 \neq 0$	0 = 0	0 7 0	0 = 0	0 = 0	∓ 0	0
H. undulata	0 = 0	0 = 0	0 = 0	3 ± 2	0 = 0	2 ± 2	∓ 0	0
H. glacialis	0 7 0	0 = 0	0 ± 0	0 = 0	0 7 0	$0 \neq 0$	2	7
H. convergens	$17 \pm 10 b$	0 ± 0 a	0 ∓ 0	a 0 ± 0	a 0±0a	t 0 ± 0 a	∓ 0	0 a

Means (± S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).

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Principal Component Analysis

Graphical assessment of the principal components of species and the site scores showed that the first component, which accounted for 84% of the variance, was related to intrinsic differences among coccinellid species. In this first component, the outcome of the analysis arranged the species from the most abundant, C. septempunctata on the positive side of the axis, to the least abundant, H. tibialis and A. labiculata on the negative side of the axis (Figure 23). The lack of habitat effect in this component was evident from the fact that the three habitats retained the same position along the first score axis (Figure 23). Therefore, the first component described the assemblage of coccinellid species at a scale that included all habitats. The second principal component, which accounted for 11% of the variance, was a result of site differences. B. ursina, C. munda, and C. m. lengi, which were more abundant in poplar were positioned on the positive side of the axis, while species such as C. septempunctata, H. axyridis, and H. parenthesis, which were more abundant in alfalfa and succession, were positioned on the negative side of the second component axis as a result of the analysis. The PCA scores grouped alfalfa and succession separately from poplar, which confirmed our observations that more noticeable changes in species assemblages occurred in poplar.



Figure 23 Habitat scores and principal components of fourteen species of coccinellids captured in poplar, alfalfa, and secondary succession during seven years of habitat growth at the Long Term Ecological Research site at the Kellogg Biological Station. Hickory Corners, MI.

DISCUSSION

Coccinellid species assemblages had two interesting responses in this study. The first, in plant succession, showed that maximum coccinellid species diversity occurred in second and third years. Thereafter, an increase in the dominance by *C. septempunctata* gradually reduced the diversity of coccinellids.

Although I did not measure vegetation, I observed that the increase in the abundance levels of C. septempunctata coincided with an increase in the population of goldenrod (Solidago spp.). From the perspective of biological control, it seems that managing secondary succession would be a realistic approach to take to promote predator diversity (for example, mulching the field every three years). Before considering any such managerial decisions regarding this habitat, it will be necessary to study more organisms representing a broad gamut of beneficial insects (parasitoids included). There is additional evidence, indicating that this may be the correct approach. Nentwig (1988), after his work in meadows suggested that in order to maximize diversity and density of beneficial insects, succession should be stopped or "held" by the third year. Moreover, current theories on disturbance predict a maximization of diversity in habitats where disturbances occurred frequently enough that resident and colonizing species can live in the same area (Resch et al. 1988). If disturbances are too frequent, resident species may be eliminated, and if disturbances are not frequent enough then competitive exclusion may eliminate pioneer colonizing species.

In summary "abandoned fields" in the landscape will require some sort of management if they are going to enhance the presence of beneficial insects within agroecosystems.

A second important response observed in this study was the "succession" of dominant species observed in the poplar plantations. Here plant composition was uniform, but with a different architecture (due to tree growth). The two dominant species during the first years of popar growth: C. septempunctata and C.m. lengi were associated with crops in agroecosystems. During the initial stages of growth poplar acted as an additional habitat in the landscape for these species of coccinellids. However, toward the end of this cycle, the dominant coccinellid species was that characteristic of deciduous habitats: B. ursina (Maredia 1992a). By including a wooded habitat within the landscape, the richness of coccinellids in the landscape increased, but such species may not have an impact on pests in agricultural crops. This work showed how, in a relatively short time (seven years), there is a shift in species at different stages of deciduous habitats. In fact, it has been reported that species of predators in wooded habitats are different from species living in agricultural crops (Usher 1995). Deciduous habitats, from a pest management perspective, are considered important not because they provide more beneficial insects species but because of the refuge they provide to beneficial insects living in agricultural crops in agroecosystems. This involves all the vegetation associated with deciduous trees. In this study, poplars were treated as a crop, and except for the presence of some grass, there was not additional vegetation.

Finally, the response of coccinellids in alfalfa, showed no patterns that can be attributable to the maturation of this habitat. This observation, coincides with Kieckhefer et al. (1992) and suggests that the variation observed in alfalfa may be due to other factors such as changes in temperature and/or food availability (Honek and Kocourek 1986).

CASE 2: CORN-SOYBEAN ROTATION UNDER CONVENTIONAL TILLAGE

Crop rotation is an agricultural practice designed to improve the quality of the soil (Copeland and Crookston 1992), but it is also an important feature in pest management (Flint and Roberts 1988). Crop rotation has been more successful against pests with limited mobility and a narrow host range such as soil insects (Brust and Stinner 1991). Since highly mobile polyphagous herbivores are not affected by this practice, I hypothesized that a similar criteria could be applied to coccinellids (generalist predators with high mobility).

Since one of the treatments at the KBS LTER was a corn-soybean rotation under conventional tillage, I analyzed the response of the assemblage of coccinellids to such management practice conducted during 1989-1994.

METHODS

Study area. This aspect of the study was conducted at the Long Term Ecological Research (LTER) site at the Kellogg Biological Station (KBS), MI from 1993-1994. The experimental design was established in 1989 consisting of seven treatments: four wheat-corn-soybean rotations, two perennial biomass plantations: (alfalfa and poplar) and a secondary succession. All treatments were replicated six times using one hectare plots as experimental units (Figure 24). A rotation of Corn *Zea mays* and Soybean *Glycine max* under high input conventional tillage was studied from 1989 to 1994.



Figure 24. Experimental design of the Long Term Ecological Research site Kellogg Biological Station showing the spatial distribution of treatments and replicates. Hickory Corners, MI.

Sampling method. In each plot, five double-sided, yellow cardboard sticky trap (22.5 x 14.0 cm) suspended 1.2 m above the ground from a metal trap (as described by Maredia et al 1992b), were placed at permanent geopositioned locations. Yellow cardboards were replaced every second week. Coccinellid adults caught on traps were counted, recorded, and removed every week. The duration of the sampling was from May to August of each year.

Data analysis. Data analysis was conducted using the same procedure described in page 55 of this chapter.

RESULTS

Species diversity

The eleven species of coccinellids sampled in this study were, Coccinella septempunctata (L.), Coleomegilla maculata lengi Timberlake, Cycloneda munda (Say), Adalia bipunctata (L.), Hippodamia parenthesis (Say), Brachiacantha ursina (Fab.), Hippodamia convergens Guerin-Meneville, Chilocorus stigma (Say), Coccinella trifasciata perplexa Mulsant, Anatis labiculata (Say), and Harmonia axyridis (Pallas). H. axyridis (an exotic species) was first captured in 1994.

C.m. lengi was the only species that significantly responded to the crop rotation process, since it was more abundant during the corn phase (Table 7). *C. septempunctata*, the other dominant species, showed a pattern of variation in abundance that did not relate to rotation. No pattern of relative abundance was observed with the rest of the species.

Significant differences were found on total relative abundance during 1989, and species diversity during 1994 (Figure 25). Species richness remained the same during the whole rotation scheme.

Coefficient of similarity

Regarding species concordance, a significant similarity was found between 1990 and 1992 (soybean years) and 1991 and 1993 (corn years) (Table 8).

Species Name						Year							
I	1989	19	06	1661		1992		1993		1994	-	1995	
C. septempunctata	566 ± 46	c 71 ±	- 20 b	17 ±	8 ab	12 ±	3 ab	7 ₹	3 a	25 ±	23 a	∓ 0	0 a
C.m. lengi	8 ± 5	a 467 ±	: 93 c	1155 ±	121 d	7 ±	20 b	7 ₹	3 a	23 ±	9 ab	10 ±	3 а
H. parenthesis	8 ± 5	∓ 0	0	2 ±	7	2 ±	7	4 +	3	4 ++	4	∓ 0	0
C. munda	8 ± 5	a 75 ±	: 30 ab	221 ±	76 b	40 ±	15 ab	146 ±	51 b	138 ±	51 b	188 ±	40 b
C. stigma	5 ± 5	a . 0 ±	- 0 a	∓ 0	0 a	3 H	2 a	++ ∞	6 b	13 ±	5 b	5 ±	5 a
A. bipunctata	17 ± 7	ab 70 ±	- 13 b	62 ±	33 ab	22 ±	16 ab	2 ±	2 a	∓ 0	0 a	∓ 0	0 a
B. ursina	0 = 0	a 2 ±	- 2a	∓ 0	0 a	∓ 0	0 a	246 ±	73 b	330 ±	84 b	1665 ±	243 c
C.t. perplexa	0 7 0	2	5	3 ±	ε	∓ 0	0	∓ 0	0	∓ 0	0	Ŧ 0	0
H. axyridis	0 7 0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	7 ±	S
A. labiculata	0 = 0	∓ 0	0	∓ 0	0	∓ 0	0	∓	0	∓ 0	0	∓ 0	0
H.t.tibialis	0 = 0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	+ 0	0
H. undulata	0 7 0	∓ 0	0	∓ 0	0	3 H	7	∓ 0	0	2 ±	2	∓ 0	0
H. glacialis	0 ∓ 0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	∓ 0	0	7 ⊭	5
H. convergens	17 ± 10	p 0 ≢	- 0a	∓ 0	0 a	∓ 0	0 a	+ 0	0 a	∓ 0	0 a	∓ 0	0 a

Means (± S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).



Means (\pm S.E.) which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).

Figure 25. Relative abundance, species diversity, and richness of a complex of predatory coccinellids in a six year corn-soybean rotation under high input conventional tillage at the Long Term Ecological research site at the Kellogg Biological station. Hickory Corners, MI.

Principal Component Analysis

Graphical assessment of the principal components of species and the site scores showed that the first component, which accounted for 72% of the variance, was

related to intrinsic differences among coccinellid species. In this first component, the analysis arranged the species from the most abundant, *C. septempunctata* on the positive side of the axis, to the least abundant ones on the negative side of the axis (Figure 26).

Table 8. Kendall's coefficients for coccinellid species concordance between consecutive years in a corn-soybean rotation at the KBS LTER, Hickory Corners, MI. (P= statistical significance level).

	1989	1990	1991	1992	1993
	corn	soybean	corn	soybean	corn
1990	0.4 (P=0.33)				
1991	0.4 (P=0.33)	0.6 (P=0.14)			
1992	0.6 (P=0.14)	0.8 (P=0.05)	0.4 (P=0.33)		
1993	0.6 (P=0.14)	0.4 (P=0.33)	0.8 (P=0.05)	0.2 (P=0.62)	
1994	0.2 (P=0.62)	0.4 (P=0.33)	0 (P=1.00)	0.6 (P=0.14)	-0.2 (P=0.62)

The second principal component, which accounted for 14% of the variance, was primarily a result of habitat preferences. Species which preferred corn positioned on the positive side of the axis: *B. ursina*, *C.m. lengi*, *C.t. perplexa*, and *C. munda*. Species such as *H. parenthesis*, and *A. labiculata* which preferred soybean, were positioned on the negative side of the second component axis.

DISCUSSION

The most important finding of this work is the change in dominant species observed from year to year during the rotation process, in which C.m. lengi seemed

more affected than the others. C. septempunctata was the dominant species during the soybean phase, while C.m. lengi was dominant (except in 1989) in the corn phase. The potential implications of this rotation on dominance lies in the fact that it will never be possible to take advantage of the population of coccinellids produced the previous year. For example, in a corn year, the population of C.m. lengi increases in the landscape. That will potentially produce great numbers of overwintering C.m. lengi ready to populate the landscape during the following year. The following year, however, the crop rotation scheme dictates that it will be soybean, which is a habitat that promotes the population build-up of C. septempunctata, and probably deters C.m. lengi. Therefore, in some sense all the C.m. lengi population generated during a corn year are wasted during the soybean year. Probably the same process occurs with C. septempunctata, although potentially, as shown during 1989, this species can occur in large numbers during corn years. In this study, however, it was not possible to evaluate the full impact of rotation on coccinellid populations because the surrounding landscape always provided an alternate food resource. For example, during soybean years, corn was present in other fields nearby the experimental area. However, it is evident that this agricultural practice, besides disrupting the population dynamics of several pests, can also produce the same effect on beneficial insects. Presence of alternate crop habitats in early spring (wheat, alfalfa) could provide a survival opportunity for coccinellid populations that were produced during a previous season.



Figure 26. Habitat scores and principal components of eleven species of coccinellids captured in a six year corn- soybean rotation under high input conventional tillage at the Long Term Ecological Research site at the Kellogg Biological Station. Hickory Corners, MI.

CHAPTER 4: ASSEMBLAGE OF PREDATORY COCCINELLIDAE (COLEOPTERA) IN RESPONSE TO HABITAT MANAGEMENT (TILLAGE AND CHEMICAL INPUTS) WITHIN AN AGROECOSYSTEM

The influence of humans on agroecosystems through all of the activities conducted to produce crops has long been recognized (Risser 1986). Many of these activities, aimed to address increased crop production (such as plant nutrients, pest control, etc.) had unexpected consequences over the long run (soil erosion, water pollution, pest resistance, etc.) (de la Court 1992, Wheeler 1992). This situation motivated the search for ecological alternatives to make agriculture sustainable (Hetch 1987). The goal would be to achieve an equilibrium of energy flow in agroecosystems which eventually will allow for the reduction of elimination of the need for artificial inputs (Crews et al. 1991). In this process, a systems perspective will be needed to evaluate the impact of recommended ecological practices in the context of the whole agroecosystem. Conservation tillage, for example, recommended for ecological management of the soil (Hilner 1985), requires the reconsideration of pest management approaches (Kells and Meggitt 1985, Kirby 1985, Ruppel and Sharp 1985). From a pest management point of view low input agricultural practices are considered to diversify agroecosystems which makes them less susceptible to pest outbreaks (Reijntjes et al. 1992, Altieri 1994).

The KBS LTER principle hypothesis is that "agronomic management based on ecological concepts can effectively substitute for reliance on chemical subsidies in production-level cropping systems" (VanCleve and Martin 1991). To test this hypothesis, the comparison of crop production under different tillage and chemical input treatments using a corn-soybean-wheat rotation was included in its experimental design. Conservation tillage practices change the ground microenvironment affecting soil and litter dwelling insects (Musick and Petty 1973, Steffey et al. 1992). These practices encourage the development of organisms that benefit from increased humidity provided by crop residues or from the presence of weeds (Musick and Petty 1973, Steffey et al. 1992). However, there is a higher proportion of pests whose population density and subsequent damage decreases as tillage decreases (Stinner and House 1990). Such reduction in pest populations may be due to the increase in beneficial insect fauna. Reduction of soil disturbance and a higher presence of weeds favor important predators such as ground beetles, rove beetles, spiders, and ants (Stinner and House 1990, Clark et al. 1993).

Studies on coccinellids to evaluate the effect of conservation tillage and reduced chemical input practices on beneficial arthropods showed different results depending on the crop and on the insect species. *C.m. lengi*, for example, had large populations of adults in conventional tillage corn (Tonhasca and Stinner 1991), while *H. convergens* had higher density in no tillage wheat (Rice and Wilde 1991).

The present work was conducted to evaluate the effect of tillage and chemical input practices on the species assemblages of predatory coccinellids.

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METHODS

Study area. This study was conducted at the Long Term Ecological Research (LTER) site at the Kellogg Biological Station (KBS), MI from 1993-1995. The experimental design was established in 1989 consisting of seven treatments: four wheat-corn-soybean rotations, two perennial biomass plantations: (alfalfa and poplar) and a secondary succession. All treatments were replicated six times using one hectare plots as experimental units (Figure 27).



Figure 27. Experimental design of the Long Term Ecological Research site Kellogg Biological Station showing the spatial distribution of treatments and replicates. Hickory Corners, MI. 1993-1995 **Treatments.** Four management practices were tested: High Input Conventional Tillage, High Input No Tillage, Low Chemical Input, and Zero Chemical Input. Field crops used were: Corn Zea mays L. In 1993, Soybean Glycine max L. In 1994, and Wheat Triticum aestivum L. A description of the agronomy protocols are described in the Table 9.

Sampling method. In each plot, five double-sided, yellow cardboard sticky trap (22.5 x 14.0 cm) suspended 1.2 m above the ground from a metal trap (as described by Maredia et al. 1992b), were placed at permanent geopositioned locations. Yellow cardboards were replaced every second week. Coccinellid adults caught on traps were counted, recorded, and removed every week. The duration of the sampling was from May to August of each year, except during the wheat year in which sampling was interrupted when the crop was harvested.

Data analysis. Data analysis was conducted using the same procedure described in page 55 of this chapter.

Table 9. Agronomic protocol for each one of the different field crops in the KBS-LTER. 1993-1995. CT =conventional tillage, NT =no tillage, LCI =low chemical input, and ZCI = zero chemical input.

AGRONOMIC		CORN	N 1993	
PRACTICE	СТ	NT	LCI	ZI
Tillage	Y	N	N	N
Herbicide (No)	Y (1)	Y (2)	N	N
Fertilizer	Y	Y	Y	N
Cultivation (No.)	Ν	Ν	Y (5)	Y (5)
Cover crop (before and after the crop)	Ν	Ν	Y	Y

		SOYBEA	N (1994)	
	СТ	NT	LCI	ZI
Tillage	Y	N	Y	Y
Herbicide	Y (1)	Y (2)	Y (1)	Ν
Fertilizer	Ν	Ν	Ν	Ν
Cultivation	Y (1)	Ν	Y (3)	Y (3)
Cover crop	Ν	Ν	Ν	Ν

		WHEA	T (1995)	
	СТ	NT	LCI	ZI
Tillage	Y	N	Y	Y
Herbicide (No.)	Y (2)	Y (2)	Ν	N
Fertilizer	Y	Y	Y	Ν
Cultivation (No.)	N	N	Y (5)	Y (5)
Cover crop (before and after	N	Ν	Y	Y
the crop)				

RESULTS

The thirteen species of coccinellids found in this study were: Coccinella septempunctata (L.), Coleomegilla maculata lengi Timberlake, Cycloneda munda (Say), Adalia bipunctata (L.), Hippodamia parenthesis (Say), Brachiacantha ursina (Fab.), Hippodamia convergens Guerin-Meneville, Chilocorus stigma (Say), Coccinella trifasciata perplexa Mulsant, Hippodamia tredecimpunctata tibialis (Say), Anatis labiculata (Say) and Hippodamia glacialis glacialis (F.), and Harmonia axyridis (Pallas). H. axyridis (an exotic species) was first captured in 1994.

Corn 1993

Total relative abundance, Shannon-Wiener, and Richness indices were significantly different between high input treatments (conventional and no tillage) and low and zero chemical input treatments (Figure 28). *C. maculata* and *C. septempunctata*, the two dominant species in this habitat, were most abundant in the high input treatments (Table 10).

The only significant similarity in species concordance was found between No till and Low Chemical Input (Table 11). High dissimilarities in species concordance were found between the Zero Chemical Input and the rest of the treatments.



Means (\pm S.E.) within a crop which are followed by the same letter are not significantly different at the 0.05 level (Tukey HSD method).

Figure 28. Relative abundance, species diversity, and richness of a complex of predatory coccinellids in corn, soybean, and wheat under four agronomic practices at the Long Term Ecological Research site at the Kellogg Biological Station. Hickory Corners, MI.1993-1995. CT =conventional tillage, NT =no tillage, LI =low chemical input, and ZI = zero chemical input.

		Treatme	ent	
Species name	Conventional tillage	No tillage	Low chemical input	Zero chemical input
C. septempunctata	171 + 38 bc	231 + 43 c	33 + 19 a	65 + 21 ab
C.m. lengi	339 + 72 c	119 + 47 b	36 + 18 ab	4 + 4 a
H. parenthesis	0 + 0	5 + 3	3 + 3	0 + 0
C. munda	24 + 10	17 + 8	4 + 4	0 + 0
H. axyridis	0 + 0	0 + 0	0 + 0	0 + 0
H. glacialis	0 + 0	0 + 0	0 + 0	0 + 0
B. ursina	10 + 10	2 + 2	0 + 0	6 + 6
A. bipunctata	2 + 2	2 + 2	0 + 0	0 + 0
A. labiculata	0 + 0	0 + 0	0 + 0	0 + 0
C.t. perplexa	2 + 2	0 + 0	0 + 0	0 + 0
H. convergens	0 + 0	0 + 0	0 + 0	0 + 0
H.t.tibialis	0 + 0	0 + 0	0 + 0	0 + 0
C. stigma	0 + 0	0 + 0	0 + 0	0 + 0

Table 10. Yearly mean trap captures (x 100) ±S.E. of adults of thirteen species of coccinellids sampled using yellow sticky traps in corn under four management practices. Long Term Ecological Research- Kellogg Biological Station, Hickory Corners, MI. 1993.

Means (\pm S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).

Table 1	1. Kendall's coefficients for coccinellid species concordance
	in corn under different management practices at the KBS
	LTER, Hickory Corners, MI. 1993. CT =conventional tillage,
	NT = no tillage, LCI = low chemical input, and ZCI = zero
	chemical input.

	СТ	NT	LCI
NT	0.59		
	(P=0.068)		
LCI	0.62	0.84	
	(P=0.06)	(P=0.011)	
ZCI	0.51	0.46	0.30
	(P=0.132)	(P=0.176)	(P=0.384)

Soybean 1994

The most important observation in this habitat was the dominance of C. septempunctata in all treatments and the low relative abundance of this species in the low chemical input treatment (Table 12). This, in turn, caused a significantly low relative abundance for the total of coccinellids (Figure 28). No significant differences were found in either diversity (Shannon index) or species richness (Figure 28).

A highly significant similarity was found between no tillage and zero chemical input treatments (Table 13). The rest of the treatments were dissimilar.

11. 1

Table 12. Yearly mean trap captures (x 100) ±S.E. of adults of thirteen species of coccinellids sampled using yellow sticky traps in soybeans under four management practices. Long Term Ecological Research- Kellogg Biological Station, Hickory Corners, MI. 1994.

	Treatment				
Species name	Conventional tillage	No tillage	Low chemical input	Zero chemical input	
C. septempunctata	710 + 93 b	1063 + 121 b	228 + 69 a	611 + 104 b	
C.m. lengi	6 + 3	22 + 4	29 + 12	23 + 7	
H. parenthesis	15 + 6	23 + 7	5 + 3	11 + 7	
C. munda	4 + 3	4 + 3	10 + 7	2 + 2	
H. axyridis	2 + 2	4 + 3	6 + 6	2 + 2	
H. glacialis	0 + 0	2 + 2	0 + 0	0 + 0	
B. ursina	0 + 0	0 + 0	0 + 0	7 + 3	
A. bipunctata	8 + 5	6 + 3	0 + 0	12 + 5	
A. labiculata	10 + 2	0 + 0	0 + 0	2 + 2	
C.t. perplexa	0 + 0	0 + 0	0 + 0	0 + 0	
H. convergens	0 + 0	2 + 2	0 + 0	3 + 3	
H.t.tibialis	0 + 0	0 + 0	0 + 0	0 + 0	
C. stigma	2 + 2	0 + 0	0 + 0	0 + 0	

Means (\pm S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).
Table	 Kendall's coefficients in soybean under diff KBS LTER, Hickory C tillage, NT =no tillage, zero chemical input 	 Kendall's coefficients for coccinellid species concordance in soybean under different management practices at the KBS LTER, Hickory Corners, MI. 1994. CT =conventional tillage, NT =no tillage, LCI =low chemical input, and ZCI = zero chemical input 					
	СТ	NT	LCI	-			
NT	0.59			-			

NT	0.59		
	(P=0.032)		
LCI	0.34	0.57	
	(P=0.226)	(P=0.044)	
ZCI	0.41	0.67	0.41
	(P=0.134)	(P=0.017)	(P=0.147)

Wheat 1995

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In this habitat, the highest species diversity was found under conventional tillage, while the highest total relative abundance was in the zero chemical input treatment (Figure 28). C.m. lengi and C. septempunctata, the dominant species, preferred the zero chemical input treatment, although C.m. lengi was also attracted to conventional tillage treatment (Table 14).

The Kendall's coefficient of concordance showed a significant similarity between all treatments (Table 15).

Table 14. Yearly mean trap captures (x 100) ±S.E. of adults of thirteen species of coccinellids sampled using yellow sticky traps in wheat under four management practices. Long Term Ecological Research- Kellogg Biological Station, Hickory Corners, MI. 1995.

	Treatment					
Species name	Conventional tillage	No tillage	Low chemical input	Zero chemical input		
C. septempunctata	361 + 52 a	519 + 66 ab	450 + 45 ab	719 + 100 b		
C.m. lengi	72 + 16 c	6 + 6 a	22 + 16 ab	72 + 20 bc		
H. parenthesis	39 + 10	28 + 10	22 + 16	50 + 11		
C. munda	6 + 6	11 + 7	19 + 14	6 + 6		
H. axyridis	22 + 16	22 + 7	11 + 11	17 + 17		
H. glacialis	17 + 11	6 + 6	11 + 7	11 + 7		
B. ursina	0 + 0	0 + 0	0 + 0	6 + 6		
A. bipunctata	0 + 0	0 + 0	0 + 0	0 + 0		
A. labiculata	0 + 0	11 + 7	0 + 0	0 + 0		
C.t. perplexa	6 + 6	0 + 0	6 + 6	0 + 0		
H. convergens	6 + 6	0 + 0	0 + 0	0 + 0		
H.t.tibialis	6 + 6	0 + 0	0 + 0	0 + 0		
C. stigma	0 + 0	0 + 0	0 + 0	0 + 0		

Means (\pm S.E.) within a row which are followed by different letters are significantly different at the 0.05 level (Tukey HSD method).

	NT =no tillage, LCI =l chemical input.	ow chemical inp	ut, and ZCI = zer
	СТ	NT	LCI
NT	0.61		
	(P=0.016)		
LCI	0.85	0.70	
	(P=0.001)	(P=0.007)	
ZCI	0.88	0.611	0.85
	(P=0.001)	(P=0.016)	(P=0.0017)

Table 15. Kendall's coefficients for coccinellid species concordance in wheat under different management practices at the KBS LTER, Hickory Corners, MI. 1995. CT =conventional tillage, NT =no tillage, LCI =low chemical input, and ZCI = zero chemical input.

Principal Component Analysis

Graphical assessment of the principal components of species and the site scores showed that the first component, which accounted for 63% of the variance, was related to intrinsic differences among coccinellid species. In this first component, the analysis arranged the species from the most abundant, *C. septempunctata* on the positive side of the axis, to the least abundant, *H. tibialis and C. stigma* on the negative side of the axis (Figure 29).



Figure 29. Habitat scores and principal components of thirteen species of coccinellids captured in corn, soybean, and wheat under four management practices at the Long Term Ecological Research site at the Kellogg Biological Station. Hickory Corners, MI. 1993-1995. CT =conventional tillage, NT =no tillage, LCI =low chemical input, and ZCI = zero chemical input. The second principal component, which accounted for 14% of the variance, was mostly the result of habitat preferences. Species which preferred corn such as *B. ursina* and *A. bipunctata*, were positioned at the extreme end of the positive side of the axis, while species such as *H. parenthesis*, *H. axyridis*, and *H.g.glacialis* which preferred wheat, were positioned at the extreme end of the negative side of the axis (Figure 29). An additional treatment grouping was observed between corn and soybean under both low and zero chemical input treatments.

DISCUSSION

The most important response by coccinellids to management treatments occurred in corn. Total abundance, species diversity, and species richness of predatory coccinellids were higher in the high chemical input systems (conventional and no till) and significantly lower in low and zero chemical input treatments. *C.m. lengi* and *C. septempunctata*, the dominant species in this habitat, were significantly more abundant in high chemical input systems. In the LTER experiment, differences in chemical inputs caused differences in weed management, since up to five cultivations in low and zero chemical input treatments were necessary for weed control. Presence of weeds increases both plant diversity and plant density in agroecosystems (Koskinen and McWhorter 1986) and *C.m. lengi* is negatively affected when plant density increases (Risch et al. 1982).

The result that conventional tillage corn harbored higher numbers of *C.m. lengi* coincides with observations by Tonhasca and Stinner (1991), although they found significantly smaller populations in no tillage corn. No tillage practices promote the increase of weed populations (Kells and Meggitt 1985). However in the KBS LTER weeds were rapidly controlled by the use of herbicides, which may have been the reason for the similarity on *C.m lengi* abundance in both tillage treatments (conventional and no tillage).

The observation that *C. septempunctata* was also more abundant in high input treatments was unexpected because this species has not been reported to be affected by plant density or plant diversity. A possible cause was the intense disturbance due to weed management that low and zero chemical input treatments were subject to during the season. The peak of abundance of *C. septempunctata* in corn corresponded with early phenological stages of the plant, and most of the cultivations were made at that time. This constant disturbance may have rendered the habitat unsuitable for this species.

Another interesting pattern in predator abundance was observed in wheat. This crop did not require any cultivation for weed control in low and zero chemical input treatments. This situation meant that disturbance was not an issue in these treatments. Under these circumstances, the zero chemical input treatment registered a high relative abundance of coccinellid, including the two dominant species: *C.m. lengi* and *C. septempunctata*.

The results on coccinellid abundance obtained in corn and wheat illustrates the complexity that exists within sustainable systems. It also shows the importance of not making generalizations from what occurs in one crop nor what occurs with one group of beneficial insects. If it is true that the presence of weeds may deter some beneficial insects such as *C.m. lengi*, it may also enhance the activity of other beneficial insects such as the ground beetles. In wheat, small population of weeds may diminish the population density of some predators but it also promotes the activity of other predators such as coccinellids.

CHAPTER 5: DEVELOPING A MODEL OF INTERACTIONS BETWEEN PREDATORY COCCINELLIDS (COLEOPTERA) AND LANDSCAPE STRUCTURE IN FIELD CROP AGROECOSYSTEMS.

INTRODUCTION

Agricultural systems are considered to have lower complexity when compared to natural systems (Risch 1987, Stinner and Stinner 1989). This distinction has been made based on the agricultural model of the 70's and 80's where monoculture fields with high-yield hybrids grow under intense chemical inputs provided by the farmer (Bird 1994). Concerns for the need for adequate knowledge to manage agroecosystems ecologically have made researchers aware of the potential complexity that agroecosystems have (Kogan 1986, Vandermeer 1995). For example, interactions between vegetation (cultivated and natural), herbivores, and beneficial insects occur at different spatial scales that transcend the single plant to the landscape (Levins and Wilson 1980, Risser 1986) (Figure 30). Moreover, these interactions can be highly influenced by weather (Wellington and Trimble 1984) and human management (Stinner and Stinner 1989). When issues increase in complexity, a systems approach becomes necessary to provide the holistic view required to obtain a thorough understanding of the interactions that occur among the different components or subsystems in agricultural landscapes (Jeffers 1978, Bird et al. 1990).



Interactions of Subsystems in Agroecosystems

beneficial organisms sub-system

Figure 30. Interactions of different subsystems in agroecosystems at different hierarchical spatial scales.

Modeling is the step within the systems approach in which the interactions that occur between different elements of the system are expressed mathematically (Tait 1987, Bird et al. 1990). This allows researchers to evaluate their degree of understanding of the system of interest and propose further or alternative studies (Getz and Gutierrez 1982).

Modeling has been extensively used to study interactions between organisms and the landscape (Saarenmaa et al. 1988, Folse et al. 1989, Hyman et al. 1991, Turner and Dale 1991, Doak et al. 1992, Milne et al. 1992). In landscape ecology, modeling has become particularly useful because of the difficulty in conducting experiments at larger spatial or temporal scales (Baker 1989, Turner et al. 1989, Hargrove and Pickering 1992).

Simulation models allow researchers to explore scenarios difficult to reproduce in the landscape, and as a result of several simulations and analyses, hypotheses can be formulated and tested with an appropriate experimental design (Fahrig 1991, Pickett et al. 1994).

Different aspects of the interactions between ladybird beetles and the landscape were described in previous chapters. This chapter will describe the development of a model designed to integrate the results obtained in those chapters. Ladybird beetles have been the subject of multitrophic simulation models (Carter et al. 1982, Gutierrez and Baumgaentner 1984). In these studies however, only one habitat was included. A model including a group of ladybird beetle species and a landscape may become very complex because the large number of potential interactions that exist among environmental conditions, landscape elements, and ladybird beetles (Figure 31). For example, environmental conditions including temperature, rain, wind, and photoperiod change through the season and drive the population dynamics of ladybird beetles. In addition, the structure (type, number, shape, size, and configuration of patches), the function (flow of energy), and anthropogenic disturbances in the landscape have been shown to affect the population dynamics of ladybird beetles (Chapters 3 and 4).

Thus, the challenge for a researcher is to determine the amount of knowledge sufficient to include in the model (Berryman 1991a,b, Onstad 1991). In this process, it is fundamental to assess the appropriate scale needed to evaluate the interactions that occur in the system to be modeled (see Chapter 2).

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Figure 31. Life system of ladybird beetles in the landscape

OBJECTIVE

The objective of this part of the research was to develop a simulation model to synthesize the observations and results obtained as part of the KBS LTER project (described in chapters 3 and 4). This model will be used to study the response of assemblages of ladybird beetles to changes in the structural configuration of the landscape. The ultimate goal of this model with regard to the KBS LTER program is to assess the implications of modifying the agricultural landscape design in the composition of the beneficial insects community.

METHODOLOGY

A systems approach (Tummala and Haynes 1977, Kitching 1983) was used to develop the model in this study. This consisted of several steps beginning with the definition of the problem and culminating with the validation of the model (Figure 32). The last step however, was not accomplished at the present stage of development of the model. Since most of the steps described in the methodological diagram (Figure 32) are self descriptive, I will provide a detailed explanation of each step in the Results.

There are some terms, however, that require a definition in advance to understand the diagram. They are:

- a) Universe of Concern. The system under study.
- b) <u>Object of control</u>. The part of the system (universe of concern) that we want to manage.
- c) <u>Associate environment</u>. The part of the system that influences the object of control but that will not be managed.
- d) <u>Stimuli or inputs</u>. Factors of the object of control that affect the response of the system.
- e) <u>Response or outputs</u>. The responses to inputs/stimuli factors.
- f) <u>Sensitivity analysis</u>. Test of the different variables of the model to see how changes in those variables affect the output of the model.
- g) <u>Validation</u>. Test of the model to assess the degree of accuracy and precision of its predictions compared to real observations.



Figure 32. Methodological approach followed during the development of the model on interactions between the landscape and ladybird beetles.

RESULTS

1. Definition of the problem

As part of the KBS LTER project, a seven years of study (1989-1995) has revealed patterns of habitat utilization by a complex of coccinellids in a variety of field crops (under different management practices), perennial habitats, and secondary succession vegetation. This information needed to be synthesized so it could be studied the response of assemblages of coccinellid species to different landscape scenarios in agroecosystems.

2. Delimitation of the universe of concern

The <u>universe of concern</u> was the agricultural landscape comprised of field crops and uncultivated habitats in which plants, herbivores, and beneficial insects interact among themselves under the influence of weather and human management (Figure 30).

3. Object of control and associated environment

The objects of control were a complex of 13 ladybird beetle species and a group of six habitat types (corn, wheat, alfalfa, soybean, poplar, and secondary succession). The associated environment was defined by weather and human management. However, after analyzing the universe of concern (Figure 30), an important consideration had to be made with respect to the herbivore subsystem. It seems that by considering vegetation in the landscape (producers) and a complex of predators (secondary consumers), the model could have included the herbivore subsystem (primary consumers) as has been the case in some tri-trophic models reported in the literature (Carter et al. 1982, Gutierrez and

Baumgaertner 1984). This approach, however, was not followed in this study because of the following reasons.

- a) The potential complexity that would be added to the model. Ladybird beetles are generalist predators which have a wide range of prey preferences (Hodek 1967).
 Moreover, some species can alternatively feed on plant products such as pollen and extrafloral nectars (Pemberton et al. 1993).
- b) The assumption made that, at the scale of this study, the habitat effect on ladybird beetles includes the effect of the herbivore subsystem. This assumption is based on the numerical response of coccinellids to insect outbreaks (Frazer and Raworth 1985). Therefore if a habitat registers a high number of coccinellids, it is reasonable to expect that prey availability is also high.

4. Determination of Stimuli-Results

The decision on the type of results expected from the model was made during earlier stages in the model's development. It was decided that results would include the temporal and spatial distribution for each species within the ladybird beetle complex. The selection of the stimuli that could determine the above results was further complicated because there were multiple factors related to both the landscape and to the ladybird beetles (Figure 33)

An important step toward the selection of the appropriate stimuli was the analysis of the temporal and spatial scales in relation to population dynamics of coccinellids described in Chapter 2. This analysis determined that a "year" was an appropriate temporal scale for the model. This determination had important implications in the selection of the stimuli

since several of the potential factors that can affect the life system of coccinellids vary within a season. Thus considering yearly abundance of coccinellids, by averaging withinseason factors, will reduce the complexity of the model.



Figure 33. Factors involved in the interactions between beneficial insects and the landscape in agroecosystems.

A model that focuses on across season variability can be affected by four factors: a) habitat type, b) habitat age, c) habitat management, and d) habitat influence. These factors were used as the stimulus inputs. They were provided to the model based on information derived from the spatial configuration of the landscape, and the results were the temporal and spatial distribution of the ladybird beetles (Figure 34).



Figure 34. Stimuli (inputs) and response (outputs) of a landscape simulation model involving 13 species of ladybird beetles.

<u>Habitat type</u> was based on the six habitats chosen and manipulated in the KBS LTER design: corn, wheat, soybean, alfalfa, poplar, and secondary succession. <u>Habitat age</u> was based on habitat aging of perennial habitats and secondary succession. <u>Habitat management</u> was due to tillage and chemical input practices utilized on corn, soybean, and wheat. Finally, <u>habitat influence</u> was based on the interaction of different habitats within the landscape.

5. Selection of model type

A spatially explicit type of population model, which combines a population simulator with a landscape map that characterizes the spatial distribution of the landscape features, best fit the proposed objectives(Dunning et al. 1995). In this type of model, also know as *spatial mosaic model* (Baker 1989), the landscape is divided into equal-sized grid cells (Figure 35). Change in the abundance of each ladybird beetle species was modeled on an individual-cell basis. Results (outputs) were in the form of computer files containing digital maps of the spatial distribution of ladybird beetles. These files were accessible by Geographic Information Systems (GIS) technology for further spatial analysis. An important initial step in the implementation of this model is the selection of the grain or resolution of the model i.e. "the size of the individual units of observation" (Wiens 1989). Since the information needed to estimate parameters of population abundance was obtained from one hectare field plots (chapters 3 and 4), this was chosen (1 ha.) as the grain of this model.

6. Selection of computer technology

The computer model was coded using Quick Basic version 4.5. This language permitted a structured program based on modules called by a main module. The model was documented to facilitate an eventual translation to other computer language, such as C or C++. Output maps from the model were produced in ASCII format ready to be accessed by GIS software such as ARC INFO for additional spatial analyses.



Figure 35. Spatially explicit population model in which temporal abundance of predators is evaluated on a cell by cell basis based on the habitat status in each cell for each time step (i).

7. Mathematical relationships

The abundance of each ladybird beetle species as a function of the stimuli (inputs) used in the model is given by the following equation:

Abundance (time, cell) = 10,000 x Habitat type (time, cell) x Habitat age (time, cell) x Habitat management (time, cell) x Habitat influence (time, cell).

where time is in years, and each cell is one hectare with row and column coordinates (see Figure 35)

Each of the habitat effects provide a value between 0-1 in which "1" is the best condition. The model currently assumes that at the beginning of each year, there is a potential population density of 10,000 beetles of each species per hectare (i.e. one beetle of each species per m²). This constant supply of beetles each year was made by assuming that the KBS LTER experimental area was surrounded by habitats that potentially could have supplied habitats with beetles at the beginning of each year. While this assumption may be acceptable for small landscapes, its validity will decrease as the size of the landscape in a simulation increases. It is expected that further analysis of field data will allow me to account for population dynamics within a season. This information will provide a mathematical relationship which in addition to the effect of the habitat factors, will account for the density of ladybird beetles during the previous year to predict the population density for the following year.

8. Parameter estimation

a) Habitat type

Determination of species abundance as a function of habitat type was designed with a stochastic process based on probabilities of levels of abundance. The level of abundance was coded as a range of values named with terms such as "very low" or "high". The determination of levels of abundance and the estimation of their respective probabilities for each species in each habitat will be described in the following paragraphs and shown in Figure 36, and Figure 37.

Determination of levels of abundance.

C. septempunctata was selected as a model species because it had the broadest range of abundance in the KBS LTER study. All the annual trap catches per treatment per year (49 combinations) were used for pairwise comparisons to obtain groups of means that were not statistically different (P > 0.05). Prior to statistical analysis data were normalized using a $\sqrt{x+0.001}$ transformation. Analysis of variance (ANOVA) and the Tukey-HSD test were used to test for statistically significant differences among treatments or years (SPSS 1993).

As a result of this analysis, 18 groups of means were obtained. Five of them were selected to cover the possible range in values of abundance for the dominant species: *C. septempunctata and C.m. lengi*. These five groups were classified as very low, low, medium, high and very high (Figure 36).



Species model C. septempunctata

Figure 36. Determination of levels of abundance for ladybird beetle species based on groups of abundance means of *C. septempunctata* after a pairwise comparison (Tukey HSD).

A different set of groups was selected for the other ladybird beetle species because their range in abundance was lower than the dominant species. The values for all the 18 groups that resulted from the Tukey-HSD analysis, as well as the values selected for the different levels of abundance, are shown in the Appendix A.

Estimation of probabilities for levels of abundance.

Maximum coccinellid abundance was selected from each of the following habitats: corn (1993), soybean (1994), wheat (1995), alfalfa, poplar, and secondary succession (1989-1995). Then, I determined the frequency of each level of abundance. Frequencies were converted to percentages, and the original values used for levels of abundance were normalized to a scale of 0-100 (Figure 37). The resulting probabilities for abundance levels per species in each habitat are shown in the Appendix B.

b) Habitat age

The effect of habitat age was provided by perennial habitats (poplar and alfalfa) and secondary succession in accordance with the analysis conducted in Chapter 3. For each ladybird beetle species all annual means in each of the habitats were normalized to a scale of 0 to 1; where 1 corresponded to the highest mean. The resulting estimations (expressed in percentages) are shown in the Appendix C. For agronomic treatments (corn, soybean, and wheat) values were always 1 since they did not provide any age effect (annual crops).



Figure 37. Process of estimation of probabilities for levels of abundance using C. *septempunctata* in corn as an example.

c) Habitat management

Habitat management is the influence of agronomic practices on corn, soybean, and wheat, based on the analysis conducted in Chapter 4. Practices considered were conventional tillage (also considered as high chemical input), no tillage, low chemical input, and zero chemical input.

For each species all treatment means in each habitat were normalized to a scale of 0 to 1; where 1 corresponded to the highest mean. The resulting estimations (expressed in percentages) are shown in the Appendix D. Alfalfa, poplar, and secondary succession were considered without agronomic management and were assigned a value of 0.

d) Habitat influence.

Habitat influence is considered a key factor in determining the spatial distribution of ladybird beetles in the landscape. For example, the presence of deciduous habitats in the landscape promotes the presence of species such as *B. ursina* and *C. munda* (Colunga-Garcia et al. in review). Also, preliminary analyses showed that wheat may influence the abundance of ladybird beetles in corn or soybean. The estimation of this parameter, however, requires the determination of the ratio of influence for each habitat. For example, it is necessary to know how far into the landscape a hectare of poplar can influence the presence of *B. ursina* and *C. munda* in other habitats. Answers to this question, will require elaborate initial assumptions which can be tested with subsequent analysis based on simulation tests. This approach will be implemented in the future

development of the program after conducting sensitivity analyses of the model with respect to the other three factors.

d) Probability of being in a crop.

This parameter was incorporated to account for factors not included in the model at its current stage because some species are rarely present in annual crops, but when present, they may occur in high numbers. This parameter was calculated by determining the frequency (%) for species presence in a field crop habitat across the seven years of the study. The resulting estimates are shown in Appendix E.

9. Programming

The structure of the computer code for the model consists of a main module which includes a time controller and calls eight sub-modules (Figure 38). The computer code is shown in Appendix F.

The first three modules set the initial condition of the model before proceeding with the actual simulation. The <u>variable definition</u> module defines the types of variables and sets the dimensions of the arrays used in the model. The <u>parameters acquisition</u> module accesses a digital file that contains the numerical values of the parameters of the model (habitat type, habitat age, habitat management, habitat influence, and habitat probability).



Figure 38. Modular organization of a model that simulates the response of thirteen species of ladybird beetles to landscape configurations.

The <u>landscape initialization</u> module creates temporary files for landscape structure to be used in the simulation process.

The following modules analyze information about landscape structure, estimate insect abundance and produce the output files. The time controller allows the model to run the simulation for variable number of years. The landscape configuration module reads an external digital file (provided by the user) which contains information on X,Y coordinates, habitat type, habitat age, and habitat management for each cell in the landscape. The coccinellid abundance module estimates the abundance of each species in each cell based on the information obtained in the landscape configuration module. The species diversity analysis module computes means, variances, and standard errors for the total abundance of ladybird beetles, species richness, and the Shannon Wiener index in the whole landscape. The species spatial distribution module produces ASCII files that contain information on the spatial distribution of each species per time unit (year) and that can be accessed by a Geographic Information System software such as ARC INFO. Finally, the landscape change module, "updates" the landscape configuration for the following year of the simulation based on management criteria. For example, this module can be manipulated so it follows a corn-soybean-wheat rotation and alfalfa is replanted every four years. By modifying the input file used in the landscape configuration module, or changing the management criteria in the landscape change module the user can produce different landscape configurations to be used as "treatments" in the simulation.

10. Sensitivity analysis

Three approaches were used to conduct the sensitivity analysis of the model. The first approach was to compare species assemblages between observed (field observations) and expected (model output) data. Yearly ladybird beetle total abundance, species richness, and species diversity for the entire KBS LTER landscape was estimated for the years 1989-1994. Then a computer simulation was conducted using the KBS LTER landscape configuration based on the same habitats and planting sequence. The simulation was replicated 10 times for each year to obtain yearly means of total abundance, species richness and species diversity. Two tests were used to compare between the observed data and the model output: a) the Kolmogorov-Smirnov goodness of fit test, which is a more powerful test than the chi-square test when n is small (Zar 1984), and b) the Pearson product-moment correlation test (SPSS 1993).

There was no statistical difference (P > 0.1) between the distribution of the observed data and the output of the model for the three variables measured (Figure 39). High correlation was found with species diversity (r=0.8, P = 0.056), and total abundance (r=0.77, P = 0.075). No correlation was detected with species richness.



Figure 39. Comparison between model output and field data in relation to total relative abundance, species richness, and species diversity of ladybird beetles.

The results of the simulation and subsequent analysis in relation to total abundance and species diversity were considered acceptable because the major disagreement between the model output and the field data was with respect to observations made in 1989. Coccinellid abundance during 1989 was highly influenced by the abundance of C. *septempunctata* in the whole landscape and in particular that in wheat. Subsequent observations during the following years have lead me to the hypothesis that the high abundance observed in 1989 was the exception rather than the rule.

Another observation of this analysis, was that both richness and diversity were overestimated in all years of simulation. An analysis of species abundance as a result of the simulation showed that this overestimation occurred because the "very low interval" for the non-dominant species (Appendix A) may have been too broad, increasing the probability for a species to be present in the landscape. If that probability is too high, then species richness and species diversity will be overestimated, although the trend would remain the same.

The second approach was an analysis of variance of species abundance under different agronomic treatments (in field crops) and habitat aging (in perennial and succession habitats). For the agronomic treatments, I designed an "experimental landscape" for each of the field crops (corn, soybean, and wheat) consisting of 25 replicates of each of the following agronomic treatments: conventional tillage, no tillage, low chemical input, and zero chemical input. This information was used to conduct a simulation and the mean abundance of each ladybird beetle species per crop per treatment was estimated in each

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simulation. Data were normalized using a $\sqrt{x+0.001}$ transformation for statistical analysis. The simulation in each crop was replicated 10 times and the means of the 10 simulations were used for the analysis of variance (ANOVA) and the Tukey-HSD test to test for statistically significant differences among agronomic treatments (SPSS 1993). For treatments on habitat aging in perennial and successional habitats, a same approach that was implemented for agronomic treatments was used. The difference was that instead of agronomic treatments I included different ages (from 1 to 6 years) as treatments. The number of simulations, data normalization, and statistical tests were also the same.

The results of the statistical analysis conducted on field data (see Table 3, p. 63 for habitat aging, and Tables 8, 10, and 12, p. 89-94 for agronomic treatments), were compared with the results of the statistical analyses conducted on the outputs of the model.

The combination of species and treatments produced 234 pairwise comparisons for agronomic treatments and 182 for aging treatments. Of these pairwise comparisons, 15% in agronomic treatments and 35% in perennial treatments produced significant statistical differences when the same comparisons conducted on field data did not produce significant statistical differences. A revision of the structure of the model indicated that those cases in which there was a statistical analysis conflict between data from the model and field data, were cases in which pair of treatments had field data with means that differed in 50% or more, but were not significantly different (P > 0.05). For example, field data on *C.m. lengi* in soybeans under conventional and no tillage had a mean (\pm S.E.) of 0.06 \pm 0.03 adults per trap and 0.22 \pm 0.04 adults per trap respectively. In this example, the abundance in conventional tillage is 1/3 less than the abundance with no tillage but

differences were not statistically significant because of the high degree of variability in conventional tillage. However, after the proportional differences between treatments were included in the model, the estimates of abundance for *C.m. lengi* as a result of the simulation showed statistically significance. An easy solution would be to assign the same value to the parameters of both treatments since they are not statistical different. This way, the simulation would produce similar values and there would not be conflict with the statistical analysis. I think however that the solution to this problem will require a more detailed analysis of the variance that occur within each treatment.

The third approach was to hypothesize, based on analysis of field data, the potential response of ladybird beetle assemblages to changes in complexity in the landscape, and observe if such predictions could be supported by the model.

Three ways were selected to increase the complexity of the landscape such that the abundance and diversity of ladybird beetles might be affected: a) increasing the numbers of habitats in the landscape (Chapter 1), b) changing management practices to reduce chemical inputs (Chapter 4), and c) causing periodical disturbances to revert secondary succession fields to earlier stages of succession (Chapter 3).

The "experimental design" implemented in the model used a landscape whose dimensions were 10*10 hectares, and a simulation length of 9 years. Specifics of treatments were as follows.

- 1) Modifying complexity by increasing the number of habitats. The model consisted of a corn-soybean-wheat rotation scheme under high chemical input with two treatments
 - a) The entire area planted to corn at the beginning of the simulation

- b) Half of the area planted to corn, and the other half planted to wheat at the beginning of the simulation.
- Modifying complexity by changing management practices. It consisted of a cornsoybean-wheat rotation scheme with two treatments:
 - a) The entire area planted to corn under high chemical input at the beginning of the simulation.
 - b) The entire area planted to corn under zero chemical input at the beginning of the simulation.
- Modifying complexity by managing disturbance in succession. It consisted of a secondary succession habitat with two treatments
 - a) The entire area started with a succession field of age 1 and succession continued undisturbed.
 - b) One third of the area had secondary succession of age 1,one third of age 2, and one third of age 3. After a succession field reached four years of age, fields were "plowed" and reverted to age 1.

All simulations were replicated ten times.

Based on the data analyses conducted in previous chapters, it was predicted that the increase in complexity would cause:

- a stabilization of diversity and number of beetles in 1) and 3),
- an increase in the fluctuation in number of beetles and a decrease of diversity in
 2)

As a measure of stabilization or fluctuation the coefficient of variation (C.V.) was used such that the lower the C.V. the greater the stability, while the higher the C.V. the greater the change the change in abundance existed.

The results of these simulations are shown in the Figure 40, Figure 41, and Figure 42. The observed trends occurred as predicted. An increase in landscape complexity occurred by increasing the number of crops, showed a reduction in the coefficient of variation while maintaining the same mean with respect to the one-crop treatment (Table 16). Changes in landscape complexity by reductions in chemical inputs increased the coefficient of variation of abundance and richness, and reduced the diversity. Finally, The change in landscape complexity by managing secondary succession habitats reduced the coefficient of variation and increased the diversity of coccinellids in the landscape. At the current state of the model I could not test the statistical significance of some the outcomes (see discussion on the second approach for sensitivity analysis), however, I expect to be able to do that after tuning some of the parameters in the model. Nevertheless, I considered the fact that trends in model simulation followed patterns observed in the field.

Table 16. Mean and coefficient of variation (c.v.)(%) of the abundance, species richness and species diversity of a complex of ladybird beetles described by a simulation model in response to different landscape configuration treatments. Number of crops and chemical input treatments were applied on a rotation scheme of cornsoybean-wheat.

Treatment	Abundance		Richness		Diversi	Diversity	
	mean	c . v .	mean	c . v .	mean	c . v .	
Number of initial crops					·····		
one (corn)	5070	10	4.3	12	0.9	27	
two (corn, wheat)	5090	5	4.3	6	0.9	14	
Chemical inputs							
high	5070	10	4.3	12	0.9	27	
zero	4400	63	3.8	30	0.6	33	
Secondary succession							
natural	5410	36	6.7	7	0.8	47	
managed	4780	16	6.6	3	1.1	10	

DISCUSSION

This resulting model during this first iteration produced trends in species diversity and abundance of ladybird beetles that followed the temporal patterns observed in the field. Simulation results are promising because of the potential for comparative analysis of studies that involve the interactions between species assemblages of ladybird beetles and the landscape.


Figure 40. Changes in abundance, species richness, and diversity of a complex of ladybird beetle species predicted by a simulation model on a corn-soybean-wheat rotation scheme in response to increasing from one initial crop (corn) to two initial crops (corn and wheat).



Figure 41. Changes in abundance, species richness, and diversity of a complex of ladybird beetle species predicted by a simulation model on a corn-soybean-wheat rotation scheme in response to reduction on chemical inputs.



Figure 42. Changes in abundance, species richness, and diversity of a complex of ladybird beetle species predicted by a simulation model on secondary succession habitats in response to changes from natural succession to a managed succession (different succession ages, 1 to 3, and plowing after the four year).

Some discrepancies were observed between the results of statistical tests applied to field data and the results of tests applied to estimates of abundance of beetles produced by the model. This shows the need for conducting more detailed analyses on the variance in abundance observed by some species of ladybird beetles in response to treatments.

Although the trends in species diversity and species richness produced by the model were similar to those observed in the field data, they were overestimated. This indicates the need to fine tune the "very low" and "low" intervals of abundance.

Once the sensitivity analysis of the <u>habitat type</u>, <u>habitat age</u>, and <u>habitat management</u> parameters produces satisfactory results, it will be possible to start the next iteration in the development of the model which includes estimates of the <u>habitat influence</u> parameter. This will be very important because the model currently simulates only temporal patterns, even though it has also been designed to produce spatial patterns.

The next step will be to validate the model. This process can be achieved using primarily new data collected at the KBS LTER. Alternatively, the model can also be validated by conducting experiments that test the predictions of the model. Because, the design of the model is directed toward comparative analysis, predictions of the model for field validations should be comparative by nature.

Another important step in the near future will be to expand the temporal scope of the model to include intra-seasonal variability. Important information in the simulation process will be gained by dividing a season into early, middle and late season. The implications that such subdivisions will have on the abundance and species diversity of ladybird beetles will be important since *C. septempunctata*, the dominant species, is a mid-season species while the rest of the species are more abundant early or late in the season.

In the future the model could be adapted to account for other groups of predators such as lacewings or ground beetles. These groups form part of the KBS LTER project (Gage et al. 1993) and several years of data have been collected following the same general approach as that used for the ladybird beetles. A model including these groups will produce a more holistic view on use of the landscape by generalist predators.

SUMMARY AND CONCLUSIONS

The Long Term Ecological Research (LTER) program for agricultural ecology located at the Kellogg Biological Station (KBS) stated as a general hypothesis that "agronomic management based on ecological concepts can effectively substitute for reliance on chemical subsidies in production-level cropping systems (VanCleve and Martin 1991). In the experimental design an array of field crops (corn, wheat, soybean) under different management practices were interspersed with perennial biomass plantations (alfalfa and poplar) and secondary succession habitats making a complex agricultural landscape.

A long term program designed to characterize the flow of organisms within the KBS LTER landscape was established in 1988 (Gage et al. 1993). This program focused primarily on insect predators because of their role in the natural regulation of pest populations in agroecosystems. Among the predator groups, ladybird beetles were selected to measure the effect that agroecological management of field crop systems could have on the population dynamics of beneficial insects. Ladybird beetles were ideal for this study because they have a large number of species with a wide range of habitat utilization and they are very mobile organisms.

In 1992, I joined the KBS LTER program and decided to conduct my research within the context of the existing KBS LTER ladybird beetles project. The goal of my research was to obtain and analyze habitat utilization patterns by a complex of 14 species of

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coccinellids, and to synthesize the results in a landscape-coccinellid model. To achieve this goal I conducted

- a) a study of the life system of Coleomegilla maculata lengi to characterize their use of tree related habitats during the winter, and their patterns of field crops use during the summer.
- b) an assessment of the temporal and spatial scales required to conduct long term studies of coccinellids, as well as an evaluation of sticky traps as a sampling tool for ladybird beetles.
- c) an analysis of the response of coccinellid species assemblages to two types of temporal diversity in the landscape. One was a six-year corn-soybean rotation, and the second was the habitat aging of alfalfa, poplar, and early secondary succession.
- d) an analysis of the response of coccinellid species assemblages to agricultural management in a corn-soybean-wheat rotation with practices that included conventional and no tillage under high chemical inputs, as well as low and zero chemical inputs.
- e) the first iteration of a spatially explicit population model that will be used as a tool for comparative analysis in studies involving landscape ladybird beetle interactions.

The major findings in this study were:

- Aging of deciduous habitats such as poplar plantations causes a "succession" of dominant species within the ladybird beetle complex. Dominant beetle species in young plantations (1-4 years) are also important inhabitants of field crops. Thereafter, the dominant ladybird beetle species are species typical of only deciduous habitats.
- 2. Ladybird beetles in secondary succession reach their peak abundance and species diversity between the second and fourth years of plant succession. Ecological management of agroecosystems that involve succession habitats may require some practices aimed to maintain those fields within earlier stages of succession.
- 3. Reducing chemical inputs in field crops have different effects on ladybird beetle species depending on the crop. Abundance and species diversity are significantly reduced in corn when chemical inputs (herbicides and fertilizers) are reduced, but in wheat the reduction of chemical inputs increases abundance and diversity of beetles.
- Corn-soybean rotation schemes can affect the abundance of ladybird beetle species.
 C.m. lengi populations become abundant during "corn years" but decrease their abundance during "soybean years".
- 5. Ladybird beetles can use woodlots, hedgerows, and rows of trees as aggregation sites during the winter as long as they have a southern exposure to sunlight, and are not subject to disturbance. Large aggregates of beetles may be located in woodlots or hedgerows near agricultural fields where corn or alfalfa was grown the previous summer.

- 6. Spring flowers are important sources of food for ladybird beetles that aggregate during the winter in woodlots, hedgerows, or individual trees. Therefore, weeds such as dandelions could be controlled when they are within agricultural fields but should be preserved when they are near tree related habitats.
- 7. Habitat preference by ladybird beetles in field crop agroecosystems vary through the summer. *C.m. lengi* populations prefer alfalfa or wheat during spring but switch its preference to corn during late summer.
- 8. Sticky traps prove to be the appropriate sampling method for large temporal and spatial scale measurements of adult ladybird beetles in diversified landscapes.
- 9. The applicability of the systems analysis used during the development of the model provided a framework to organize the approach to landscape level research on insect dynamics.

Within the framework of the KBS LTER general hypothesis, this work contributed to the understanding of the potential impact that agroecological management can have on beneficial insects. It also completed an important phase of a long term project initiated in 1988 on insect predators in the landscape. Finally, this work provides a framework for future research on beneficial insect and their interactions with the landscape.

Future research can be scaled down to address specific issues related with the fluctuation in abundance and diversity of beneficial insects in some field crop management practices. More effort is also needed to determine why ladybird beetles are attracted to the early years of secondary succession. Research can also scale up to study patterns of response by ladybird beetles to different landscape configurations by comparing diversified landscapes versus simple landscapes.

The model in this research could be adapted to account for other groups of predators such as lacewings or ground beetles to produce a more holistic view of the interactions between beneficial insects and agricultural landscapes. **APPENDICES**

Appendix A. Minimum and maximum values of 18 groups of abundance means of C. septempunctata that resulted from a pairwise comparison (Tukey-HSD) of 49 treatments. Numbers in bold are the intervals selected for levels of abundance of ladybird beetles during the development of a simulation model.

	Inte	erval	Level of a	bundance
Group	Minimum	Maximum	C. septempunctata	Rest of ladybird
			C.m. lengi	beetles
1	0	0.83	very low	very low
2	0.06	1.06		low
3	0.25	1.32		
4	0.41	2.28	low	
5	0.65	2.37		
6	0.71	2.79		
7	0.83	3.04		medium
8	1.32	3.81		
9	1.71	4.55	medium	
10	2.28	5.02		
11	2.31	5.19		
12	2.37	5.66		
13	2.79	6.35		high
14	3.61	7.35		
15	3.81	7.69	high	
16	4.03	8.47		
17	6.11	10.63		
18	7.10	11.85	very high	

Appendix B. Probabilities (%) of levels of abundance for ladybird beetle species in different habitats in field crop agroecosystem. C7=C. septempunctata, Cmac=C.m. lengi, Hpam=H. parenthesis, Cmund=C. munda, Cstig=C. stigma, Abipn=A. bipunctata, Bursi=B. ursina, Ctrif=C.t. perplexa, Alabi=A. labiculata, H13=H.t. tibialis, Hundu=H. undulata, Hglac=H.g. glacialis, and Hconv=H.

	colivei geno.													
	Level of					Ladyb	ird beetle	species						
Habitat	abundance	C7	Cmac	Hparn	Cmund	Cstig	Abipn	Bursi	Ctrif	Alabi	H13	Hundu	Hglac	Hco
	Very Low	0	0	50	50	0	50	50	50	0	0	50	0	20
	Low	44	2	50	50	0	50	50	50	0	0	20	0	50
Corn	Medium	44 44	44	0	0	100	0	0	0	0	0	0	0	0
	High	12	34	0	0	0	0	0	0	0	0	0	0	0
	Very High	0	0	0	0	0	0	0	0	0	0	0	0	0
	Very Low	0	80	50	50	50	50	50	50	50	0	0	50	50
	Low	0	20	50	50	50	50	50	50	50	0	0	50	50
Soybean	Medium	0	0	0	0	0	0	0	0	0	0	0	0	0
•	High	25	0	0	0	0	0	0	0	0	0	0	0	0
	Very High	75	0	0	0	0	0	0	0	0	0	0	0	0
	Very Low	0	50	50	25	50	50	50	50	50	50	50	50	50
	Low	0	50	50	50	50	50	50	50	50	50	50	50	50
Wheat	Medium	14	0	0	25	0	0	0	0	0	0	0	0	0
	High	57	0	0	0	0	0	0	0	0	0	0	0	0
	Very High	29	0	0	0	0	0	0	0	0	0	0	0	0
	Very Low	0	0	50	11	50	25	0	50	0	0	20	50	50
	Low	0	0	50	33	50	50	0	50	0	0	50	50	50
Poplar	Medium	17	0	0	33	0	25	0	0	0	0	0	0	0
,	High	83	33	0	23	0	0	100	0	0	0	0	0	0
	Very High	0	67	0	0	0	0	0	0	0	0	0	0	0
	Very Low	0	50	44	50	0	50	50	50	0	0	50	0	50
	Low	0	38	4	50	0	50	50	50	0	0	50	0	50
Alfalfa	Medium	0	12	12	0	0	0	0	0	0	0	0	0	0
	High	0	0	0	0	100	0	0	0	0	0	0	0	0
	Very High	100	0	0	0	0	0	0	0	0	0	0	0	0
	Very Low	0	57	45	25	50	40	50	50	50	50	50	50	50
Secondary	Low	0	43	45	25	50	50	50	50	50	50	50	50	50
Succession	Medium	0	0	9	38	0	9	0	0	0	0	0	0	0
	High	67	0	0	12	0	0	0	0	0	0	0	0	0
	Very High	33	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C. Relative abundance (%) of ladybird beetle species at different ages of growth of perennial habitats and secondary succession in field crop agroecosystem. C7=C. septempunctata, Cmac=C.m. lengi, Hpam=H. parenthesis, Cmund=C. munda, Cstig=C stigma, Abipn=A. bipunctata, Bursi=B. ursina, Ctrif=C.t. perplexa, Alabi=A. labiculata, H13=H.t. tibialis, Hundu=H. undulata,

÷	Hglac= <i>H.g. gl</i>	acialis, ar	Nd Hconv	≡H. conv	<i>lergens.</i> .									
	Age					Ladybirc	d beetle sp	ecies						
Habitat	(years)	C7	Cmac	Hparn	Cmund	Cstig	Abipn	Bursi	Ctrif	Alabi	H13	Hundu	Hglac	Hcon
	-	100	-	100	5	40	25	0	0	0	0	0	0	100
	7	15	40	0	35	-	100	0	75	0	0	0	0	0
	n	5	100	30	100	-	85	0	100	0	0	0	0	0
Poplar	4	-	10	20	20	25	30	0	0	0	0	100	0	0
	5	-	-	50	65	65	5	5	0	0	0	-	0	0
	9	5	-	50	60	100	0	20	0	0	0	65	0	0
	7	0	-	-	85	40	0	100	0	0	0	0	100	0
	-	100	20	20	65	S	15	0	0	0	0	0	0	0
	0	40	50	-	35	100	100	0	0	0	0	0	0	0
Alfalfa	ю	30	20	-	-	0	-	0	0	0	0	0	0	0
	4	30	100	100	35	0	10	0	0	0	0	0	0	70
	ŝ	40	S	25	-	0	-	30	100	0	0	75	0	~
	-	95	5	50	-	100	15	0	0	0	0	0	0	30
	7	70	60	100	100	0	100	0	0	0	0	0	0	100
Secondary	ю	S	100	20	-	0	10	0	100	0	0	0	0	-
succession	4	35	35	85	5 C	40	15	0	0	0	0	100	0	70
	S	50	S	25	20	0	10	30	0	0	0	0	0	-
	9	100	ŝ	65	15	0	10	-	0	0	0	0	0	30
	7	15	20	75	15	0	9	100	0	100	100	0	100	30

Appendix D. Relative abundance (%) of ladybird beetle species under different agronomic practices in com, soybean, and wheat. C7=C. septempunctata, Cmac=C.m. lengi, Hparn=H. parenthesis, Cmund=C. munda, Cstig=C. stigma, Abipn=A. bipunctata, Bursi=B. ursina, Ctrif=C.t. perplexa, Alabi=A. labiculata, H13=H.t. tibialis, Hundu=H. undulata, Hglac=H.g. glacialis, and Hconv=H.

	convergens.													
						Ladybirc	d beetle s	oecies						
Habitat	Management	C7	Cmac	Hparn	Cmund	Cstig	Abipn	Bursi	Ctrif	Alabi	H13	Hundu	Hglac	Hcon
	Conv. Tillage	75	100	0	100	0	100	100	100	0	0	0	0	0
Corn	No Tilalge	100	35	100	70	0	100	25	0	0	0	0	0	0
	Low Chem. Inp.	15	10	70	20	0	0	0	0	0	0	0	0	0
	Zero Chem. Inp.	30	-	0	0	0	0	60	0	0	0	0	0	0
	Conv. Tillage	65	20	65	40	100	20	0	0	100	0	0	0	0
Soybean	No Tilalge	100	75	100	40	0	50	0	0	0	0	0	100	75
	Low Chem. Inp.	20	100	20	100	0	0	0	0	0	0	0	0	0
	Zero Chem. Inp.	60	80	50	25	0	100	100	0	25	0	0	0	75
	Conv. Tillage	50	100	80	30	0	0	0	100	0	100	0	100	100
Wheat	No Tilalge	70	10	55	55	0	0	0	0	100	0	0	35	0
-	Low Chem. Inp.	65	30	45	100	0	0	0	100	0	0	0	65	0
	Zero Chem. Inp.	100	100	100	30	0	0	100	0	ο	0	0	65	0

Appendix E. Probability for ladybird beetle species to be present in annual field crop agroecosystems. C7=*C*. septempunctata, Cmac=*C.m. lengi*, Hpam=*H. parenthesis*, Cmund=*C. munda*, Cstig=*C. stigma*, Abipn=*A. bipunctata*, Bursi=*B. ursina*, Ctrif=*C.t. perplexa*, Alabi=*A. labiculata*, H13=*H.t. tibialis*, Hundu=*H. undulata*, Hglac=*H.g. glacialis*, and Hconv=*H. convergens*.

				Ladybiro	l beetle sp	ecies						
	mac	Hparn	Cmund	Cstig	Abipn	Bursi	Ctrif	Alabi	H13	Hundu	Hglac	Hcon
Corn 100	100	60	70	10	70	30	10	0	0	10	0	10
Soybean 100	100	60	60	10	06	10	10	30	0	0	10	50
Wheat 100	100	100	06	30	40	10	30	10	10	30	50	30

Appendix F. Computer code of the computer simulation model to simulate the effect of different habitat configurations on the relative abundance of 13 species of coccinellids

MAIN PROGRAM

REM \$INCLUDE: 'c:\LANDYBUG\LANDYBUG.DCL'

'LANDYBUG: A Landscape - Coccinellids model to simulate the effect of

- the landscape configuration in the species assemblages of
 - predatory coccinellids.

Developed by Manuel Colunga-Garcia

' This model simulates the effect of different habitat configurations

' on the relative abundance of 13 species of coccinellids.

' Field crop habitats (corn, soybean, and wheat) are subject to different

' agronomic practices (conventional tillage, no till, low chemical input,

' zero chemical input). Poplar, alfalfa, and and secondary succession are

' subject to different years of maturation.

'The statement [\$INCLUDE: 'LANDYBUG.DCL'] at the beginning of this program 'declares subprograms, functions, variables, and arrays to be used during

declares subprograms, functions, variables, and arrays to be u

' the simulation.

.

- 'Accessing the module that contain the parameters to acquire them. CALL Parameters
- 'Accessing the module that initializes temporal landscape files. CALL Landini
- 'Turning the random generator on. It uses the computer clock as a seed. RANDOMIZE TIMER:
- 'Begins the simulation using a [For:Next] loop as a time controller. FOR year = 1 TO NoYears
 - ¹ Determination of the landscape configuration. CALL Landiconf
 - 'Estimation of the abundance of coccinellids. CALL CoccAbund
 - ' Analysis of coccinellid species diversity. CALL Analysis
 - ' Generation of species distribution output maps. 'CALL MapOutput
 - ' Changeing the landscape for the following year. CALL Landichange

NEXT year

1. VARIABLES DEFINITION

DECLARE SUB MapOutput () DECLARE SUB CoccAbund () DECLARE SUB Landichange () DECLARE SUB Analysis () DECLARE SUB Landini () DECLARE FUNCTION Degree! (hab%, spp%) DECLARE SUB Landiconf () DECLARE SUB Parameters ()

'Declaration of and Initialization of Variables and Arrays:

Directories and data files (Variables)
DIM SHARED DataProg AS STRING: ' directory for the landybug program
DIM SHARED DataDir AS STRING: ' directory for data files (*.dat)
DIM SHARED SimuFile AS STRING: ' name of temporal simulation file

'directory for the landybug program LET DataProg = "c:\landybug\"

'directory for data files (*.dat) LET DataDir = "c:\landybug\mydata\"

'Related to habitat parameters
'(Variables)
DIM SHARED NoHab AS INTEGER: ' habitats considered in the model
DIM SHARED NoAge AS INTEGER: ' maximum age for perennial habitats
DIM SHARED NoLevel AS INTEGER: ' levels of species abundance
DIM SHARED NoMngt AS INTEGER: ' number of management practices for crops
DIM SHARED NoSpp AS INTEGER: ' species considered in the model

' habitats considered in the model LET NoHab = 7

' maximum age for perennial habitats LET NoAge = 7

' levels of species abundance LET NoLevel = 5

' number of management practices for crops LET NoMngt = 4

' species considered in the model LET NoSpp = 13

'(Arrays)

DIM SHARED HabType(0 TO NoHab, 1 TO NoSpp, 1 TO NoLevel) AS INTEGER DIM SHARED HabAge(0 TO NoHab, 1 TO NoSpp, 1 TO NoAge) AS SINGLE DIM SHARED HabMngt(0 TO NoHab, 1 TO NoSpp, 0 TO NoMngt) AS SINGLE DIM SHARED HabInf(0 TO NoHab, 1 TO NoSpp, 1 TO NoHab) AS SINGLE DIM SHARED HabProb(0 TO NoHab, 1 TO NoSpp) AS SINGLE

'Landscape map dimensions (Variables) DIM SHARED FirstRow AS INTEGER: 'first row in the landscape map DIM SHARED LastRow AS INTEGER: 'last row in the landscape map DIM SHARED FirstCol AS INTEGER: 'first column in the landscape map DIM SHARED LastCol AS INTEGER: 'last column in the landscape map

' first row in the landscape map LET FirstRow = 1

' last row in the landscape map LET LastRow = 10

' first column in the landscape map LET FirstCol = 1

' last column in the landscape map LET LastCol = 10

'Time controller (Variables) DIM SHARED NoYears AS INTEGER: 'number of years for the simulation DIM SHARED year AS INTEGER: ' year counter LET NoYears = 2

'For Diversity Analysis (Arrays)

DIM SHARED SppDensity(FirstRow TO LastRow, FirstCol TO LastCol, 1 TO NoSpp) AS INTEGER DIM SHARED Total(FirstRow TO LastRow, FirstCol TO LastCol) AS INTEGER: 'Total of coccinellids DIM SHARED Richness(FirstRow TO LastRow, FirstCol TO LastCol) AS INTEGER: 'Richness (No. species)

DIM SHARED Diversity(FirstRow TO LastRow, FirstCol TO LastCol) AS SINGLE: 'Diversity index (Shannon)

DIM SHARED Mtotal(1 TO NoYears) AS SINGLE: 'Mean

DIM SHARED Vtotal(1 TO NoYears) AS SINGLE: 'Variance

DIM SHARED SEtotal(1 TO NoYears) AS SINGLE: 'Standard error

DIM SHARED Mrichness(1 TO NoYears) AS SINGLE: 'Mean

DIM SHARED Vrichness(1 TO NoYears) AS SINGLE: 'Variance

DIM SHARED SErichness(1 TO NoYears) AS SINGLE: 'Standard error

DIM SHARED Mdiversity(1 TO NoYears) AS SINGLE: 'Mean

DIM SHARED Vdiversity(1 TO NoYears) AS SINGLE: 'Variance

DIM SHARED SEdiversity(1 TO NoYears) AS SINGLE: 'Standard error

' Others

'(Variable)

DIM SHARED Ratio AS INTEGER: ' ratio of influence in the landscape

' ratio of influence in the landscape LET Ratio = 1000

'(Arrays)

DIM SHARED HabCell(FirstRow TO LastRow, FirstCol TO LastCol) AS INTEGER DIM SHARED MngtCell(FirstRow TO LastRow, FirstCol TO LastCol) AS INTEGER DIM SHARED AgeCell(FirstRow TO LastRow, FirstCol TO LastCol) AS INTEGER DIM SHARED HabAround(FirstRow TO LastRow, FirstCol TO LastCol, 1 TO NoHab) AS SINGLE DIM SHARED HabTotal(0 TO NoHab) AS INTEGER DIM SHARED HabProp(0 TO NoHab) AS SINGLE DIM SHARED Around(0 TO NoHab) AS INTEGER

2. PARAMETERS ACQUISITION

SUB Parameters

'This module reads parameters from tables in the file LANDYBUG.PAR.

'Open the file to input parameters OPEN DataProg + "landybug.par" FOR INPUT AS #1

******** 'Description of habitat type codes corn = 1'soybean = 2'wheat = 3'orchard = 4 (information not determined yet) 'poplar = 5'alfalfa = 6'succession = 7'Input parameters for level abundance according to habitat type. LINE INPUT #1, Title\$ LINE INPUT #1. Labels\$ FOR hab% = 1 TO NoHab FOR level% = 1 TO NoLevel INPUT #1, Value1, Value2 IF Value1 \diamond hab% OR Value2 \diamond level% THEN PRINT "Error: Table "; Title\$: PRINT "Check the sequence of parameters" **END** END IF FOR spp% = 1 TO NoSpp INPUT #1, HabType(hab%, spp%, level%) NEXT spp% NEXT level% NEXT hab% ******* 'Input parameters for habitat age effect on abundance (years) LINE INPUT #1, Title\$ LINE INPUT #1, Labels\$ FOR hab% = 1 TO NoHab FOR age% = 1 TO NoAge INPUT #1, Value1, Value2 IF Value1 \diamond hab% OR Value2 \diamond age% THEN PRINT "Error: Table "; Title\$: PRINT "Check the sequence of parameters" END END IF FOR spp% = 1 TO NoSpp

```
INPUT #1, HabAge(hab%, spp%, age%)
     NEXT spp%
    NEXT age%
  NEXT hab%
***********
'Description of management type codes
 ' no management
                   = 0 (or management effect not determined)
 ' conventional tillage = 1 (also high chemical input)
 ' no tillage
              = 2
 ' low chemical input = 3
 'zero chemical input = 4
'Input parameters for habitat management effect on abundance.
  LINE INPUT #1, Title$
  LINE INPUT #1. Labels$
  FOR hab% = 1 TO NoHab
    FOR mngt% = 0 TO NoMngt
      INPUT #1, Value1, Value2
      IF Value1 <> hab% OR Value2 <> mngt% THEN
        PRINT "Error: Table "; Title$: PRINT "Check the sequence of parameters"
        END
      END IF
      FOR spp% = 1 TO NoSpp
        INPUT #1, HabMngt(hab%, spp%, mngt%)
      NEXT spp%
    NEXT mngt%
  NEXT hab%
'Input parameters for inter-habitat influence on abundance.
  LINE INPUT #1, Title$
  LINE INPUT #1, Labels$
  FOR hab% = 1 TO NoHab
    FOR hab2% = 1 TO NoHab
      INPUT #1, Value1, Value2
      IF Value1 \diamond hab% OR Value2 \diamond hab2% THEN
        PRINT "Error: Table "; Title$: PRINT "Check the sequence of parameters"
        END
      END IF
      FOR spp\% = 1 TO NoSpp
        INPUT #1, HabInf(hab%, spp%, hab2%)
      NEXT spp%
    NEXT hab2%
  NEXT hab%
*******
'Input parameters of probability for a species to be in a field crop habitat.
  LINE INPUT #1, Title$
  LINE INPUT #1, Labels$
  FOR hab% = 0 TO NoHab
      INPUT #1, Value1
      IF Value1 <> hab% THEN
        PRINT "Error: Table "; Title$: PRINT "Check the sequence of parameters"
```

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```

END END IF FOR spp% = 1 TO NoSpp INPUT #1, HabProb(hab%, spp%) NEXT spp% NEXT hab%

CLOSE #1: ' closes the file

END SUB

3. LANDSCAPE INITIALIZATION

SUB Landini

```
***********
'Checking the data directory.
CLS
LOCATE 5, 1: PRINT "Is < "; DataDir; " > the directory for your data files? <Y> <N>";
DO
  INPUT Response$
  IF UCASE$(Response$) = "N" THEN
   LOCATE 7, 1: PRINT "You have to correct the directory address of the program"
   LOCATE 8, 1: PRINT " in the file < landybug.dcl >"
   LOCATE 10, 1: PRINT "The program has ended"
   END
  ELSEIF UCASE$(Response$) = "Y" THEN
    EXIT DO
  ELSE
  END IF
LOOP
**************
'Input of the data file for the simulation
CLS
DO
  LOCATE 3, 1: FILES DataDir + "*.dat"
  PRINT : PRINT "Input the data file name for this simulation (without the extension '.dat')"
  INPUT File$
  PRINT : PRINT "Is "; File$; ".dat"; " the correct name? <Y> <N>";
  INPUT Response$
  IF UCASE$(Response$) = "Y" THEN
      EXIT DO
  ELSEIF UCASE$(Response$) = "N" THEN
    CLS : LOCATE 1, 1: PRINT "TRY AGAIN"
  ELSE
  END IF
LOOP
```

END SUB

4. LANDSCAPE CONFIGURATION (INPUT)

SUB Landiconf

'Input of habitat data in the temporal file Lanbug??.dat.

OPEN DataDir + SimuFile + ".dat" FOR INPUT AS #4

LINE INPUT #4, Title\$ LINE INPUT #4, Label\$ FOR row% = FirstRow TO LastRow FOR col% = FirstCol TO LastCol INPUT #4, Value1: 'row coordenate in the file IF Value1 <> row% THEN PRINT "Error row" INPUT #4, Value2: 'column coordinate in the file IF Value2 <> col% THEN PRINT "Error column" INPUT #4, HabCell(row%, col%): 'habitat type INPUT #4, MngtCell(row%, col%): 'habitat age NEXT col% NEXT row% CLOSE

'Habitat proportion in the landscape

Reseting values to 0 FOR habitat% = 1 TO NoHab HabTotal(habitat%) = 0 NEXT habitat% AllCells% = 0

```
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```

```
'Calculating the amount of cells for each habitat type (absolute)
  FOR row% = FirstRow TO LastRow
    FOR col% = FirstCol TO LastCol
       habitat% = HabCell(row%, col%)
      HabTotal(habitat%) = HabTotal(habitat%) + 1
       AllCells% = AllCells% + 1
    NEXT col%
  NEXT row%
  'Calculating the proportion of cell for each habitat type (relative)
  FOR habitat% = 1 TO NoHab
    HabProp(habitat%) = HabTotal(habitat%) / AllCells% * 100
  NEXT habitat%
EXIT SUB: ' This instruction skips the next part of the module. It should
      be eliminated once habitat influence is ready for this program.
*********
'Habitat influence
```

```
FOR row% = FirstRow TO LastRow
  FOR col% = FirstCol TO LastCol
    left% = row% - Ratio: right% = row% + Ratio
    upper% = col% - Ratio: lower% = col% + Ratio
    'Resetting values to 0
    FOR habitat% = 1 TO NoHab
       Around(habitat%) = 0
    NEXT habitat%
    AllCells\% = 0
    FOR windrow% = left% TO right%
       FOR windcol% = upper% TO lower%
         IF windrow% >= FirstRow AND windrow% <= LastRow THEN
          IF windcol% >= FirstCol AND windcol% <= LastCol THEN
            'Calculating the amount of cells for
            ' each habitat type (absolute)
            habitat% = HabCell(windrow%, windcol%)
            Around(habitat%) = Around(habitat%) + 1
            AllCells% = AllCells% + 1
          END IF
         END IF
         NEXT windcol%
       NEXT windrow%
       habitat% = HabCell(row%, col%)
       Around(habitat%) = Around(habitat%) - 1
       AllCells\% = AllCells\% + 1
       'Calculating the proportion of cell for each habitat type (relative)
       FOR habitat% = 1 TO NoHab
         HabAround(row%, col%, habitat%) = Around(habitat%) / AllCells%
       NEXT habitat%
```

NEXT col% NEXT row% *******

END SUB

5. COCCINELLID ABUNDANCE ESTIMATION

SUB CoccAbund

```
'Description of species code
 'C. septempunctata = 1 C. maculata
                                      = 2
 'H. parenthesis = 3 C. munda
                                    = 4
 'C. stigma
               = 5 A. bipunctata
                                   = 6
 'B. ursina
              = 7 C. trifasciata = 8
 'A. labiculata = 9 H. tredecimpunctata = 10
                = 11 H. glacialis
 H. undulata
                                   = 12
 'H. convergens
                 = 13
***********
  FOR row% = FirstRow TO LastRow
    FOR col% = FirstCol TO LastCol
      hab% = HabCell(row%, col%)
      FOR spp% = 1 TO NoSpp
                                 ***
       'Determine if the species is in a habitat based on its
       'probability of being in a habitat.
       Value\% = INT((100 - 0 + 1) * RND + 0)
       IF Value% > HabProb(hab%, spp%) THEN
         Abundance4 = 0
       ELSEIF Value% <= HabProb(hab%, spp%) THEN
         'Initial value of a cell (1 ha) considering one beetle per m2.
         Abundance = 10000
         'Times habitat type effect
         'Degree(hab%, spp%) is a module located in other part of the program
         Abundance1 = Abundance * Degree(hab%, spp%)
         'Times management effect
         mngt% = MngtCell(row%, col%)
         Abundance2 = Abundance1 * HabMngt(hab%, spp%, mngt%)
         'Times age effect
         age% = AgeCell(row%, col%)
         Abundance3 = Abundance2 * HabAge(hab%, spp%, age%)
         'Times habitat influence effect. (No determined yet)
         Abundance4 = Abundance3
                                *****
       END IF
```

' Final asignation of abundance to each species

```
SppDensity(row%, col%, spp%) = Abundance4
NEXT spp%
NEXT col%
NEXT row%
```

END SUB

FUNCTION Degree (hab%, spp%)

```
'Probability for different levels of abundance for the habitat (hab%)
' and the species (spp%)
Level1% = HabType(hab%, spp%, 1)
Level2% = HabType(hab%, spp%, 2)
Level3% = HabType(hab%, spp%, 3)
Level4% = HabType(hab%, spp%, 4)
Level5% = HabType(hab%, spp%, 5)
'Determines if the sum of levels of abundance is > 0. Otherwise
'the abundance is 0 and exits this function
IF Level1% + Level2% + Level3% + Level4% + Level5% = 0 THEN
Degree = 0
EXIT FUNCTION
END IF
*********
'Generates a random number between 0 and 100
Value\% = INT((100 - 0 + 1) * RND + 0)
IF spp% >= 1 AND spp% <= 2 THEN
' For species C. septempunctata and C. maculata
'Lower and Upper values of abundance per each abundance level
L1\% = 0: U1\% = 7
L2% = 3: U2% = 19
L3% = 14: U3% = 38
L4% = 32: U4% = 64
L5% = 59: U5% = 100
SELECT CASE Value%
   CASE IS <= Level1%
     Abundance = INT((U1\% - L1\% + 1) * RND + L1\%)
   CASE (Level1% + 1) TO Level2%
     Abundance = INT((U2\% - L2\% + 1) * RND + L2\%)
   CASE (Level2% + 1) TO Level3%
    Abundance = INT((U3\% - L3\% + 1) * RND + L3\%)
   CASE (Level3% + 1) TO Level4%
     Abundance = INT((U4\% - L4\% + 1) * RND + L4\%)
   CASE (Level4% + 1) TO Level5%
    Abundance = INT((U5\% - L5\% + 1) * RND + L5\%)
   CASE ELSE
END SELECT
```

```
ELSEIF spp% >= 3 AND spp% <= 13 THEN
' For the rest of the species
'Lower and Upper values of abundance per each abundance level
L1% = 0: U1% = 7
 L2\% = 1: U2\% = 9
 L3% = 7: U3% = 25
 L4% = 23: U4% = 53
 SELECT CASE Value%
   CASE IS <= Level1%
     Abundance = INT((U1\% - L1\% + 1) * RND + L1\%)
   CASE (Level1% + 1) TO Level2%
      Abundance = INT((U2\% - L2\% + 1) * RND + L2\%)
   CASE (Level2% + 1) TO Level3%
     Abundance = INT((U3\% - L3\% + 1) * RND + L3\%)
   CASE (Level3% + 1) TO Level4%
     Abundance = INT((U4\% - L4\% + 1) * RND + L4\%)
   CASE (Level4% + 1) TO Level5%
     Abundance = INT((U5\% - L5\% + 1) * RND + L5\%)
   CASE ELSE
END SELECT
END IF
```

Degree = Abundance / 100

END FUNCTION

6. SPECIES DIVERSITY ANALYSIS

SUB Analysis

'Determination of the number of cells Num = (LastRow - FirstRow + 1) * (LastCol - FirstCol + 1)

'Calculation of total adults per cell (all species) FOR row% = FirstRow TO LastRow FOR col% = FirstCol TO LastCol Tot = 0 FOR spp% = 1 TO NoSpp Tot = Tot + SppDensity(row%, col%, spp%) NEXT spp% Total(row%, col%) = Tot NEXT col% NEXT row%

'Estimation of mean, variance, and standard error. T = 0: T2 = 0
FOR row% = FirstRow TO LastRow FOR col% = FirstCol TO LastCol T = T + Total(row%, col%)

```
T2 = T2 + (Total(row\%, col\%)^{2})
  NEXT col%
NEXT row%
Mtotal(year) = T / Num
Vtotal(year) = (T2 - ((T^2) / Num)) / (Num - 1)
SEtotal(year) = SQR(Vtotal(year)) / Num
***************
'Calculation of no. species (richness).
FOR row% = FirstRow TO LastRow
  FOR col% = FirstCol TO LastCol
    rich = 0
    FOR spp\% = 1 TO NoSpp
      IF SppDensity(row%, col%, spp%) > 0 THEN
        rich = rich + 1
      END IF
    NEXT spp%
    Richness(row%, col%) = rich
  NEXT col%
NEXT row%
'Estimation of mean, variance, and standard error.
R = 0: R2 = 0
FOR row% = FirstRow TO LastRow
  FOR col% = FirstCol TO LastCol
    R = R + Richness(row\%, col\%)
    R2 = R2 + (Richness(row\%, col\%)^{2})
  NEXT col%
NEXT row%
Mrichness(year) = R / Num
Vrichness(vear) = (R2 - ((R^2) / Num)) / (Num - 1)
SErichness(year) = SQR(Vrichness(year)) / Num
********
'Calculation of diversity index
FOR row% = FirstRow TO LastRow
  FOR col% = FirstCol TO LastCol
    div = 0
    FOR spp% = 1 TO NoSpp
      IF Total(row%, col%) > 0 THEN
        prop = SppDensity(row%, col%, spp%) / Total(row%, col%)
      ELSE
        prop = 0
      END IF
      IF prop > 0 THEN
        logprop = LOG(prop)
      ELSE
        logprop = 0
      END IF
      div = div + (prop * logprop)
    NEXT spp%
    Diversity(row\%, col\%) = (-1) * div
  NEXT col%
```

NEXT row%

'Estimation of mean, variance, and standard error. D = 0: D2 = 0 FOR row% = FirstRow TO LastRow FOR col% = FirstCol TO LastCol D = D + Diversity(row%, col%) D2 = D2 + (Diversity(row%, col%) ^ 2) NEXT col% NEXT row% Mdiversity(year) = D / Num Vdiversity(year) = D / Num Vdiversity(year) = (D2 - ((D ^ 2) / Num)) / (Num - 1) SEdiversity(year) = SQR(Vdiversity(year)) / Num

END SUB

7. SPECIES SPATIAL DISTRIBUTION (OUTPUT)

SUB MapOutput

FOR spp% = 1 TO NoSpp
' Creating the file for the species/year
IF spp% < 10 AND year < 10 THEN
$MapFile\$ = "sp0" + LTRIM\$(STR\$(spp\%)) + "_0" + LTRIM\$(STR\$(year))$
ELSEIF spp% < 10 AND year >= 10 THEN
MapFile\$ = "sp0" + LTRIM\$(STR\$(spp%)) + "_" + LTRIM\$(STR\$(year))
ELSEIF spp% >= 10 AND year < 10 THEN
MapFile\$ = "sp" + LTRIM\$(STR\$(spp%)) + "_0" + LTRIM\$(STR\$(year))
ELSEIF spp% >= 10 AND year >= 10 THEN
MapFile\$ = "sp" + LTRIM\$(STR\$(spp%)) + "_" + LTRIM\$(STR\$(year))
ELSE
PRINT "Error"
END IF
OPEN DataDir + MapFile\$ + ".txt" FOR OUTPUT AS #5
'Header for an ascii file to be imported by ArcInfo
PRINT #5, "NCOLS "; (LastCol - FirstCol + 1)
PRINT #5, "NROWS "; (LastRow - FirstRow + 1)
PRINT #5, "XLLCORNER "; 1
PRINT #5, "YLLCORNER "; 1
PRINT #5, "CELLSIZE "; 30

'Print ASCII data by row and columns
FOR row% = FirstRow TO LastRow
FOR col% = FirstCol TO LastCol
PRINT #5, SppDensity(row%, col%, spp%);
NEXT col%
PRINT #5, ""
NEXT row%

CLOSE #5

NEXT spp%

END SUB

8. LANDSCAPE CHANGE

SUB Landichange

'Skips subrutine if the years for simulation are complete IF year = NoYears THEN KILL DataDir + SimuFile + ".dat" EXIT SUB END IF

'Read landscape information from OlfFile and updates to a NewFile. OPEN DataDir + OldFile\$ + ".dat" FOR INPUT AS #6 OPEN DataDir + NewFile\$ + ".dat" FOR OUTPUT AS #7

LINE INPUT #6, Title\$: PRINT #7, Title\$ LINE INPUT #6, Label\$: PRINT #7, Label\$

FOR row% = FirstRow TO LastRow FOR col% = FirstCol TO LastCol INPUT #6, RowCell%: 'row coordenate in the file IF RowCell% <> row% THEN PRINT "Error row" INPUT #6, ColCell%: 'column coordinate in the file IF ColCell% <> col% THEN PRINT "Error column" INPUT #6, HabCell%: 'habitat type INPUT #6, AgeCell%: 'management type INPUT #6, AgeCell%: 'habitat age

' Updating information according with the current habitat/age SELECT CASE HabCell% CASE IS = 1: 'Corn HabCell% = 2: ' rotates to soybean CASE IS = 2: 'Soybean HabCell% = 3: 'rotates to wheat CASE IS = 3: 'Wheat HabCell% = 1: ' rotates to corn CASE IS = 5: ' Poplar IF AgeCell% < 7 THEN AgeCell% = AgeCell% + 1ELSE AgeCell% = 7END IF CASE IS = 6: 'Alfalfa IF AgeCell% < 5 THEN AgeCell% = AgeCell% + 1ELSE AgeCell% = 1END IF CASE IS = 7: 'Succession IF AgeCell% < 6 THEN AgeCell% = AgeCell% + 1ELSE AgeCell% = 6END IF CASE ELSE END SELECT 'Writing in new file the updated information WRITE #7, RowCell%, ColCell%, HabCell%, MngtCell%, AgeCell% NEXT col% NEXT row%

CLOSE #6 CLOSE #7

'Renaming the temporal file with the new name SimuFile = NewFile\$ KILL DataDir + OldFile\$ + ".dat" END SUB

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